Precipitation mediate the distribution of phytoplankton communities in a tributary of Three Gorges Reservoir

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Research Article

Keywords: Precipitation, Phytoplankton bloom, Distribution, Mixing regime, Spatiotemporal difference

Posted Date: June 22nd, 2021

DOI: https://doi.org/10.21203/rs.3.rs-218622/v1

Abstract

Precipitation is a driver of changes in spatiotemporal distribution of phytoplankton communities. The ecological consequences of precipitation is importance but the underlying processes are not clear. Here we conducted an immediate prior- and after-event short-interval investigation in the Three Gorges Reservoir region, to test whether the short-term changes in the phytoplankton communities and functional groups could be predicted based on the precipitation level. We found that precipitation of moderate and high levels immediately changed the phytoplankton distribution and altered functional groups. According to structural equation model, the vertical velocity (λ = -0.81), Z_{eu}/Z_{mix} (λ = 0.47) and RWCS (λ = 0.38) were important parameters for phytoplankton distribution during the precipitation event. Water quality was not directly affected phytoplankton distribution (λ = -0.11) and effects of precipitation on the water quality only lasted 1–2 days. Phytoplankton community was redistributed with some tolerance functional groups appearance, such as group F, Lo, M and groups M, MP, TB, W1 appeared during- and after-precipitation event, respectively. We also found that the mixing rather than flushing was the driving force for the decrease of phytoplankton biomass. Our study provided valuable data for reservoir regulation and evidence for predictions of phytoplankton during the precipitation events under different climate change scenarios.

1. Introduction

Phytoplankton are essential organisms of aquatic food webs, but they can reach unusually high concentrations under suitable conditions. Phytoplankton blooms are becoming increasingly common in aquatic ecosystems worldwide(Chen et al., 2018). The dynamics and maximal biomass of phytoplankton are driven by a wide range of factors including abiotic factors such as hydrological conditions and biotic variables like the presence of filter-feeders (Havens et al., 2017; Kuo and Wu, 2016). As a result, the distribution of phytoplankton is site-specific and notoriously patchy and dynamic (Cyr, 2017).Distribution is often disturbed by factors such as precipitation or wind over short-term scales(Serra et al., 2007; Vidal et al., 2014; Yang et al., 2017). Understanding the ecological consequences of phytoplankton community and distribution change in the water column caused by different variables acting on spatial and temporal scales is a challenge for controlling ecosystem productivity (Serra et al., 2007). Previous studies have reported that precipitation can change phytoplankton community structure (Ahn et al., 2002b; Jeong et al., 2007; Sung et al., 2002)and succession (Znachor et al., 2008), and can delay the outbreak of phytoplankton blooms(Iriarte and Purdie, 2004).The physical processes by which precipitation changes phytoplankton aggregation in space and in time are not entirely clear. In this study, we examine how precipitation affects the distribution and composition of phytoplankton in the Three Gorges Reservoir (TGR) region, China, which is one of the largest reservoirs in the world and has experienced frequent phytoplankton blooms since completion of the dam in 2003.

The effects of precipitation on freshwater ecosystems have received increasing attention in recent decades, because extreme precipitation events are predicted to increase due to climate change in the near future(IPCC, 2013), and more extreme precipitation events are now being observed globally(Lehmann et al., 2015; Richardson et al., 2019). Freshwater ecosystems in China are directly influenced by the East Asian monsoon which drives concentrated precipitation spikes in summer, andmight play a key role in influencing water quality and aquatic biota (Guo et al., 2018). Some studies have examined the relationship between precipitation and phytoplankton (Ahn et al., 2002a; Richardson et al., 2019; Sung-Su-Hong et al., 2002; Wu et al., 2013; Zhou et al., 2012), and precipitation and water quality (Jeong et al., 2011). Thefields observation also displayed a disappearance of phytoplankton bloom and decrease of biomassafter precipitation.A question that remains unanswered is how precipitation regulates phytoplankton assemblage and distribution. Additionally, previous studies were limited to rivers, shallow lakes, or small reservoirs as study systems,where precipitation can strongly affect phytoplankton assemblage through flushing and changes in selection pressures such as nutrient concentrations or mixing depth (Badylak et al., 2016; Richardson et al., 2019; Sadro and Melack, 2012),due to the high fluidity or limited storage capacity of the water body.Inlarge and deep reservoirs, precipitation events may have different impacts on phytoplankton assemblage and dynamics(Paerl et al., 2016; Perga et al., 2018).Precipitation is difficult to predict accurately; a rigorous and immediate prior- and after-event short-interval sampling program is required to measure its effects.The potential for global climate change highlights the importance of understanding the ecological consequences of precipitation in terms of the structure and function of aquatic ecosystems in the TGR region and other large water bodies.Huge, deep reservoirs are of particular ecological interest as 57,000+ large dams have been constructed on half of the Earth's major rivers.

Phytoplankton are sorted into functional groups based on their ecological and physiological traits rather than common morphological characteristics or phylogenetic origins;the functional groups concept better characterizes their role in biogeochemical cycles and reflects environmental changes(Reynolds et al., 2002; Yang et al., 2016), such as *Microcystis* from Group M and *Merismopedia* from Group Lo survive in distinct adaptive strategieswith different favor habitat, but they belong to same taxa, Chrococcaceae of Cyanophyta.The phytoplankton structure of the TGRand its relationship to water management and flood regulation has been previously described, with different functional groups dominating during the stratification and mixing seasons(Peng et al., 2013; Zhu et al., 2013). However, the effect of precipitation events, including that of the spikes associated with the annual East Asian monsoon, has yet to be adequately measured.

Here,we describe an*insitu*timely sampling programina tributary of TGRduring the cyanobacteria bloom period, andtest whether short-term changes in the phytoplankton assemblage andfunctional groups can be predicted from precipitation amount.We tested the hypotheses that: (a) precipitationevents would rapidly change the distributionofthe phytoplanktonassemblage and functional groups; (b) precipitation would result in a loss of phytoplankton biomass, and (c) taxonomic composition of phytoplankton communities differs between prior- and after-precipitation events.

2. Materials And Methods

2.1 Sampling site and sampling methods

This study was performed in the Xiangxi River, atributary of the TGR and eventually the Yangtze River. It has a watershed of 3095 km^2, annual average flow 47.4 m^3/s (Liu et al., 2012), and annual precipitation ranging from 670 mm to 1700 mm (Han et al., 2014). Daily precipitation and wind data were obtained from the nearest official weather station of Xingshan,which was about 5 km from the sampling site(Fig. 1). During a *Microcystis* sp. dominated cyanobacteria bloom in summer, phytoplankton and water quality parameters were measured every day at the sampling site (Fig. 1), anddata of 10 consecutive days were selected to analyzeonce continuous precipitation appeared.

Water samples were collected from depths of 0.5, 1.0, 2.0, 5.0,and 10.0 m below the water surface, and the water qualityparametersof each depths were measured synchronously*in situ*.Water temperature (WT)anddissolved oxygen (DO) weremeasured with a YSI Professional Plus (YSI Incorporated, Yellow Springs, OH, USA). The photosyntheticallyactive radiation (PAR) in the air and underwater was measured with a LI-1400 data logger (LI-COR, Lincoln, NE, USA). The flow fields of the sampling sites were surveyed with FlowQuest 600 (LinkQuest Incorporated, San Diego, CA, USA) installed on a boat.Three-dimensional velocity and discharge at the sampling site were analyzed with the FlowQuest 600 Discharge Measurement 6.0.0 package with the offline analysis according to the user's manual.

Total nitrogen (TN) and permanganate index (COD_{Mn}) were determined in accordance with standard methods for water and wastewater(APHA, 2012). Bulk water samples for phytoplankton analysis were preserved with 1.5% Lugolsolution and concentrated to 30 mL after sedimentation for more than 48 h, then counted with an optical microscope (Olympus CX21, Tokyo, Japan) under ×400 magnification. Phytoplankton were identified according to algal taxonomy keys(Hu and Wei, 2006; John et al., 2002). Mean biovolume (organism mm^3 L^{-1}) of main taxa wascalculated by assigning geometric shapes to each cell or filament (Brierley et al., 2007), and assuming the biomass unit as expressed in mass, where 1 mm^3 L^{-1} = 1 mg L^{-1}(Napiórkowska-Krzebietke and Kobos, 2016). Phytoplankton were classified into functional groups, using the criteria established by Reynolds et al. (Reynolds et al., 2002) and Padisák et al. (Padisak et al., 2009).

2.3 Data analysis

In order to assess the immediate effect of precipitation on water quality, a minimum water quality index (WQI_{min}) method was established according to the equation below(Pesce and Wunderlin, 2000):

$$WQI_{min} = \sum_{i=1}^{n} \frac{C_i}{n} \quad (1)$$

where n is the total number of parameters and Ci is the value after normalization. In this study,DO, TN, and COD_{Mn}were normalized based on normalization factors and used to calculate the WQI_{min}, following the methods of a water quality assessment atLake Taihu, China, a largelake at a similar latitude, where WQI_{min} values were positive correlated with water quality (Wang et al., 2019b).

The euphotic zone (Z_{eu}) was calculated as the depth where underwater PAR is 1% of its surface strength(Kirk, 1994). A minimum temperature gradient of 0.2 °C overthe depth spacing of the temperature profiles was used to identify the mixing depth(Z_{mix}) (Amaral et al., 2018). The ratio between the euphotic zone andthe mixing zone (Z_{eu}/Z_{mix}) was used as a measure of light availability(Jensen et al., 1994).

The dimensionless parameter of relative water column stability (RWCS) was used to describe the hydrodynamic conditions, and calculated according to the following formula (Padisák et al., 2003):

$$RWCS = \frac{D_b - D_S}{D_4 - D_5} \quad (2)$$

Where $D_b$is the density of bottom waters; $D_s$is the density of the surface waters; and D_4 and $D_5$are the densities of pure water at 4°C and 5°C, respectively.

Morisita's index was used to evaluate the distribution of phytoplankton in the water column. The index was calculated as (Hills and Thomason, 1996; Thackeray et al., 2006):

$$I_\delta = N \cdot \frac{(\sum_{i=1}^{N} xi^2 - \sum_{i=1}^{N} xi)}{\left[(\sum_{i=1}^{N} xi)^2 - \sum_{i=1}^{N} xi\right]} \quad (3)$$

Where N is the total number of layers in water column; Xi is the number of individuals in the i^{th} layer. The index is equal to 1 for a random distribution, less than 1 for a uniform distribution, and greater than 1 for a clumped distribution.

2.4 Statistical analysis

Based on the precipitation events, the sampling days were divided into two periods (Fig. 2): thecontinuousprecipitation period (P1)which included moderate precipitation (Jun 21-Jun24) and heavy precipitation (Jun 25)days,and the five day post-precipitation period (P2; Jun 26-30). The precipitation effect is believed to persist for 3-5 days (Baek et al., 2009).

The significant dissimilarities of phytoplankton assemblage structure between P1 and P2 were tested by applying analysis of similarity (ANOSIM) based on permutation procedures with 999 runs(Clarke, 1993). ANOSIM was carried out with the software package Primer 6.0. The differences of selected parameterswereseparately compared with P1 and P2 using a Wilcoxon rank-sum tests.Time-series analysis of a cross-correlation statistical method was used to show time lag of the influence of precipitation on selected parameters(Baek et al., 2009; Zhang et al., 2019). Statistical analysis was carried out in the IBM SPSS Statistics 25 package.To characterize the variation of functional groups during- and after- precipitation event, coefficient of variation (CV) was calculated based on standard deviation divided by the mean value.

Structural equation model (SEM)analyses wereused to analyze the significance of the hypothesized causal relationships among precipitation, water quality (WQI_{min}), hydrologic regime (velocity, RWCS, Z_{eu}/Z_{mix}), and phytoplankton assemblage distribution (I_{δ}). The best-fit model was obtained by using maximum likelihood estimationand improved iteratively by modification in prior models according to a set of modification indices, such as chi-square test (χ^2), *p* values, degrees of freedom(df), goodness-of-fit index (GFI), and root mean square errors of approximation (RMSEA)(Wang et al., 2019a). SEM analyses wereperformed using the IBMAmos 24package.

3. Results

3.1 Effects of precipitation on water quality

The WQI_{min}fluctuated during the observation period, ranging from 31.8 to 76.7 (Fig. 3a), representing trophic state indices from hypereutrophic to mesotrophic, and the overall WQI_{min} showed significant change between P1 and P2 (Wilcoxon tests, $p< 0.05$). Before the five-day precipitation event, the sampling site was experiencing a cyanobacteria bloom, which was dominated by *Microcystis*, and the spatial distribution of WQI_{min} was uneven across different depths, with a relatively low average WQI_{min} of 45.1. The WQI_{min}decreased, with trophic state worsening, with the continuousmoderate precipitation. The highest peak was observed 2 m below the water surface during heavy precipitation (Jun 25).After precipitation, the average WQI_{min} was much higher, though the spatial distribution of WQI_{min} was uneven in the water column. Cross-correlation indicated thatthe water quality of the upper layer (0-5 m) increased the day of precipitation, but that of the lower layer (5-10 m) increased 1 day after the precipitation event (Fig. 3b).The effects of precipitation on the water quality lasted 1-2 days, then the water columngradually reverted to pre-precipitation state.

3.2 Effects of precipitation on hydrodynamics

The horizontal and vertical velocity in the water columnshowed different patterns, with the vertical velocity being much higher than horizontal velocity during the study period (Fig. 4a and 4b).The horizontal velocity at different depths in the water column remained relatively stable during rainy days, even during heavy precipitation, and the overall horizontal velocity showed no significant change between P1 and P2 (Wilcoxon tests, $p> 0.05$). However, the vertical velocity at different depths in the water column varied greatly during rainy days, especially in the upper layer, in which it increased almost two times during heavy precipitation, and vertical velocity changed significantly between P1 and P2 (Wilcoxon tests, $p< 0.05$).The RWCS decreased as the water column started mixing across the precipitation period (Fig. 4c) andbecame almost completely mixed during the heavy precipitation day. Stratification resumed 1 day after the precipitation disturbance and RWCS showed significant change between P1 and P2 (Wilcoxon tests, $p < 0.05$). Cross-correlation indicated that precipitation affected flow field and stratification of the water column at different times.The vertical velocity increased and RWCS decreased the day of precipitation, while the horizontal velocity changed 1 day after the precipitation event (Fig. 4d).

3.3 Phytoplankton assemblage dynamics

During the study period, the phytoplankton assemblage was dominated by *Microcystis* sp., and a total of 36 algal taxa belonging to 6 phyla were recorded. 16 functional groups were classified, including the 28 descriptor taxa (Tab.S1). The M, H1, G, A, and Y functional groups were the main contributors to the phytoplankton assemblage in the Xiangxi River across the study period (Fig. 5a). Before the precipitation event, the phytoplankton community was dominated by M and H1 functional groups, but there was marked temporal and spatial variation in representation of the functional groups of phytoplankton during rainy days (Fig. 5a). Group Y sharply decreased in the water column after the start of precipitation. During the heavy precipitation day, the phytoplankton community was dominated by Groups M, A, and G, and the deeper layer of water column was dominated by Groups A, D, P, and M.The overall phytoplankton assemblage structure showed no detectable change between P1 and P2 (ANOSIM,$p > 0.05$).The dominanttaxon was cyanobacteria over the entire course of the study, withthe proportion of cyanobacteria remaining higher than that of the other taxa. After the precipitation event, the proportion of bacillariophyta increased slowly, but this phenomenon just last 3 days.The vertical distribution of phytoplankton biomass changed significantly during the precipitation period (Fig. 5c).The biomass was higher in the upper layer than in the deeper layer during the continuous moderate precipitation period, while it became very low in the entire water column during the heavy precipitation day. However, the distribution of phytoplankton recovered quickly from this stage after the cessation of heavy precipitation, with the biomass increasing, and even being higher, in the upper layer than before precipitation occurred.

CV valuesfor each functional group were calculated and used to identifyvariation of functional groups during- and after- precipitation event(Tab. S2). High CVmeans the presence of strongdistribution heterogeneity. Low CVindicates low cohort heterogeneity in relation to distribution.For our study, in most functional groups the values of CVare rather high, indicating heterogeneity of thespatiotemporal distribution. Groups F, Lo, Mand groups M, MP, TB, W1shared the last 20% average CV values at all sampling depth in the P1 and P2, respectively (Tab. S2), indicated their relatively stability along the time course.Group M (i.e. cyanobacteria) could persist during- and after- precipitation event, even after ca. 80 mm precipitation in 5 days.

Distribution of phytoplankton in the water column was affected by the precipitation event. Before the precipitation period, Morisita's index was higher than during the precipitation period, indicating that the phytoplankton had a clumped distribution (Fig. 5c and 6). During the continuous precipitation, Morisita's index decreased over time. The lowest value was observed during heavy precipitation; the value was close to 1, revealing that the vertical distribution of phytoplankton was significantly affected by the precipitation.Phytoplankton was randomly distributed during this time. After the rainy period, the distribution of phytoplankton returned to a clumped distribution.Corresponding to the cross-correlation coefficient, the lag was negative, indicating no direct significant effect of precipitation on Morisita's index (Fig. 6b).

3.4 Structural equation model (SEM)

The fitting parameters of all minimal adequate path analysis explained 61% of the variance in phytoplankton distribution (Fig. 7a).Vertical velocity (λ=-0.81) was the strongest predictor ofphytoplankton distribution (Fig. 7b) and was positively driven by precipitation (r=0.59, p< 0.001). The vertical velocity directly affected phytoplankton distribution (r=-0.72, p< 0.001), also strongly explained the variance of RWCS and Z_{eu}/Z_{mix}, which directly contributed to the phytoplankton distribution in the water column (Fig. 7a).

4. Discussion

Precipitation governs water quality variation in river systems, especially when the river is regulated by dams(Jeong et al., 2011; Wolf et al., 2020). But there is a knowledge gap in the physical processes by which precipitation changes phytoplankton aggregation in space and in time.Surface water nutrient concentrations often increase markedly during and immediately after precipitation events(Sherson et al., 2015; Walker, 1991). Nutrients from precipitation-runoff lead to deterioration of water quality in the TGR basin. This phenomenon was observed in the current study, where continuous moderate precipitation increased the concentration of many nutrients in the water column (unpublished data), and the WQI_{min} decreased (Fig. 3a). However, the water quality of surface water increasedduring heavy precipitation,which may be due to a dilution effect. Although WQI_{min}increased slightly during heavy precipitation, it returned to pre-precipitation values quickly,and even continued to decrease.Water quality variationwas observed 0 and 1 day following precipitation at the depths of 0-5 m and 10 m, respectively (Fig. 3b). The results of cross-correlation statistical analysis imply that water qualitysynchronized with discharge after precipitation, which is a main cue for dynamics of phytoplankton population during thesummer season(Baek et al., 2009). The possibility that the East Asian monsoon summer rains drive phytoplankton dynamics in the TGR deserves further study.

Wind plays an important role in the distribution of phytoplankton by mixing the surface layer (Cyr, 2017; Liu et al., 2012; Monismith and MacIntyre, 2009).The strength and effect of these shear forces depends on the wind speed (Boegman, 2009; Cyr, 2017; Kim et al., 2014). The patchiness of phytoplankton in lakes and reservoirs disappears at wind speeds above 3-4 m s^{-1}(Hunter et al., 2008; Vidal et al., 2014). During this study, the maximum wind speed reached 12.3 m s^{-1}, but the mean wind speed was only 1.1 m s^{-1}, with the main wind direction from the south-southwest (Fig. S1). The influence of winds on mixing of the surface layer is small: the horizontal velocity atall depths in the water column remained relatively low during rainy days, even during heavy precipitation (Fig. 4a and 4b). This fresh water probably reached the sampling site 1 day after precipitation (Fig. 4d).The RWCS decreased as the mixing increased: the water column started mixing the day of precipitation (Fig. 4d), and almost completely mixed in the heavy precipitation day (Fig. 4c).Mixing regime governs the phytoplankton composition(Becker et al., 2010); the structure of phytoplankton communities is mainly determined by resource availability (Reynolds, 2006) and hydrological conditions (Cyr, 2017; Monismith and MacIntyre, 2009). Hydrological conditions are integral drivers of community assemblages in short-term weather events.During the precipitation days, mixing may have selectedfor groups tolerant to mixing regime and low light, such as groupsF, Lo and M.After the precipitation event, groups M, MP, TB, W1 were more stable than other groups. Contrarily to the traditional paradigm that short-term and abrupt changes in water column attenuate cyanobacterial blooms, the results showed that in some cases (after ca. 80 mm precipitation in 5 days), cyanobacteria (i.e. group M) can persist over time.

During the study period, the dominant taxon in the Xiangxi River was cyanobacteria, primarily*Microcystis* sp., and accounted for nearly 90% of the cell density. Previous research showed that an intense East Asian monsoon reduceda cyanobacteria bloom while a weak monsoon increased it (An and Jones, 2000). However, our data suggested that phytoplankton concentrated in the upper layer of water column after continuous moderate precipitation, resulting in low cell density of phytoplankton in the deeper layer of the water column. Cell density of phytoplankton in the entire water column was significantly lower on the day of heavy precipitation than during other days (Fig. 5c), providing partial support for our second hypothesis. However, cell density recovered and proliferated from the precipitationevent quickly, faster than other studies have reported (Ye et al., 2007; Zhou et al., 2011). There are several potential explanations for this rapidity: an increased concentration of nutrients in the upper layers of the water column after moderate rain drew phytoplankton there (evidenced by their clumped distribution), and/or subsequentheavy rains caused phytoplankton migrated horizontally and vertically due to the destabilization of the water column (resulting in random distribution; Fig. 6).

The most important precondition for a cyanobacteria bloom is water column stability (Park et al., 2000). Previous studies showed that the phytoplankton diversity is low during blooms (Jacobsen and Simonsen, 1993; Sung-Su-Hong et al., 2002). Our study similarly found that during the cyanobacteria bloom, phytoplankton diversity in the water column was also low. When the hydrological conditions of Xiangxi River were significantly affected by heavy precipitation, the cyanobacteria bloom disappeared (Fig. 5c). We observed changes in phytoplankton distribution after the precipitation event, in support of our first hypothesis. The physical disturbance caused by heavy precipitation may generate a uniform phytoplankton distribution in the water column and enable benthic taxa to co-exist in surface water (Sung-Su-Hong et al., 2002). This positively affects phytoplankton diversity, and a tendency of diversity to increase at lower biomass is also observed (Moustaka-Gouni, 1993). Similarly, during the heavy precipitation period of this study, phytoplankton diversity slightly increased in the lower water column even though the biomass decreased. During moderate continuous precipitation, Morisita's index decreased, suggesting that the distribution of phytoplankton in the water column was affected (Fig. 6); however, there were no obvious changes in phytoplankton composition structure during the continuous precipitation period (Fig. 5a).

Precipitationcan abruptly affect environmental conditions and community assemblages. In the current study, a precipitation event altered water quality and phytoplankton distribution. However, no overarching changes to the phytoplankton taxonomic compositionwere found during the study period. This is likely because cyanobacteria overwhelmingly dominated the community (>90%), while other taxawere scarce. The reason for the disappearance of the cyanobacteria bloom during heavy precipitation is the phytoplanktonvertical migration driven by vertical velocity (Fig. 7). The measured water quality parameters and phytoplankton biomass returned to pre-rain levels quickly (Fig. 3a and 5c), after sedimentation of suspended particles and an increase in light availability. Precipitation has the potential to show long-term effects on aquatic ecosystems,in particularly there may be a massive phytoplankton bloom after precipitation event due to the high input of nutrients and light availability.

After the completion of the damat the TGR, ecological changes to tributary backwaters have attracted widespread attention and study due to high incidence of phytoplankton blooms(Ministry of Environmental Protection of China, 2019). Some studies have indicated that a mixing regime caused by sufficiently large water level fluctuations might be an effective way to inhibit phytoplankton blooms(Liu et al., 2012; Paillisson and Marion, 2011; Yang et al., 2010). Unfortunately, it is impossible for the TGR to maintain regular, sufficiently large water level fluctuations and meet the goals of flood management, water resource supplies, and hydropower production. Flood-operations and flow-operationsare carried out each year in the TGR according to the Directive of the Ministry of Water Resources of the People's Republic of China; however, these hydrological approaches are based on flow, without consideration of biology. A practical approach for phytoplankton bloom or productivity control is still needed. Our results suggest that under future climate change scenarios, precipitation might be a valuable signal for reservoirregulationdue to the widespread climate monitoring network that makes it easy to obtain real-time precipitation information, and timely flow-operation can flush more phytoplankton when they are mixed by precipitation, limiting harmful blooms.

Declarations

Authors’ contributions **Chengrong Peng:** Conceptualization, Investigation, Formalanalysis, Writing - original draft. **Zhengyu Hu:**Resources. **Yonghong Bi:** Conceptualization, writing - review and editing.

Funding This study was supported by the National Natural Science Foundation of China (No: 31901156) and National Key Research and Development Project (2019YFD0900603). We are thankful to Yijun Yuan, Yi Yang, and Yongmei Lei for their assistance with field work and analysis of water samples.

Availability of data and materials Not applicable.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

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Figures

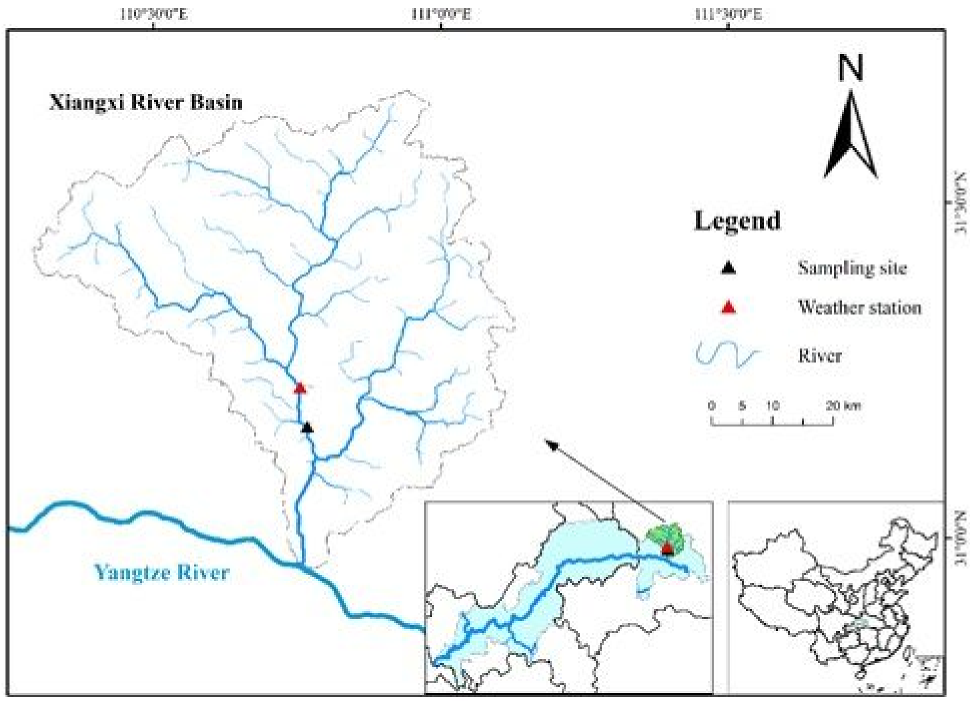

Figure 1

Location of sampling site and weather station in the Xiangxi River of Three Gorges Reservoir. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

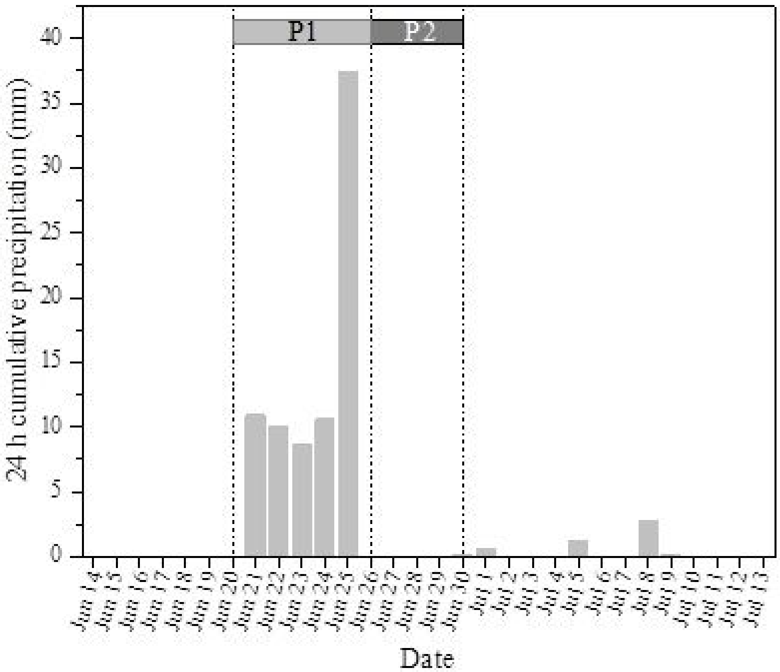

Figure 2

Daily precipitation at the sampling site during the study period.

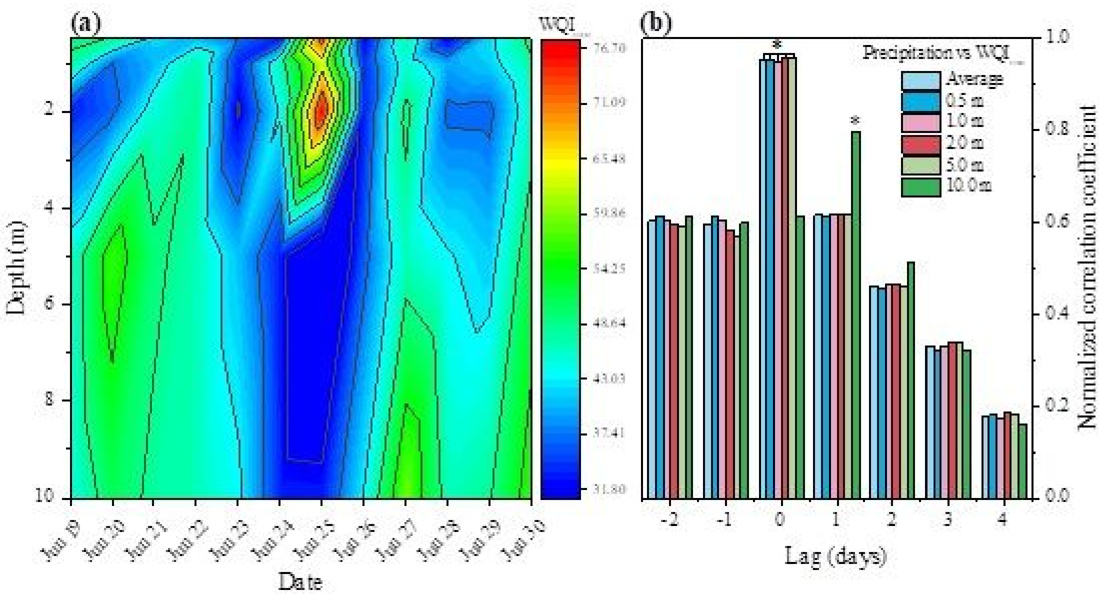

Figure 3

(a) Spatiotemporal variation in WQIminat the sampling site during the study period; (b) Time lagged cross-correlation between precipitation and WQImin at different depths.Asterisk indicate precipitation and corresponding parameter change with a time lag (days).

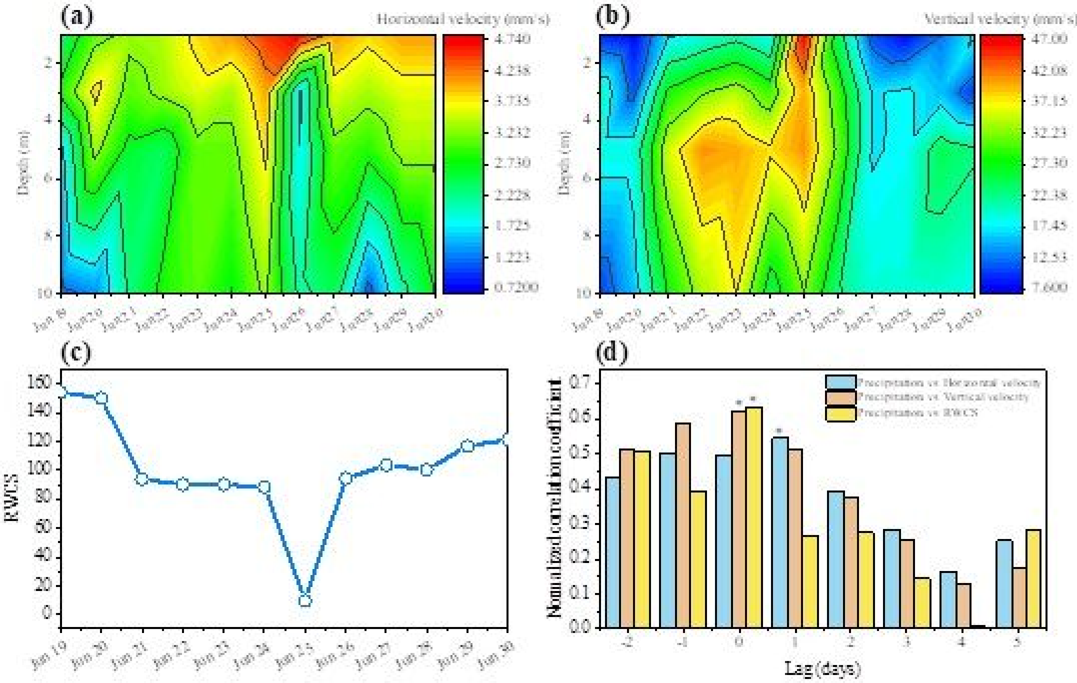

Figure 4

Spatiotemporal variation in (a) horizontal velocity, (b) vertical velocity, and (c) RWCS at the sampling site during the study period; (d) time lagged cross-correlation between precipitation and horizontal velocity, vertical velocity, and RWCS. Asteriskindicate precipitation and corresponding parameter change with a time lag (days).

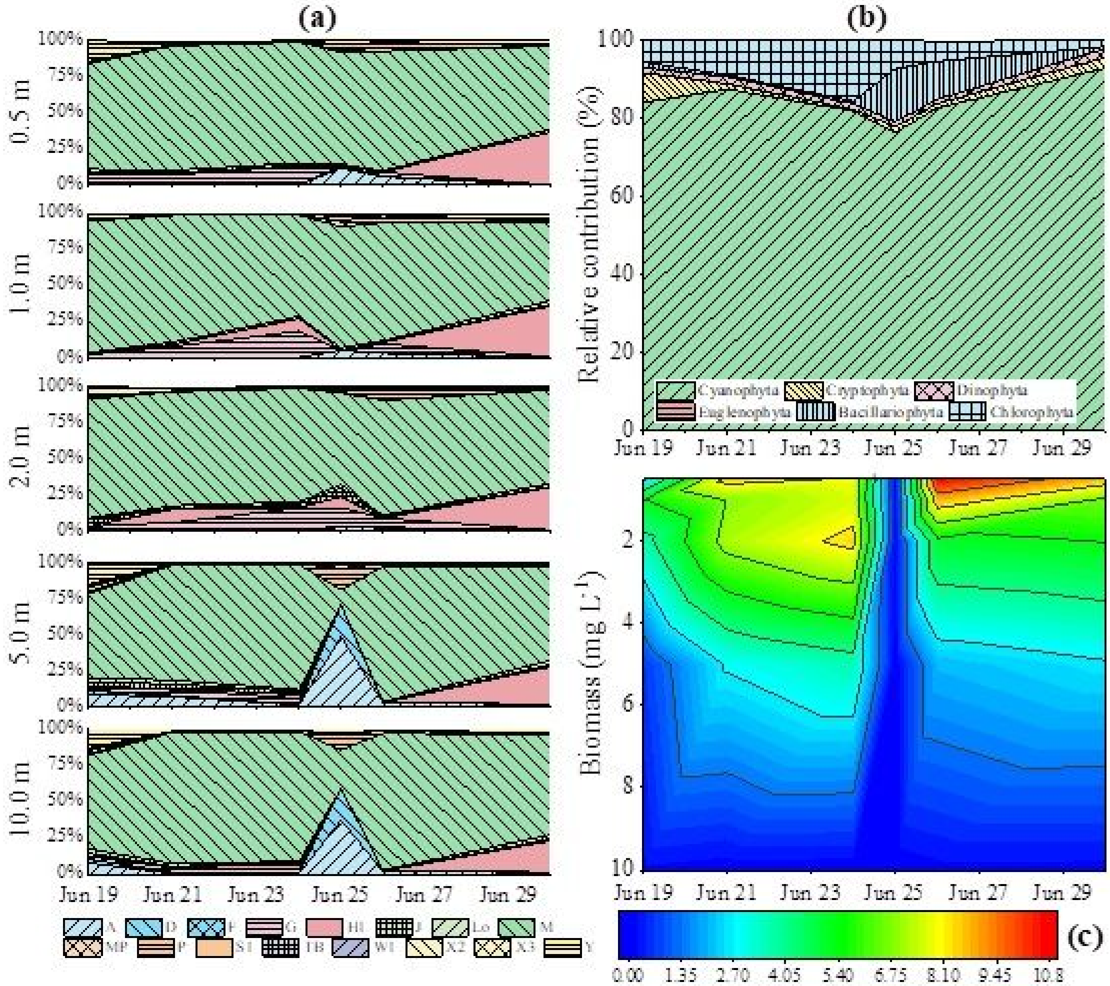

Figure 5

Variation of phytoplankton assemblage in the Xiangxi River during the study period. (a) Vertical distribution of phytoplankton function groups, (b) Relative contribution of phytoplankton, (c) Vertical distribution of phytoplankton biomass.

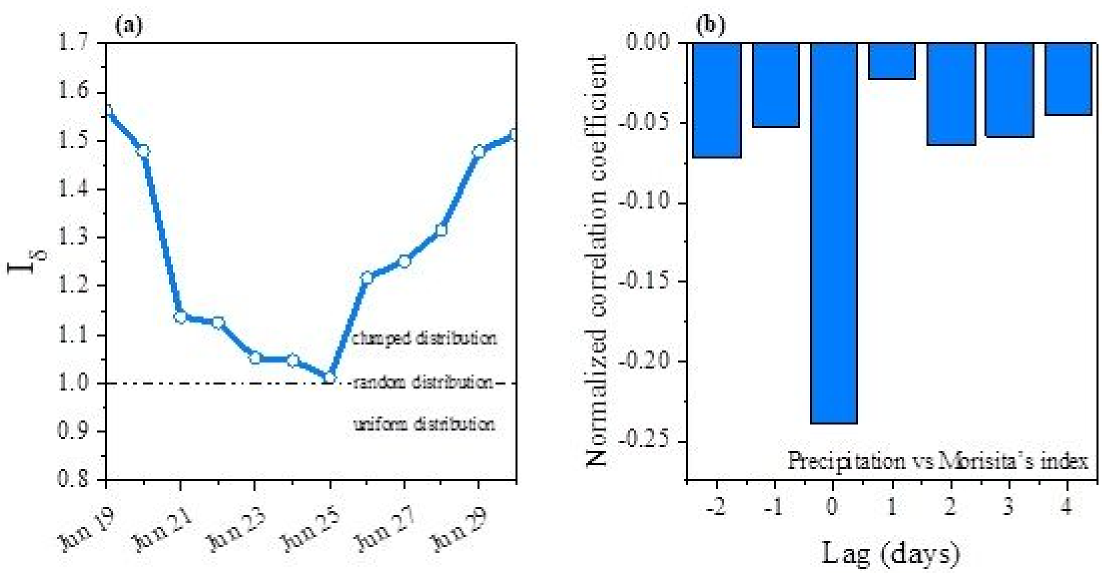

Figure 6

(a) Temporal variation in Morisita's index during the study period; (b) time lagged cross-correlation between precipitation and Morisita's index.

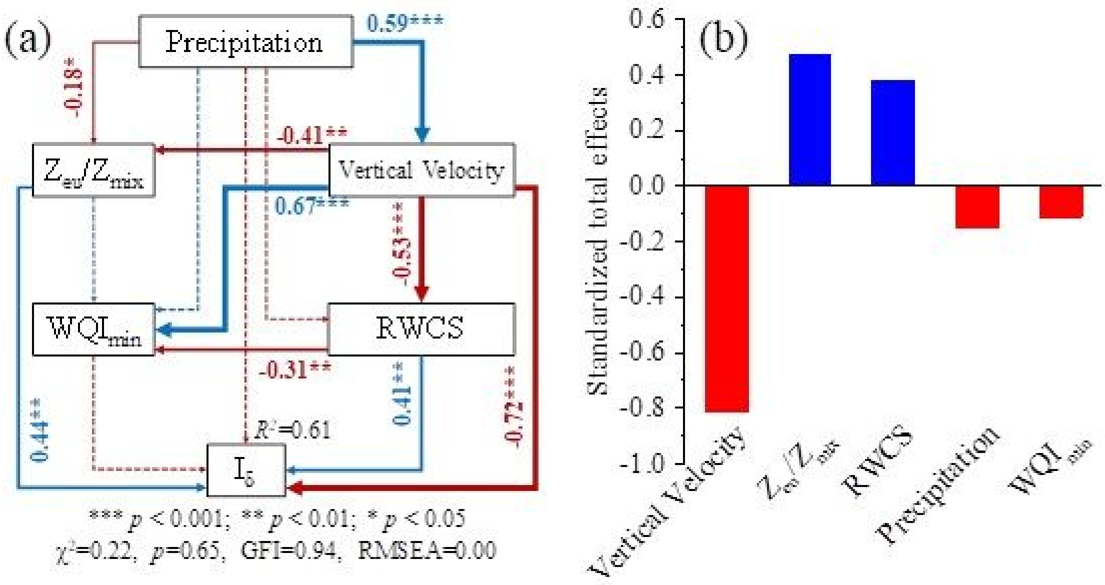

Figure 7

The direct (a) and total (b) effects of five variables on phytoplankton distribution, as determined by structural equation modeling. Arrow width and the numbers on the arrows correspond to the standardized path coefficients;significant and nonsignificant path coefficients are indicated by solid and dotted lines, respectively; blue and red arrows indicate positive and negative flows of causality (p<0.05), respectively.

Supplementary Files

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- SupplementaryMaterials.pdf