Front. Earth Sci. 2015, 9(1): 137–151
DOI 10.1007/s11707-014-0369-3

RESEARCH ARTICLE

Comparison of the spatial and temporal variability of macroinvertebrate and periphyton-based metrics in a macrophyte-dominated shallow lake

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Abstract The influence of spatial differences, which are caused by different anthropogenic disturbances, and temporal changes, which are caused by natural conditions, on macroinvertebrates with periphyton communities in Baiyangdian Lake was compared. Periphyton and macrobenthos assemblage samples were simultaneously collected on four occasions during 2009 and 2010. Based on the physical and chemical attributes in the water and sediment, the 8 sampling sites can be divided into 5 habitat types by using cluster analysis. According to coefficients variation analysis (CV), three primary conclusions can be drawn : (1) the metrics of Hilsenhoff Biotic Index (HBI), Percent Tolerant Taxa (PTT), Percent dominant taxon (PDT), and community loss index (CLI), based on macroinvertebrates, and the metrics of algal density (AD), the proportion of chlorophyta (CHL), and the proportion of cyanophyta (CYA), based on periphytons, were mostly constant throughout our study; (2) in terms of spatial variation, the CV values in the macroinvertebrate-based metrics were lower than the CV values in the periphyton-based metrics, and these findings may be caused by the effects of changes in environmental factors; whereas, the CV values in the macroinvertebrate-based metrics were higher than those in the periphyton-based metrics, and these results may be linked to the influences of phenology and life history patterns of the macroinvertebrate individuals; and (3) the CV values for the functional-based metrics were higher than those for the structural-based metrics. Therefore, spatial and temporal variation for metrics should be considered when assessing applying the biometrics.

Keywords Baiyangdian Lake, biomonitoring, coefficient variation, structural metrics, functional metrics

1 Introduction

Lakes are notably important freshwater ecosystems because they can provide essential ecosystem services (Costanza et al., 1998). However, due to the increasing impact of anthropogenic activities, such as chemical pollution and the overexploitation of living resources, the ecological quality of many lake ecosystems has seriously deteriorated. A series of policies, such as the 1972 Clean Water Act (CWA) (published by the United States Congress) and the Water Framework Directive (WFD), explicitly recognized that the assessment of the status of the ecological quality of lakes has become increasingly important (Borja, 2005). Therefore, the development of reliable and effective methods to assess the status of aquatic ecosystems has been a primary objective of resource managers (Beck et al., 2010).

Aquatic organisms, which integrate all biotic and abiotic parameters into their habitats, can provide a continuous record of environmental quality and reveal various environmental changes from natural and anthropogenic origins (Gold et al., 2002). Therefore, biomonitoring offers some obvious advantages, including a high level of sensitivity, high integration, and wide applicability (Zhou et al., 2008). Biomonitoring is largely based on bioindicators, which are highly useful in biomonitoring and recording biologic responses. Bioindicators, including fish (Karr, 1981; An et al., 2002), plants (Rothrock et al., 2008), diatoms (Seele et al., 2000; Kireta et al., 2012), macrophytes (Beck et al., 2010; Moore et al., 2012), phytoplanktons (Xu et al., 2001; Fano et al., 2003), birds (O'Connor et al., 1998; Sorace et al., 2002), macrobenthos

Received January 24, 2013; accepted March 6, 2014

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(Borja et al., 2000; Gabriels et al., 2010), periphytons (Griffith et al., 2005), and other types of species (Wefering et al., 2000) have been used.

Macroinvertebrate and periphyton communities have been widely examined due to their utility as bioindicators (Hill et al., 2000; Blocksom et al., 2002) in lake ecosystems, especially for lakes with high levels of existing anthropogenic disturbances (Ma et al., 2011). The advantages of macroinvertebrate communities include their sedentary ecology and the relative simplicity of qualitative field sampling. The disadvantages involve variation in the distribution of individuals, laborious taxonomic identification, and high temporal variability. Periphyton assemblages have relatively simple sampling protocols and are useful for paleolimnology, but they have high temporal variability (Berkman and Rabeni, 1987; USEPA, 1998a, b; Tangen et al., 2003; Beck and Hatch, 2009). The differences in physical and chemical tolerances among taxa, differences in life-history (Wallace and Anderson, 1996; Hill et al., 2000), recolonization mechanisms, and biogeography of taxa among these assemblages (Barbour et al., 1999; Angermeier et al., 2000) may affect their responses to changes in anthropogenic disturbances and natural conditions within an aquatic ecosystem (Townsend and Hildrew, 1994). Thus, in order to select appropriate biometrics, spatial and temporal distributions of benthic macroinvertebrate communities have been studied in lakes in relation to predation by fish (Gilinsky, 1984; Diehl, 1992), eutrophication (Bazzanti and Seminara, 1995), drought (Gérard, 2000), and the effects of biologic assessment (Johnson, 1998; Kashian and Burton, 2000; Hamalainen et al., 2003). In contrast, few studies have dealt with the effects of the spatial and temporal variation of periphyton communities on the biologic assessment of lakes (Ledger and Hildrew, 1998). In addition, within a lake, few studies have compared the spatial difference and temporal variation of these assemblages when collected concurrently at different occasions and habitats.

Therefore, in order to select appropriate biometrics for a lake, it is essential to understand temporal variations, caused by natural origins, and spatial differences, caused by anthropogenic origins, of ecological communities in biomonitoring studies because these factors may obscure biomonitor results (Trigal et al., 2006; Kröncke and Reiss, 2010). In this study, our objectives were to (i) assess the variability of a number of macroinvertebrate and periphyton metrics that are potentially useful as bioindicators, (ii) evaluate the spatial and temporal variation of metrics in biomonitoring programs, and (iii) evaluate the difference in variability for structural and functional-based metrics for a Chinese macrophyte-dominated shallow lake. Baiyangdian Lake was chosen as the study case because of its physical and chemical characteristics and a plant community that is representative of other lake habitats in the region.

2 Material and methods

2.1 Study site

Baiyangdian Lake (38°44′–38°59′N, 115°45′–116°06′E) has an area of approximately 366 km^2 and is located in the city of Baoding in the Hebei Province, China. It is a typical macrophyte-dominated shallow lake with an average depth of 2–4 m, surrounded by roughly 143 lake parks adjacent to 36 villages and 67 km^2 of reed marshes on the North China Plain. The water area of the lake changes according to hydrological conditions. Annual precipitation is 350–750 mm, and annual evaporation is 1,750 mm. The *Phragmites australis var. bai-yangdiansis* is the most dominant macrophyte, although other submerged vegetation species such as *Ceratophyllum Linn.*, *Potamogeton pectinatus*, and *Myriophyllum L.* may be numerically important. Because of rapid population growth and economic development in the drainage area of the lake during recent decades, this region has suffered intensive anthropogenic disturbances, particularly with the Fu River serving as the only inflow river, which brings in a large quantity of pollutants and intercepted runoff from the dam established along its upper reaches. In addition, non-point source pollution arising from the daily lives of residents, aquaculture, farming, and villages cause excessive nutrient-rich pollutants to discharge into the lake directly. Recently, Baiyangdian Lake has been designated meso-trophic-eutrophic (Zhang et al., 2013).

2.2 Sampling methods

Eight study sites were located in water depths between 1.11–2.01 m, and the anthropogenic levels were different in these sampling sites (Table 1). Sampling dates were selected depending on biologic community development. Samples were collected in late June 2009 (maximum peak vegetation), late August 2009 (maximum periphyton peaks), early November 2009 (minimum benthic macroinvertebrates), and early April 2010 (beginning of the growing season).

2.2.1 Physical and chemical parameters

Five 4 L samples of lake water were collected in low-density polyethylene containers, appropriately filtered, and preserved in the field and the laboratory until analysis. Water depth (WD), temperature (T), pH, and dissolved oxygen (DO) were determined directly in the field. Ammonium (NH_4–N), chemical oxygen demand (COD_{Mn}), biochemical oxygen demand (BOD_5), and the remaining parameters were determined according to standard protocols (CBEP, 2002) (Table 2). Total organic carbon (TOC) was measured with a carbon analyzer. With the exception of T and pH, the mean values for the

Table 1 The anthropogenic disturbance levels of the sampling sites

Sample site	Coordinates	Land-use characteristics
S1	N38.9044° E115.9238°	Greatly influenced by wastewater inflow from Baoding City
S2	N38.9045° E115.9348°	Greatly influenced by wastewater inflow from the Fu River, minor aquaculture, small village
S3	N38.9177° E116.0114°	Major aquaculture, dense village
S4	N38.9407° E115.9997°	Minor aquaculture
S5	N38.9021° E116.0804°	The outlet of the Baiyangdian, minor human disturbances
S6	N38.8604° E116.0282°	Major aquaculture, near to village
S7	N38.8249° E116.0102°	Minor aquaculture, small village
S8	N38.8470° E115.9506°	Major aquaculture, dense village

Table 2 General water quality characteristics at the 8 sampling sites

Sample site	T/°C	pH	DO /($\mathrm{mg \cdot L^{-1}}$)	NO_3^- /($\mathrm{mg \cdot L^{-1}}$)	NO_2^- /(mg/L)	NH_4^+–N /($\mathrm{mg \cdot L^{-1}}$)	TN /($\mathrm{mg \cdot L^{-1}}$)	PO_4^{3-}–P /($\mathrm{mg \cdot L^{-1}}$)	TP /($\mathrm{mg \cdot L^{-1}}$)	SO_4^{2-} /($\mathrm{mg \cdot L^{-1}}$)	Cl^- /($\mathrm{mg \cdot L^{-1}}$)	TOC /($\mathrm{mg \cdot L^{-1}}$)
S1	20.75	7.90	4.15	2.14	0.24	7.59	10.80	0.60	0.41	169.93	160.85	5.35
S2	19.88	7.90	4.75	2.02	0.21	6.69	9.05	0.27	0.22	152.26	143.96	6.35
S3	20.63	8.13	6.95	0.69	0.13	2.55	5.76	0.42	0.19	142.67	163.70	9.58
S4	22.80	8.05	8.93	0.20	ND	1.54	2.51	0.03	0.07	99.64	135.21	10.85
S5	21.18	8.13	7.10	0.67	0.05	1.34	1.28	0.02	0.03	78.20	118.08	8.20
S6	20.70	8.10	8.63	0.73	ND	1.67	1.94	0.03	0.06	88.27	141.23	8.85
S7	20.40	8.33	7.93	0.24	ND	1.51	1.92	0.02	0.04	90.51	125.71	10.45
S8	21.13	8.13	7.35	0.67	0.05	2.62	3.68	0.23	0.16	156.355	148.06	8.95

Note: ND represents not detected.

examined environmental parameters in Baiyangdian Lake exceeded the standards for surface water (GB 3838-2002).

Sediment samples were collected in triplicate at each site using a 0.0625 m^2 Peterson grab. Sediment samples for physical and chemical analysis were transferred to re-sealable plastic bags, placed on ice, and sent to the analytical laboratory. The collected sediment samples were air-dried and sieved through a 2 mm polyethylene sieve to remove stones and plant roots. Sediment pH was measured in suspension (soil∶water, 1∶2.5) with glass pH electrodes (Lu, 2000). TN and TP were determined according to standard protocols (GB 7173-1987 and GB 9387-1988). The organic carbon contents in the soil were determined using the potassium bichromate method (Institute of Soil Science, Chinese Academy of Sciences, 1978). A laser grain-size analyzer was used to analyze the mechanical composition of the sediment (Table 3). The sediment samples were ground with a wooden roller by hand until fine particles (<0.149 mm) were obtained. TOC_s, and dissolved organic carbon (DOC) were measured according to the method based on GB 9834-1988 and GB 7857-1987.

Table 3 Physical-chemical variables of the sediment at the 8 sampling sites

Sample site	Grain size (Gr)/%			TOC_s	DOC	TN_s	TP_s
	Gr < 2 μm	2 μm < Gr < 50 μm	Gr > 50 μm	/($\mathrm{mg \cdot kg^{-1}}$)	/($\mathrm{mg \cdot kg^{-1}}$)	/($\mathrm{mg \cdot kg^{-1}}$)	/($\mathrm{mg \cdot kg^{-1}}$)
S1	0.39	64.85	34.76	7.45	0.19	3.20	2.69
S2	0.27	60.83	38.90	9.47	0.35	1.81	1.75
S3	0.64	54.23	45.13	9.16	0.16	1.71	2.28
S4	0.08	42.78	57.14	37.80	0.27	1.83	1.38
S5	0.04	41.95	58.01	13.70	0.30	1.32	1.29
S6	0.00	27.48	72.52	25.60	0.15	2.14	1.12
S7	0.00	24.62	75.38	52.10	0.34	1.92	1.44
S8	0.70	56.28	43.02	27.05	0.24	2.20	1.64

2.2.2 Benthic communities collection

Benthic macroinvertebrate samples were collected with a 1/16 m^2 Peterson grab, and three replicate samplings were taken at each of the eight stations. The samples were sieved through 0.595 mm mesh and fixed in 5% buffered formaldehyde. After sorting and determining the species abundance, the organisms were preserved in 75% alcohol. In the laboratory, samples were identified to the lowest possible taxonomic level, which were usually genera. Several macroinvertebrate metrics were calculated using the corresponding methods (Table 4).

To obtain the periphyton sample, an artificial substrate (carbon fiber) was exposed in the littoral zone. Three Perspex carriers with 10 activated carbon fiber coupons (each fiber was 2 cm wide and 10 cm long) were placed near the Phragmites bed of every sampling site. The carriers were placed horizontally and positioned at a depth of 20 cm below the water surface. The fibers were placed vertically and exposed to lake water for 15 days. The samples were scratched off by brush tweezers, and the fibers were repeatedly washed with sterile water to ensure that no periphyton residues remained on the fibers. The detached periphyton samples were subsequently divided into two parts. One part of the wet periphyton samples was added to a 5% formalin solution in filtered lake water for composition studies, and the other part of the wet periphyton was transferred into plastic bottles for other studies.

Several periphyton attributes were analyzed in periphytons grown on activated carbon fibers (TK-1600, Jiangsu Tongkang Activated Carbon Fiber co., Ltd., China, specific area was 1,450–1,550 $m^2 \cdot g^{-1}$, pore size was 18–21 A). Samples taken for structural (chlorophyll, ash-free dry weight, algal density and composition, polysaccharide content) and functional (extracellular enzyme activities) attributes were transported into the laboratory in a dark, cool box. Samples for chlorophyll and polysaccharide content were kept frozen until analysis. The analysis method of the ash-free dry weight (AFDW), chlorophyll concentration, polysaccharide content (PSC), extracellular enzyme activities, and algal density and composition was shown in our previous study (Table 5).

Table 4 The 12 metrics in the macroinvertebrate community of Baiyangdian Lake

Metric type		Metric	Definition	References
Structural Metrics (10)	Tolerance metrics	Hilsenhoff biotic index (HBI)	$\sum_i p_i t_i$, where p_i is the proportion of individuals in taxon i and t_i is the PTV for taxon i	Hilsenhoff, 1987; Plafkin et al., 1989
		Percent tolerant taxa (PTT)	(Number of tolerant taxa/all taxa) *100	Blocksom et al., 2002
		Percent intolerant taxa (PIT)	(Number of intolerant taxa/all taxa) *100	Lewis et al., 2001;
	Richness metrics	Taxa richness (TR)	Total number of distinct taxa in the sample	Barbour et al., 1996
		Number of Diptera taxa (NDT)	Number of Diptera taxa	Blocksom et al., 2002
	Composition metrics	Percent non-insects (PNI)	(Number of non-insects taxa/all taxa) *100	Mason et al., 1971; Lewis et al., 2001; Blocksom et al., 2002
		Percent chironomidae (PC)	(Number of chironomidae taxa/all taxa) *100	Brinkhurst et al., 1968; Trigal et al., 2006
		Percent dominant taxon (PDT)	(Number of individuals in the dominant taxon / total individuals in the sample) *100	Plafkin et al., 1989; Trigal et al., 2006
		Community loss index (CLI)	$CLI = \frac{d-a}{e}$, where a is the number of taxa common to both stations; d is the total number of taxa percent at a reference station; and e is the total number of taxa percent at the station of comparison	Plafkin et al., 1989; Lewis et al., 2001
		Community similarity index (CSI)	$CSI = \frac{2C}{A+B}$, where A is the total number of taxa at reference station; B is the total number of taxa at comparison station; and C is the number of taxa common to both stations	Plafkin et al., 1989; Lewis et al., 2001
Functional metrics (2)	Trophic metrics	Percent collector-gatherer taxa (PCGT)	(Number of collector-gatherers taxa/all taxa)*100	Blocksom et al., 2002; Trigal et al., 2006
		Percent predators (PP)	(Number of predators taxa/all taxa)*100	Blocksom et al., 2002; Trigal et al., 2006

Notes: The range of pollution tolerance value (PTV) is 0–10, ($PTV < 4$ Intolerant taxa; $4 \leqslant PTV \geqslant 6$ Facultative taxa; $PTV > 6$ Tolerant taxa); PTV values are described in USEPA, 1999. (PFT = Percent Facultative Taxa, due to the PFT can be obtained by the PIT and PTT, so we did not list the metrics).

Table 5 The 14 metrics in the periphyton community of Baiyangdian Lake

Metrics type	Metrics Metrics	References
Structural metrics (9)	Algal density (AD)/(10^4 cells·cm^{-2})	Sierra and Gomez, 2007
	Chlorophyll a (Chl a)/(μg·cm^{-2})	Ma et al., 2011
	Chlorophyll b (Chl b)/(μg·cm^{-2})	Ma et al., 2011
	Chlorophyll c (Chl c)/(μg·cm^{-2})	Ma et al., 2011
	Chlorophyll b/ Chlorophyll a (Chl b/a)	Ma et al., 2011
	Chlorophyll c/ Chlorophyll a (Chl c/a)	Ma et al., 2011
	The proportion of bacillariophyta (BAC)/%	Ma et al., 2011
	The proportion of chlorophyta (CHL)/%	Ma et al., 2011
	The proportion of cyanophyta (CYA)/%	Ma et al., 2011
Functional metrics (5)	Alkaline phosphatase (APA)/(nmol·cm^{-2}·h^{-1})	Findlay and Sinsabaugh, 2006
	β- Glucose Glycosidase (GLU)/(nmol·cm^{-2}·h^{-1})	Findlay and Sinsabaugh, 2006
	Leucine amino peptide enzymes (LEU) /(nmol·cm^{-2}·h^{-1})	Findlay and Sinsabaugh, 2006
	Polysaccharide content (PSC)/(mg·cm^{-2})	Ma et al., 2011
	Ash-free dry weight (AFDW)/(μg·cm^{-2})	Fellows et al., 2006

2.3 Metric selection and data analysis

Spatial and temporal variations of macroinvertebrate and periphyton assemblages were analyzed in terms of taxon richness and relative abundance. Due to the reduced number of studies focusing on macroinvertebrate and periphyton communities as indicators of water quality in Baiyangdian Lake, biotic metrics were chosen by reviewing the literature for those that would be appropriate for lakes (Brinkhurst et al., 1968; Mason et al., 1971; Hilsenhoff, 1987; Plafkin et al., 1989; Barbour et al., 1996; Lewis et al., 2001; Blocksom et al., 2002; Fellows et al., 2006; Findlay and Sinsabaugh, 2006; Sierra and Gomez, 2007; Lunde and Resh, 2012; Ma et al., 2011). We selected 12 metrics based on the macroinvertebrate community (Table 4), and selected 14 metrics based on the periphyton community, these metrics can be subdivided into structural and functional types (Table 5).

2.4 Statistical analysis

2.4.1 Cluster analysis

To investigate the relationships between the physical-chemical variables and the biotic indices, non-parametric Spearman rank correlation was used, due to a non-normal distribution of the data. Significance levels were represented by $*p < 0.05$ and $**p < 0.01$. Statistical analyses were performed using SPSS 16.0. Samples were classified according to their physical-chemical and biologic composition, and hierarchically agglomerative cluster analysis based on minimum variance strategy with the Squared Euclidian Distance as dissimilarity index was chosen (Jongman et al., 1987) as the statistical method.

2.4.2 Coefficients of variation

Coefficients of variation, expressed as percentages, were used to quantify the effect of among-habitat (5×habitat) and seasonal (4×month) variations on the selected metrics (Johnson, 1998). As a preliminary approach, metrics with a coefficient of variation of less than 50% were considered to be potentially useful in the assessment of water quality in the lake (Kashian and Burton, 2000; Trigal et al., 2006).

Among-habitat variability over the one-year cycle ($CV_{\text{h-month}}$) was calculated as the coefficient of variation among the 5 habitats over the four sampling dates in the year 2009–2010:

$$CV_{\text{h}-\text{month}} = \sum CV_{(\text{h})\text{m}}/m, \qquad (1)$$

where $CV_{(\text{h})\text{m}}$ (where h refers to habitat and m refers to months) is the coefficient of variation among the 5 habitats on each sampling occasion (June 2009, August 2009, November 2009, and April 2010), and m is the number of sampling dates (4×month).

Seasonality (CV_{s}) was calculated as the coefficient of variation among the four sampling dates (June 2009, August 2009, November 2009, and April 2010). The coefficient of variation was estimated for each habitat type, and the mean value was taken over the four habitats:

$$CV_{\text{s}} = \sum CV_{(\text{m})\text{h}}/h, \qquad (2)$$

where $CV_{(\text{m})\text{h}}$ is the coefficient of variation among the four sampling dates (June 2009, August 2009, November 2009, and April 2010) for each habitat type, and h is the number of habitats (5×habitat).

3 Results

3.1 The habitat type

General water quality characteristics and sediment parameters measured at the 8 sampling sites are summarized in Tables 2 and 3. Significant differences ($p < 0.01$) in DO, PO_4^{3-}, TN, TP, NH_4^+, NO_3^-, NO_2^-, Cl^-, SO_4^{2-}, TOC, and DOC were observed between lake's inlet (S1, S2) and outlet (S5). The sampling sites were divided into 5 habitat types based on these eight microhabitats, which included physical and chemical parameters in the water and sediment, through hierarchically agglomerative cluster analysis. S1 served as Habitat 1, S2 and S8 served as the Habitat 2, S3 served as Habitat 3, S5 served as Habitat 4, and S4, S6, and S7 served as Habitat 5 (Fig. 1).

3.2 Among habitat variability caused by anthropogenic origins

Among the 13 taxa collected in Baiyangdian Lake, 4 taxa were taken from Habitat 1, 6 taxa from Habitat 2, 5 taxa from Habitat 3, 8 taxa from Habitat 4, and 8 taxa from Habitat 5. The highest difference in the relative abundance of macroinvertebrates was PIT; while the lowest difference was PFT (Fig. 2). The tolerant taxa (*Chironomus plumosus* and *Glyptotendipes* sp.) was the dominant group in Habitats 1 and 2 (values over 68%), followed by facultative taxa (*Tendipes insolita*) (values below 32%). Habitat 3 was dominated by facultative taxa (*Cipangopaludia Chinensis* and *Bellamya purificata*) (value over 52%), followed by tolerant taxa (*Tokunagayusurika akamushi*) (value over 42%), and the intolerant taxa were rare comparatively. In Habitats 4 and 5 facultative taxa (*Cipangopaludia Chinensis* and *Cipangopaludina Cathayensis)* were highly represented, followed by intolerant taxa (*Caridina denticulate*), and the intolerant taxa were comparatively common (Table 6).

For the tolerance metrics, the $CV_{\text{h-month}}$ was below 50% for HBI ($CV_{\text{h-month}}$ = 26.7%) and PTT ($CV_{\text{h-month}}$ = 39.8%), while the $CV_{\text{h-month}}$ of PIT was up to 144.5%. Increases in the CV values were noticed for the HBI ($CV_{\text{h-month}}$ = 29.5%), PTT ($CV_{\text{h-month}}$ = 63.9%), and PIT ($CV_{\text{h-month}}$ = 223.6%) metrics in August of 2009. For the richness metrics, the $CV_{\text{h-month}}$ of TR ($CV_{\text{h-month}}$ = 62.2%) and NDT ($CV_{\text{h-month}}$ = 65.7%) were high, with CV values exceeding 60% on most occasions. For composition metrics, the $CV_{\text{h-month}}$ for PNI ($CV_{\text{h-month}}$ = 90.9%), PC ($CV_{\text{h-month}}$ = 80.6%), and CSI ($CV_{\text{h-month}}$ = 71.9%) were higher than 70%, while the PDT ($CV_{\text{h-month}}$ = 29.0%) and CLI ($CV_{\text{h-month}}$ = 48.9%) were lower than 50%. For the trophic metrics, the CV values for PCGT ($CV_{\text{h-month}}$ = 73.1%) and PPT ($CV_{\text{h-month}}$ = 69.0%) were higher than 50% on all sampling dates (Table 7).

Among the 3 algal taxa collected in the lake, CHL was the dominant group in each habitat. In Habitat 1, the annual average percentage of CHL was 62.38%, CYA was 26.42%, and BAC was 11.2%. The algal composition in Habitats 2 and 3 was similar to that in Habitat 1. The annual average percentage of CHL was above 57%, followed by CYA (above 22%) and BAC (below 17%). In Habitats 4 and 5, CHL was above 54%, followed by BAC (above 22%), and CYA (below 20%). It can be seen from Fig. 3 that the maximum difference in algal composition was BAC, and the minimum difference was CHL.

For the structural metrics, the $CV_{\text{h-month}}$ of AD ($CV_{\text{h-month}}$ = 40.2%), Chl c ($CV_{\text{h-month}}$ = 44.2%), Chl b/a ($CV_{\text{h-month}}$ = 43.6%), BAC ($CV_{\text{h-month}}$ = 37.5%), CHL ($CV_{\text{h-month}}$ = 7.8%), and CYA ($CV_{\text{h-month}}$ = 25.3%) were lower than 50%, while the $CV_{\text{h-month}}$ of Chl a ($CV_{\text{h-month}}$ = 55.9%), Chl b ($CV_{\text{h-month}}$ = 81.3%), and Chl c/a ($CV_{\text{h-month}}$ = 68.9%) were higher than 50%. Increases in the CV values were noticed for Chl a ($CV_{\text{h-month}}$ = 74.5%) and Chl b ($CV_{\text{h-month}}$ = 96.4%) in June 2009, and Chl c/a ($CV_{\text{h-month}}$ = 85.5%), BAC ($CV_{\text{h-month}}$ = 60.5%), and CYA ($CV_{\text{h-month}}$ = 45.5%) in November 2009 (Table 7). For the functional

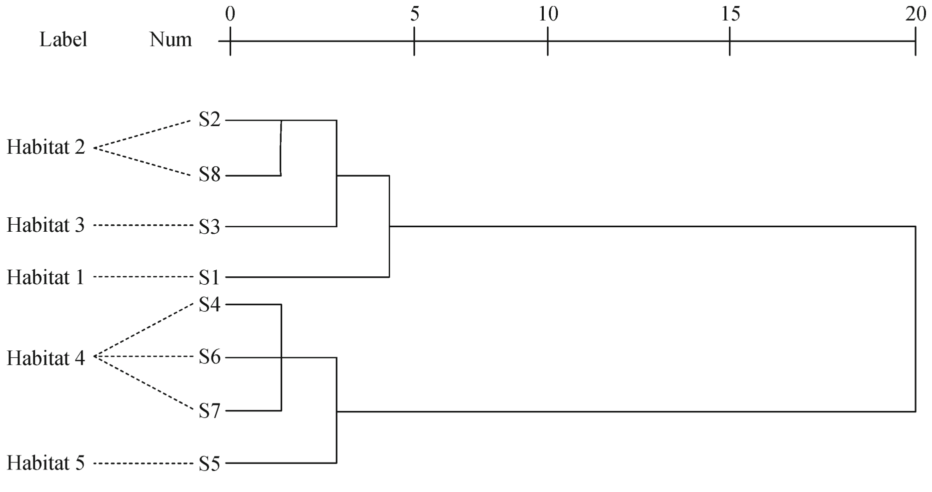
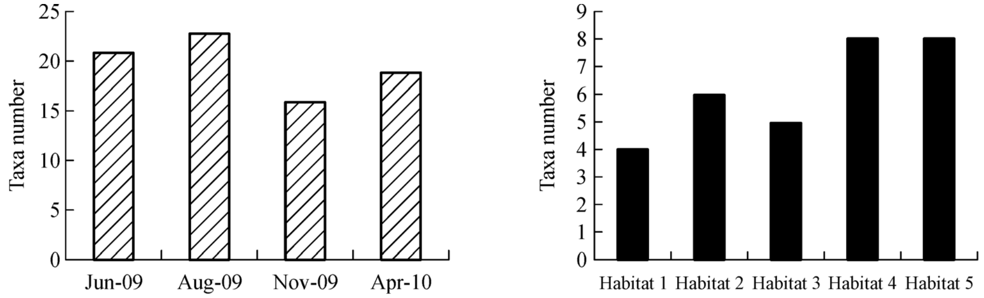
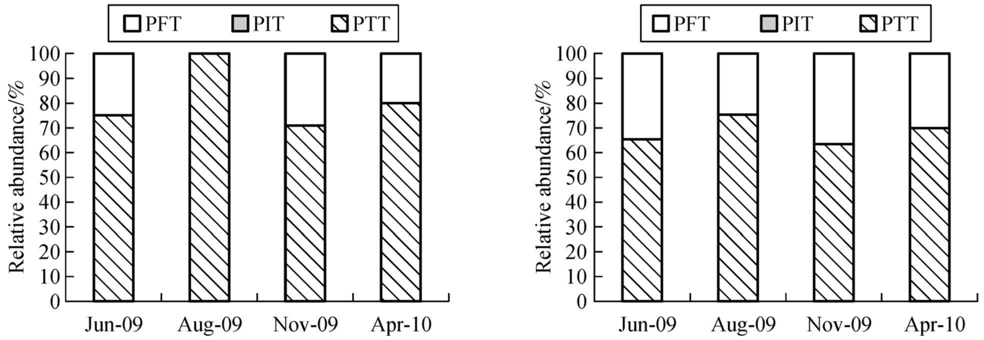


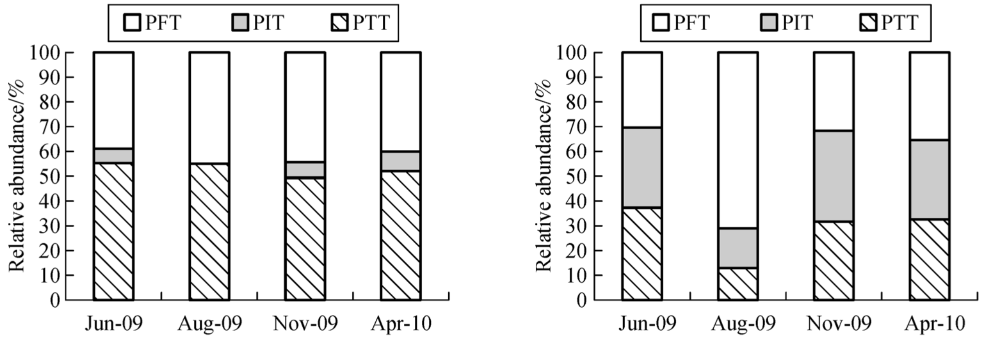
Fig. 1 The cluster results of sampling sites based on physical and chemical parameters of water and sediment.



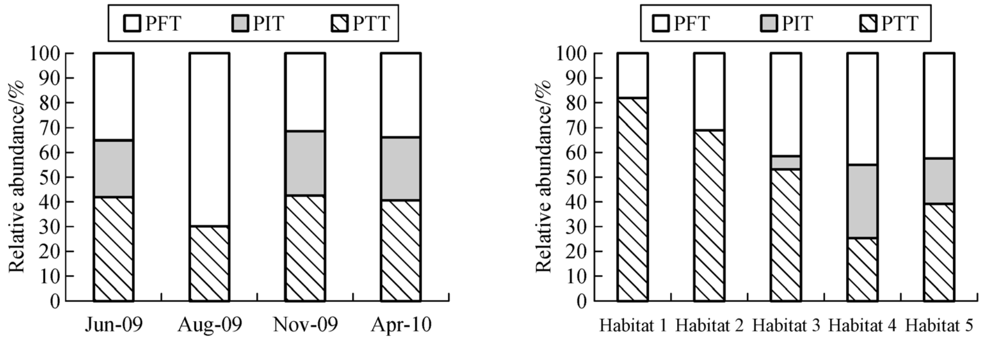
(a) Seasonal variations of total richness (b) Among-habitat variations of total richness



(c) Seasonal variations in Habitat 1 (d) Seasonal variations in Habitat 2



(e) Seasonal variations in Habitat 3 (f) Seasonal variations in Habitat 4



(g) Seasonal variations in Habitat 5 (h) Among-habitat variation

Fig. 2 Among-habitat and temporal variations of the relative abundance of macroinvertebrate taxa collected from 5 habitats on each sampling occasion (PTT = percent tolerant taxa; PIT = percent intolerant taxa; PFT = percent facultative taxa).

metrics, the $CV_{\text{h-month}}$ was higher than 50%. Important declines were also noticed for the CV values of APA ($CV_{\text{h-month}}$ = 39.3%) and GLU ($CV_{\text{h-month}}$ = 40.0%) in April 2010, LEU ($CV_{\text{h-month}}$ = 26.7%) and PSC ($CV_{\text{h-month}}$ = 31.0%) in June 2009, and AFDW ($CV_{\text{h-month}}$ = 33.6%) in August 2009 (Table 8).

3.3 Seasonal variation caused by natural variation

The results presented in Fig. 4 indicate that total taxa richness showed a seasonal trend. The maximum and minimum values were reached in August (23) and November (16), respectively. Sharp declines in facultative

Table 6 Benthic macroinvertebrate composition of Baiyangdian Lake

Phylum	Scientific name	Kinds of taxa	Habitat 1	Habitat 2		Habitat 3	Habitat 4	Habitat 5		
			S1	S2	S8	S3	S5	S4	S6	S7
Annelida	*Whitmania pigra*	Facultative taxa						o		
Mollusca	*Cipangopaludia chinensis*	Facultative taxa			X	X	X	X	X	X
	Cipangopaludina cathayensis	Facultative taxa				o	+	o		
	Bellamya purificata	Facultative taxa				X	X	X	XX	O
	Radix sp.	Tolerant taxa					o		o	o
	Bithynia sp.	Tolerant taxa			X		X	X	+	O
Arthropoda	*Caridina denticulata*	Intolerant taxa				o	O	o		
	Eriocheir sinensis	Tolerant taxa					o			
	Tokunagayusurika akamushi	Tolerant taxa	O	+	O	X				XX
	Tendipes insolita	Tolerant taxa	+	O						
	Chironomus plumosus	Tolerant taxa	XX	XX	X					
	Glyptotendipes sp.	Tolerant taxa	X	O						
	Pantala flarescens	Tolerant taxa					o			

Notes: Abundance classes of the macroinvertebrate taxa are indicated by o: < 2%; +: 2%–5%; O: 5%–10%; X: 10%–50%; XX:50%–95%

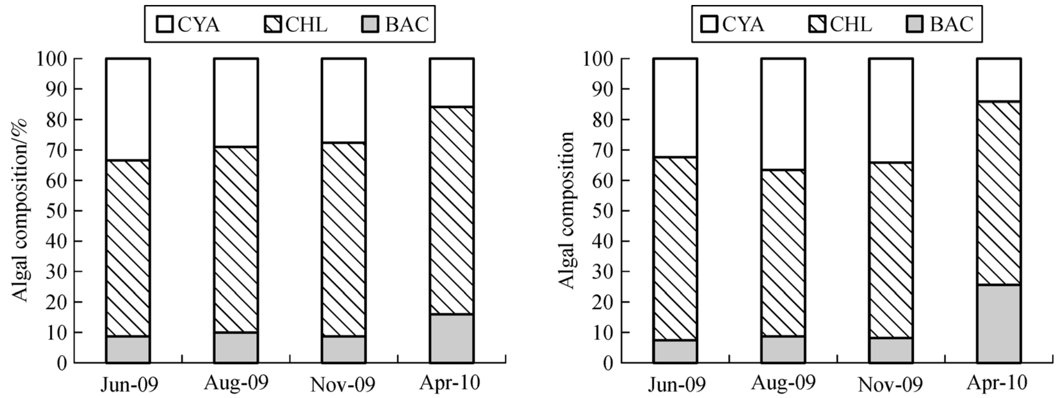
Table 7 Coefficients of variation expressed as percentages for the 12 selected biologic metrics in the macroinvertebrate community

Metrics	Coefficients of among-habitat variability/%				
	$CV_{\mathrm{(h)m}}$ Jun 09	$CV_{\mathrm{(h)m}}$ Aug 09	$CV_{\mathrm{(h)m}}$ Nov 09	$CV_{\mathrm{(h)m}}$ Apr 10	$CV_{\mathrm{h\text{-}month}}$
HBI	23.7	29.5	26.5	27.4	26.7
PTT	29.1	63.9	30.3	36.0	39.8
PIT	120.2	223.6	120.1	114.1	144.5
TR	95.8	28.1	70.8	54.3	62.2
NDT	81.4	68.2	60.1	53.4	65.7
PNI	59.5	97.9	104.0	102.5	90.9
PC	90.7	99.9	59.4	72.7	80.6
PDT	29.3	30.1	31.4	25.2	29.0
CLI	23.1	49.4	61.2	62.2	48.9
CSI	46.3	92.7	64.9	83.9	71.9
PCGT	65.9	73.2	71.9	81.4	73.1
PPT	56.7	69.8	72.4	76.9	69.0

Notes: $CV_{\mathrm{(h)m}}$ among-habitat variability for each sampling period; $CV_{\mathrm{h\text{-}month}}$ among-habitat variability over the one-year cycle.

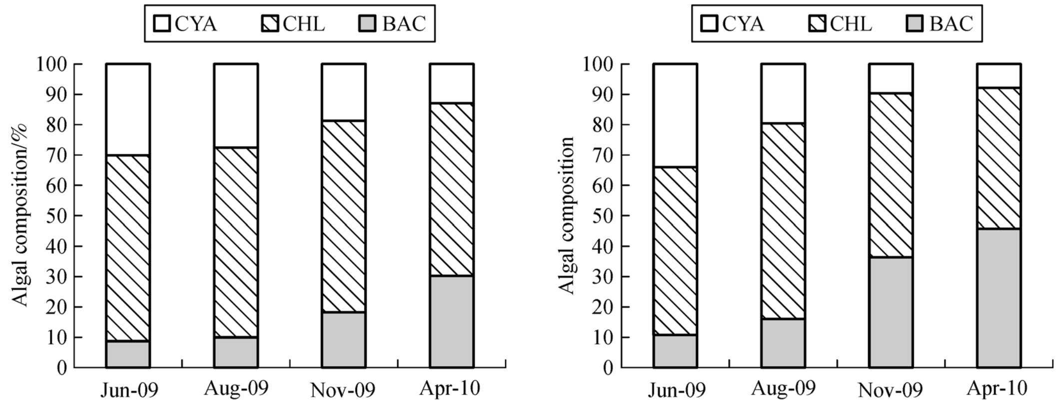
taxa richness were noted in November 2009. These variations were mainly represented by the disappearance of Mollusca from Habitats 4 and 5 in November 2009. The variation of tolerant taxa and intolerant taxa slightly declined in November 2009. The highest densities of macroinvertebrates taxa appeared in August and declined in November, April, and June. Tolerant taxa were the tolerance group that contributed most to the total density on any occasion, followed by facultative taxa and intolerant taxa (Fig. 4).

The lowest CV_{s} was measured for PDT (CV_{s} = 4.5%), while the highest CV_{s} was measured for PNI (CV_{s} = 106.8%). For the tolerance metrics, the CV_{s} of HBI (CV_{s} = 4.9%) and PTT (CV_{s} = 16.5%) were usually lower than 50%, while the CV_{s} of PIT (CV_{s} = 55.2%) was higher than 50%. For the richness metrics, the CV_{s} of TR (CV_{s} = 50.7%) was higher than 50%, while the CV_{s} of NDT (CV_{s} = 35.3%) was lower than 50%. For the composition metrics, the CV_{s} of PNI (CV_{s} = 106.8%), PC (CV_{s} = 52.0%), and CSI (CV_{s} = 67.3%) were higher than 50%, while the PDT (CV_{s} = 4.5%) and CLI (CV_{s} = 26.6%) were lower than 50%. For the trophic metrics, the CV_{s} of PCGT (CV_{s} = 59.3%) and PPT (CV_{s} = 69.5%) were higher than 50%. The results demonstrated the CV_{s} of macroinvertebrate metrics with significant differences, such as PIT (30.6%–67.8%), PNI (25.8%–200.0%), PC (18.0%–87.4%), and CSI (15.9%–200.0%), with higher CV values, and those with lower CV values, HBI (2.9%–6.6%), PTT



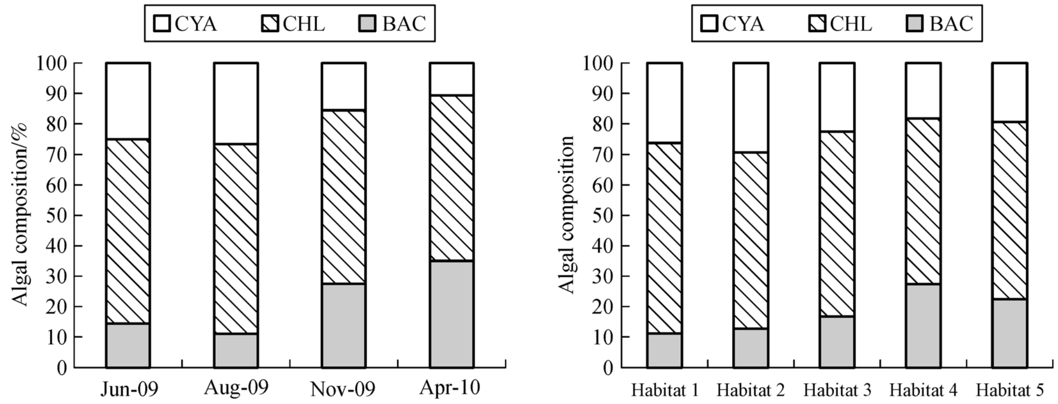
(a) Seasonal variations in Habitat 1

(b) Seasonal variations in Habitat 2



(c) Seasonal variations in Habitat 3

(d) Seasonal variations in Habitat 4



(e) Seasonal variations in Habitat 5

(f) Among-habitat variations

Fig. 3 Among-habitat and temporal changes of the algal composition in the periphyton community and in 5 habitats investigated.

(5.4%–37.9%), PDT (2.9%–6.1%) and CLI (15.6%–36.0%) in each habitat (Table 9).

Similarly, the density of algae had a seasonal trend. The maximum and minimum values of AD were reached in August (80.05×10^4 cells·cm^{-2}) and April (30.553×10^4 cells·cm^{-2}), respectively (Fig. 5). CHL (58.745% annual average) was the taxonomic group that contributed most of the algal density on any occasion, followed by CYA (23.3% annual average), and BAC (17.96% annual average). At the same time, the composition of algae also had a seasonal trend. The maximum and minimum values of BAC were reached in April (30.57%) and June (10.04%), respectively. These variations mostly correlated with the seasonal trends of the macroinvertebrate community. The maximum and minimum values of CYA were reached in June (31.18%) and April (12.48%), respectively. The trends were primarily caused by the seasonal trend of the physical and chemical parameters of the water (TN, TP, T, etc.). No seasonal trend was noticed for CHL (Fig. 5).

Table 8 Coefficients of variation expressed as percentages for the 14 selected biologic metrics of the periphyton community

Metrics	Among-habitat variability				
	$CV_{(h)m}$ Jun 09	$CV_{(h)m}$ Aug 09	$CV_{(h)m}$ Nov 09	$CV_{(h)m}$ Apr 10	$CV_{h\text{-month}}$
AD	47.8	49.5	36.7	26.7	40.2
Chl a	74.5	57.7	48.3	43.1	55.9
Chl b	96.4	76.4	72.7	79.7	81.3
Chl c	44.7	65.6	46.4	20.2	44.2
Chl b/a	37.7	50.1	37.9	48.5	43.6
Chl c/a	66.9	74.6	85.5	48.5	68.9
BAC	29.0	25.1	60.5	35.4	37.5
CHL	4.0	6.0	7.1	14.1	7.8
CYA	11.3	21.3	45.5	22.9	25.3
APA	73.3	66.2	55.9	39.3	58.7
GLU	71.8	64.3	91	40	66.8
LEU	26.7	53.9	77	64	55.4
PSC	31.0	91.2	93.2	88.4	76.0
AFDW	82.4	33.6	62.2	36.9	53.8

Notes: $CV_{(h)m}$ among-habitat variability for each habitat; $CV_{h\text{-month}}$ among-habitat variability over the one-year cycle.

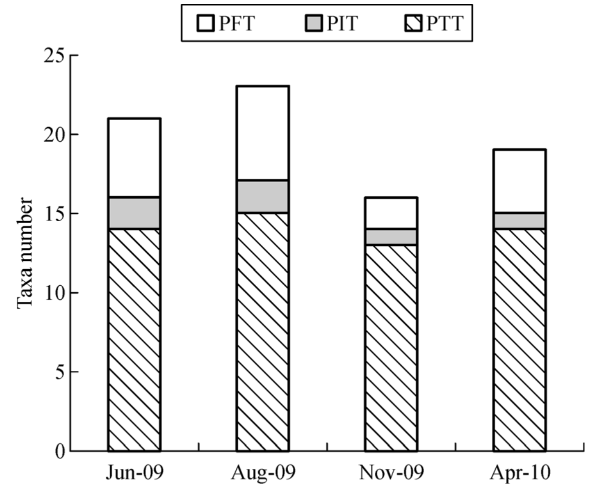
The lowest CV_s was measured for CHL (CV_s = 7.1%). The highest CV_s was measured for Chl b (CV_s = 132.4%). For the structural metrics, the CV_s of Chl a (CV_s = 124.9%), Chl b (CV_s = 132.4%), Chl c (CV_s = 107.5%), Chl b/a (CV_s = 54.0%), and BAC (CV_s = 54.3%) were higher than 50%, while the CV_s of AD (CV_s = 35.7%), Chl c/a (CV_s = 44.7%), CHL (CV_s = 7.1%), and CYA (CV_s = 40.6%) were lower than 50%. For the functional metrics, the CV_s of APA (CV_s = 58.8%), GLU (CV_s = 101.3%), LEU (CV_s = 68.3%), PSC (CV_s = 77.0%), and AFDW (CV_s = 57.5%) were higher than 50%. The obtained results demonstrated the CV values of periphyton metrics with significant differences, such as AD (26.9%–45.5%), Chl c/a (23.5%–68.6%), CHL (4.3%–13.4%), and CYA (28.8%–64.7%), with lower CV values, and Chl a (114.2%–136.2%), Chl b (118.3%–156.9%), Chl c (77.6%–129.9%), and GLU (75.3%–116.2%) with higher CV values (Table 10).

4 Discussion

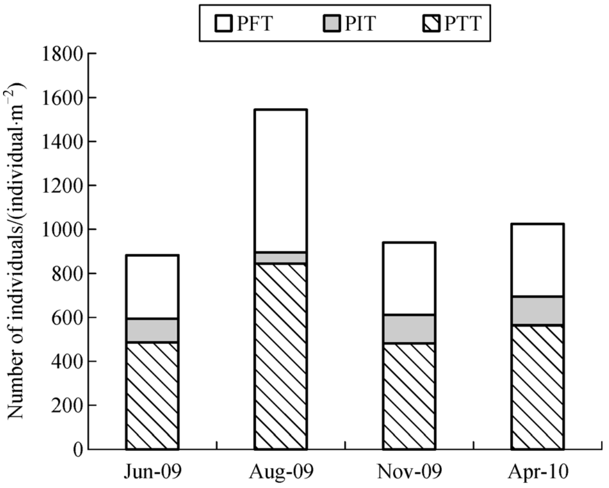
The spatial and temporal heterogeneity of biologic communities, as well as errors introduced during sampling and analytical stages of research, imply that any expression of ecological status needs to have an associated measure of uncertainty, depending upon the variability associated with these communities over time and across space (Kelly et al., 2009). Not only natural variability but also anthropogenic-generated effects can result in profound changes in macroinvertebrate communities (Trigal et al., 2007) and periphyton assemblages (Iwaniec et al., 2006). Understanding the natural and anthropogenic variation of ecological communities is essential in biomonitoring programs (Ledger and Hildrew, 1998; Trigal et al., 2006; Kröncke and Reiss, 2010). Spatial and temporal changes of the macroinvertebrate and periphyton communities lead to variations in the metrics commonly used in bioassessment studies. As a result, the confounding effects from variations naturally occurring in the community may obscure the effects caused by anthropogenic disturbances.

4.1 Among-habitat variability

For macroinvertebrate communities of lake littoral habitats, aquatic vegetation (Gilinsky, 1984; Rennie and Jackson, 2005), fish (Zimmer et al., 2001; Tangen et al., 2003; Hornung and Foote, 2006), trophic status (Kornijów, 1989; Brodersen et al., 2008), acidification (Tipping et al., 2002), and contaminants (Melaas et al., 2001; De Lange et al., 2005) have been presented as important predictors. In addition, habitat complexity strongly influences the composition of macroinvertebrate assemblages in aquatic systems (Heino, 2000; White and Irvine, 2003; Trigal et al., 2006). The results of our study suggest that the differences among microhabitats within Baiyangdian Lake may have led to high levels of change in the composition of the macroinvertebrate and periphyton communities. The relatively high variance explained by habitat type (defined here as the physical and chemical parameters in water and sediment), and often recognized as a strong predictor (Cyr and Downing, 1988; Tolonen et al., 2001, 2003; Cheruvelil et al., 2002; Biggs et al., 2005), was expected, as the sampling sites had different physical and chemical parameters in water and sediment. In other words, unlike studies where in microhabitat conditions are the focus, the

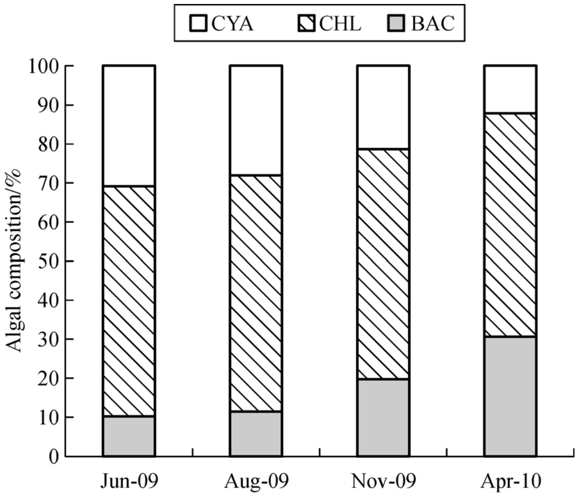


(a) Seasonal variations of taxa number

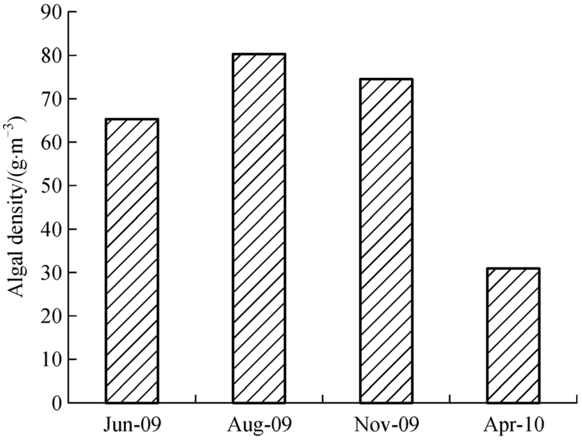


(b) Seasonal variations of total density

Fig. 4 Seasonal variations in the total number and total density (individuals/m^2) of the macroinvertebrate taxa in the lake.



(a) Seasonal variations of taxa composition



(b) Seasonal variations of algal density

Fig. 5 Seasonal variations of the algae composition and algae density of the periphyton community in the lake.

Table 9 Coefficients of variation expressed as percentages for the 12 selected biologic metrics of the macroinvertebrate community

Metrics	Seasonal temporal variability					
	$CV_{(m)h}$ Habitat 1	$CV_{(m)h}$ Habitat 2	$CV_{(m)h}$ Habitat 3	$CV_{(m)h}$ Habitat 4	$CV_{(m)h}$ Habitat 5	CV_s
HBI	5.8	6.6	5.6	3.8	2.9	4.9
PTT	16.2	7.9	5.4	37.9	15.2	16.5
PIT	–	–	67.8	30.6	67.2	55.2
TR	127.7	81.6	8.9	11.8	23.5	50.7
NDT	22.2	15.4	27.2	40.0	71.9	35.3
PNI	200.0	200.0	63.4	25.8	44.7	106.8
PC	18.0	22.2	45.0	87.4	87.4	52.0
PDT	3.1	2.9	6.1	4.6	5.8	4.5
CLI	36.0	30.6	24.6	15.6	26.0	26.6
CSI	200.0	84.4	18.7	15.9	17.3	67.3
PCGT	200.0	19.7	27.2	17.0	32.6	59.3
PPT	200.0	42.8	35.9	27.6	41.2	69.5

Notes: $CV_{(h)m}$ among-habitat variability for each habitat; $CV_{h\text{-month}}$ among-habitat variability over the one-year cycle.

Table 10 Coefficients of variation expressed as percentages for the 14 selected biologic metrics of the periphyton community

Metrics	Seasonal temporal variability					
	$CV_{(m)h}$ Habitat 1	$CV_{(m)h}$ Habitat 2	$CV_{(m)h}$ Habitat 3	$CV_{(m)h}$ Habitat 4	$CV_{(m)h}$ Habitat 5	CV_s
AD	45.5	34.4	29.4	26.9	42.3	35.7
Chl a	117.7	114.2	135.7	120.7	136.2	124.9
Chl b	119.0	118.3	132.3	156.9	135.7	132.4
Chl c	77.6	129.9	109	99.3	121.6	107.5
Chl b/a	39.4	50.3	52.7	72.3	55.1	54.0
Chl c/a	68.6	65.7	27.9	23.5	37.6	44.7
BAC	31.9	70.1	59.2	60.8	49.5	54.3
CHL	7.0	4.8	4.3	13.4	5.9	7.1
CYA	28.8	35.1	35.6	64.7	38.7	40.6
APA	56.4	80.0	50.3	59.5	47.7	58.8
GLU	104.6	112.1	98.4	116.2	75.3	101.3
LEU	58.0	72.8	40	105.5	65.0	68.3
PSC	148.3	56.3	48.9	53.9	77.4	77.0
AFDW	69.2	73.5	46.6	58.6	39.8	57.5

Notes: $CV_{(m)h}$ seasonal variability for each habitat; CV_s seasonal variability for the samples.

habitatgradient studied here was broad enough to assess the importance of habitat variability on macroinvertebrate/periphyton metrics and community structures adequately.

The CV analysis revealed that most of the richness metrics, composition metrics, and trophic metrics (except NDT, PDT, and CLI) were highly variable among the 5 habitats ($CV > 50\%$), but the tolerance metrics (except PIT) were rather constant throughout the investigated habitats. Data collected from this one lake study suggest that NDT, PDT, CLI, HBI, and PTT metrics were not largely affected by the choice of sampling location within a lake. For such metrics, a multi-habitat sampling approach, similar to the one proposed by Lewis et al. (2001) and Blocksom et al. (2002), may be useful in the context of biomonitoring, because among-lakes differences proved to have low variation in the CV values of several metrics used in bioassessment, but they may not be useful in the context of biomonitoring within-lake samples. Most of the richness metrics, composition metrics, and trophic metrics (except NDT, PDT, and CLI) may be useful in the context of biomonitoring, because within-lake samples proved to have high variation. Hence it is helpful to create different management criteria in Baiyangdian Lake. In the periphyton community, the coefficient variations of the functional metrics were highly variable among the five habitats ($CV > 57\%$), whereas the AD, Chl c/a, CHL, and CYA structure-based metrics were mostly constant among the five habitats. From this study, it can be concluded that AD, Chl c/a, CHL, and CYA are slightly affected by the choice of sampling location within a lake, and that functional metrics may be useful in the context of bioassessment within a lake.

By comparing the macroinvertebrate-based metrics with periphyton-based metrics of spatial variation, we can conclude the following: 1) the CV values of the macroinvertebrate-based metrics were lower than the CV values of the periphyton-based metrics; and 2) the CV values of the functional-based metrics were higher than those of the structural-based metrics. To reflect the difference between different microhabitats, in future studies, we would be used this way to select the periphyton metrics and the functional metrics, such as APA, GLU, LEU, PSC, and AFDW.

4.2 Temporal variability

Temporal variability also adds difficulty to biologic surveys in bioassessment studies, causing the values of many metrics to vary in accordance with the time of the year (Trigal et al., 2006; Kröncke and Reiss, 2010). In this study, the effects of temporal variability on the macroinvertebrate assemblages collected were most apparent in the high values registered for the coefficients of variation of the metrics based on richness, composition (except PDT and CLI), and trophism. The present work showed that richness-based metrics, composition-based metrics, and trophic-based metrics were highly variable over the seasons ($CV > 62\%$). The potential influences of changes in the assemblages and the phenology of plant communities related to the availability of substrates for epiphytes should also be acknowledged (de Szalay and Resh, 2000; Trigal et al., 2006), especially in a macrophyte-dominated shallow lake.

In the present work, the temporal variations of the periphyton community were most apparent in the high values for the CV of the metrics based on function. This study showed that functional-based metrics were highly variable over the seasons (CV > 53%). The potential influences of changes in the assemblages and phenology of macroinvertebrate communities were related to the number of consumers (Ledger and Hildrew, 1998). The metrics based on structure (except Chl a, Chl b, and Chl c/a) were slightly variable over the seasons (CV < 45%).

Based on a comparison of macroinvertebrate-based metrics with periphyton-based metrics of temporal variation, the following conclusions were drawn: 1) the CV values of the macroinvertebrate-based metrics were higher than the CV values of the periphyton-based metrics, and 2) the CV values of the functional-based metrics were higher than that of the structural-based metrics. To decrease the influence of sampling time, the metrics based on periphytons and structural metrics would be used in future biomonitoring, such as Chl a, Chl b, and Chl c/a.

5 Conclusions

Spatial and temporal changes of macroinvertebrate and periphyton communities can lead to variations in the metrics commonly used in bioassessment studies. Coefficients of variation, expressed as percentages, were used to quantify the effect of among-habitat (5×habitat) and seasonal (4×month) influences on the selected metrics, and to compare the spatial and temporal variation of macroinvertebrate-based metrics with periphyton-based metrics. For spatial variation, we can conclude the following: 1) the CV values of the macroinvertebrate-based metrics were lower than the CV values of the periphyton-based metrics, and 2) the CV values of the functional-based metrics were higher than those of the structural-based metrics. For temporal variation, we can conclude the following: 1) the CV values of the macroinvertebrate-based metrics were higher than the CV values of the periphyton-based metrics, and 2) the CV values of the functional-based metrics were higher than those of the structural-based metrics. Therefore, the impact of spatial and temporal variation on metrics should be considered when assessing the application of biometrics. In addition, structural metrics based on macroinvertebrates and periphytons may be promising tools in biomonitoring programs of China's macrophyte-dominated shallow lakes, because of their relatively low variability.

Acknowledgements This study was supported by the National Water Pollution Control Major Project of China (2012ZX07203-006), and the National Science Foundation for Innovative Research Group (No. 51121003). We also want to thank Q.Y. Chen for providing critical feedback during the preparation of the manuscript. Lastly, we thank M.Y. Ma and X.M. Wang for providing the calculating and collection methods regarding periphytons.

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