

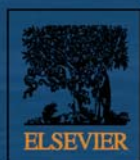
JES

JOURNAL OF
ENVIRONMENTAL
SCIENCES

January 1, 2015 Volume 27
www.jesc.ac.cn

ISSN 1001-0742
CN 11-2629/X

Could wastewater analysis be a useful tool for China?



Sponsored by
Research Center for Eco-Environmental Sciences
Chinese Academy of Sciences

-
- 1 The potential risk assessment for different arsenic species in the aquatic environment
Meng Du, Dongbin Wei, Zhuowei Tan, Aiwu Lin, and Yuguo Du
 - 9 Synthesis of linear low-density polyethylene-*g*-poly (acrylic acid)-co-starch/organo-montmorillonite hydrogel composite as an adsorbent for removal of Pb(II) from aqueous solutions
Maryam Irani, Hanafi Ismail, Zulkifli Ahmad, and Maohong Fan
 - 21 Research and application of kapok fiber as an absorbing material: A mini review
Yian Zheng, Jintao Wang, Yongfeng Zhu, and Aiqin Wang
 - 33 Relationship between types of urban forest and PM_{2.5} capture at three growth stages of leaves
Thithanhthao Nguyen, Xinxiao Yu, Zhenming Zhang, Mengmeng Liu, and Xuhui Liu
 - 42 Bioaugmentation of DDT-contaminated soil by dissemination of the catabolic plasmid pDOD
Chunming Gao, Xiangxiang Jin, Jingbei Ren, Hua Fang, and Yunlong Yu
 - 51 Comparison of different combined treatment processes to address the source water with high concentration of natural organic matter during snowmelt period
Pengfei Lin, Xiaojian Zhang, Jun Wang, Yani Zeng, Shuming Liu, and Chao Chen
 - 59 Chemical and optical properties of aerosols and their interrelationship in winter in the megacity Shanghai of China
Tingting Han, Liping Qiao, Min Zhou, Yu Qu, Jianfei Du, Xingang Liu, Shengrong Lou, Changhong Chen, Hongli Wang, Fang Zhang, Qing Yu, and Qiong Wu
 - 70 Could wastewater analysis be a useful tool for China? – A review
Jianfa Gao, Jake O'Brien, Foon Yin Lai, Alexander L.N. van Nuijs, Jun He, Jochen F. Mueller, Jingsha Xu, and Phong K. Thai
 - 80 Controlling cyanobacterial blooms by managing nutrient ratio and limitation in a large hypereutrophic lake: Lake Taihu, China
Jianrong Ma, Boqiang Qin, Pan Wu, Jian Zhou, Cheng Niu, Jianming Deng, and Hailin Niu
 - 87 Reduction of NO by CO using Pd-CeTb and Pd-CeZr catalysts supported on SiO₂ and La₂O₃-Al₂O₃
Victor Ferrer, Dora Finol, Roger Solano, Alexander Moronta, and Miguel Ramos
 - 97 Development and case study of a science-based software platform to support policy making on air quality
Yun Zhu, Yanwen Lao, Carey Jang, Chen-Jen Lin, Jia Xing, Shuxiao Wang, Joshua S. Fu, Shuang Deng, Junping Xie, and Shicheng Long
 - 108 Modulation of the DNA repair system and ATR-p53 mediated apoptosis is relevant for tributyltin-induced genotoxic effects in human hepatoma G2 cells
Bowen Li, Lingbin Sun, Jiali Cai, Chonggang Wang, Mengmeng Wang, Huiling Qiu, and Zhenghong Zuo
 - 115 Impact of dissolved organic matter on the photolysis of the ionizable antibiotic norfloxacin
Chen Liang, Huimin Zhao, Minjie Deng, Xie Quan, Shuo Chen, and Hua Wang
 - 124 Enhanced bio-decolorization of 1-amino-4-bromoanthraquinone-2-sulfonic acid by *Sphingomonas xenophaga* with nutrient amendment
Hong Lu, Xiaofan Guan, Jing Wang, Jiti Zhou, Haikun Zhang
 - 131 Winter survival of microbial contaminants in soil: An *in situ* verification
Antonio Bucci, Vincenzo Allocca, Gino Naclerio, Giovanni Capobianco, Fabio Divino, Francesco Fiorillo, and Fulvio Celico
 - 139 Assessment of potential dermal and inhalation exposure of workers to the insecticide imidacloprid using whole-body dosimetry in China
Lidong Cao, Bo Chen, Li Zheng, Dongwei Wang, Feng Liu, and Qiliang Huang

CONTENTS

- 147 Biochemical and microbial soil functioning after application of the insecticide imidacloprid
Mariusz Cycoń and Zofia Piotrowska-Seget
- 159 Comparison of three-dimensional fluorescence analysis methods for predicting formation of trihalomethanes and haloacetic acids
Nicolás M. Peleato and Robert C. Andrews
- 168 The migration and transformation of dissolved organic matter during the freezing processes of water
Shuang Xue, Yang Wen, Xiujuan Hui, Lina Zhang, Zhaohong Zhang, Jie Wang, and Ying Zhang
- 179 Genomic analyses of metal resistance genes in three plant growth promoting bacteria of legume plants in Northwest mine tailings, China
Pin Xie, Xiuli Hao, Martin Herzberg, Yantao Luo, Dietrich H. Nies, and Gehong Wei
- 188 Effect of environmental factors on the complexation of iron and humic acid
Kai Fang, Dongxing Yuan, Lei Zhang, Lifeng Feng, Yaojin Chen, and Yuzhou Wang
- 197 Resolving the influence of nitrogen abundances on sediment organic matter in macrophyte-dominated lakes, using fluorescence spectroscopy
Xin Yao, Shengrui Wang, Lixin Jiao, Caihong Yan, and Xiangcan Jin
- 207 Predicting heavy metals' adsorption edges and adsorption isotherms on MnO_2 with the parameters determined from Langmuir kinetics
Qinghai Hu, Zhongjin Xiao, Xinmei Xiong, Gongming Zhou, and Xiaohong Guan
- 217 Applying a new method for direct collection, volume quantification and determination of N_2 emission from water
Xinhong Liu, Yan Gao, Honglian Wang, Junyao Guo, and Shaohua Yan
- 225 Effects of water management on arsenic and cadmium speciation and accumulation in an upland rice cultivar
Pengjie Hu, Younan Ouyang, Longhua Wu, Libo Shen, Yongming Luo, and Peter Christie
- 232 Acid-assisted hydrothermal synthesis of nanocrystalline TiO_2 from titanate nanotubes: Influence of acids on the photodegradation of gaseous toluene
Kunyang Chen, Lizhong Zhu, and Kun Yang
- 241 Air-soil exchange of organochlorine pesticides in a sealed chamber
Bing Yang, Baolu Han, Nandong Xue, Lingli Zhou, and Fasheng Li
- 251 Effects of elevated CO_2 on dynamics of microcystin-producing and non-microcystin-producing strains during *Microcystis* blooms
Li Yu, Fanxiang Kong, Xiaoli Shi, Zhen Yang, Min Zhang, and Yang Yu
- 259 Sulfide elimination by intermittent nitrate dosing in sewer sediments
Yanchen Liu, Chen Wu, Xiaohong Zhou, David Z. Zhu, and Hanchang Shi
- 266 Steel slag carbonation in a flow-through reactor system: The role of fluid-flux
Eleanor J. Berryman, Anthony E. Williams-Jones, and Artashes A. Migdisov
- 276 Amine reclaiming technologies in post-combustion carbon dioxide capture
Tielin Wang, Jon Hovland, and Klaus J. Jens
- 290 Do vehicular emissions dominate the source of C6-C8 aromatics in the megacity Shanghai of eastern China?
Hongli Wang, Qian Wang, Jianmin Chen, Changhong Chen, Cheng Huang, Liping Qiao, Shengrong Lou, and Jun Lu
- 298 Insights into metals in individual fine particles from municipal solid waste using synchrotron radiation-based micro-analytical techniques
Yumin Zhu, Hua Zhang, Liming Shao, and Pinjing He

Available online at www.sciencedirect.com

ScienceDirect

www.journals.elsevier.com/journal-of-environmental-sciences
IFS
 JOURNAL OF
 ENVIRONMENTAL
 SCIENCES
www.jesc.ac.cn

Effects of elevated CO₂ on dynamics of microcystin-producing and non-microcystin-producing strains during *Microcystis* blooms

Li Yu^{1,2}, Fanxiang Kong^{1,*}, Xiaoli Shi¹, Zhen Yang¹, Min Zhang¹, Yang Yu¹

1. State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, China. E-mail: yuli514605@163.com

2. University of Chinese Academy of Sciences, Beijing 100049, China

ARTICLE INFO

Article history:

Received 20 February 2014

Revised 30 April 2014

Accepted 27 May 2014

Available online 24 November 2014

Keywords:

Microcystis

Microcystin

Inorganic carbon

Real-time PCR

Harmful cyanobacterial blooms

ABSTRACT

In an attempt to elucidate the effects of different CO₂ concentrations (270, 380, and 750 μL/L) on the competition of microcystin-producing (MC-producing) and non-MC-producing *Microcystis* strains during dense cyanobacteria blooms, an *in situ* simulation experiment was conducted in the Meiliang Bay of Lake Taihu in the summer of 2012. The abundance of total *Microcystis* and MC-producing *Microcystis* genotypes was quantified based on the 16S rDNA and *mcyD* gene using real-time PCR. The results showed that atmospheric CO₂ elevation would significantly decrease the pH value and increase the dissolved inorganic carbon (DIC) concentration. Changes in CO₂ concentration did not show significant influence on the abundance of total *Microcystis* population. However, CO₂ concentrations may be an important factor in determining the subpopulation structure of *Microcystis*. The enhancement of CO₂ concentrations could largely increase the competitive ability of non-MC-producing over MC-producing *Microcystis*, resulting in a higher proportion of non-MC-producing subpopulation in treatments using high CO₂ concentrations. Concurrently, MC concentration in water declined when CO₂ concentrations were elevated. Therefore, we concluded that the increase of CO₂ concentrations might decrease potential health risks of MC for human and animals in the future.

© 2014 The Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences.

Published by Elsevier B.V.

Introduction

In recent decades, harmful cyanobacterial blooms have occurred with increasing frequency and intensity in freshwater ecosystems worldwide (Paerl and Huisman, 2008). *Microcystis* is the most commonly reported bloom-forming cyanobacterial genus and can be classified as microcystin-producing (MC-producing) and non-MC-producing strains according to the presence or absence of microcystin synthetase genes (Fastner et al., 2001; Kaebernick and Neilan, 2001; Kurmayer et al., 2002). MC-producing strains release a wide variety of MCs that pose a health risk for both humans and animals (Chorus and Bartram, 1999; Carmichael, 2001). The waxing and waning of MC-producing and non-MC-producing *Microcystis*

has been considered as the most important factor regulating MC concentrations in freshwater (Chorus and Bartram, 1999). Nutrient availability and environmental factors including light and temperature can influence the dynamics of MC-producing and non-MC-producing *Microcystis* genotypes and MC production (Briand et al., 2012; Davis et al., 2009; Kardinaal et al., 2007; Vézic et al., 2002; Yoshida et al., 2007).

The relentless combustion of fossil fuels has significantly increased the concentrations of atmospheric carbon dioxide, which have increased from the pre-industrial level of 270 μL/L to the present level of 380 μL/L, and it is predicted to double by the end of this century (Caldeira and Wickett, 2003; Solomon et al., 2007). Rising CO₂ concentrations can alter aquatic chemistry, and

* Corresponding author. E-mail: fxkong@niglas.ac.cn (Fanxiang Kong).

this is likely to have a profound effect on the ecophysiological characteristics and community structure of cyanobacteria (O'Neil et al., 2012; Qiu and Gao, 2002; Verschoor et al., 2013). During the outbreak of cyanobacterial blooms, the high photosynthetic activity of dense algae blooms can remove CO₂ from the surface water layer, thereby inducing high pH and carbon-limited growth conditions (Hein, 1997; Ibelings and Maberly, 1998; Talling, 1976). In contrast, the rising concentrations of dissolved CO₂ cause the pH to decrease and the concentration of dissolved inorganic carbon (DIC) to rise (Doney et al., 2009; O'Neil et al., 2012; Orr et al., 2005; Riebesell et al., 2007). Laboratory studies have revealed that an increase in the availability of inorganic carbon can alter microcystin production and *Microcystis* population, favoring the dominance of non-MC-producing cells over MC-producing cells (Jähnichen et al., 2007; Van de Waal et al., 2011). However, there is a lack of field studies investigating how CO₂ availability affects the competition of MC-producing and non-MC-producing strains in natural freshwater ecosystems.

Lake Taihu is the third largest freshwater lake in China, which is the primary drinking water source for 30 million residents in the Lake Basin and Shanghai (Ye et al., 2009). With a rapid economic development and excessive exploitation of the environment, Lake Taihu has become a hypertrophic lake, and MC-producing cyanobacteria blooms have been occurring annually during the summer over the past two decades. MC concentrations have exceeded the provisional guideline of 1 µg/L set by the World Health Organization (WHO) in some lake regions, e.g., Meiliang Bay (Song et al., 2007; Xu et al., 2005). Therefore, it is urgent to understand how rising atmospheric CO₂ levels influence MC-producing and non-MC-producing *Microcystis* population and MC concentrations in Lake Taihu.

The aim of this study is to investigate the effects of elevated atmospheric CO₂ concentrations on the dynamics of MC-producing and non-MC-producing *Microcystis* strains during dense cyanobacteria blooms and to determine the competitive dominance of those two subpopulations at high and low CO₂ concentrations. To accomplish this, we performed an *in situ* mesocosm experiment and utilized real-time PCR to quantify the abundance of *Microcystis* genotypes and MC-producing *Microcystis* genotypes based on the 16S rDNA and *mcyD* genes. Our study verifies the results of laboratory experiments and predicts the response of toxic cyanobacterial bloom in Lake Taihu to future climate change.

1. Materials and methods

1.1. Experimental design

We collected lake water from Meiliang Bay. Lake water was passed through a 100 µm pore size nylon screen to remove large zooplankton and pumped into nine white 200 L plastic buckets. The buckets were placed in a pool at the Taihu Ecosystem Research Station (31°24'N and 120°13'E) to simulate the temperature and light of the Lake. The mesocosm experiment started from 16 August 2012 and lasted for 21 days.

We performed three treatments in this study using various CO₂ concentrations: pre-industrial concentration (270 µL/L), current concentration (380 µL/L), and future concentration (750 µL/L). The enriched CO₂ concentration was a mixture of ambient air and pure CO₂ that was automatically controlled by continuous CO₂-sensing and controlling systems equipped with a CO₂ chamber. This system varied the CO₂ concentrations by less than 5%. The low CO₂ concentration was obtained by pumping natural air through a CO₂ absorber (i.e., a sodium carbonate solution). The air with three concentrations of CO₂

was released into the water just above the bottom of the mesocosm, where it was released through a pipe system equipped with a nozzle at its end at a rate of approximately 1.0 L/min. The CO₂ concentration of the air used to aerate the water and atmosphere was measured regularly using a CO₂ gas analyzer (Testo 535, Testo, Lenzkirch, Germany). Each treatment was triplicated. Nitrogen and phosphorus nutrients in plastic buckets and the ambient lake water were measured every two days. Phosphate, ammonium, and nitrate were added timely to ensure that the nutrient concentration between the plastic buckets and the ambient lake water body was nearly equal. Water samples were collected on days 0, 3, 6, 9, 12, 15, 18, 21 between 09:00 and 10:00 a.m.

1.2. pH and DIC concentration

The pH was measured with a pH meter (PHSJ-4A, Leici Ltd., Shanghai, China), DIC concentrations were measured by sampling filtered over GF/F glass fiber membrane filter (pore size, ~1.2 µm; Whatman, Maidstone, England, UK; via burning in the muffle furnace for 4 hr at 500°C), and DIC was analyzed by high temperature burning method with a TOC analyzer (Torch, Teledyne Tekmar, Ohio, USA).

1.3. Quantitative real-time PCR

Water samples were filtered onto GF/C filters and immediately stored at –80°C until extraction. Total DNA was extracted using the potassium xanthogenate sodium dodecyl sulfate method as described previously (Tillett and Neilan, 2000).

The real-time PCR assay was used to quantify the 16S rDNA and *mcyD* gene regions. The 16S rDNA gene was amplified using the 184F (5'-GCCGCRAGGTGAAAMCTAA-3') and 431R (5'-AATCCAAARACCTTCCTCCC-3') primers (Neilan et al., 1997), and the *mcyD* gene was amplified using the F2 (5'-GGTTCGCCTGTCAAAGTAA-3') and R2 (5'-CCTCGCTAAAGAAGGGTTGA-3') primers (Kaebernick et al., 2000). The *Microcystis* 16S rDNA gene, which is specific to the *Microcystis* genus, was used to quantify the abundance of the total *Microcystis* population. The *mcyD* gene, found within the microcystin synthetase gene operon, only appears in toxic strains of *Microcystis* (Tillett et al., 2000), enabling the quantification of toxic *Microcystis* population.

External standards used to determine 16S rDNA and *mcyD* gene copy numbers were prepared using genomic DNA of *Microcystis aeruginosa* strain PCC7806 obtained from the FACHB-Collection (Freshwater Algal Culture Collection of Institute of Hydrobiology, China). Cells from a known volume of the *M. aeruginosa* PCC 7806 culture were filtered through GF/C filters, and the DNA extraction was as described above. The DNA concentration and purity were determined by a spectrophotometer at 260 and 280 nm. The copy numbers of two genes above were calculated by Vaitomaa et al. (2003). A 10-fold dilution series of the DNAs was prepared and amplified with the 16S rDNA and *mcyD* gene real-time PCR assays.

The real-time PCR was performed with the Mastercycler realplex 4 system (Eppendorf, Hamburg, Germany) using 25 µL of a reaction mixture, containing 12.5 µL of SYBR Premix EX Taq™ (TaKaRa, Kusatsu, Japan), 10 µmol of each primer, 10.5 µL of distilled water, and 1 µL of the template DNA. Amplification was performed as follows: The first step was an initial preheating for

2 min at 95°C for 16S rDNA and *mcyD*, and the initial preheating step was followed by 40 cycles: 95°C for 30 sec, 55°C for 30 sec, and 72°C for 30 sec. The melting temperature for the real-time PCR products was determined using the manufacturer's software. All of the samples were amplified in triplicate.

1.4. MC analysis

For intracellular MC analysis, 200 mL of the water samples was filtered in triplicate using GF/C filters (pore size, ~1.2 µm; Whatman, Maidstone, England, UK). The filters were lyophilized and extracted with 5% (V/V) acetic acid solution followed by 80% (V/V) aqueous methanol (Barco et al., 2005), with an additional step for grinding of the filters using in a Fast Prep-24 automated homogenizer (MP Biomedicals, Santa Ana, USA) with 0.5 mm silica beads. After centrifugation (9500 r/min, 10 min), the supernatants were pooled and diluted with distilled water. The distilled supernatants were concentrated using solid phase extraction cartridges (C18, 0.5 g), eluted with 100% (0.1% TFA) methanol. Blown dry using nitrogen at 40°C, the residue was then re-suspended in 150 µL of 50% aqueous methanol prior to HPLC analysis.

MCs were analyzed using high performance liquid chromatography with photodiode array detection (Agilent 1200, Agilent, Palo Alto, CA, USA) equipped with an ODS column (Agilent Eclipse XDB-C18, 5 µm, 4.6 mm × 150 mm), using a gradient of 30 to 70% (V/V) acetonitrile (with 0.05% (V/V) trifluoroacetic acid) at a flow rate of 1 mL/min. MCs were identified using their characteristic UV spectra. Total MC concentrations were quantified as the sum of all MC peaks using MC-LR, -RR, and -YR standards (Sigma, München, Germany).

1.5. Statistical analysis

All experiments were performed in triplicate. The data were expressed as the mean values ± standard deviation (SD). Statistical analysis of data was performed using SPSS 16.0 for Windows (SPSS Inc. Chicago, USA). Statistical significance of the data was tested with one-way analysis of variance (ANOVA), with the significance level set at 0.05.

2. Results

2.1. Chemical environment

Rising concentrations of dissolved CO₂ led to a decline in pH, the elevated CO₂ treatments had a lower pH value than the control treatments by 0.37 ($p < 0.01$), and pH in the high CO₂ treatments was significantly lower than in the low CO₂ treatments by 0.59 ($p < 0.01$) (Fig. 1a). In contrast, rising CO₂ caused an increase in DIC concentration. The average levels of DIC were 13.08 mg/L under 270 µL/L of CO₂ concentration, and 15.76 mg/L under 750 µL/L of CO₂ concentration. Significant differences were observed for DIC concentration among the three treatments ($p < 0.05$) (Fig. 1b).

2.2. Standard curve for real-time PCR

Standard curves were established by conducting serial dilutions of genomic DNA extracted from *M. aeruginosa* PCC 7806

culture. From the standard curves for the 16S rDNA and *mcyD* gene, a highly significant linear curve was observed between the threshold value and the log value of the template DNA copy numbers. The real time PCR data show that the range of 16S rDNA copy numbers was from 5.78×10^1 to 5.78×10^7 copies in the reaction mixture, and the detection range of *mcyD* copy numbers was from 2.06×10^1 to 2.06×10^7 (Fig. 2). The melting temperature of the 16S rDNA and *mcyD* real-time PCR products showed a peak at approximately 89.2 and 84.5°C, respectively, corresponding to the melting temperature of the standard strain, *M. aeruginosa* PCC 7806 (data not shown), which demonstrated the reliability of the real-time PCR amplification.

2.3. Variations in the abundance of total *Microcystis* population at different CO₂ treatments

The abundance of total *Microcystis* population increased in three CO₂ treatments during the experiment. The initial growth of the *Microcystis* population was slow on days 0–6 but then increased rapidly on day 9 until it reached steady growth on days 12–21. The total *Microcystis* abundance varied from 6.52×10^6 to 2.09×10^7 copies/mL (270 µL/L), from 6.54×10^6 to 2.15×10^7 copies/mL (380 µL/L), from 6.53×10^6 to 2.43×10^7 copies/mL (750 µL/L), respectively. No significant difference was found between three CO₂ treatments ($p > 0.05$) (Fig. 3).

2.4. Changes in the proportions of MC-producing and non-MC-producing *Microcystis*

In the low CO₂ treatments, the initial proportion of MC-producing *Microcystis* was 45%, and this proportion rapidly increased from 53% to 63% from day 6 onwards. Thus, MC-producing *Microcystis* became predominant by the end of experiment, leading to the higher MC-producing *Microcystis* abundance. In the control treatments, the proportion of MC-producing *Microcystis* remained stable at approximately 55% from day 6 until the end of the experiment. In the high CO₂ treatments, the proportion of MC-producing *Microcystis* increased to 52% on day 6 and subsequently decreased to less than 30% within 15 days, whereas the proportion of non-MC-producing *Microcystis* increased from 48% to 71% in the same period (Fig. 4), resulting in the lower MC-producing *Microcystis* abundance. A significant difference was observed in the abundance of MC-producing *Microcystis* at different CO₂ treatments ($p < 0.05$).

2.5. MC production

In the initial six days, the intracellular MC concentration increased rapidly, ranging from 4.21 to 8.91 µg/L, and it was not significantly different among the three CO₂ treatments ($p > 0.05$). From day 9 onwards, the MC concentration in the all treatments was stable. However, the intracellular MC concentration in the high CO₂ treatments was significantly lower than that in another two treatments, especially that in the low CO₂ treatments ($p < 0.05$) (Fig. 5). For all CO₂ treatments, MC concentrations were positively correlated

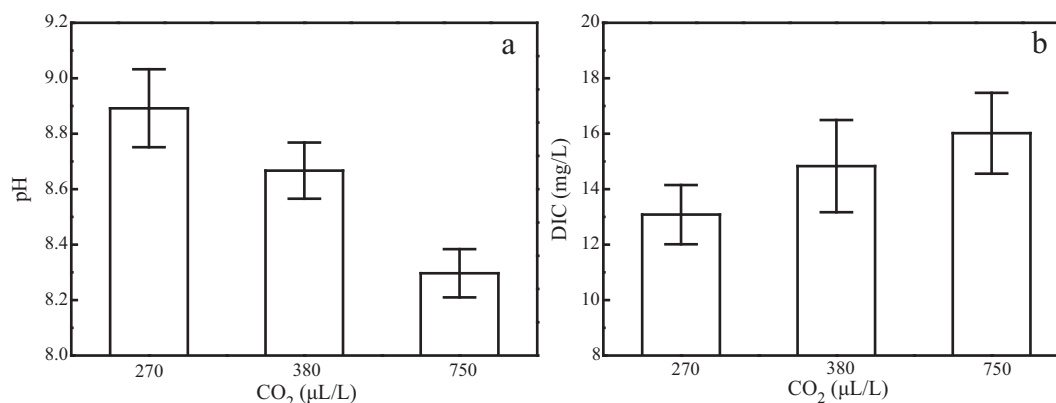


Fig. 1 – pH (a) and dissolved inorganic carbon (DIC) concentration (b) at different CO₂ concentrations. The data represent the means of all measurements during the experiment \pm standard deviation ($n = 21$).

with MC-producing *Microcystis* abundance ($r = 0.85$, $p < 0.01$, data not shown).

3. Discussion

In this study, to investigate competition for dissolved CO₂ between MC-producing and non-MC-producing *Microcystis* during dense cyanobacteria blooms, we examined their dynamic changes in chemical environment, MC production, and the proportions of MC-producing and non-MC-producing genotypes. The results suggested that MC-producing *Microcystis* could outcompete non-MC-producing ones at low CO₂ concentration, whereas non-MC-producing *Microcystis* became dominant at high CO₂ concentration.

Rising concentration of atmospheric CO₂ can change the carbon chemical environment. In our experiment, the low CO₂

concentrations might be insufficient to compensate for the high photosynthetic rates of the dense algal blooms, which cause dissolved DIC to be depleted and the pH to rise. In contrast, carbon chemistry was reversed at elevated CO₂ concentrations. Doubling of CO₂ concentration could enhance CO₂ dissolution and lower the pH values (Fig. 1). Previous laboratory and field studies reported similar results showing that dense phytoplankton blooms could lead to CO₂ depletion accompanied by an increase of pH (Ibelings and Maberly, 1998; Maberly, 1996; Talling, 1976), and elevated CO₂ concentrations depressed the pH in freshwater (Verschoor et al., 2013).

The effects of atmospheric elevated CO₂ concentrations on growth of bloom-forming cyanobacteria remain controversial. Laboratory study has shown that the growth rate of *M. aeruginosa* increases by 52%–77% under doubling of CO₂ concentrations (Qiu and Gao, 2002). A recent model also indicated that the abundance of marine phytoplankton may increase by as much as 40% between current CO₂ concentration and 700 μL/L CO₂ (Schippers et al., 2004). As observed in our experiments, the abundance of total *Microcystis* quantified by 16S rDNA gene was not significantly different among three CO₂ concentrations (Fig. 3). This suggests that the abundance of *Microcystis* population was not sensitive to elevated CO₂ concentrations in summer. Likewise, several studies have indicated that the growth and photosynthetic rate of phytoplankton do not respond significantly to rising atmospheric CO₂ (Goldman, 1999; Tortell et al., 2000, 2002). This inconsistency can be explained by the synergistic effects of nutrient availability and environmental factors on algal growth in natural water ecosystems (Boyd and Hutchins, 2012). In fact, the growth of *Microcystis* in Meiliang Bay of Lake Taihu is largely limited by the availability of nitrogen and phosphorus in summer (Xu et al., 2010). Under this nutrient-depleted condition, the effect of elevated CO₂ may not be so significant on the *Microcystis* growth.

Interestingly, our results showed that the rise in atmospheric CO₂ caused a shift in the dominant subpopulations of *Microcystis* community from MC-producing strains to non-MC-producing strains (Fig. 4). The rise in atmospheric CO₂ could increase the concentration of DIC (CO₂, H₂CO₃, HCO₃⁻, CO₃²⁻) in water. Although many phytoplankton species can utilize both dissolved CO₂ and HCO₃⁻

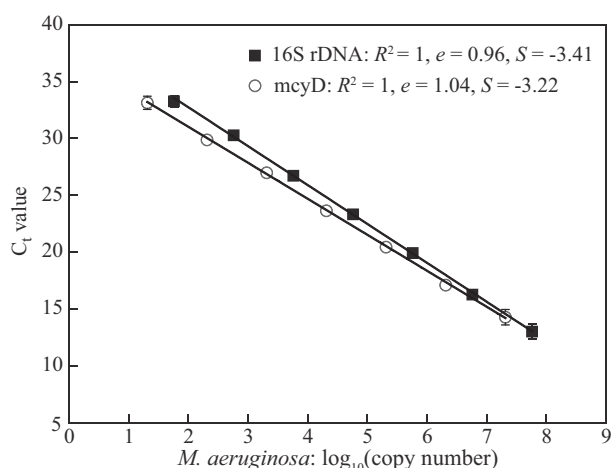


Fig. 2 – Standard curves obtained by the 16S rDNA gene and mcyD real-time PCR assays with the *Microcystis aeruginosa* strain PCC7806 as a function of gene copy numbers. Each data point shows the threshold cycle (C_t) of standard DNA samples performed in triplicate. Amplification efficiency (e , %) was calculated as follows: $e = 10^{-1/S} - 1$, where S is the slope. Error bars represent the standard deviations.

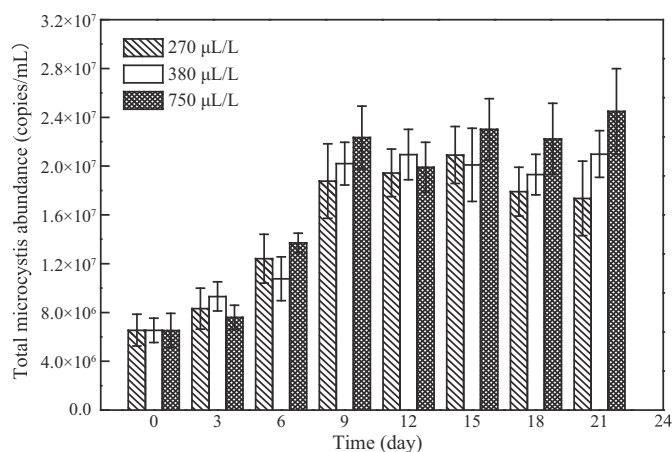


Fig. 3 – Changes in the abundance of total *Microcystis* population at different CO₂ concentrations. Error bars represent the standard deviations in triplicate.

as carbon source (Kaplan and Reinhold, 1999; Price et al., 2008), the affinity of phytoplankton for HCO₃⁻ is much lower than for CO₂ (Kranz et al., 2009; Rost et al., 2003). The uptake ability of CO₂ might be one factor in determining which species has a competitive advantage when the atmospheric CO₂ concentration rises. Van de Waal et al. (2011) conducted monoculture experiments to compare the fitness of a toxic and non-toxic strain of *M. aeruginosa* cultured under carbon-limited conditions; they found that the lower half-saturation constants for CO₂ and HCO₃⁻ of the toxic strain allowed it to outcompete the non-toxic ones at low CO₂ levels. Our results based on an *in situ* mesocosm experiment were consistent with the results from this laboratory study.

The difference in uptake ability of CO₂ between MC-producing and non-MC-producing *Microcystis* might be attributable to genetic diversity in the CCM gene. Cyanobacteria possess efficient CO₂-concentrating mechanisms (CCMs) that enable them to grow well at low CO₂ concentrations (Giordano et al., 2005; Raven et al., 2012). *bicA* and *sbtA* are two bicarbonate transporter genes in bicarbonate uptake systems (Price et al., 2004; Shibata et al., 2002). A recent study showed that genetic variation in inorganic carbon uptake systems provides *Microcystis* with the potential for microevolutionary adaptation to changing CO₂ conditions. According to that result, strains with *sbtA* were a superior competitor at low CO₂ concentrations, whereas strains with both *bicA* and *sbtA* were dominant at high CO₂ concentrations (Sandrini et al., 2013). This may explain our finding of the shift in competitive dominance from MC-producing *Microcystis* with only *sbtA* at low CO₂ concentrations towards non-MC-producing *Microcystis* with *bicA* and *sbtA* at high CO₂ concentrations.

The superior competitive ability of MC-producing *Microcystis* under low CO₂ concentrations can be attributed to the ecological function of MC. The MC analysis in our study showed that dominance of MC-producing *Microcystis* at low CO₂ concentrations leads to a higher MC concentration (Fig. 5). MC is a secondary metabolite, and it can reduce the RUBISCO level and CO₂ consumption to increase intracellular inorganic carbon accumulation under conditions of C-limitations (Gerbersdorf, 2006; Jähnichen et al., 2001). The function of MC under a

carbon-limited environment was further confirmed by the experiment comparing the wild type strain *M. aeruginosa* PCC 7806 with its *mcvB* mutant strain, which showed that the MC-producing wild type had a strong selective advantage over the mutant strain at low CO₂ levels (Van de Waal et al., 2011).

In addition, the dominance of non-MC-producing *Microcystis* over MC-producing *Microcystis* at rising CO₂ concentrations may associate with the energy costs and benefits of producing MC. At low CO₂ concentrations, the benefits of producing MC under growth-limiting conditions, outweigh its cost, thus leading to the predominance of microcystin-producing strains. At high CO₂ concentrations, the cost of producing microcystin under optimum growth condition, might outweigh the benefits, which induced the counter-selection of microcystin-producing strains. The similar results were reported by Briand et al. (2008), who found that the microcystin-producing strains of *Planktothrix agardhii* exhibited better fitness than non-microcystin-producing strains under growth-limiting conditions; in contrast, the non-microcystin-producing strains showed greater fitness under environment condition favorable for growth. In the further study, They using the microcystin-producing *M. aeruginosa* PCC 7806 strain (WT) and its non-microcystin-producing mutant (MT) in co-culture experiments under different growth conditions, the result demonstrated that the effective competitors of these two strains under optimum growth conditions were attributable to the cost of producing microcystins by microcystin-producing cells (Briand et al. 2012).

4. Conclusions

As an important factor of climate change, the atmospheric CO₂ elevation may influence the proliferation and community composition of harmful algal blooms. In this study, we investigate the effects of elevated atmospheric CO₂ concentrations on the dynamics of MC-producing and non-MC-producing *Microcystis* strains during dense cyanobacteria blooms based on real-time PCR method. The results suggest that rising CO₂ availability can lead to a turnover in outcome of the competition between MC-producing and non-MC-producing strains of

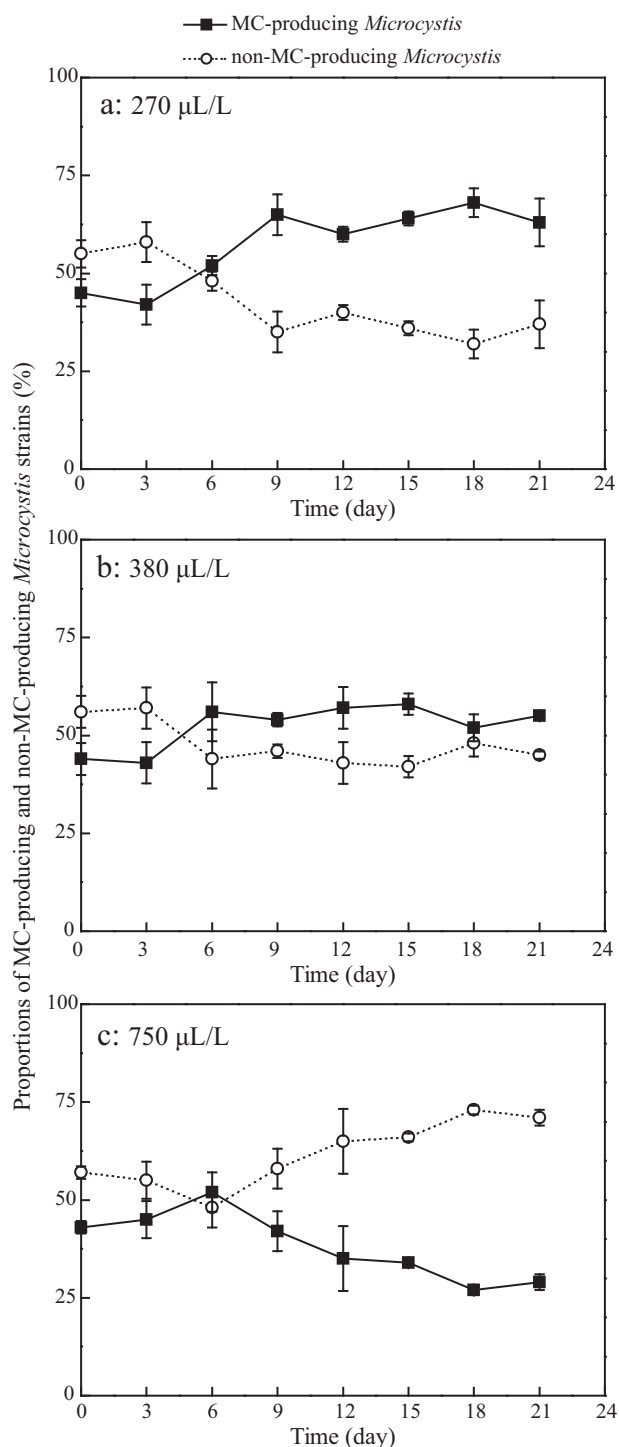


Fig. 4 – Time-course of the proportions of microcystin-producing (MC-producing) and non-MC-producing *Microcystis* strains at different CO_2 concentrations. Error bars represent the standard deviations in triplicate.

Microcystis. Rising atmospheric CO_2 concentrations cause non-MC-producing strains to outcompete MC-producing strains, thereby reducing MC concentrations, whereas the reverse is true under low CO_2 concentrations. The variation of MC concentrations at high and low CO_2 concentrations suggest

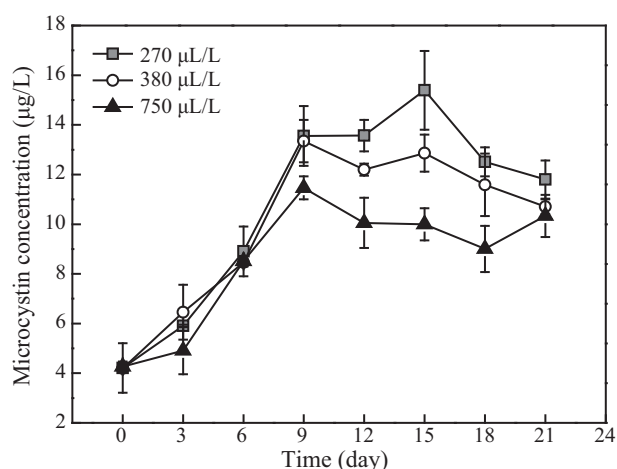


Fig. 5 – Variations in microcystin concentration at different CO_2 concentrations. Error bars represent the standard deviations in triplicate.

that differing CO_2 availability may shift the MC genotype composition in the total *Microcystis* population, which in turn can change the MC levels in the water column. These results highlight the need for future field research to obtain a better understanding of the interactions between CO_2 availability, the competitive success of *Microcystis*, and MC dynamics. It is important for monitoring and predicting the potential health risks associated with MC levels that are changing in response to climate change.

Acknowledgments

This work was supported by the National Natural Science Foundation (Nos. 31070420, 31270507), the International Innovation Partnership Program, and Chinese Academy of Sciences (No. KZZD-EW-TZ-08). We thank the Lake Taihu Ecosystems Station for providing the space to perform *in situ* mesocosm experiments.

REFERENCES

- Barco, M., Lawton, L.A., Rivera, J., Caixac, J., 2005. Optimization of intracellular microcystin extraction for their subsequent analysis by high-performance liquid chromatography. *J. Chromatogr. A* 1074 (1–2), 23–30.
- Boyd, P.W., Hutchins, D.A., 2012. Understanding the responses of ocean biota to a complex matrix of cumulative anthropogenic change. *Mar. Ecol. Prog. Ser.* 470, 125–135.
- Briand, E., Yéprémian, C., Humbert, J.F., Quiblier, C., 2008. Competition between microcystin-producing and non-microcystin-producing *Planktothrix agardhii* (cyanobacteria) strains under different environmental conditions. *Environ. Microbiol.* 10 (12), 3337–3348.
- Briand, E., Bormans, M., Quiblier, C., Salençon, M.J., Humbert, J.F., 2012. Evidence of the cost of the production of microcystins by *Microcystis aeruginosa* under differing light and nitrate environmental conditions. *PLoS ONE* 7 (1), e29981.

- Caldeira, K., Wickett, M.E., 2003. Oceanography: anthropogenic carbon and ocean pH. *Nature* 425 (6956), 365.
- Carmichael, W.W., 2001. Health effects of toxin-producing cyanobacteria: "The CyanoHABs". *Hum. Ecol. Risk Assess.* 7 (5), 1393–1407.
- Chorus, I., Bartram, J., 1999. *Toxic Cyanobacteria in Water: A Guide to Their Public Health Consequences, Monitoring and Management*. E&FN Spon, London, UK.
- Davis, T.W., Berry, D.L., Boyer, G.L., Gobler, C.J., 2009. The effects of temperature and nutrients on the growth and dynamics of toxic and non-toxic strains of *Microcystis* during cyanobacteria blooms. *Harmful Algae* 8 (5), 715–725.
- Doney, S.C., Fabry, V.J., Feely, R.A., Kleypas, J.A., 2009. Ocean acidification: the other CO₂ problem. *Annu. Rev. Mar. Sci.* 1 (1), 169–192.
- Fastner, J., Erhard, M., von Döhren, H., 2001. Determination of oligopeptide diversity within a natural population of *Microcystis* spp. (cyanobacteria) by typing single colonies by matrix-assisted laser desorption ionization—time of flight mass spectrometry. *Appl. Environ. Microbiol.* 67 (11), 5069–5076.
- Gerbersdorf, S.U., 2006. An advanced technique for immuno-labelling of microcystins in cryosectioned cells of *Microcystis aeruginosa* PCC7806 (cyanobacteria): implementations of an experiment with varying light scenarios and culture densities. *Toxicon* 47 (2), 218–228.
- Giordano, M., Beardall, J., Raven, J.A., 2005. CO₂ concentrating mechanisms in algae: mechanisms, environmental modulation, and evolution. *Annu. Rev. Plant Biol.* 56 (1), 99–131.
- Goldman, J.C., 1999. Inorganic carbon availability and the growth of large marine diatoms. *Mar. Ecol. Prog. Ser.* 180, 81–91.
- Hein, M., 1997. Inorganic carbon limitation of photosynthesis in lake phytoplankton. *Freshw. Biol.* 37 (3), 545–552.
- Ibelings, B.W., Maberly, S.C., 1998. Photoinhibition and the availability of inorganic carbon restrict photosynthesis by surface blooms of cyanobacteria. *Limnol. Oceanogr.* 43 (3), 408–419.
- Jähnichen, S., Petzoldt, T., Benndorf, J., 2001. Evidence for control of microcystin dynamics in Bautzen Reservoir (Germany) by cyanobacterial population growth rates and dissolved inorganic carbon. *Arch. Hydrobiol.* 150 (2), 177–196.
- Jähnichen, S., Ihle, T., Petzoldt, T., Benndorf, J., 2007. Impact of inorganic carbon availability on microcystin production by *Microcystis aeruginosa* PCC 7806. *Appl. Environ. Microbiol.* 73 (21), 6994–7002.
- Kaebernick, M., Neilan, B.A., 2001. Ecological and molecular investigations of cyanotoxin production. *FEMS Microbiol. Ecol.* 35 (1), 1–9.
- Kaebernick, M., Neilan, B.A., Börner, T., Dittmann, E., 2000. Light and the transcriptional response of the microcystin biosynthesis gene cluster. *Appl. Environ. Microbiol.* 66 (8), 3387–3392.
- Kaplan, A., Reinhold, L., 1999. CO₂ concentrating mechanisms in photosynthetic microorganisms. *Annu. Rev. Plant Physiol. Plant Mol. Biol.* 50 (1), 539–570.
- Kardinaal, W.E.A., Tonk, L., Janse, I., Hol, S., Slot, P., Huisman, J., et al., 2007. Competition for light between toxic and nontoxic strains of the harmful cyanobacterium *Microcystis*. *Appl. Environ. Microbiol.* 73 (9), 2939–2946.
- Kranz, S., Sültemeyer, D., Richter, K.U., Rost, B., 2009. Carbon acquisition in trichodesmium: the effect of pCO₂ and diurnal changes. *Limnol. Oceanogr.* 54 (3), 548–559.
- Kurmayer, R., Dittmann, E., Fastner, J., Chorus, I., 2002. Diversity of microcystin genes within a population of the toxic cyanobacterium *Microcystis* spp. in Lake Wannsee (Berlin, Germany). *Microb. Ecol.* 43 (1), 107–118.
- Maberly, S.C., 1996. Diel, episodic and seasonal changes in pH and concentrations of inorganic carbon in a productive lake. *Freshw. Biol.* 35 (3), 579–598.
- Neilan, B.A., Jacobs, D., Del Dot, T., Blackall, L.L., Hawkins, P.R., Cox, P.T., et al., 1997. rRNA sequences and evolutionary relationships among toxic and nontoxic cyanobacteria of the genus *Microcystis*. *Int. J. Syst. Bacteriol.* 47 (3), 693–697.
- O'Neil, J., Davis, T., Burford, M.A., Gobler, C., 2012. The rise of harmful cyanobacteria blooms: the potential roles of eutrophication and climate change. *Harmful Algae* 14, 313–334.
- Orr, J.C., Fabry, V.J., Aumont, O., Bopp, L., Doney, S.C., Feely, R.A., et al., 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature* 437 (7059), 681–686.
- Paerl, H.W., Huisman, J., 2008. Blooms like it hot. *Science* 320 (5872), 57–58.
- Price, G.D., Woodger, F.J., Badger, M.R., Howitt, S.M., Tucker, L., 2004. Identification of a SulP-type bicarbonate transporter in marine cyanobacteria. *Proc. Natl. Acad. Sci. U. S. A.* 101 (52), 18228–18233.
- Price, G.D., Badger, M.R., Woodger, F.J., Long, B.M., 2008. Advances in understanding the cyanobacterial CO₂-concentrating-mechanism (CCM): functional components, C_i transporters, diversity, genetic regulation and prospects for engineering into plants. *J. Exp. Bot.* 59 (7), 1441–1461.
- Qiu, B.S., Gao, K.S., 2002. Effects of CO₂ enrichment on the bloom-forming cyanobacterium *Microcystis aeruginosa* (Cyanophyceae): physiological responses and relationships with the availability of dissolved inorganic carbon. *J. Phycol.* 38 (4), 721–729.
- Raven, J.A., Giordano, M., Beardall, J., Maberly, S.C., 2012. Algal evolution in relation to atmospheric CO₂: carboxylases, carbon-concentrating mechanisms and carbon oxidation cycles. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 367 (1588), 493–507.
- Riebesell, U., Schulz, K.G., Bellerby, R.G.J., Botros, M., Fritzsche, P., Meyerhöfer, M., et al., 2007. Enhanced biological carbon consumption in a high CO₂ ocean. *Nature* 450 (7169), 545–548.
- Rost, B., Riebesell, U., Burkhardt, S., Sültemeyer, D., 2003. Carbon acquisition of bloom-forming marine phytoplankton. *Limnol. Oceanogr.* 48 (1), 55–67.
- Sandrini, G., Matthijs, H.C.P., Verspagen, J.M.H., Muyzer, G., Huisman, J., 2013. Genetic diversity of inorganic carbon uptake systems causes variation in CO₂ response of the cyanobacterium *Microcystis*. *ISME J.* 8 (3), 589–600.
- Schippers, P., Lüring, M., Scheffer, M., 2004. Increase of atmospheric CO₂ promotes phytoplankton productivity. *Ecol. Lett.* 7 (6), 446–451.
- Shibata, M., Katoh, H., Sonoda, M., Ohkawa, H., Shimoyama, M., Fukuzawa, H., et al., 2002. Genes essential to sodium-dependent bicarbonate transport in cyanobacteria. *J. Biol. Chem.* 277 (21), 18658–18664.
- Solomon, S., Qin, D., Manning, M., Marquis, M., Averyt, K., Tignor, M. B., et al., 2007. *Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change*. Cambridge University Press, New York.
- Song, L.R., Chen, W., Peng, L., Wan, N., Gan, N.Q., Zhang, X.M., 2007. Distribution and bioaccumulation of microcystin in water columns: a systematic investigation into the environmental fate and the risks associated with microcystin in Meiliang Bay, Lake Taihu. *Water Res.* 41 (13), 2853–2864.
- Talling, J., 1976. The depletion of carbon dioxide from lake water by phytoplankton. *J. Ecol.* 64 (1), 79–121.
- Tillett, D., Neilan, B.A., 2000. Xanthogenate nucleic acid isolation from cultured and environmental cyanobacteria. *J. Phycol.* 36 (1), 251–258.
- Tillett, D., Dittmann, E., Erhard, M., von Döhren, H., Börner, T., Neilan, B.A., 2000. Structural organization of microcystin biosynthesis in *Microcystis aeruginosa* PCC7806: an integrated peptide-polyketide synthetase system. *Chem. Biol.* 7 (10), 753–764.

- Tortell, P.D., Rau, G.H., Morel, F.M., 2000. Inorganic carbon acquisition in coastal Pacific phytoplankton communities. *Limnol. Oceanogr.* 45 (7), 1485–1500.
- Tortell, P.D., DiTullio, G.R., Sigman, D.M., Morel, F., 2002. CO₂ effects on taxonomic composition and nutrient utilization in an Equatorial Pacific phytoplankton assemblage. *Mar. Ecol. Prog. Ser.* 236, 37–43.
- Vaitomaa, J., Rantala, A., Halinen, K., Rouhiainen, L., Tallberg, P., Møkelke, L., et al., 2003. Quantitative real-time PCR for determination of microcystin synthetase E copy numbers for *Microcystis* and *Anabaena* in lakes. *Appl. Environ. Microbiol.* 69 (12), 7289–7297.
- Van de Waal, D.B., Verspagen, J.M., Finke, J.F., Vournazou, V., Immers, A.K., Kardinaal, W.E.A., et al., 2011. Reversal in competitive dominance of a toxic versus non-toxic cyanobacterium in response to rising CO₂. *ISME J.* 5 (9), 1438–1450.
- Verschoor, A.M., Van Dijk, M.A., Huisman, J.E.F., Van Donk, E., 2013. Elevated CO₂ concentrations affect the elemental stoichiometry and species composition of an experimental phytoplankton community. *Freshw. Biol.* 58 (3), 597–611.
- Vézie, C., Rapala, J., Vaitomaa, J., Seitsonen, J., Sivonen, K., 2002. Effect of nitrogen and phosphorus on growth of toxic and nontoxic *Microcystis* strains and on intracellular microcystin concentrations. *Microb. Ecol.* 43 (4), 443–454.
- Xu, Q.J., Gao, G., Chen, W.M., 2005. Periodical change of microcystin in Taihu Lake and its relationship with plankton. *China Environ. Sci.* 25 (1), 28–31.
- Xu, H., Paerl, H.W., Qin, B.Q., Zhu, G.W., Gao, G., 2010. Nitrogen and phosphorus inputs control phytoplankton growth in eutrophic Lake Taihu, China. *Limnol. Oceanogr.* 55 (1), 420–432.
- Ye, W.J., Liu, X.L., Tan, J., Li, D.T., Yang, H., 2009. Diversity and dynamics of microcystin—producing cyanobacteria in China's third largest lake, Lake Taihu. *Harmful Algae* 8 (5), 637–644.
- Yoshida, M., Yoshida, T., Takashima, Y., Hosoda, N., Hiroishi, S., 2007. Dynamics of microcystin-producing and non-microcystin-producing *Microcystis* populations is correlated with nitrate concentration in a Japanese lake. *FEMS Microbiol. Lett.* 266 (1), 49–53.



Editorial Board of Journal of Environmental Sciences

Editor-in-Chief

X. Chris Le University of Alberta, Canada

Associate Editors-in-Chief

Jiuhui Qu Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Shu Tao Peking University, China
Nigel Bell Imperial College London, UK
Po-Keung Wong The Chinese University of Hong Kong, Hong Kong, China

Editorial Board

Aquatic environment

Baoyu Gao Shandong University, China
Maohong Fan University of Wyoming, USA
Chihpin Huang National Chiao Tung University, Taiwan, China
Ng Wun Jern Nanyang Environment & Water Research Institute, Singapore
Clark C. K. Liu University of Hawaii at Manoa, USA
Hokyong Shon University of Technology, Sydney, Australia
Zijian Wang Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Zhiwu Wang The Ohio State University, USA
Yuxiang Wang Queen's University, Canada
Min Yang Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Zhifeng Yang Beijing Normal University, China
Han-Qing Yu University of Science & Technology of China, China

Terrestrial environment

Christopher Anderson Massey University, New Zealand
Zucong Cai Nanjing Normal University, China
Xinbin Feng Institute of Geochemistry, Chinese Academy of Sciences, China
Hongqing Hu Huazhong Agricultural University, China
Kin-Che Lam The Chinese University of Hong Kong, Hong Kong, China
Erwin Klumpp Research Centre Juelich, Agrosphere Institute, Germany

Peijun Li

Institute of Applied Ecology, Chinese Academy of Sciences, China
Michael Schlöter German Research Center for Environmental Health, Germany
Xuejun Wang Peking University, China
Lizhong Zhu Zhejiang University, China

Atmospheric environment

Jianmin Chen Fudan University, China
Abdelwahid Mellouki Centre National de la Recherche Scientifique, France
Yujing Mu Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Min Shao Peking University, China
James Jay Schauer University of Wisconsin-Madison, USA
Yuesi Wang Institute of Atmospheric Physics, Chinese Academy of Sciences, China
Xin Yang University of Cambridge, UK

Environmental biology

Yong Cai Florida International University, USA
Henner Hollert RWTH Aachen University, Germany
Jae-Seong Lee Sungkyunkwan University, South Korea
Christopher Rensing University of Copenhagen, Denmark
Bojan Sedmak National Institute of Biology, Slovenia
Lirong Song Institute of Hydrobiology, Chinese Academy of Sciences, China
Chunxia Wang National Natural Science Foundation of China
Gehong Wei Northwest A & F University, China

Daqiang Yin

Tongji University, China
Zhongtang Yu The Ohio State University, USA

Environmental toxicology and health

Jingwen Chen Dalian University of Technology, China
Jianying Hu Peking University, China
Guibin Jiang Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Sijin Liu Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Tsuyoshi Nakanishi Gifu Pharmaceutical University, Japan

Willie Peijnenburg University of Leiden, The Netherlands
Bingsheng Zhou Institute of Hydrobiology, Chinese Academy of Sciences, China

Environmental catalysis and materials

Hong He Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Junhua Li Tsinghua University, China
Wenfeng Shangguan Shanghai Jiao Tong University, China
Ralph T. Yang University of Michigan, USA

Environmental analysis and method

Zongwei Cai Hong Kong Baptist University, Hong Kong, China
Jiping Chen Dalian Institute of Chemical Physics, Chinese Academy of Sciences, China
Minghui Zheng Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Municipal solid waste and green chemistry
Pinjing He Tongji University, China

Editorial office staff

Managing editor Qingcai Feng
Editors Zixuan Wang Suqin Liu Kuo Liu Zhengang Mao
English editor Catherine Rice (USA)

JOURNAL OF ENVIRONMENTAL SCIENCES

环境科学学报(英文版)

www.jesc.ac.cn

Aims and scope

Journal of Environmental Sciences is an international academic journal supervised by Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. The journal publishes original, peer-reviewed innovative research and valuable findings in environmental sciences. The types of articles published are research article, critical review, rapid communications, and special issues.

The scope of the journal embraces the treatment processes for natural groundwater, municipal, agricultural and industrial water and wastewaters; physical and chemical methods for limitation of pollutants emission into the atmospheric environment; chemical and biological and phytoremediation of contaminated soil; fate and transport of pollutants in environments; toxicological effects of terrorist chemical release on the natural environment and human health; development of environmental catalysts and materials.

For subscription to electronic edition

Elsevier is responsible for subscription of the journal. Please subscribe to the journal via <http://www.elsevier.com/locate/jes>.

For subscription to print edition

China: Please contact the customer service, Science Press, 16 Donghuangchenggen North Street, Beijing 100717, China. Tel: +86-10-64017032; E-mail: journal@mail.sciencep.com, or the local post office throughout China (domestic postcode: 2-580).

Outside China: Please order the journal from the Elsevier Customer Service Department at the Regional Sales Office nearest you.

Submission declaration

Submission of the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis), that it is not under consideration for publication elsewhere. The publication should be approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out. If the manuscript accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

Editorial

Authors should submit manuscript online at <http://www.jesc.ac.cn>. In case of queries, please contact editorial office, Tel: +86-10-62920553, E-mail: jesc@rcees.ac.cn. Instruction to authors is available at <http://www.jesc.ac.cn>.

Journal of Environmental Sciences (Established in 1989) Volume 27 2015

Supervised by	Chinese Academy of Sciences	Published by	Science Press, Beijing, China
Sponsored by	Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences		Elsevier Limited, The Netherlands
Edited by	Editorial Office of Journal of Environmental Sciences P. O. Box 2871, Beijing 100085, China Tel: 86-10-62920553; http://www.jesc.ac.cn E-mail: jesc@rcees.ac.cn	Distributed by	
		Domestic	Science Press, 16 Donghuangchenggen North Street, Beijing 100717, China Local Post Offices through China
		Foreign	Elsevier Limited http://www.elsevier.com/locate/jes
Editor-in-chief	X. Chris Le	Printed by	Beijing Beilin Printing House, 100083, China

CN 11-2629/X

Domestic postcode: 2-580

Domestic price per issue RMB ¥ 110.00

ISSN 1001-0742



9 771001 074154