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Morphology of *Aulacoseira* filaments as indicator of the aquatic environment in a large subtropical river: The Pearl River, China

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ABSTRACT

To identify new indicators of aquatic environmental parameters, both qualitative (the percentages of curved filaments and filaments with ending separation spines) and quantitative morphological parameters (filament and cell size) of a dominant chain colony-forming planktonic diatom (*Aulacoseira granulata*) were determined in the large, subtropical Pearl River, China. The qualitative parameters mainly exhibited a spatial pattern. The percentage of curved filaments was a good bioindicator of spatial patterns because it varied along the nutrient gradient. Furthermore, the percentage of filaments with ending separation spines was a good bioindicator of seasonal variation. Although the quantitative parameters exhibited a clear temporal pattern, no single parameter could be used as a bioindicator of either spatial or temporal patterns. The link between qualitative and quantitative parameters reflected the internal adaptation mechanism of filamentous diatoms to the external environment. The methods of the present study can also be applied to ecological indicators in other aquatic ecosystems dominated by chain colony-forming diatoms.

1. Introduction

Freshwater ecosystems including streams, rivers, lakes, and reservoirs are under increasing ecological stress from anthropogenic activities globally (Spatharis and Tsirtsis, 2010). Phytoplankton are efficient indicators of changes in nutrient load, and are also effective in evaluating responses to many other environmental stressors because they respond quickly to changes in water quality, hydrology, and climate (Domingues et al., 2008). A recent review revealed that phytoplankton studies outnumber periphyton studies in lakes by an order of magnitude (Cantonati and Lowe, 2014). In rivers, the situation is very different because benthic diatoms have been the most commonly used micro-algal ecological indicator for several decades (Butcher, 1947; Fjerdingstad, 1950; Kelly and Whitton, 1995). In China, phytoplankton metrics including biomass (proxy with chl a), community changes (composition and species abundance), and diversity indices are still mainly used as indicators in riverine environmental parameters (Pang et al., 2011; Wang et al., 2015a, 2014, 2016). Moreover, epiphytic algae are also used by some researchers to determine water quality in streams, which is mainly based on diatom community composition and habitat preferences in different taxa (Jia et al., 2009; Wu et al., 2009). However, planktonic diatoms, often dominant in riverine phytoplankton communities, have rarely been used as indicators of water quality in China's large rivers.

Aulacoseira Thwaites is a cosmopolitan and widespread genus inhabiting lacustrine and lotic freshwaters where it is an important component of the phytoplankton developing in various trophic conditions (Denys et al., 2003; Bicudo et al., 2016). The dominance of this genus in different aquatic areas has been studied by many researchers who found correlations between populations and environmental parameters, which shed light on the organism's role within their habitat (Hötzel and Croome, 1996; Wang et al., 2009; Horn et al., 2011; Bicudo et al., 2016). Moreover, some researchers have studied the relationships between *Aulacoseira* morphology and environmental factors in different aquatic ecosystems (Davey, 1987; Gómez et al., 1995; Turkia and Lepistö, 1999; O'Farrell et al., 2001), which are considered more sensitive ecological indicators than population dynamics. Furthermore, researchers have found that *Aulacoseira* species population dynamics and life cycles are closely associated with size variations in both cell and filament dimension (Bedoshvili et al., 2007; Poister et al., 2012; Jewson and Granin, 2015). Morphological size parameters have become ecological indicators for both internal population dynamics and

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external environmental parameters. In fact, all of the *Aulacoseira* morphological size parameters (filament and cell size) have been collected and measured microscopically by experts and can be defined as quantitative parameters. However, qualitative *Aulacoseira* morphological parameters, such as filament shape (linear vs. curved, with/without a spine), have rarely been used as ecological indicators.

The Pearl River is the largest river in southern China, and is a classic subtropical lotic ecosystem. *Aulacoseira granulata* dominance and population dynamics have been reported in the downstream and river estuary of the Pearl River (Wang et al., 2009, 2012). The relationship between size and environment has also been explored based on a time series dataset from the Pearl River in which cell diameter was the most sensitive indicator of temporal variations (Wang et al., 2015b). However, associated functions indicated by the both spatial and temporal patterns exhibited by this filamentous diatom are yet to be investigated.

The present paper focuses on investigating *A. granulata* complex morphological parameters as indicators of the aquatic environmental parameters in the middle and downstream of the Pearl River, both qualitative and quantitative parameters were studied. The aim was to identify new indicators of aquatic environmental parameters based on planktonic diatoms in a large river both spatially and temporally.

2. Materials and methods

2.1. Study site

The Pearl River (PR), the largest river in southern China (Yang et al., 2010), comprises the West River, North River, East River, and the Pearl River Delta (PRD). Fig. 1 shows the general layout of the PR basin: the basin location, main tributaries, PRD, and the 16 spatial sampling sites. The PRD (21°40′–23°N, 112°–113°20′E) is approximately 9750 km^2, wherein the West and North River deltas account for approximately 93.7% of the total area of the PRD, and the East River delta accounts for 6.3%. The topography of the PRD consists of an interweaving network of rivers and channels, with shoals and river mouths.

A total of 16 sampling sites that encompass the key sections of the mainstream of West River and PRD were investigated, these included Fengkai (FK), Deqing (DQ), Zhaoqing (ZQ), Qingqi (QQ), Zuotan (ZT), Waihai (WH), Xinwei (XW), Xiaolan (XL), Xiaotang (XT), Beijiao (BJ), Lanhe (LH), Hengli (HL), Chencun (CC), Shiqiao (SQ), Lianhuashan (LHS), and Zhujiangqiao (ZJQ). FK, DQ, ZQ, QQ, ZT, WH, and XW were located along the main channel of the West River. ZJQ and LHS were located on the other side of the delta, near the city center of Guangzhou. ZJQ was located in the Guangzhou channel and LHS was close to the East River. The other sites were located in the central PRD (Fig. 1). The site coordinates were collected using GPS (Map 621SC) and are listed in Table 1.

Table 1
The coordinates of sampling sites.

Station	Longitude	Latitude
FK	111°30′26.6”	23°23′15.7”
DQ	111°48′30.4”	23°8′13.81”
ZQ	112°27′36.3”	23°02′43.5”
QQ	112°47′11.0”	23°10′14.5”
ZT	113°03′26.0”	22°48′46.6”
WH	113°09′20.3”	22°36′14.5”
XW	113°16′41.5”	22°22′45.6”
XL	113°17′17.9”	22°38′13.8”
XT	112°57′51.1”	23°05′27.4”
BJ	113°11′54.5”	22°54′04.1”
LH	113°19′53.4”	22°49′15.2”
HL	113°27′02.5”	22°44′05.4”
CC	113°14′55.7”	22°58′15.1”
SQ	113°24′49.0”	22°55′24.2”
LHS	113°30′37.0”	23°00′58.0”
ZJQ	113°13′16.5”	23°08′12.6”

2.2. Sampling and data collection

Qualitative subsurface phytoplankton samples were collected seasonally (March, June, September, and December) in 2015, over a period of 1 week for each investigation. For each sample, a plankton net with a mesh size of 64 μm (standard size for qualitative phytoplankton study in China) was set along the river flow direction to collect according to

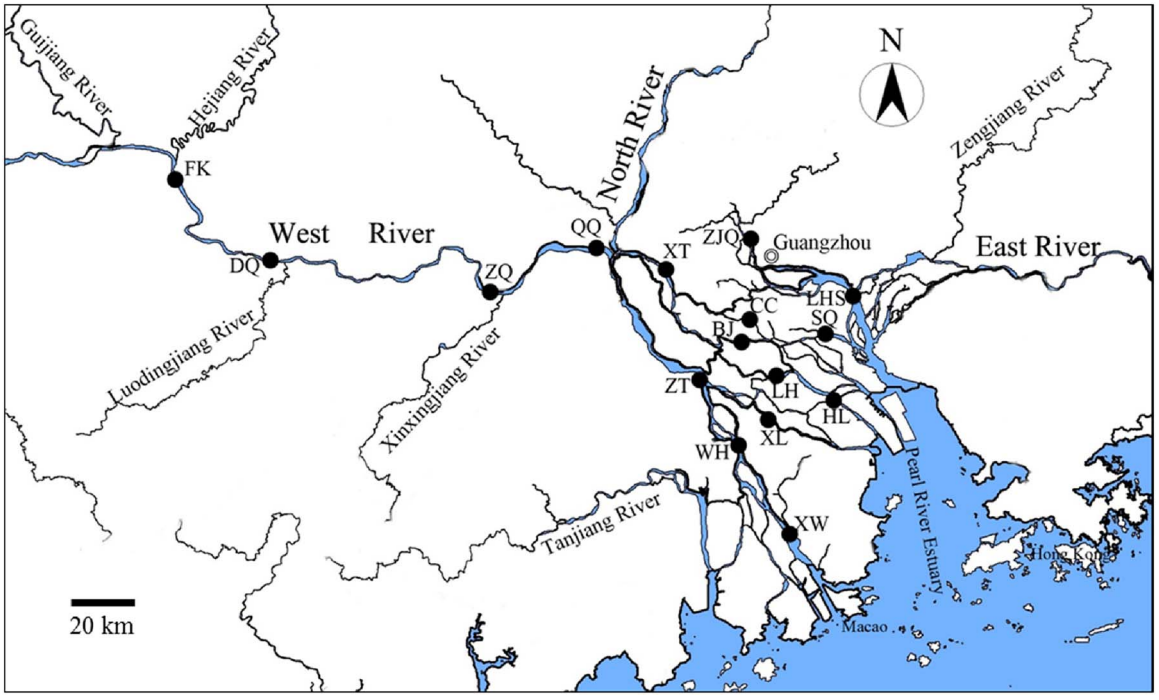

Fig. 1. The middle and downstream of the Pearl River, including the three main tributaries of the Pearl River (West, North and East River) and the Pearl River Delta system. Sampling sites represented by black dots and named with 2 characters: FK—Fengkai, DQ—Deqing, ZQ—Zhaoqing, QQ—Qingqi, ZT—Zuotan, WH—Waihai, XW—Xinwei, XL—Xiaolan, XT—Xiaotang, BJ—Beijiao, LH—Lanhe, HL—Hengli, CC—Chencun, LHS—Lianhuashan, ZJQ—Zhujiangqiao.