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Temporal and spatial variations in nutrient stoichiometry and regulation of phytoplankton biomass in Hong Kong waters: Influence of the Pearl River outflow and sewage inputs

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Abstract

In 2001, the Hong Kong government implemented the Harbor Area Treatment Scheme (HATS) under which 70% of the sewage that had been formerly discharged into Victoria Harbor is now collected and sent to Stonecutters Island Sewage Works where it receives chemically enhanced primary treatment (CEPT), and is then discharged into waters west of the Harbor. The relocation of the sewage discharge will possibly change the nutrient dynamics and phytoplankton biomass in this area. Therefore, there is a need to examine the factors that regulate phytoplankton growth in Hong Kong waters in order to understand future impacts. Based on a historic nutrient data set (1986–2001), a comparison of ambient nutrient ratios with the Redfield ratio (N:P:Si = 16:1:16) showed clear spatial variations in the factors that regulate phytoplankton biomass along a west (estuary) to east (coastal/oceanic) transect through Hong Kong waters. Algal biomass was constrained by a combination of low light conditions, a rapid change in salinity, and strong turbulent mixing in western waters throughout the year. Potential stoichiometric Si limitation (up to 94% of the cases in winter) occurred in Victoria Harbor due to the contribution of sewage effluent with high N and P enrichment all year, except for summer when the frequency of stoichiometric Si limitation (48%) was the same as P, owing to the influence of the high Si in the Pearl River discharge. In the eastern waters, potential N limitation and N and P co-limitation occurred in autumn and winter respectively, because of the dominance of coastal/oceanic water with low nutrients and low N:P ratios. In contrast, potential Si limitation occurred in spring and a switch to potential N, P and Si limitation occurred in eastern waters in summer. In southern waters, there was a shift from P limitation (80%) in summer due to the influence of the N-rich Pearl River discharge, to N limitation (68%) in autumn, and to N and P co-limitation in winter due to the dominance of N-poor oceanic water from the oligotrophic South China Sea. Our results show clear temporal and spatial variations in the nutrient stoichiometry which indicates potential regulation of phytoplankton biomass in HK waters due to the combination of the seasonal exchange of the Pearl River discharge and oceanic water, sewage effluent inputs, and strong hydrodynamic mixing from SW monsoon winds in summer and the NE monsoon winds in winter.

Keywords: Stoichiometric nutrient limitation; Pearl River discharge; Sewage effluent; Hong Kong waters; Monsoon

1. Introduction

Eutrophication of coastal ecosystems is caused by excessive nutrients such as nitrate and phosphate. The increased

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input of nutrients from riverine outflow and domestic sewage effluent into coastal waters has several ecological consequences: increased algal blooms, the formation of hypoxia or anoxia in the bottom water due to the sedimentation of unused organic matter as stratification develops (Malone et al., 1988; Cooper and Brush, 1991; Welsh and Eller, 1991), and a change in the phytoplankton species composition due to alterations in ambient nutrient ratios and quantities (Jickells, 1988). Usually, N:P and N:Si ratios increase due to high N in fertilizers and in rainfall. An increase in the N:Si ratio has been shown to cause a shift in the dominant siliceous and non-siliceous species (Officer and Ryther, 1980; Fisher et al., 1992). A typical case is in the North Sea, where there had been a dramatic increase in the biomass of flagellates relative to that of diatoms as a result of the increased N:Si ratio in recent decades (Smayda, 1990).

It has been debated which nutrient, N or P, is limiting primary production in the marine environment. Nitrogen has traditionally been considered as the nutrient that limits productivity in coastal waters (Ryther and Dunstan, 1971; Oviatt et al., 1995). Recent studies have shown that P can also be a limiting nutrient in coastal areas associated with periods of high river runoff with high N: P loading ratios (Harrison et al., 1990). In contrast, N, or N + P limitation is linked to low river runoff and a rather greater influence of seawater having a Redfield N:P ratio (Fisher et al., 1992).

Hong Kong is situated on the eastern side of the Pearl River estuary. The coastal waters of Hong Kong are profoundly influenced by three nutrient inputs: the N-rich summer Pearl River discharge, relatively nutrient-poor oceanic waters from the South China Coastal Current, and year round domestic sewage effluent. These water regimes are strongly affected by two seasonal monsoons. In winter when the northeast monsoon prevails, the effect of the Pearl River discharge is minimal as the discharge volume is low, and the South China Coastal Current and oceanic waters with relatively low nutrients dominate the coastal waters of Hong Kong. In summer, when the southwest monsoon prevails and the river discharge is maximal, the Pearl River discharge (with a high N:P ratio) flows into the coastal waters of Hong Kong. Hong Kong discharges >2 million tons of sewage effluent daily. In 2001, the Hong Kong government implemented the Harbor Area Treatment Scheme (HATS), which collects 70% of the sewage previously discharged into Victoria Harbor, treats it and discharges it into waters two km west near Stonecutters Island. This relocation of sewage effluent is likely to have a significant effect on the dynamics of nutrients and phytoplankton biomass.

However, previous studies have mainly focused on the Pearl River estuary and adjacent areas in summer (Yin et al., 2000, 2001), and more studies are needed to examine Victoria Harbor and the adjacent areas (Yin and Harrison, 2007). Little is known about the impact of the nutrient-rich sewage on the nutrients dynamics and phytoplankton biomass in Hong Kong waters on a seasonal basis. A first step in this regard is to examine the spatial and temporal variability in nutrient stoichiometry over the 15 year period before HATS was implemented in Hong Kong waters and to investigate the implications for nutrient limitation of phytoplankton growth. This will provide a background for comparison with future trends after HATS. Here we describe an analysis of the 15 year (1986–2001) monitoring dataset from the Environmental Protection Department of Hong Kong, with a focus on the spatial and seasonal variations in nutrients, nutrient ratios and phytoplankton biomass in Hong Kong waters.

2. Materials and methods

The Environmental Protection Department (EPD) of the Hong Kong government has maintained a comprehensive sampling program to monitor water quality at >76 monitoring stations in the territorial waters for over 15 years (website: www.epd.gov.hk). Twelve stations located in the western waters (NM2, WM4 and WM3), southern waters (SM9, SM10, SM6 and WM1), Victoria Harbor (VM7, VM5 and VM2) and eastern waters (EM3 and MM8) were selected (Table 1 and Fig. 1). In this paper, only data of five representative stations (NM2, WM3, VM5, MM8 and SM6) are presented since the same conclusions on nutrient limitation apply to the other stations (Xu, 2007). These five stations represent the following Hong Kong geographical regions and water quality zones: estuarine influence (NM2, WM3 and SM6), sewage effluents (VM5) and coastal/oceanic conditions (MM8). Monthly or bimonthly sampling was conducted. A SEACAT 19 CTD was used to take vertical profiles of salinity, temperature and other parameters. Water samples were taken at three depths: surface, middle and bottom (1 m above the bottom) for chlorophyll *a* (Chl *a*) and nutrients (NO_3, NH_4, NO_2, PO_4 and SiO_4). The analytical methods followed standard methods for the examination of water and wastewater, and are given in the Marine Water Quality Report, Hong Kong (EPD, 1999). Basically, Chl *a* was extracted using acetone and measured spectrophotomeri-

Table 1
The latitude, longitude and depth of the stations

Stations	WCZ (EPD)	Depth (m)	Latitude (°N)	Longitude (°E)
NM2	North Western	11	22.35	113.98
WM4	Western Buffer	29	22.35	114.07
WM3	Western Buffer	20	22.32	114.10
VM7	Victoria Harbour	11	22.30	114.14
VM5	Victoria Harbour	13	22.29	114.18
VM2	Victoria Harbour	13	22.30	114.21
EM3	Eastern Buffer	24	22.23	114.27
MM8	Mirs Bay	30	22.20	114.32
SM10	Southern	6	22.30	114.03
SM9	Southern	9	22.27	114.07
WM1	Western Buffer	33	22.25	114.12
SM6	Southern	15	22.19	114.08