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The relationship between light intensity and nutrient uptake kinetics in six freshwater diatoms

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ABSTRACT

In order to find effective measures to control diatom blooms, a better understanding of the physiological characteristics of nutrient uptake in diatoms is needed. A study of P and Si-uptake kinetics for diatom species from two light regimes was conducted at low (LL), moderate (ML) and high light intensities (HL) (2, 25 and 80 μmol photons/(m^2·sec)), respectively. The results showed that P uptake of diatoms was heavily influenced by historic light regimes. P affinity changed with growth and photosynthetic activity. The lowest half saturation constant for P uptake ($K_{m(P)}$) was under HL for high-light adapted diatoms while the lowest half-saturation constant for low-light adapted diatoms was observed under LL. The Si half-saturation constant ($K_{m(Si)}$) increased with increasing light intensities for pennate diatoms but decreased for centric diatoms. Diatom volumes were correlated with the maximum Si uptake rates ($V_{m(Si)}$) at HL and $K_{m(Si)}$ at ML and HL for six diatom species. Our results imply that when we assess the development of diatom blooms we should consider light intensity and cell volume in addition to ambient Si or P concentration. The relationship between light intensity and P-uptake suggests that we can find suitable methods to control diatom blooms on the basis of reducing phytoplankton activity of P-uptake and photosynthesis simultaneously.

Introduction

Building dams on the rivers not only impact on the hydrological conditions but also bring out the trapping effect of nutrient retention in reservoirs. In Australia, the retention of phosphorus by Chaffey Dam was in the range of 16%–95% (Sherman et al., 2001). The dissolved silicon (DSi) concentration in the lower reaches of the Danube River dropped more than 50% since the IornGate Dam had been built in 1970 (Jickells, 1998). The DSi concentration dropped from 210 to 10 μmol/L in the Nile River after the construction of the Aswan High Dam (Wahby and Bishara, 1980). Zeng (2006) pointed out that the large amounts of phosphate and silicate were trapped after building the Three Gorges Dam, which causes the chain reactions, especially decrease of nutrient concentration, occurred in the lower Yangtze River. After the water storage of the Three Gorges Reservoir, the decrease of DSi concentration in the Yangtze River estuary was about six times higher than before and the blocking effect of the Three Gorges Dam led to the retention rate of total phosphorus up to 80% (Yu et

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al., 2006). Although Si and P load decreased dramatically in the lower reaches, diatom blooms still broke out frequently in the middle–lower reaches of the Yangtze River after building the Three Gorges Dam (*e.g.*, Wang et al., 2011; Liang et al., 2012).

Nutrient uptake in algae can be influenced by light (Chisholm and Stross, 1976), temperature (Agawin et al., 2000), cell size (Stolte and Riegman, 1995), nutritional status of algal cells (Ritchie et al., 2001), pH (Thoreson et al., 1984) and other factors. In oligotrophic ecosystems, some species with highly efficient Si or P-uptake systems can develop diatom biomass with optimum conditions (Krause et al., 2012). Light intensity might be considered the important factor because photosynthesis provides energy for active absorption of nutrients (Deane and O'Brien, 1981).

Diatoms from distinct light regimes can have dramatic differences in light adaptation (Gameiro et al., 2011; Kropuenske et al., 2009). In this study, we hypothesized that light intensity has different effects on uptake of Si and P in diatoms isolated from various light regimes. We conducted nutrient kinetics experiments to explore: (1) whether light intensity has an obvious effect on Si or P uptake in diatoms isolated from two different light regimes; (2) if the optimal light intensity for nutrient uptake is the same as that for growth of diatoms and (3) which factors are most critical in controlling nutrient uptake rates in diatoms? The results will help to assess and predict the growth and development of phytoplankton blooms and select suitable measures for controlling diatom blooms.

1. Materials and methods

1.1. Diatoms isolation and culture

Six species of diatoms were isolated from two freshwater ecosystems: Lake Taihu (30–31°N, 119–120°E) and Hangjiang River (30–34°N, 106–114°E). According to the underwater light intensities in these ecosystems and chlorophyll *a* fluorescence in the six diatoms species measured in preliminary experiment, 3 species (*Cyclotella meneghiniana*, *Stephanodiscus parvus* and *Synedra acus*) from Lake Taihu were defined as high-light adapted (HLA) species and 3 species (*Stephanodiscus hantzschii*, *Fragilaria crotonensis* and *Nitzschia palea*) from Hanjiang River were defined as low-light adapted (LLA) species. *C. meneghiniana* was the dominant species in Lake Taihu while *S. hantzschii* is the dominant species in the Hanjiang River during spring. Sub-dominant species found in the Lake Taihu were *S. parvus* and *S. acus* while in the Hanjiang River were *F. crotonensis* and *N. palea*. The information of diatom stains and two field sites are listed in Table 1.

The six species of diatoms were cultured at eight light intensities (from 2 to 300 μmol photons/(m^2·sec)) in the preliminary experiment. Diatoms from the Hanjiang River showed high photosynthetic activities and growth rates at light intensities less than 25 μmol photons/(m^2·sec) but showed photoinhibition at light intensity of 80 μmol photons/(m^2·sec). Growth rates of diatoms from Lake Taihu increased with higher light intensities but showed light-limited growth rates at an intensity of 2 μmol photons/(m^2·sec).

The isolation and purification of diatoms were conducted according to standard phycological methods (Stein and Hellebust, 1980). Concentrated diatom cells were observed with a scanning electron microscope (JSM-6390LV, NTC, Japan) after sulfuric acid treatment (Zhang and Huang, 1991). Identification of algal species was based on the pattern and shape of the shell of the diatom (Hu and Wei, 2006). Monoclonal diatoms of six strains were cultured in D1 medium (Zhang and Huang, 1991).

Stock cultures were transferred weekly to fresh medium to maintain exponential growth. All glassware was soaked in 5% HCl for 24 hr and rinsed with double-distilled water before use. Flasks and D1 medium were sterilized at 121°C for 30 min. All treatments were kept at identical conditions and were conducted in triplicate. Each step was carried out under axenic conditions.

1.2. Growth experiment

Growth experiments were conducted in illumination incubators with 20°C/18°C temperature regimes and 14/10 light/dark cycle. The light treatment was set at 2, 12.5, 25, 60 and 80 μmol photons/(m^2·sec) with cool-white fluorescent light. We used 80 μmol photons/(m^2·sec)[1] as the highest light treatment because the light treatment of 80 μmol photons/(m^2·sec) was enough to cause photoinhibition to LLA diatoms from the results of the preliminary experiment.

Table 1 – Dominant species volume and environmental concentration of total phosphorus (TP–P) and dissolved silicon (DSi–Si) in sampling sites where diatom isolated.

Dominate species	Average volume (μm^3)	Aquatic ecosystems	Light intensity (μmol photons/(m^2·sec))	TP–P (μmol/L)	DSi–Si (μmol/L)
Cyclotella meneghiniana	144.32	Lake Taihu	564.3	3.37 ± 1.31	88.01 ± 5.52
Stephanodiscus parvus	320.713	Lake Taihu	564.3	3.37 ± 1.31	88.01 ± 5.52
Synedra acus	2161.03	Lake Taihu	564.3	3.37 ± 1.31	88.01 ± 5.52
Stephanodiscus hantzschii	930.14	Hanjiang River	85.7	2.49 ± 0.23	71.97 ± 9.34
Fragilaria crotonensis	1558.59	Hanjiang River	85.7	2.49 ± 0.23	71.97 ± 9.34
Nitzschia palea	1058.28	Hanjiang River	85.7	2.49 ± 0.23	71.97 ± 9.34

Light intensity indicated underwater light intensity at 0.5 m depth. Light intensity of Lake Taihu was cited from Zhang et al., 2004. Light intensity of Hanjiang River was measured in spring of 2010 using illuminometer (wi97178, Ruida, China).