Spatial and temporal variations of phytoplankton communities in a large inland river, the Huai River, China

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Abstract: The longitudinal distribution and seasonal fluctuation of phytoplankton communities were studied along the headwater to stream outlet of a regulated river system, Huai River, China. To determine longitudinal changes in phytoplankton composition and biomass in the HuaiRiver (China), several single water parcels were followed from it upstream to estuary during in May, June, September and December in 2011. Diatoms formed the majority of cells in most sections, with green algae second and cryptomonads third in importance. Among the diatoms, centrics were relatively more abundant at upstream reaches and downstream reaches of the river. Phytoplankton biomass increased sharply in the middle part of the river (LK, XCK, BBZ sections), and decreased at the downstream reaches of the river. In contrast, there was lower algal biomass value at WJB section and higher in nutrient concentrations (NH_4-N, TP). In the main channel, small centric diatoms (*Melosira*), pennate diatoms (*Synedra, Fragilaria*) were dominant from December to March. A mixed community of chlorophyta (*Eudorina elegans*, *Pandorina morum*, and *Pediastrum*), flagellates (cryptophyceae), cyanophyta (*Microcystis*, *Oscillatoria*), and centric diatoms (*M.granulata*, *M.granulata* var. *angustssima f.spiralis*) were dominant in June. In September (the late summer season), the large diatoms (*Melosira*, *Synedra*) were dominant, being a large diatoms community phase, accompanying with blue-green algae (*Planktolyngbya subtilis*, *Oscillatoria* and *Pediastrum*. *Melosira*.*granulata*. Phytoplankton dynamics and species selection in regulated rivers may be controlled by discharge-related factors; such as confluence of major tributaries，Bengbu dam.The results showed that the dam had a strong influence on ecohydrological conditions.

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1. Introduction

The River Continuum Concept (RCC) is a generalized conceptual framework for characterization of pristine running water ecocystems(Statzner and Higler, 1985, Vannote et al., 1980). The River Contimuum Concept, a downstream directed plankton development has been observed in many larger rivers abroad and inland (Xu et al., 2008, Zimmermann-Timm et al., 2007, Wehr and Descy, 1998, Vadrucci et al., 2003, Phlips et al., 2010, Ietswaart et al., 1999). But this views of longitudinal potamoplankton development excludes hydromorphological channel diversity and has therefore been criticized(Reckendorfer et al., 1999). Longitudinal discontinuities, such as dams and reservoirs, as well as fluvial lakes, could constitute a source of plankton and influence the growth and production of plankton(Popovich and Marcovecchio, 2008, Bowes et al., 2012).

Biodiversity is complexly distributed across ecosystems. This complexity has proved to be difficult to describe and predict, and typically a proper characterization of the biodiversity of multiple taxonomic groups necessitates much efforts, expertise and money(Heino, 2010). From the headwater to mouth, the physical variables within a system present a continuous gradient of physical conditions(Vincent and James, 1996, Carleton Ray, 1996). This gradient should elicit a series of responsewithin the constituent populations as a result of a continuum of biotic adjustments mechanisms (grazing, competition) and consistent patterns of loading such as chemical (nutrient concentrations), physical (light condition), transport, utilization, and storage of organic matter along the length of a river(Descy, 1993). Spatio-temporal patchiness of phytoplankton has been the central focus of the aquatic research for decades.

In lakes, phytoplankton biomass has been used for decades to assess trophic status and to identify artificial eutrophication induced by human activities. Moreover, detailed studies based on long-term records of phytoplankton numbers and taxonomic compositions have shown that, in general, phytoplankton was a very sensitive indicator of environmental changes. Especially in rivers, the water regimes are strongly affected by two seasonal monsoons. In winter river discharge volume is low; in summer, when the southwest monsoon prevails, the river discharge is maximal. The relocation of sewage effluent is likely to have a significant effect on the dynamics of nutrients and phytoplankton biomass(Xu et al., 2008).

The HuaiRiver is located in east China, originated in TongbaiMountain, in Henan province, fed into HongzeLake in Jiangsu province. HuaiRiver stretched across Henan, Anhui and Jiangsu provinces. The original zone was one of the zones with highest population density and the fastest economic growth in Eastern China. Humans development in coastal river basins has greatly increased nutrient, sediment, and other pollutant loads to these waters, resulting in deterioration of water quality, losses of fisheries habitat and resources, and an overall decline in ecological condition (Paerl et al., 2010).

The HuaiRiver is between two big river basins, the Yangtze River and Yellow River.This area, located in the transit zone between warm temperature zone and North Asia tropical climatic zone, with four distinct seasons, rain hot recorded,is one of the major grain producing areas and important agricultural bases in China. The HuaiRiver Basin is one of the most flood-prone basins in China because it is frequently affected by collapses of the south levee of the Huanghe (Yellow River) over a long period in addition to its transitional climate and poor drainage topography. In the early stage, scientists mainly more attention has been paid to the effect of the surface heat conditions on the atmospheric circulation and drought / flooding weather(Bomin and Shuqing, 1994).

The ability to apply phytoplankton-based assessments of the ecological status of large and lowland rivers lies in a better understanding of the growth rates and requirements of suspended algal species in rivers. As some studies have shown, major changes in a watershed can be detected by biomass changes and by alteration of the growth pattern of certain potamoplankton species(De Ruyter van Steveninck et al., 1992, Descy, 1993). Therefore, a system may be devised that can evaluate ecological change by contrasting the present community with reference data from unaltered stretches or time periods. So the phytoplankton community reference data are crucial for the use of planktonic algae in river management because of their importance in large rivers and the growing need for ecosystem-level studies on river plankton. Recognition of this need will be beneficial to adoption of a new paradigm for biodiversity protection and freshwater ecosystem management.Understanding this will also provide scientific and background basis for HuaiRiver biodiversity maintenance mechanism and management.

However, much less research has focused on the spatio-temporal dynamics and the possible controlling factors in HuaiRiver. This paper reported comprehensively and systematically the spatial and temporal pattern of phytoplankton community seasonal structure in HuaiRiver.

2. Description of sites studied

The HuaiRiver basin lies in the area from 112 °E to 121 °E and 31 °N to 36 °N, and belongs to the warm temperate monsoon and sub-humid climate region. The HuaiRiver is 1000km long with a total drainage area of 270,000km^2.The population density of the HuaiRiver basin is over 600 people per square km, which is four times more than the country's average.

The HuaiRiver is the third longest river, between two big river basins, the Yangtze River and Yellow River (Figure 1). HuaiRiver basin lies in the subtropical monsoon region, and the annual precipitation pattern is distinctive in that locale. Annual precipitation at the central part of the basin was about 1000mm during the study period. Rainfall during the summer months (June-September) provided about 62% of the total annual precipitation, while the winter (December-February) was dry with scant precipitation. The studied river reach was about 382km. The main river canals were about upstream reach (inclued LLZ, GA, YS and HB sites), middle-section reach (WJB, LK, XCK, BBZ, LH, XY) and downstream reach (HZH). The sampling sites were set as Figure 1 showed.

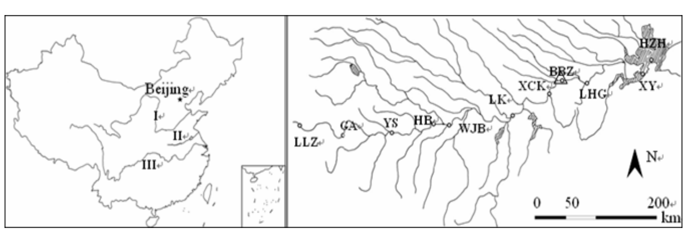

Figure 1. Maps showing the locations of Huai River (I: Huang River; II: Huai River; III: Yangtze River) and the sampled sites (LLZ(833 km): Liulaozhuang; GA(805 km): Ganan; YS(697 km): Yinshan; HB(629 km): Huaibin; WJB(473 km): Wangjiaba; LK(308 km): Lukou; XCK(233 km): Xinchenkou; BBZ(203 km): Bengbuzha; LHG(182 km): Linhuaiguan; XY(64 km): Xuyi; HZH(0 km): Hongzehukou), km indicates the river kilometer upward the HZH estuary,Δ represented dam.

3. Material and Methods

At each site and on each sampling occasion, approximately 50 mL of surface water was collected for nutrient analyses,and3L for determining chlorophyll a(chl.a)and phytoplankton species composition and cell abundance.

Water temperature (WT), and pH were recorded in situ using a portable instrument (WMP-5, produced by Beijing China Invent Instrument Tech. Co., Ltd.) that was placed in the middle of water column at about 0.5m beneath the water surface. And *Secchi* depth (SD) was measured using a *Secchi* disk. Water depth (WD) was also recorded on each sampling occasion. 50mL surface water sample was collected for nutrientmeasurement; including ammonium (NH_4-N), total phosphorus (TP),and 3L surface water sample was collected using 5L Van Dorn sampler for phytoplankton quantitative investigations. The samples for dissolved substance analyses were stored in a pre-cleaned plastic bottle, acidified in situ with sulfuric acid to make pH≤2 and hele on ice until laboratory measurement(Zhang and Huang, 1991). The concentrations of NH_4-N, TP were analyzed on a segmented flow analyzer according to the user manual of the instrument. Appropriate quality control procedures were adopted involving the use of standard samples,blanks and replicates.

The qualitative samples for phytoplankton identification were preserved in situ with standard Lugol's solution. A sedimentation method was used to concentrate 1L of water samples to 30 mL of quantitative sub-samples for phytoplankton species composition and cell abundance analyses, and those sub-samples were fixed in formaldehyde (5% final concentration). Cell abundance was counted and species was identified under microscope (OlympusCX32-32RFL) at×100 and ×400 magnifications.

Additional 800mL sample water was filtered through Whatman GF/F glass filters (0.45 and 0.22μm) for chlorophyll a (chl.a) determination, usually on the same day of collection, and the filter was immediately placed in a dark cooler and packed in ice until the laboratory analysis.Chl a concentration was measured using the non-acidification spectrophotometric method. Chl a was extracted from the filters using 90% acetone in the dark for 24h at 4℃, and the absorptions of the resultant solutions were measured using a spectrometer (UV759s), after centrifugation. Absorptions at 630,647,664 and 750nm were measured and chl a concentration was calculated(Huang et al., 1999).

Following the counting strategy of Jin and Tu(Jin and Tu, 1990), we examined 0.1 mL of sub-sample in a Fuchs-Rosenthal counting chamber, and counted a minimum of 300 visual field at 400× magnifications with an Olympus CX32-32RFL microscope. Phytoplankton abundance was expressed as cell L^{-1}. Taxa were identified to the species level wherever possible following Hu et al(Hu, 2006). Phytoplankton biomass was calculated by the biovolumes and assumed 1mm^3 equals 10^{-6}μg fresh weight. Biovolumes of common phytoplankton taxa were calculated based in cell size measurements for at least 30 individuals and formulae for geometric shapes approximating cell shapes(Zhang and Huang, 1991). For less common taxa, biovolumes were estimated using occasional measurements.

Prior to statistical analysis, the values measured for the environmental variables were ln (x+1) or square-root transformed to achieve the most normal distribution possible and to increase homogeneity within data sets. WT, pH, TP and NH_4-N were used to examine correlations between phytoplankton cell abundance and biomass.

Phytoplankton species abundance and biomass were averaged for each sampling station and was ln transformed in order to obtain a normal distribution within the data sets.

The relationship between biomass, chlorophylla a (chl.a) and other parameters was analyzed using Sigmaplot and the SPSS (SPSS13.0) program. The Pearson test was performed to examine the influence of various environmental variables on phytoplankton community dynamics. Statistical significance was judged by a criterion of p<0.05.

4. Results

River water chemistry

Water temperature showed apparent variation during the study period. The atmospheric temperature was ranged from 1℃to 37℃. The pH value ranged from 7.12 to 8.36, and the mean value was 7.63±0.39.

For the eleven sections (Figure 2), the mean annual water temperature at all study sites in river was 18.1℃, with typical inter-sections variation of about ±6.2℃ for 2011 year. The lowest temperature (~1℃) occurred in January and highest temperatures (~31℃) occurred in July. All sections in the main channel were mesotrophic to eutrophic according to their NH_4-N and TP contents(China, 2002, Cai Qinghua, 1992). Nutrient concentration about 0.06-2.0 mg/L of NH_4-N and 0.03-0.18 mg/L of TP were observed in study sections during 2011 year-study periods. There was a general decrease in trophic state expressed by nutrient concentration from LLZ to WJBsection, and a decrease from LK to HZH section upward the estuary. Seasonal changes of NH_4-N concentration in the HuaiRiver were marked in all study sections compared to present TP, with high concentration in the WJB sections in the midreach of river. There was a peak value at WJB section, and the value decreased sharply to downreach of river (Table 1, Figure 2). The most notable increases in NH_4-N and TP occurred at WJB section, due to the influence of the major tributaries DahongRiver, which passes through urban areas and agricultural lands.

Table 1. Summary of the physical and chemical variables in the 11 sections of HuaiRiver (2011, sample number in each study section=5): Mean±SD, range (mix.-max.)

	Water temp.℃	pH	chl.aμ gL^{-1}	DO mgL^{-1}	COD mgL^{-1}	NH_4-N mgL^{-1}	TP mgL^{-1}	Flow velocity cm/s
LLZ	15.6±6.5(9.7-24.8)	7.5±0.4(7.1-7.9)	2.1±2.3(0.3-5.7)	7.5±2.2(4.5-9.2)	15.9±2.4(14.2-17.6)	0.3±0.3(0.1-0.7)	0.049±0.018(0.03-0.08)	67.3±35.4(3.7-133.4)
GA	15.6±6.8(9.8-25.2)	7.6±0.5(7.1-8.1)	1.5±0.9(0.1-2.5)	9.2±0.6(8.4-9.7)	17.3±2.2(14.8-18.7)	0.3±0.2(0.1-0.6)	0.088±0.014(0.07-0.10)	27.4±16.9(5.1-44.4)
YS	19.6±6.8(12.4-26.1)	7.5±0.1(7.4-7.6)	3.9±5.7(0.6-12.5)	8.3±1.5(7.3-10.1)	18.4±3.8(16.0-22.9)	0.3±0.2(0.1-0.5)	0.078±0.006(0.07-0.08)	11.6±8.8(4.1-24.2)
HB	18.4±6.5(12.3-26.1)	7.3±0.1(7.2-7.5)	0.8±0.4(0.3-1.3)	9.0±0.5(7.3-10.1)	14.9±1.4(13.4-16.1)	0.4±0.1(0.3-0.5)	0.083±0.031(0.04-0.12)	14.2±10.8(3.5-25.7)
WJB	20.1±7.0(14.0-26.9)	7.4±0.2(7.2-7.6)	2.8±2.8(0.8-7.0)	7.5±1.9(5.8-9.7)	16.9±2.7(15.0-20.1)	1.1±0.7(0.3-2.0)	0.143±0.037(0.11-0.18)	14.8±10.0(3.3-23.8)
LK	18.3±7.4(10.6-27.2)	7.7±0.5(7.1-8.3)	3.3±1.5(1.4-4.8)	7.5±2.1(5.0-10.1)	18.1±4.3(14.5-23.0)	0.6±0.5(0.2-1.5)	0.119±0.034(0.09-0.17)	12.8±7.5(4.2-22.5)
XCK	18.8±7.3(10.3-26.5)	7.8±0.5(7.2-8.2)	5.6±0.8(1.5-3.4)	7.7±2.1(4.8-10.0)	14.7±3.6(10.3-18.6)	0.5±0.4(0.2-1.0)	0.086±0.055(0.04-0.16)	6.6±2.4(3.3-8.9)
BBZ	18.4±7.6(9.9-26.3)	7.9±0.4(7.3-8.3)	2.2±5.7(1.6-13.7)	7.9±1.9(5.2-10.0)	13.0±2.1(10.6-14.6)	0.5±0.4(0.3-1.3)	0.058±0.024(0.03-0.09)	27.3±36.5(5.7-81.6)
LH	18.6±7.0(10.8-25.5)	7.4±0.4(7.1-8.1)	1.5±1.2(0.3-1.6)	6.7±1.2(5.6-8.2)	13.4±1.4(11.9-14.6)	0.6±0.1(0.19-1.4)	0.116±0.045(0.09-0.18)	13.2±3.4(8.5-16.0)
XX	17.9±6.9(10.1-24.4)	7.7±0.2(7.5-8.1)	3.7±4.3(1.0-10.2)	7.3±1.7(5.2-9.4)	13.0±3.6(10.3-17.1)	0.4±0.3(0.13-0.84)	0.074±0.021(0.06-0.10)	13.6±1.5(11.9-15.0)
HZH	17.4±6.9(10.0-24.2)	7.8±0.4(7.4-8.3)	3.0±2.5(1.1-7.0)	7.7±2.0(5.1-9.9)	11.1±1.2(10.2-12.8)	0.2±0.1(0.15-0.34)	0.056±0.026(0.03-0.08)	8.3±0.6(7.6-8.9)

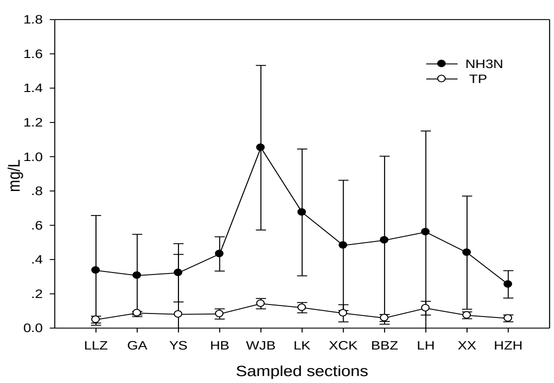

Figure 2. Variation of NH_4-N and TP contents at sampled sections in HuaiRiver averaged over 4 months from March to December 2011.

Seasonal changes of TP concentration in the HuaiRiver were smooth, and the highest content was at WJB section. At the other sections, no clear seasonal variability in both NH_4-N and TP was observed.

Phytoplankton taxonomic composition and community structure

The phytoplankton assemblage comprised 147 taxa (Table 2), which included Chlorophyta (71), Bacillariophyta (31), Cyanophyta (18), Euglenophyta (14), Dinophyta (2), Chrysophyta (5), Xanthophyta (3) and Cryptophyta (3). Phytoplankton community in the mainstream was dominated by Cyanobacteria species, centric diatoms and green algae (Table 2), which accounted for 58.51%, 31.84%and 28.02%, respectively, over all sections averaged. The dominant species were similar at all study sections in spite of the difference in trophic state. High density of *Melosira granulata*, *M.granulata* var. *angustissima*, *Oscillatoria*.sp., *Planktolyngbya subtilis*,*Synedra acus*, *Navicula exigua*, *Asterionella formosa*was observed in year 2011. Seasonal variation of phytoplankton density was dramatic. The average densities were 320.8×10^4 cells/L in September, 207.7×10^4 cells/L in June, 6.9×10^4 cells/L in March, and 20.98×10^4 cells/L in December, respectively. During low water level (in March), phytoplankton abundance was low, ranging from 0.45×10^4cells/L to13.76×10^4cells/L, and the diatom *Melosira granulata* was predominant in the sparse phytoplankton of the upreach of river, but did not exceed a density of 10^2 cells per ml.

Considerable phytoplankton diversity (*H'*) was observed both spatially and seasonally within the sections of the river examined. Average diversity of year 2011 in each reaches was 1.45±0.58 (n=44) at upreach, 1.69±0.50 (n=44) at midreach, and 1.33±0.47 (n=33) at downreach. Parametric two-way ANOVA revealed significant differences in diversity among sections and months (for sections, $p<0.05$, $F=3.11$; months, $p<0.05$, $F=5.01$). Highest diversity was observed at LK section and the diversity significantly decreased as the river runs down except section of HZH (the inlet of Hongze Lake). Much higher diversity was observed in wet seasons (June and September) than dry seasons (March and December). Via the *H'* values, the water quality of Huai River was under moderate pollution stage(Wilhm and Dorris, 1968).

Dominance index showed negative pattern of diversity index. Average diversity of year 2011 in each study section was 0.13±0.11(n=44) at LLZ, 0.17±0.21(n=44) at GA, 0.16±0.17(n=44) at YS, 0.25±0.13(n=44) at HB, 0.09±0.11(n=44) at WJB, 0.08±0.15(n=44) at KL, 0.11±0.13(n=44) at XCK, 0.09±0.14(n=44) at BBZ, 0.10±0.14(n=44) at LH, 0.13±0.15(n=44) at XY, and 0.08±0.17(n=44)at HZH upward the estuary. Parametric ANOVA also revealed significant differences in dominance among sections and months (for sections, $p<0.05$, $F=3.01$; months, $p<0.05$, $F=5.77$). Highest dominance was observed at HB, which showed lowest level in diversity analysis. In all study sections, higher dominance was observed in September. The dominant species were *Melosira granulata*, *M.granulata* var. *angustissima*, *Oscillatoria*.sp., *P. subtilis*, and *Pediastrum biradiatum*.

Seasonal and spatial fluctuation of majorgroups

Almost identical seasonal succession pattern of phytoplankton was observed at all river sections. There was a high proportion of *Melosira* sp. and *P. subtilis* at studied river during the winter (December) and spring (March). Three seasonal phases in the phytoplankton succession were found (Figure 3)

(1)From December to March, the first taxa of dominate were small pennate diatoms and centricae diatoms (*Melosira*, *Synedra*, and *Fragilaria*), follow by cyanophyta (*P. subtilis*). *Melosira granulata* had highest density rather than other phytoplankton species during the winter season.

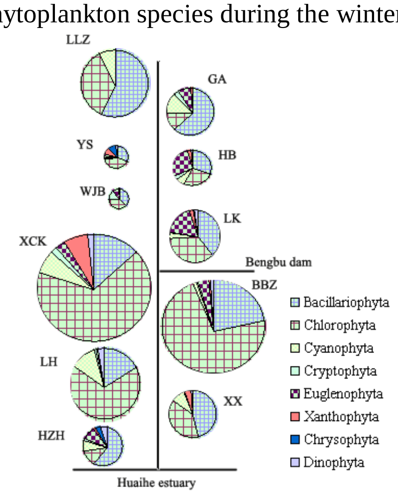

Figure3.Longitudinal dynamics of percent abundance of phytoplankton groups along headwaterto estuary HuaiRiver of 2011 (based on cell biovolume).

In the June, a mixed community immediately followed a rainy season phase. The community was dominated by chlorophyta (*Eudorina elegans*, *Pandorina morum*, and *Pediastrum*), flagellates (cryptophyceae), cyanophyta (*Microcystis*, *Oscillatoria*), and centric diatoms (*M.granulata*, *M.granulata* var. *angustssima f.spiralis*). Large pennate diatoms (*Synedra acus*) began to dominate just before wet season events in September. *Eudorina elegans*, *Pandorina morum* were found in all other seasons except winter. *Pediastrum* began to dominate before summer with rainfall events in June.

(1) In the September (the late summer season), the large diatoms (*Melosira*, *Synedra*) were dominated, being a large diatoms community phase, accompanying with blue-green algae (*Planktolyngbya subtilis*, *Oscillatoria* and *Pediastrum*. *Melosira.granulata* having highest density rather than other phytoplankton species during this autumn season.

The longitudinal percent abundance of major groups in the HuaiRiver was relatively similar (Figure 4). At all study sections, excepted XCK, BBZ and LH sections, the diatom community dominated the phytoplankton during year 2011, producing winter, summer and later fall peaks. The abundance of diatoms was different at each section, and this group occupied 13-60% of the total community. The following group was greens with11-40%, occupying 70% of total community at BBZsection. Although the general succession was similar among sections, certain species showed alongitual pattern. A high proportion coenobial greens (*Pediastrum*) characterized the middle part of the river (233, 203 and 182 km upward the estuary). The groups rapidly declined from XY section (64 km), and the diatoms increased more than two-fold.*Melosira* was abundant at all study sites, but a high abundance of pennate diatoms (*Synedra* and *Navicula*) were also maintained from midreach and after where, it markedly declined at HZH section (0 km upward estuary). The longitudinal transition of centric diatoms was most remarkable. The centric diatom, *Melosira*, maintained dominance down to midreach of the river during spring and autumn, *Melosira granulata* occupying 30% of the total community at the YS section.

Table 2. Percent biovolume of dominant species over 1% of total biomass in main sampling sites of HuaiRiver (2011, n=20)

	Dominant taxa	LLZ	GA	YS	HB	WJB	LK	XCK	BBZ	LHG	XY	HZH
Bacillariophyta	*Melosira varians*	10.57		6.5	3.89	2.35	3.35					
	Tabellaria fenestrata						3.04				0.3	
	Navicula exigua			1.01			2.5		2.1		2	3.05
	Synedra acus	0.09			2.1	2.55		5.76	2.1	0.35	0.23	
	Melosira granulata	1.67	5.72	1.5			3.05	5.07	8.89	3	3.02	0.59
	Asterionella formosa						4.5		8			
	Synedra ulna	1.02						3.88				
	Subtotal	13.35	5.72	9.01	5.99	5.9	16.44	14.71	21.09	3.35	5.55	3.64
Chlorophyta	*Pediastrum duplex*	8.76		10.02	3.2	6.37	3.54	11.05	12.24	4.36	0.55	5.07
	Eudorina elegans	1.97	5.1				2.35	5.07	0.5	10.05	2.01	
	Desmidium aptogonum	3.03		1.04		3.5	7.01	3.02	5.2	5.05	1.05	
	Pandorina morum	7.27			10.02			3.02	5.2			3.05
	Subtotal	21.03		11.06	13.22	9.87	12.9	22.16	23.14	19.46	3.61	8.12
Cyanophyta	*Anabaena variabilis*	1.2		2.05						0.55		
	Microcystis aeruginsa	5.44	1.2	10.05		2.5	1.03	5.9	5.37	5.01	0.05	12.05
	Oscillatoria spp.	3.4		2.5		1.05	4.85		4.43	3.33	5.01	10.05
	Aphanizomenon flos-aquae	7.32							3.2		0.3	
	Planktolyngbya subtilis	10.76			5.65		5.05	9.87	12	8.55	20.01	15.01
	Merismopedia marssonii								3	0.85	0.04	
	Subtotal	28.12		14.6	5.65	3.55	10.93	15.77	28	18.29	5.41	37.11
Cryptophyta	*Cryptomonas erosa*	1.24			10.05	4.54						2.05
	C.ovata	1.94										1.85
Euglenophyta	*Phacus longicauda*				6.55	5.45			0.5	0.13		0.37
	P. acuminatus						0.9	0.15				
	Euglena acus	0.66										0.11
Chrysophyta	*Dinobryon divergens*		0.7	0.32			0.75		0.2		0.02	3.02
	Di.n bavaricum						1.76					0.02
Dinophyta	*Ceratium hirundinella*			2.5			0.09	0.15		0.54		1.05

Algal biomass

Spatial and seasonal variations of phytoplankton biomass (analogized to cell biovolume) were dramatic (Figure 4). Biomass gradually increased toward downreach direction, showing peaks in the middle part of the river (XCK and BBZ upward the estuary). There were statistically significant seasonal and temporal differences in phytoplankton (biomass, ANOVA, for sections, p<0.05, F=2.01; months, p<0.05, F=4.22, n=44). Seasonal fluctuations of biomass at XCK and BBZ sections were more drastic than those of other sections in the HuaiRiver. A summer biomass peak occurred in June (mainly by blue-green algae and diatoms) and a winter peak occurred in December (mainly pennate diatoms) at the same section of XCK and BBZ sections. The biomass data indicated that biomass mainly consisted of chlorophyta. Especially, extreme higher abundance of *Eudorina elegans*, *Pandorina morum* was observed at XCK section (233km upward the estuary). There was little seasonal dynamics of biomass at YS section.

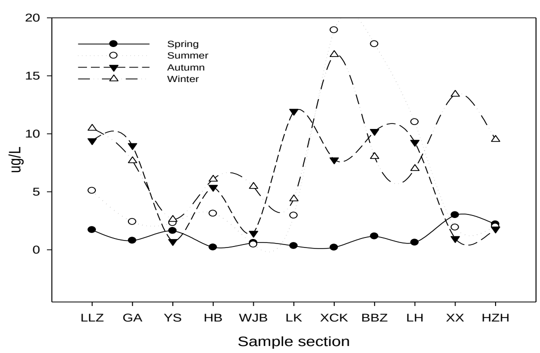

Figure 4. Seasonal changes of phytoplankton biomass concentration in the HuaiRiver from the upstream to downstream reach.

There was a midreach fluctuation by influence of the water retention time and the dam. In the midreach of HuaiRiver, there is a large dam at Bengbu sites (203km). The WJB section has high nutrient concentration (annual mean of NH_4-N, 1.05±0.48mg/L; TP, 0.14±0.03mg/L). In contrast, XCK section has clean water (annual mean of NH_4-N, 0.48±0.38mg/L; TP, 0.09±0.05mg/L).Five-fold increase of alga biomass at XCK section compared with that of WJB section was marked aboveBengbu dam. There was a positive correlation between chl.a and WT in December (r=0.755, p<0.01, r=44), in addition to the weak positive correlation between biomass and NH_4-N contents (r=0.690, p<0.05, r=44) in June.

Cluster analysis using single linkage and the Euclidean distance metric confirmed the existence of spatial and temporal similarities in the relative divisional biovolume between sections (Figure 5). In the year 2011, XCK and BBZ sections had the greatest distance from all other sections, and were closely linked, both with similar dominance species and showed more mixed populations in terms of algal divisions in summer and autumn seasons.

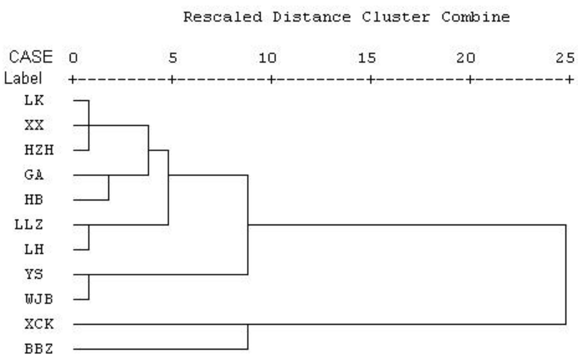

Figure 5. A comparsion of the dominance structure of algal division at the eleven sampled sections using cluster analysis.

5. Discussions

In the HuaiRiver, there were dramatic midstream reach fluctuations in dominant phytoplankton dynamics, concerning about pronounced differences in nutrient concentrations (TP and NH_4-N) and water flow velocity. The changes of phytoplankton diversity in the HuaiRiver were marked and the peak values were all at midreach sections. Different factors and processes acted to control phytoplankton dynamics in the HuaiRiver. Based on the results, the mesotrophic state and hydrologic states could be considered as the major factors determining phytoplankton dynamics and dominance of algal species in this river system. We suspect that along the length of river, a mesotrophic gradient supports a particular succession of phytoplankton, and that the installation of the Bengbu dam, which suppressed flow and increased water residence time, created the reservoir-like channel. When this condition occurred, the hydrological changes depending on precipitation pattern became the main driving factor for phytoplankton succession.

A gradual increase of suspended algae downreach is a typical characteristic of large rivers. This event can be explained by the extra time for plankton to develop as well as greater inputs of nutrients from agricultural lands and cities, which tend to increase downstream in large rivers(Hutchins, 2012). But a progressive increase in planktonic diversity and biomass was observed from the upreach to the midreach sections of the HuaiRiver, and then in the downreach the values decreased. Average diversity of year 2011 was 1.45±0.58 (n=44) at upreach, 1.69±0.50 (n=44) at midreach, and 1.33±0.47(n=33) at downreach. Much higher diversity was observed in wet seasons (June and September) than dry seasons (March and December). In particular, when diatoms was abundant at all study sections in spring and winter seasons, this community consistently had high density in the period of water stagnation and low water velocity conditions. In 2011 study of HuaiRiver, 10 times of higher abundance of phytoplankton at the LK and XCK sections (upward the BBZ dam) than other study sections was observed during long water residence time in dry seasons. The water flow velocity peaked up to 30.11 cm/s and 14.71 cm/s at sections at upreach and midreach, respectively, with the phytoplankton biomass and diversity lower at upreach sections than at midreach sections. The peak of nutrient concentration was observed at WJB section, at the midreach of the river, which intend to increase at midreach in large rivers in China(Eugene Turner et al., 1990), due to the major tributaries of Dahong River inputs of nutrients from cities untreated sewage and agricultural lands. Then at the LK section, with the confluence of clear water rivers (mainly ShiRiver and Pi River) which originate from the DabieMountains, the nutrient concentrationdecreased after WJBsection. Observations on the Vaal, Meuse and Provo rivers and Hong Kong streams also indicated that confluence of the major tributaries related to discharge affect the diversity of phytoplankton communities in the riverine environment(Descy et al., 2012).

The longitudinal patterns of chl *a*concentration in the Huai River did not follow a regular pattern of increase, and the expected pattern of planktonic chlorophyll a in large rivers is of a downreach increase, associated with time available for increase in available nutrients downreach, followed by a decrease as the river deepens and the transparency lowers(Jones, 1984). In the HuaiRiver, the longitudinal patterns of nutrients and chl *a*did not closely match this model. The absence of longitudinal coincidence between nutrients and chl *a* reinforces the role that hydraulicsand perhaps other factors exerts influence on the development in large rivers(Neal et al., 2006, Reynolds and Descy, 1996). Therefore, phytoplankton biomass in the midreach of Huai River could be stimulated by the flush water and longer water retention time (Ha et al., 2002, Sabater et al., 2008).

From upstream reach to the middle-reach, there was a shift from diatoms to green algae, where centric diatoms were dominated by *M.granulata*, *M.granulata* var. *angustssima f.spiralis*, and green algae were *Eudorina elegans*, *Pandorina morum* and *Pediastrum*. Diatoms characterized more turbulent conditions, while chlorophytes were dominated in more lentic conditions(Reynolds, 1988, Sabater et al., 2008). However, large centric diatom communities were frequently observed at the downreach of the river (XY and HZH section).

Both nutrient concentrations and hydrological factors seem to be important to influence phytoplankton community assemblages in this river. Analysis of season data shows that increase in algal biomass that have occurred in recent decades in many East Asia rivers may have resulted from increased nutrient inputs coupled with hydrological changes and river regulation(Eugene Turner et al., 1990, Hu et al., 2008). The river in the present study is large and flow in East China lowlands; and it is suitable habitat for the phytoplankton community. Phytoplankton dynamics and species selection in regulated rivers may be controlled by discharge-related factors, such as hydraulic storage, retention time, confluence of major tributaries and dams, and the results showed that dams had a strong influence on ecohydrological conditions. Hydraulic structure in the river added the habitat complexity occurring in the river and would cause an optimal scenario for phytoplankton growth under more prolonged low flow situation. Whereas low water flows are associated with higher nutrient concentrations which would reinforce phytoplankton mass outgrowth. The clear water tributaries flow into the HuaiRiver could reduce the nutrient concentrations, and Bengbu dam can support ecosystem management and provide ecological operations. The HuaiRiver would be further attaining an acceptable ecological potential.

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