Quaternary International 226 (2010) 151–159

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Using temporal coherence to determine the responses of water clarity to hydrological processes in a giant subtropical canyon-shaped reservoir (China)

Yaoyang Xu [a,b], Meiling Shao [a,1], Ming Cao [a,b], Shuchan Zhou [a], Qinghua Cai [a,*]

[a] *State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan 430072, PR China*
[b] *Graduate University of Chinese Academy of Sciences, Beijing 100039, PR China*

ARTICLE INFO

Article history:
Available online 8 September 2009

ABSTRACT

Investigating whether different locations of a large lake exhibit synchronous or asynchronous fluctuations in limnological characteristics is essential to lake management. If synchronous fluctuations (termed as "temporal coherence") among sites are found to prevail, regional factors are likely to be the drivers; otherwise, local factors may be dominant. Here, this idea is tested at two spatial scales: the large scale being the mainstream of Three-Gorges reservoir (TGR, China) and the small scale being Xiangxi Bay of TGR. Data of transparency and chlorophyll *a* were gathered monthly at 26 sampling sites from July 2003 to July 2006 to evaluate temporal coherence for water clarity. High spatial and temporal variation in transparency (4–510 cm) and chlorophyll *a* (0.1–190.2 μg/L) mark the system. For the mainstream of TGR, significant high temporal coherence of water clarity among sites (correlation analysis: $0.872 \le r \le 0.991$, mean $r = 0.960$) was detected and the among-site correlations showed no significant relationship with geographical distance (Mantel test: $r = -0.186$, $p > 0.05$) or chlorophyll *a* (Mantel test: $r = 0.249$, $p > 0.05$). By contrast within Xiangxi Bay, lower synchronous fluctuations (correlation analysis: $0.396 \le r \le 0.971$, mean $r = 0.785$) occurred, and the among-site correlations decreased with an increase in geographical distance (Mantel test: $r = -0.715$, $p < 0.01$) and a decrease in temporal coherence of chlorophyll *a* (Mantel test: $r = 0.893$, $p < 0.01$). Seasonal dynamics of water clarity were very well explained by inflow discharges (regression analysis: $0.771 \le R^2 \le 0.906$) and water residence time ($0.782 \le R^2 \le 0.918$) in the mainstream, but not in Xiangxi Bay. The high coherency of the dynamics of water clarity in TGR mainstream is likely caused by regional hydrological processes driven by subtropical monsoon climate. For Xiangxi Bay, local processes such as phytoplankton dynamics may override the regional effects of hydrological processes, because the water clarity of this bay is strongly determined by phytoplankton bloom dynamics.

1. Introduction

Understanding underlying mechanisms regulating the dynamics of lake ecosystems is a key question in lake research and management. While some ecologists have emphasized the importance of lake-specific factors (Webster et al., 1996, 2000; Baron and Caine, 2000), others have shown that lake ecosystems respond strongly to regional climatic conditions (Magnuson et al., 1997; Baines et al., 2000; Winder and Schindler, 2004a,b; Morales-Baquero et al., 2006; George et al., 2007). Temporal coherence of limnological variables is often studied to draw general conclusions about the relative importance of local and regional factors affecting aquatic ecosystems. The degree to which the temporal series of limnological variables (biotic and abiotic), obtained in lake districts, are positively correlated is defined as temporal coherence (George et al., 2000). Rusak et al. (1999) defined temporal coherence as "the phenomenon of synchronous fluctuations in one or more parameters among locations within a geographic region". Synchrony is typically measured as correlation between the time series of a variable measured in paired lakes (Lloyd and May, 1999; Pace and Cole, 2002; Crump and Hobbie, 2005; Fölster et al., 2005; Kent et al., 2007). A significant pattern of synchrony might indicate the dominant role of regional, extrinsic factors (e.g., climate and hydrology) in controlling the dynamics of the limnological variables (Kratz et al., 1987). From an applied perspective, a high level of temporal coherence suggests that the results obtained in a set of sites can be reliably extrapolated to a larger region (Stoddard et al., 1998). Conversely, if a low level of temporal coherence is found, one

---

* Corresponding author.
E-mail addresses: shaomeiling@yahoo.com.cn (M. Shao), qhcai@ihb.ac.cn (Q. Cai).
[1] Present address: College of Life Science, Anhui Normal University, Wuhu 241000, PR China.

1040-6182/$ – see front matter © 2010 Elsevier Ltd and INQUA. All rights reserved.
doi:10.1016/j.quaint.2009.08.013

may infer the predominance of local-scale regulators (Rusak et al., 1999; Post and Forchhammer, 2006).

Previous studies addressing temporal coherence were made across a series of distinct lakes at different temporal and spatial scales (Baines et al., 2000; Baron and Caine, 2000; Benson et al., 2000; George et al., 2000; Chrzanowski and Grover, 2005; Fölster et al., 2005; Knowlton and Jones, 2007). In recent studies for zooplankton dynamics, some researchers pointed out that the level of temporal coherence may vary even within a single aquatic system and emphasized that temporal coherence of limnological variables of different sampling sites within a single ecosystem should also be extensively investigated (Alves et al., 2008; Lansac-Tôha et al., 2008; Takahashi et al., 2008). For example, Alves et al. (2008) investigated the existence of coherent patterns in temporal fluctuations of testate amoebae population abundances from a river floodplain (the Upper Paraná River Floodplain, Brazil). They concluded that regional factors in the Upper Paraná River floodplain are not the main determinants of the population dynamics of testate amoebae and that existence of the high floodplain heterogeneity seems to indicate a great relevance of local factors. Similar results were observed by Takahashi et al. (2008), who investigated the existence of synchronic fluctuation patterns in cladoceran populations of the Upper Paraná River floodplain. Lansac-Tôha et al. (2008) evaluated patterns of temporal coherence for zooplankton densities based on data gathered at 11 sites in a tropical reservoir (Corumbá Reservoir, Central Brazil) and detected high temporal coherence only between geographically adjacent sites and/or between sites with similar limnological characteristics.

With a length of over 6300 km, the Yangtze River is one of the largest rivers in the world (Wang et al., 1997), where a subtropical monsoon climate prevails (Jiang et al., 2006). The summer monsoon starts to influence the Yangtze River basin in May and generally retreats in October (Jiang et al., 2006). Temporal variation of runoff in the Yangtze River is closely related to monsoon activities and seasonal motion of subtropical highs. In order to prevent frequent summer floods that occur in the Yangtze River basin, the Three-

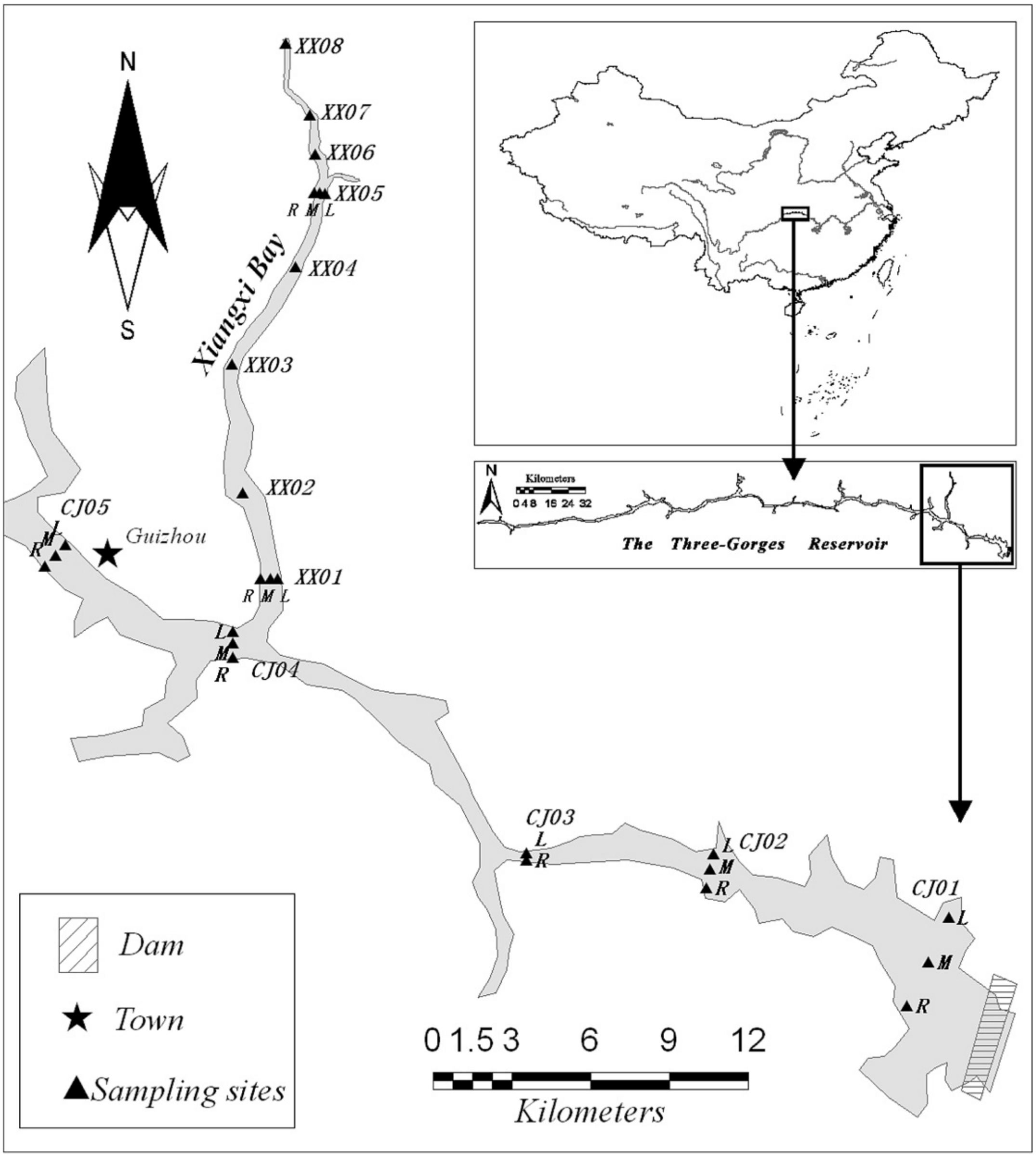

Fig. 1. Map illustrating the sampling sites in Three-Gorges reservoir in this study.

Table 1
Geographical distance (km) between sampling sites located in the mainstream of TGR.

Sites	CJ01L	CJ01	CJ01R	CJ02L	CJ02	CJ02R	CJ03L	CJ03R	CJ04L	CJ04	CJ04R	CJ05L	CJ05
CJ01	1.82												
CJ01R	3.68	1.86											
CJ02L	10.02	8.20	10.06										
CJ02	9.96	8.14	10.00	0.63									
CJ02R	9.97	8.15	10.01	1.34	0.71								
CJ03L	16.15	14.33	16.19	6.79	6.16	6.87							
CJ03R	16.17	14.35	16.21	6.85	6.22	6.93	0.33						
CJ04L	29.69	27.87	29.73	20.34	19.71	20.42	13.87	13.54					
CJ04	29.45	27.63	29.49	20.12	19.49	20.20	13.64	13.31	0.42				
CJ04R	29.39	27.57	29.43	20.25	19.62	20.33	13.55	13.22	1.04	0.62			
CJ05L	36.51	34.69	36.55	27.31	26.68	27.39	20.79	20.46	7.83	7.41	8.03		
CJ05	36.40	34.58	36.44	27.11	26.48	27.19	20.60	20.27	7.61	7.19	14.60	0.55	
CJ05R	36.41	34.59	36.45	27.22	26.59	27.30	20.70	20.37	7.00	6.58	13.77	1.08	0.53

Gorges reservoir (TGR, China) has been constructed. TGR is one of the largest human-made lakes in the world, with capacity of 3.93×10^{10} m^3, water level of 175 m a. s. l, surface area of 1080 km^2 and watershed area of over 1.00×10^6 km^2 (Huang et al., 2006). After the impoundment of TGR, there has been much more attention on seasonal dynamics of aquatic ecosystem of TGR where limnological characteristics may be determined predominantly by regional hydrological processes driven by subtropical monsoon climate (Zeng et al., 2006; Shao et al., 2008b; Xu et al., 2009). However, TGR including 40 large reservoir-bays (watershed area of each bay $>$ 100 km^2) was characterized by high spatial heterogeneity. The surface area of these bays account for 1/3 of the total surface area of the TGR (Cai and Hu, 2006; Huang et al., 2006), and the full supply volumes of the bays ranged from 0.02×10^8 to 17.11×10^8 m^3, with watershed areas and mean yearly inflow discharges ranging from 113 to 15,7990 km^2 and 0.6×10^8 to 34.24×10^8 m^3, respectively (CRAES Report, 2004). The high spatial variation in local factors of TGR may result in temporal asynchrony of limnological variables at different locations, which might be expected to be driven directly by subtropical monsoon climate. It is thus necessary to determine temporal coherence of limnological variables within TGR for better understanding the relative importance of local and regional factors affecting on this giant reservoir ecosystem.

Water clarity is one of the core variables being recommended for the detection and monitoring of aquatic ecosystem changes (Tegler et al., 2001), and is usually regarded as an important limnological variable for monitoring the effects of climate change and other stressors on aquatic ecosystems (Borkman and Smayda, 1998; Gunn et al., 2001; Swift et al., 2006). Water clarity (most commonly measured as Secchi depth) is a simple measure of the concentration of light attenuating factors in the water, such as phytoplankton cells, inorganic suspended solids and color dissolved organic matter (Borkman and Smayda, 1998; Morrison et al., 2006; Swift et al., 2006). It is well known that the seasonal patterns of sediment loadings of the Yangtze River are closely related to the summer monsoon, which initiates the coming of the flood season (Chen et al., 2008; Xu et al., 2009). Dynamics of water clarity in TGR is potentially linked to summer monsoon climate, but the degree of this link may vary within this giant reservoir ecosystem. Here, the degree of synchronous dynamics of water clarity among a set of sampling sites in TGR was measured in order to investigate the spatial extent of influence on the reservoir ecosystem by the summer monsoon.

After the first impoundment of TGR, 3-year long records of monthly observations of water clarity (measured by Secchi depth), phytoplankton biomass (measured as chlorophyll *a*), and related hydrological parameters (such as inflow discharge and water residence time) are available for the mainstream and Xiangxi Bay of TGR. This study analyzed temporal fluctuations in water clarity in the giant subtropical reservoir to determine the relative strength of the endogenous (local) and exogenous factors in controlling the lake dynamics, which are relevant for the purpose of ecosystem management.

2. Investigation area, data and methods

TGR is the primary area investigated by the Xiangxi Ecosystem Station, Chinese Academy of Sciences (CAS) and China Three-Gorges Project Corporation (CTGPC). This station is located on Xiangxi Bay (Fig. 1), which is one of the largest reservoir-bays of TGR. In order to detect monthly dynamics of the ecosystem, 5 transverse transects (CJ01-CJ05) and 8 sampling sites (XX01-XX08) are set up for the mainstream and Xiangxi Bay of TGR, respectively (Fig. 1). More detailed descriptions of the monthly sites for measurements are given elsewhere (Cai and Hu, 2006; Shao et al., 2008a,b; Xu et al., 2009). The site XX08 was excluded from this analysis, because no integrated annual samples were collected. This was because low water levels in the mainstream during the flood season prevented the sampling boat from reaching the site.

Table 2
Geographical distance (km) between sampling sites located in Xiangxi Bay of TGR.

Sites	XX01L	XX01	XX01R	XX02	XX03	XX04	XX05L	XX05	XX05R	XX06
XX01	0.33									
XX01R	0.71	0.38								
XX02	3.77	3.44	3.82							
XX03	8.70	8.37	8.75	5.00						
XX04	12.97	12.64	13.02	9.27	4.27					
XX05L	15.97	15.64	16.02	12.27	7.27	3.00				
XX05	15.94	15.61	15.99	12.23	7.23	2.96	0.28			
XX05R	16.04	15.71	16.09	12.29	7.29	3.02	0.56	0.28		
XX06	17.51	17.18	17.56	13.80	8.80	4.53	1.86	1.58	1.86	
XX07	19.04	18.71	19.09	15.31	10.31	6.04	3.44	3.16	3.44	1.56

Geographical distance between sites (Tables 1 and 2) were measured with Measure Tool based on Arc GIS 9.0 software.

This study is based on 3-year observations of transparency (SD, Secchi Depth) and chlorophyll *a* (chl. *a*) from July 2003 to July 2006. The value of SD was determined with a 20-cm Secchi disc. The chl. *a* concentration was determined by a spectrophotometer (Shimadzu UV-1601, Japan) following protocols for standard observations and measurements in aquatic ecosystems (Huang et al., 2000; Cai, 2007). The data of inflow discharges and water levels of the TGR were obtained from the CTGPC website, and the inflow discharge data of Xiangxi Bay was provided by the Hydrological Station, located upstream from XX08. The reservoir capacity of TGR and Xiangxi Bay in a given water level was obtained from Huang et al. (2006). The estimated value of water residence time is calculated by relating the annual amount of water passing through the reservoir with the volume of the whole reservoir. Here, the residence time for each month of a year was calculated as (modified from George and Hurley, 2003):

$$\tau = \frac{V_{\mathrm{T}}}{Q_{\mathrm{T}}}$$

Where τ is water residence time (days) for each month; V_{T} is the monthly volume (m^3) of the waters for $\mathrm{T} = 1, \ldots, 12$; Q_{T} is the monthly average inflow discharge ($\mathrm{m}^3\,\mathrm{d}^{-1}$).

Spearman correlation coefficients were used to estimate temporal coherence of site pairs (Magnuson et al., 1990; Baron and Caine, 2000; Alves et al., 2008; Lansac-Tôha et al., 2008; Takahashi et al., 2008). The Spearman rank correlation is a good metric because it is nonparametric and allows interpretation of the degree of association between two random variables (Baron and Caine, 2000). To investigate spatial coherency, a triangular site × site correlation matrix was constructed. Each value in this matrix represents the strength of the relationship between the temporal dynamics of variables measured in a pair of sites. Regression analysis examined the relationships between water clarity and hydrological parameters. Spearman correlation and regression analysis were all performed in the software SPSS 13.0.

The correlations between the degree of estimated synchrony and the geographic distance among environments were quantified by the standardized Mantel statistic (Shanker and Sukumar, 1999; Alves et al., 2008; Lansac-Tôha et al., 2008). Mantel's (1967) statistic is used to test the significance of the relationship between two symmetrical matrices (Legendre and Fortin, 1989). Variation in the level of temporal coherence for water clarity between sites (matrix W) was tested against geographical distance (matrix G) or temporal coherence of chl *a* between sites (matrix C) by Mantel's equation:

$$r = \sum_{i=1}^{n} \sum_{j=1}^{n} X_{ij} Y_{ij} / n - 1$$

Where X_{ij} is temporal coherence of water clarity between sites i and j (matrix W), and Y_{ij} is geographical distance between sites i and j (matrix G), or is temporal coherence of chl. *a* between sites i and j (matrix C). A high negative (and significant) r between W and G indicates that the temporal coherence of water clarity decreases as geographical distance increases. A high positive (and significant) r between W and C indicates that temporal coherence of water clarity increases as temporal coherence of chl. *a* increases. Mantel tests were performed using PC-ORD 4.0 (McCune and Mefford, 1999).

3. Results

A clear spatial and temporal variation in transparency and chlorophyll *a* was found across the whole study area of TGR (Table 3). Among the whole study, transparency ranged from 4 to 510 cm with mean and median values of 152 and 120 cm, respectively, and phytoplankton biomass (as indicated by chlorophyll *a* concentration) varied from the value below the limit of detection (0.1 μ g/L) to 190.2 μ g/L, with mean and median values of 8.3 μ g/L and 1.7 μ g/L,

Table 3
Data summary of chlorophyll *a* and transparency obtained during the study. Sd = standard deviation.

	Transparency (cm)					Chlorophyll *a* (μ g/L)				
	Mean	Median	Sd	Min	Max	Mean	Median	Sd	Min	Max
All data	152	120	118	4	510	8.3	1.7	18.7	0.1	190.2
Mainstream	158	130	138	4	510	2.6	1.0	8.0	0.1	126.5
CJ01L	151	105	131	15	431	15.4	1.8	25.7	0.1	126.5
CJ01	174	150	149	8	440	2.1	1.0	3.5	0.2	17.8
CJ01R	169	150	143	10	450	2.3	1.2	2.9	0.1	11.3
CJ02L	171	160	150	8	480	1.4	1.0	1.3	0.1	5.9
CJ02	170	110	154	6	510	1.2	0.8	1.1	0.1	5.1
CJ02R	170	150	147	12	480	2.1	1.0	2.9	0.1	12.8
CJ03L	147	115	133	4	420	1.3	0.9	1.9	0.1	10.8
CJ03R	154	120	139	5	410	1.6	0.9	2.1	0.1	11.5
CJ04L	152	120	126	5	400	3.2	1.2	4.2	0.1	16.8
CJ04	161	140	138	5	425	1.7	1.0	2.3	0.1	13.0
CJ04R	152	130	138	5	430	1.6	0.9	2.2	0.2	11.9
CJ05L	141	120	137	6	460	1.0	0.7	0.9	0.1	4.7
CJ05	150	120	139	5	465	0.9	0.7	0.9	0.1	4.5
CJ05R	146	145	127	5	430	1.2	0.9	1.1	0.1	5.5
Xiangxi Bay	145	120	84	15	460	15.6	8.2	24.9	0.2	190.2
XX01L	163	130	111	23	460	12.2	3.1	28.6	0.3	164.6
XX01	169	138	108	22	440	10.4	2.8	27.0	0.5	161.4
XX01R	165	135	106	20	380	11.1	2.8	27.8	0.4	164.8
XX02	169	130	94	25	395	12.2	3.9	27.8	0.2	167.7
XX03	158	130	81	32	385	12.6	5.3	15.8	0.4	73.1
XX04	150	120	79	32	350	14.2	6.5	17.7	0.6	93.4
XX05L	133	110	67	30	320	18.1	11.6	20.0	1.3	89.7
XX05	132	110	63	30	290	17.8	9.3	20.8	3.4	117.2
XX05R	133	110	70	35	310	18.1	11.7	23.0	2.0	132.0
XX06	115	100	52	35	225	23.3	11.8	35.7	1.0	190.2
XX07	108	100	50	15	235	21.5	13.3	22.4	1.8	103.1

Table 4
Spearman correlations (temporal coherence) between temporal trajectories of transparency (lower triangle) and chlorophyll *a* (upper triangle) in 14 sites at the mainstream of TGR.

Sites	CJ01L	CJ01	CJ01R	CJ02L	CJ02	CJ02R	CJ03L	CJ03R	CJ04L	CJ04	CJ04R	CJ05L	CJ05	CJ05R
CJ01L		0.661**	0.515**	0.626**	0.530**	0.762**	0.498**	0.617**	0.328*	0.396*	0.485**	0.314	0.406*	0.330*
CJ01	0.909**		0.627**	0.545**	0.536**	0.695**	0.730**	0.776**	0.421*	0.568**	0.536**	0.491**	0.621**	0.578**
CJ01R	0.894**	0.981**		0.556**	0.422*	0.473**	0.694**	0.470**	0.251	0.468**	0.463**	0.488**	0.412*	0.463**
CJ02L	0.882**	0.970**	0.979**		0.741**	0.486**	0.694**	0.651**	0.364*	0.463**	0.600**	0.539**	0.471**	0.481**
CJ02	0.887**	0.978**	0.974**	0.991**		0.432**	0.569**	0.683**	0.163	0.330*	0.428**	0.573**	0.584**	0.640**
CJ02R	0.904**	0.972**	0.966**	0.982**	0.976**		0.656**	0.635**	0.242	0.393*	0.434**	0.253	0.475**	0.444**
CJ03L	0.892**	0.972**	0.972**	0.988**	0.982**	0.976**		0.789**	0.454**	0.600**	0.668**	0.663**	0.678**	0.660**
CJ03R	0.906**	0.975**	0.970**	0.979**	0.976**	0.976**	0.979**		0.384*	0.471**	0.463**	0.627**	0.663**	0.569**
CJ04L	0.915**	0.955**	0.939**	0.948**	0.953**	0.955**	0.961**	0.954**		0.734**	0.651**	0.607**	0.370*	0.483**
CJ04	0.892**	0.969**	0.967**	0.986**	0.982**	0.975**	0.983**	0.986**	0.960**		0.675**	0.614**	0.613**	0.603**
CJ04R	0.872**	0.957**	0.978**	0.977**	0.969**	0.968**	0.965**	0.965**	0.919**	0.972**		0.633**	0.440**	0.484**
CJ05L	0.886**	0.978**	0.984**	0.981**	0.980**	0.973**	0.975**	0.983**	0.953**	0.978**	0.975**		0.673**	0.737**
CJ05	0.894**	0.970**	0.968**	0.978**	0.983**	0.974**	0.976**	0.988**	0.954**	0.984**	0.970**	0.986**		0.720**
CJ05R	0.895**	0.963**	0.948**	0.961**	0.972**	0.966**	0.967**	0.976**	0.964**	0.976**	0.948**	0.968**	0.984**	

** Correlation is significant at the 0.01 level 2-tailed.

* Correlation is significant at the 0.05 level 2-tailed.

respectively. Mean transparency of the TGR mainstream ranged from 141 to 174 cm, with mean and median values of 158 and 130 cm, respectively, and that of Xiangxi Bay ranged between 108 and 169 cm, with mean and median values of 145 and 120 cm, respectively. The seasonal variation of transparency in the TGR mainstream (standard deviation = 138 cm, Table 3) was higher than that in Xiangxi Bay (standard deviation = 84 cm, Table 3). Low values of phytoplankton biomass were often found in the mainstream of TGR, whereas high values were frequently observed in Xiangxi Bay. Mean concentration of chlorophyll *a* in the mainstream of TGR ranged from 0.9 to 15.4 μg/L, with mean and median values of 2.6 μg/L and 1.0 μg/L, respectively, while that in Xiangxi Bay varied between 10.4 and 23.3 μg/L, with mean and median values of 15.6 μg/L and 8.2 μg/L, respectively. The seasonal variation of chlorophyll *a* in the TGR mainstream (standard deviation = 8.0 μg/L) was lower than that in Xiangxi Bay (standard deviation = 24.9 μg/L, Table 3).

A high degree of temporal coherence in water clarity between pairs of sites was found for the TGR mainstream (ranging from 0.872 to 0.991 and mean = 0.960; Table 4). By contrast, synchrony in seasonal fluctuations of water clarity within Xianxi Bay was lower (varying from 0.396 to 0.971 and mean = 0.785; Table 5). The low level of synchronous fluctuations of water clarity was detected between the downstream sites (XX01L, XX01, and XX01R) and upstream sites (XX06 and XX07) of Xianxi Bay, and temporal coherence of water clarity is always lower than 0.5, ranging from 0.396 to 0.497 (Table 5). There is a high level of temporal coherence in water clarity between the downstream of Xiangxi Bay and the TGR mainstream, but a low level of synchronous fluctuations was found between the upstream of Xianxi Bay and the TGR mainstream (Table 6).

Mean monthly inflow discharges of the TGR mainstream and Xiangxi Bay (ranging from 4414 to 34,761 $m^3 s^{-1}$ and 13 to 180 $m^3 s^{-1}$, respectively), displayed a consistent seasonal trend, with a peak during the summer monsoon (Fig. 2a). Mean monthly residence time also showed a consistent seasonal variation in the TGR mainstream and Xianxi Bay, ranging from 5 to 39 days and 26 to 388, respectively (Fig. 2b). A high level of temporal coherence for inflow discharges and water residence time were found between the TGR mainstream and Xiangxi Bay (Spearman's correlation = 0.709 and 0.690, respectively).

Water clarity of the TGR mainstream showed a stronger response to hydrological conditions than that of Xianxi Bay. In the mainstream of TGR, both inflow discharges and water residence time were significantly related to transparency, explaining 77.1–90.6% and 78.2–91.8% of the variance, respectively (Table 7). For Xiangxi Bay, inflow discharges and water residence time only explained 11.5–52.1% and 8.8–46.0% of the variance in transparency, respectively (Table 8), although there were also significant relationships between hydrological parameters and transparency in most sites.

There is no obvious decrease in temporal coherence of water clarity with increasing geographical distance and no significant relationship between the temporal coherence of water clarity with that of chlorophyll *a* in the TGR mainstream (Mantel's test, Table 9). In addition, similar regional patterns of transparency significantly followed the seasonal dynamics of hydrological variables (Table 7). These results suggest that the water clarity of the TGR mainstream was affected by regional scale factors (subtropical monsoon climate). By contrast, temporal coherence between site pairs of Xiangxi Bay displayed a significant decline with increasing

Table 5
Spearman correlations (temporal coherence) between temporal trajectories of transparency (lower triangle) and chlorophyll *a* (upper triangle) in 11 sites at Xiangxi Bay of TGR.

Sites	XX01L	XX01	XX01R	XX02	XX03	XX04	XX05L	XX05	XX05R	XX06	XX07
XX01L		0.841**	0.869**	0.612**	0.443**	0.532**	0.371*	0.361*	0.431**	0.195	−0.027
XX01	0.971**		0.913**	0.746**	0.564**	0.600**	0.410*	0.453**	0.391*	0.167	−0.024
XX01R	0.970**	0.967**		0.803**	0.616**	0.662**	0.450**	0.408*	0.451**	0.177	0.021
XX02	0.922**	0.938**	0.929**		0.852**	0.873**	0.692**	0.657**	0.662**	0.480**	0.325
XX03	0.871**	0.890**	0.861**	0.937**		0.932**	0.741**	0.659**	0.657**	0.437**	0.219
XX04	0.893**	0.888**	0.861**	0.927**	0.963**		0.817**	0.747**	0.751**	0.502**	0.230
XX05L	0.700**	0.719**	0.694**	0.762**	0.813**	0.847**		0.833**	0.831**	0.551**	0.290
XX05	0.711**	0.724**	0.692**	0.768**	0.787**	0.827**	0.941**		0.822**	0.684**	0.312
XX05R	0.648**	0.663**	0.653**	0.744**	0.772**	0.818**	0.938**	0.955**		0.660**	0.499**
XX06	0.462**	0.497**	0.476**	0.563**	0.632**	0.670**	0.853**	0.851**	0.886**		0.678**
XX07	0.396*	0.422*	0.402*	0.524**	0.597**	0.594**	0.772**	0.800**	0.781**	0.821**	

** Correlation is significant at the 0.01 level 2-tailed.

* Correlation is significant at the 0.05 level 2-tailed.

Table 6
Spearman correlations (temporal coherence) of temporal trajectories of transparency between 14 sites at the mainstream and 11 sites at Xiangxi Bay of TGR.

Sites	XX01L	XX01	XX01R	XX02	XX03	XX04	XX05L	XX05	XX05R	XX06	XX07
CJ01L	0.857**	0.883**	0.882**	0.856**	0.828**	0.804**	0.657**	0.627**	0.545**	0.399*	0.359*
CJ01	0.871**	0.869**	0.874**	0.805**	0.780**	0.752**	0.560**	0.543**	0.450**	0.354*	0.300
CJ01R	0.864**	0.866**	0.871**	0.798**	0.779**	0.753**	0.551**	0.518**	0.438**	0.334*	0.279
CJ02L	0.861**	0.864**	0.866**	0.801**	0.782**	0.761**	0.548**	0.528**	0.447**	0.346*	0.292
CJ02	0.858**	0.858**	0.867**	0.802**	0.764**	0.744**	0.551**	0.532**	0.447**	0.349*	0.318
CJ02R	0.882**	0.873**	0.878**	0.811**	0.771**	0.773**	0.537**	0.531**	0.439**	0.318	0.257
CJ03L	0.879**	0.874**	0.877**	0.819**	0.799**	0.782**	0.572**	0.551**	0.467**	0.353*	0.296
CJ03R	0.863**	0.854**	0.847**	0.786**	0.782**	0.758**	0.535**	0.501**	0.403*	0.292	0.268
CJ04L	0.912**	0.924**	0.917**	0.878**	0.832**	0.811**	0.584**	0.587**	0.500**	0.356*	0.311
CJ04	0.872**	0.865**	0.861**	0.805**	0.785**	0.767**	0.541**	0.527**	0.434**	0.301	0.269
CJ04R	0.861**	0.840**	0.851**	0.777**	0.750**	0.744**	0.515**	0.496**	0.400*	0.284	0.254
CJ05L	0.865**	0.860**	0.872**	0.786**	0.764**	0.743**	0.522**	0.495**	0.405*	0.298	0.263
CJ05	0.861**	0.847**	0.854**	0.777**	0.766**	0.743**	0.504**	0.488**	0.393*	0.274	0.276
CJ05R	0.875**	0.862**	0.867**	0.793**	0.747**	0.730**	0.526**	0.531**	0.417*	0.282	0.259

** Correlation is significant at the 0.01 level 2-tailed.
* Correlation is significant at the 0.05 level 2-tailed.

geographical distance,(Mantel's test, Table 9) and the temporal coherence of chlorophyll *a* was a significant predictor of temporal coherence for water clarity in Xiangxi Bay (Mantel's test, Table 9), implying a predominance of local factors.

4. Discussion

In field monitoring on lakes, the optical clarity of water plays an important role in casual judgments about water quality (Pfannkuche et al., 2000; Smith et al., 2006). Water clarity is often used by the public as a basis for judging aesthetic characteristic of waters as well as the safety of water contact (Jassby et al., 1999). The attenuation of light in water can be attributed to four components: the water molecules themselves, substances dissolved in the water, phytoplankton cells, or suspended inorganic particles (Kirk, 1994). Changes in one or more of these four components should result in the dynamics in water clarity. Eutrophication, caused by excess inputs of nutrients from the watershed, always has an important impact on increase in phytoplankton biomass, resulting in decreases in water transparency (Lathrop et al., 1996; Carpenter et al., 1998, 1999; Portielje and Molen, 1999). In addition to nutrients input, suspended particles which are also carried in by streams, lead to light attenuation and decrease water clarity (Davies-Colley and Smith, 2001; Swift et al., 2006). Because

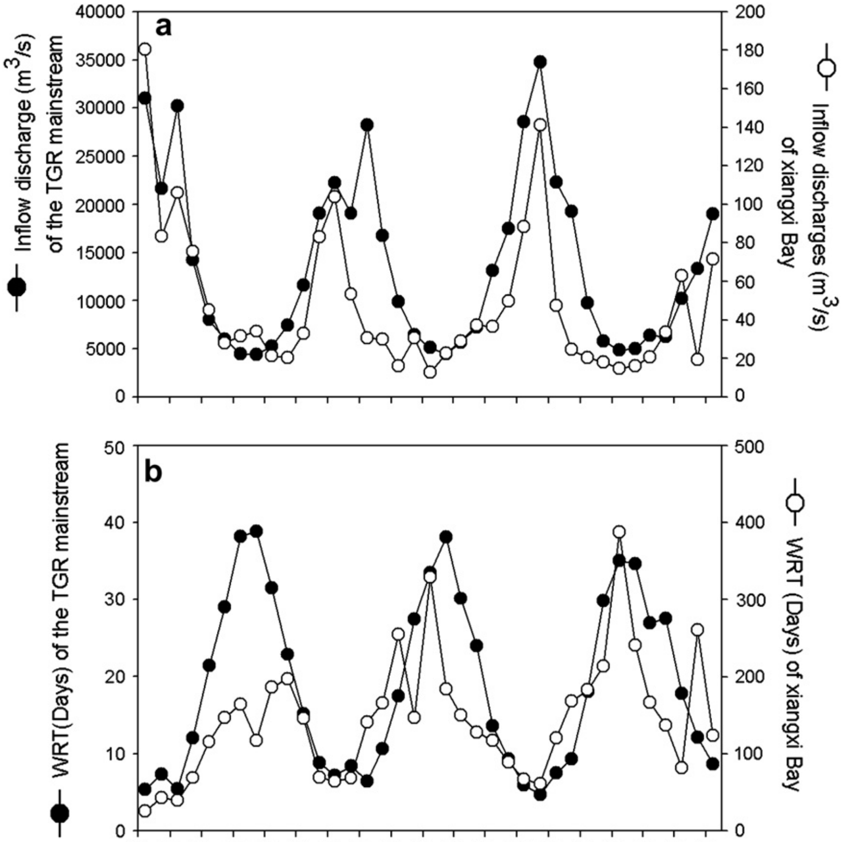

Fig. 2. Temporal changes of (a) inflow discharge and (b) water residence time (WRT) in the mainstream and Xiangxi Bay of the TGR.

Table 7
Linear relationship between water clarity and inflow discharge or water residence time of the TGR mainstream.

Sites	Inflow discharge			Water residence time		
	Constant b0	Slope b1	R^2	Constant b0	Slope b1	R^2
CJ01L	7.437	−1.348	0.771**	0.404	1.334	0.782**
CJ01	9.418	−1.840	0.894**	−0.181	1.817	0.903**
CJ01R	8.835	−1.692	0.894**	0.017	1.664	0.896**
CJ02L	9.456	−1.853	0.901**	−0.208	1.828	0.909**
CJ02	9.580	−1.887	0.893**	−0.260	1.862	0.901**
CJ02R	8.967	−1.726	0.906**	−0.039	1.707	0.918**
CJ03L	10.004	−2.014	0.876**	−0.498	1.988	0.885**
CJ03R	10.168	−2.051	0.887**	−0.531	2.025	0.896**
CJ04L	8.352	−1.581	0.789**	0.105	1.562	0.797**
CJ04	9.480	−1.864	0.890**	−0.241	1.838	0.897**
CJ04R	9.902	−1.983	0.886**	−0.436	1.954	0.891**
CJ05L	9.362	−1.854	0.878**	−0.305	1.829	0.885**
CJ05	9.381	−1.845	0.906**	−0.238	1.818	0.912**
CJ05R	8.987	−1.750	0.847**	−0.143	1.729	0.856**

** Relationship is significant at the 0.01 level 2-tailed.

management strategies to control algae and to control soil erosion are quite different, the relative importance of phytoplankton and suspended inorganic particles needs to be resolved for an effective management strategy.

The results indicate that the TGR mainstream exhibited a high degree of coherency in water clarity but Xiangxi Bay did not (Tables 4 and 5). In addition, the present study showed that mean concentration and seasonal variation of the chlorophyll *a* in the TGR mainstream were lower than that in Xiangxi Bay (Table 3). Moreover, seasonal variations of water clarity were associated with variations of chlorophyll *a* concentrations in Xianxi Bay, but not in the mainstream of TGR (Table 9). These contrasts suggest that the dynamics of water clarity in TGR mainstream is likely caused by regional hydrological processes driven by subtropical monsoon climate, while for the Xiangxi Bay, local processes such as phytoplankton dynamics may override the regional effects of hydrological processes.

In a previous study, Xu et al. (2006) revealed that phytoplankton concentration (measured as chlorophyll *a* concentrations) was the most important constituent responsible for spatial distribution and temporal variation of the PAR attenuation coefficients. In the mainstream of TGR, attenuation by phytoplankton cells may be assumed to exhibit no seasonal trend, since there have been no algal blooms reported until now. While in Xiangxi Bay, attenuation by phytoplankton cells had significant seasonal dynamics, because seasonal algal blooms were observed (Cai and Hu, 2006; Ye et al., 2007). Thus for Xiangxi Bay, reducing nutrient input should be considered as an important step in the development of effective water quality management.

Generally speaking, damming of rivers results in increases in residence time and reduction in suspended inorganic particles (Friedl and Wüest, 2002). However, the situation in the mainstream of TGR may be different. Following the classification of Straškraba and Tundisi (1999), the TGR mainstream was still a fully mixed system in the flood season and an intermediate system in the dry season (Xu et al., 2009). In addition, seasonal high sediment loadings from the drainage basin are usually induced by subtropical monsoon (Chen et al., 2008). The linkage between hydrological parameters and transparency observed in this study (Table 7) indicates that seasonal dynamics of water clarity in the TGR mainstream were caused by particle inputs from storm water runoff rather than local algal abundances. For improving water clarity, it is thus necessary to pay more attention to management strategies for soil erosion control for the mainstream.

It would be expected that data gathered for a single system should show a much higher level of temporal coherence (George et al., 2000; Kent et al., 2007). However, the variation in the levels of temporal coherence was still detected in this study. One important reason for the variation may be that the giant system was very heterogeneous in habitat type due to different combinations of lotic and lentic environments. Following the standard of Søballe and Kimmel (1987), the mainstream of TGR was often regarded as lotic systems had residence times of 2–75 days, whereas Xiangxi Bay belonged to lentic systems with average residence times higher than 120 days. In a lotic environment (mainstream), high flows and exchange of light attenuating particles overwhelmed local dynamics and resulted in a high level of synchrony fluctuations of water clarity. The fact that there is an association between

Table 8
Linear relationship between water clarity and inflow discharge or water residence time of Xiangxi Bay.

Sites	Inflow discharge			Water residence time		
	Constant b0	Slope b1	R^2	Constant b0	Slope b1	R^2
XX01L	3.293	−0.747	0.450**	0.559	0.742	0.348**
XX01	3.269	−0.722	0.463**	0.626	0.718	0.359**
XX01R	3.309	−0.756	0.469**	0.524	0.760	0.371**
XX02	3.055	−0.572	0.374**	0.897	0.599	0.321**
XX03	2.948	−0.510	0.415**	1.043	0.525	0.344**
XX04	2.992	−0.552	0.521**	0.894	0.586	0.460**
XX05L	2.786	−0.452	0.388**	1.061	0.483	0.346**
XX05	2.801	−0.459	0.441**	1.063	0.484	0.383**
XX05R	2.795	−0.459	0.396**	1.009	0.507	0.378**
XX06	2.537	−0.332	0.216**	1.257	0.361	0.200**
XX07	2.429	−0.284	0.115**	1.394	0.280	0.088**

** Relationship is significant at the 0.01 level 2-tailed.

Table 9
Mantel statistics and associated probabilities evaluating the relationships among the spatial synchrony of water clarity (W) and geographical distance (G) and the spatial synchrony of chlorophyll *a* (C).

	Matrix	C	G
Mainstream	W	0.249	−0.186
Xiangxi Bay		0.893**	−0.767**

** Correlation is significant at the 0.01 level 2-tailed.

hydrological parameters and water clarity indeed suggests that regional factors were responsible for water clarity of the TGR mainstream. In lentic environment (Xiangxi Bay), low dispersal of light attenuating particles among locations cannot overwhelm these local dynamics and caused the variation in the levels of temporal coherence for water clarity. The present study showed geographic distance and phytoplankton biomass were significant predictors of the temporal coherence variation in Xiangxi Bay.

From an applied perspective for monitoring lake dynamics, one of the important objectives of most studies on temporal coherence is to verify whether the results obtained in a single lake can be extrapolated to other lakes within the same geographical region (Arnott et al., 2003; Chrzanowski and Grover, 2005; Fölster et al., 2005). High temporal coherence indicated that data gathering in few sites is available for understanding regional lake trends, while low spatial synchrony indicated that results obtained in a single site cannot be extrapolated to the entire regional lakes (Urquhart et al., 1998; Lansac-Tôha et al., 2008). High temporal coherence for transparency within the mainstream of TGR showed that trend for water clarity observed in a single site can be extrapolated to the entire mainstream. In contrast, low temporal coherence within Xiangxi Bay indicted that a set of sampling sites should be required for a successful observation on the dynamics of the reservoir-bay.

5. Conclusion

The dynamics of transparency were studied in relation to hydrological processes and phytoplankton dynamics in the TGR. High coherency among sites across the TGR mainstream suggests a synchronizing regional response of water clarity in the mainstream to hydrological processes which are driven by summer monsoon climate. On the contrary, the dynamics of transparency within Xiangxi Bay are characterized by dissimilar seasonal patterns among sites, suggesting that local processes (phytoplankton dynamics) instead of regional hydrological processes are the main determinants of the water clarity dynamics in the reservoir-bay.

Acknowledgments

This work was funded by National Natural Science Foundation of China (No. 30330140, 40671197) and the Key Project of Knowledge Innovation Program of CAS (No. KZCX2–YW–427). We would like to thank D. Li, L. Ye, X. Han, X. Jia, F. Li, X. Fu, N. Wu, and L. Wang for their assistance in the field and in the lab. We also thank anonymous reviewers and Dr. Chih-hao Hsieh for their useful comments in improving this manuscript.

References

Alves, G.M., Lansac-Tôha, F.A., TakahashiÉ, M., Velho, L.F.M., 2008. Fluctuations of testate amoebae populations (Rhizopoda) in plankton from different environments on the Upper Paraná River Floodplain, Brazil. International Review of Hydrobiology 93, 227–242.

Arnott, S.E., Keller, B., Dillon, P.J., Yan, N., Paterson, M., Findlay, D., 2003. Using temporal coherence to determine the response to climate change in boreal shield lakes. Environmental Monitoring and Assessment 88, 365–388.

Baines, S.B., Webster, K.E., Kratz, T.K., Carpenter, S.R., Magnuson, J.J., 2000. Synchronous behavior of temperature, calcium, and chlorophyll in lakes of northern Wisconsin. Ecology 81, 815–825.

Baron, J.S., Caine, N., 2000. Temporal coherence of two alpine lake basins of the Colorado Front Range, U.S.A. Freshwater Biology 43, 463–476.

Benson, B.J., Lenters, J.D., Magnuson, J.J., Stubbs, M., Kratz, T.K., Dillon, P.J., Hecky, R.E., Lathrop, R.C., 2000. Regional coherence of climatic and lake thermal variables of four lake districts in the Upper Great Lakes Region of North America. Freshwater Biology 43, 517–527.

Borkman, D.G., Smayda, T.J., 1998. Long-term trends in water clarity revealed by Secchi-disk measurements in lower Narragansett Bay. ICES Journal of Marine Science 55, 668–679.

Cai, Q. (Ed.), 2007. Protocols for Standard Observation and Measurement in Aquatic Ecosystems. China Environmental Science Press, Beijing (in Chinese).

Cai, Q., Hu, Z., 2006. Studies on eutrophication problem and control strategy in the Three Gorges reservoir. Acta Hydrobiologica Sinica 30, 7–11 (in Chinese with English abstract).

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N., Smith, V.H., 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications 8, 559–568.

Carpenter, S.R., Ludwig, D., Brock, W.A., 1999. Management of eutrophication for lakes subject to potentially irreversible change. Ecological Applications 9, 751–771.

Chen, X., Yan, Y., Fu, R., Dou, X., Zhang, E., 2008. Sediment transport from the Yangtze River, China, into the sea over the Post-Three Gorge dam period: a discussion. Quaternary International 186, 55–64.

Chrzanowski, T.H., Grover, J.P., 2005. Temporal coherence in limnological features of two southwestern reservoirs. Lake and Reservoir Management 21, 39–48.

Chinese Research Academy of Environmental Sciences (CRAES), 2004. Studies report on the assessment standards and methods for trophic status in the Three Gorge reservoir. (in Chinese).

Crump, B.C., Hobbie, J.E., 2005. Synchrony and seasonality in bacterioplankton communities of two temperate rivers. Limnology and Oceanography 50, 1718–1729.

Davies-Colley, R.J., Smith, D.G., 2001. Turbidity, suspended sediment, and water clarity: a review. Journal of the American Water Resources Association 37, 1085–1101.

Fölster, J., Göransson, E., Johansson, K., Wilander, A., 2005. Synchronous variation in water chemistry for 80 lakes in southern Sweden. Environmental Monitoring and Assessment 102, 389–403.

Friedl, G., Wüest, A., 2002. Disrupting biogeochemical cycles – consequences of damming. Aquatic Sciences 64, 55–65.

George, D.G., Hurley, M.A., 2003. Using a continuous function for residence time to quantify the impact of climate change on the dynamics of thermally stratified lakes. Journal of Limnology 62, 21–26.

George, D.G., Talling, J.F., Rigg, E., 2000. Factors influencing the temporal coherence of five lakes in the English Lake District. Freshwater Biology 43, 449–461.

George, G., Hurley, M., Hewitt, D., 2007. The impact of climate change on the physical characteristics of the larger lakes in the English Lake District. Freshwater Biology 52, 1647–1666.

Gunn, J.M., Snucins, E., Yan, N.D., Arts, M.T., 2001. Use of water clarity to monitor the effects of climate change and other stressors on oligotrophic lakes. Environmental Monitoring and Assessment 67, 69–88.

Huang, X., Chen, W., Cai, Q., 2000. Survery, Observation and Analysis of Lake Ecology. Standards Press of China, Beijing (in Chinese).

Huang, Z., Li, Y., Chen, Y., Li, J., Xing, Z., Ye, M., Li, J., Lü, P., Li, C., Zhou, X., 2006. Water quality prediction and water environmental carrying capacity calculation for Three Gorges reservoir. China WaterPower Press, Beijing (in Chinese with English abstract).

Jassby, A.D., Goldman, C.R., Reuter, J.E., Richards, R.C., 1999. Origins and scale dependence of temporal variability in the transparency of Lake Tahoe, California–Nevada. Limnology and Oceanography 44, 282–294.

Jiang, T., Zhang, Q., Zhu, D., Wu, Y., 2006. Yangtze floods and droughts (China) and teleconnections with ENSO activities (1470–2003). Quaternary International 144, 29–37.

Kent, A.D., Yannarell, A.C., Rusak, J.A., Triplett, E.W., McMahon, K.D., 2007. Synchrony in aquatic microbial community dynamics. International Society for Microbial Ecology 1, 38–47.

Kirk, J.T.O., 1994. Light and Photosynthesis in Aquatic Ecosystems, second ed. Cambridge University Press, Cambridge.

Knowlton, M.F., Jones, J.R., 2007. Temporal coherence of water quality variables in a suite of Missouri reservoirs. Lake and Reservoir Management 23, 49–58.

Kratz, T.K., Frost, T.M., Magnuson, J.J., 1987. Inferences from spatial and temporal variability in ecosystems: long-term zooplankton data from lakes. American Naturalist 129, 830–846.

Lansac-Tôha, F.A., Bini, M.L., Velho, L.F.M., Bonecker, C.C., Takahashi, E.M., Vieira, L.C.G., 2008. Temporal coherence of zooplankton abundance in a tropical reservoir. Hydrobiologia 614, 387–399.

Lathrop, R.C., Carpenter, S.R., Rudstam, L.G., 1996. Water clarity in Lake Mendota since 1900: responses to differing levels of nutrients and herbivory. Canadian Journal of Fisheries and Aquatic Sciences 53, 2250–2261.

Legendre, P., Fortin, M.J., 1989. Spatial pattern and ecological analysis. Plant Ecology 80, 107–138.

Lloyd, A.L., May, R.M., 1999. Synchronicity, chaos and population cycles: spatial coherence in an uncertain world. Trends in Ecology & Evolution 14, 417–418.

Magnuson, J.J., Benson, B.J., Kratz, T.K., 1990. Temporal coherence in the limnology of a suite of lakes in Wisconsin, U.S.A. Freshwater Biology 23, 145–159.

Magnuson, J.J., Webster, K.E., Assel, R.A., Bowser, C.J., Dillon, P.J., Eaton, J.G., Evans, H.E., Fee, E.J., Hall, R.I., Mortsch, L.R., Schindler, D.W., Quinn, F.H., 1997. Potential effects of climate changes on aquatic systems: Laurentian Great Lakes and Precambrian Shield Region. Hydrological Processes 11, 825–871.

Mantel, N., 1967. The detection of disease clustering and a generalized regression approach. Cancer Research 27, 209–220.

McCune, B., Mefford, M.J., 1999. PC-ord Multivariate Analysis of Ecological Data, Version 4.

Morales-Baquero, R., Carrillo, P., Barea-arco, J., Pérez-Martínez, C., Villar-Argaiz, M., 2006. Climate-driven changes on phytoplankton-zooplankton coupling and nutrient availability in high mountain lakes of Southern Europe. Freshwater Biology 51, 989–998.

Morrison, G., Sherwood, E., Boler, R., Barron, J., 2006. Variations in water clarity and chlorophyll *a* in Tampa Bay, Florida, in response to annual rainfall, 1985–2004. Estuaries and Coasts 29, 926–931.

Pace, M.L., Cole, J.J., 2002. Synchronous variation of dissolved organic carbon and color in lakes. Limnology and Oceanography 47, 333–342.

Pfannkuche, J., Meisel, J., Mietz, O., 2000. Factors affecting clarity of freshwater lakes in Brandenburg, Germany. Limnologica – Ecology and Management of Inland Waters 30, 311–321.

Portielje, R., Molen, D.T.V.D., 1999. Relationships between eutrophication variables: from nutrient loading to transparency. Hydrobiologia 408/409, 375–387.

Post, E., Forchhammer, M.C., 2006. Spatially synchronous population dynamics: an indicator of Pleistocene faunal response to large-scale environmental change in the Holocene. Quaternary International 151, 99–105.

Rusak, J.A., Yan, N.D., Somers, K.M., McQueen, D.J., 1999. The temporal coherence of zooplankton population abundances in neighboring north-temperate lakes. The American Naturalist 153, 46–58.

Shanker, K., Sukumar, R., 1999. Synchrony in small mammal populations of montane forest patches in southern India. Journal of Animal Ecology 68, 50–59.

Shao, M., He, L., Han, X., Xie, Z., Li, D., Cai, Q., 2008a. Seasonal patterns of sedimentation and their associations with benthic communities in Xiangxi Bay of the Three Gorges reservoir, China. Journal of Freshwater Ecology 23, 151–160.

Shao, M., Xie, Z., Han, X., Cao, M., Cai, Q., 2008b. Macroinvertebrate community structure in Three-Gorges reservoir, China. International Review of Hydrobiology 93, 175–187.

Smith, L., Engle, V., Summers, J., 2006. Assessing water clarity as a component of water quality in Gulf of Mexico estuaries. Environmental Monitoring and Assessment 115, 291–305.

Søballe, D.M., Kimmel, B.L., 1987. A large-scale comparison of factors influencing phytoplankton abundance in rivers, lakes, and impoundments. Ecology 68, 1943–1954.

Stoddard, J.L., Driscoll, C.T., Kahl, J.S., Kellogg, J.H., 1998. Can site-specific trends be extrapolated to a region? An acidification example for the northeast. Ecological Applications 8, 288–299.

Straškraba, M., Tundisi, J.G., 1999. Guidelines of Lake Management. In: Reservoir Water Quality Management, vol. 9. International Lake Environment Committee.

Swift, T.J., Perez-Losada, J., Schladow, S.G., Reuter, J.E., Jassby, A.D., Goldman, C.R., 2006. Water clarity modeling in Lake Tahoe: linking suspended matter characteristics to Secchi depth. Aquatic Sciences 68, 1–15.

Takahashi, E.M., Lansac-Tôha, F.A., Velho, L.F.M., Bini, L.M., 2008. The temporal asynchrony of planktonic cladocerans population at different environments of the Upper Paraná River Floodplain. International Review of Hydrobiology 93, 679–689.

Tegler, B., Sharp, M., Johnson, M.A., 2001. Ecological monitoring and assessment network's proposed core monitoring variables: an early warning of environmental change. Environmental Monitoring and Assessment 67, 29–55.

Urquhart, N.S., Paulsen, S.G., Larsen, D.P., 1998. Monitoring for policy-relevant regional trends over time. Ecology Application 8, 246–257.

Wang, J., Wang, B.S., Luo, Z.Q., 1997. Dictionary of the Yangtze River. Wuhan Press, Wuhan (in Chinese).

Webster, K.E., Soranno, P.A., Baines, S.B., Kratz, T.K., Bowser, C.J., Dillon, P.J., Campbell, P., Fee, E.J., Hecky, R.E., 2000. Structuring features of lake districts: landscape controls on lake chemical responses to drought. Freshwater Biology 43, 499–515.

Webster, K.E., Kratz, T.K., Bowser, C.J., Magnuson, J.J., 1996. The influence of landscape position on lake chemical responses to drought in northern Wisconsin. Limnology and Oceanography 41, 977–984.

Winder, M., Schindler, D.E., 2004a. Climate change uncouples trophic interaction in an aquatic ecosystem. Ecology 85, 2100–2106.

Winder, M., Schindler, D.E., 2004b. Climatic effects on the phenology of lake processes. Global Change Biology 10, 1844–1856.

Xu, Y., Cai, Q., Shao, M., Han, X., Cao, M., 2009. Seasonal dynamics of suspended solids in a giant subtropical reservoir (China) in relation to internal processes and hydrological features. Quaternary International 208 (1–2), 138–144.

Xu, Y., Ye, L., Han, X., Cai, Q., 2006. Characteristic and regression analysis of the PAR attenuation coefficient in Xiangxi Bay during spring bloom. Acta Hydrobiologica Sinica 30, 84–88.

Ye, L., Han, X., Xu, Y., Cai, Q., 2007. Spatial analysis for spring bloom and nutrient limitation in Xiangxi Bay of Three Gorges reservoir. Environmental Monitoring and Assessment 127, 135–147.

Zeng, H., Song, L., Yu, Z., Chen, H., 2006. Distribution of phytoplankton in the Three-Gorge reservoir during rainy and dry seasons. Science of the Total Environment 367, 999–1009.