Phytoplankton biomass and production in northern South China Sea during summer: Influenced by Pearl River discharge and coastal upwelling

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A B S T R A C T
Chlorophyll a and primary production were studied in northern South China Sea during summer from 2007 to 2008. Microplankton dominated total phytoplankton biomass in the coast, while picoplankton dominated in the offshore. Algae bloom caused by Thalassionema nitzschioides was found at the sub-surface of upwelling regions (D2, C2) in 2008, and maximum of phytoplankton abundance reached 1.58 × 10^6 ind L^{-1}. Integrated primary production ranged from 189.3 to 976.2 mg m^{-2} d^{-1} in 2007, and ranged from 652.1 to 6601 mg m^{-2} d^{-1} in 2008. PP showed positive relationship with IPP (p < 0.01) and negative relationship with SST (p < 0.05). Coastal upwelling and Pearl River discharge sustained high PP, and played important role in regulating the phytoplankton biomass and production.

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1. Introduction

Seasonality of reversing monsoon plays an important role in determining the upper ocean circulation [1]. Physical factors control the distribution of chlorophyll a (chl a) and primary production (PP) not only by affecting nutrients transportation, light penetration and temperature etc., in the euphotic zone, but also by affecting the diffusion and aggregation of phytoplankton directly [2–3].

The Pearl River empties into the northern South China Sea (nSCS), which receives a heavy load of nutrients from increased agriculture fish farming and sewage effluents due to population growth and economic development in southern China [4–5]. Although there were reports that Pearl River discharge heavily impacted its estuarine and neighboring coastline area [6], it is not clear how far-reaching the impact on the PP and chl a in nSCS, especially during summer when river flux is maximum.

Coastal upwelling areas are among the most productive habitats of marine ecosystems [7]. During the upwelling events along the coast of central Chile, elevated levels of PP and chl a have been registered [7]. Yuedong and Taiwan bank upwelling were regarded as an important part of the nSCS upwelling systems [8], but information on PP and chl a in upwelling system in nSCS were rare.

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In present study, we aimed to understand the modulation mechanism of Pearl River discharge and upwelling on PP during summer.

2. Material and methods

2.1. Study site and sampling strategy

The 2007 open cruise was conducted between August 10th and 30th, whose coverage was influenced by the Pearl River discharge and Yuedong upwelling. Sampling was taken in upwelling region between June 28th and July 15th 2008 (Fig. 1).

Discrete samples were collected at various depths using a Rosette sampler fitted with 2.5-L Niskin Bottles and mounted on the Sea-Bird CTD (Seabird, USA) for the determination of salinity and temperature. Water samples for nutrient analyze were collected with 300 mL polypropylene bottles from each sampling depth and frozen immediately, and analyzed by a Lachat QC8500 flow injection analyzer.

2.2. Chl a and PP

Seawater sample for chl a analysis were immediately filtered through GF/F filters, and stored at −20 °C. The phytoplankton pigments retained on filters was extracted in 90% acetone [9]. Chl a in the extract was measured before and after acidification with a fluorometer (Turner-10-AU). Size fractionated chl a was measured...
through filtrating the water samples onto 25 mm polycarbonate filters (20 µm, 3 µm, 0.7 µm) by steps, pico-, nano- and micro-plankton were represented by the 0.7 µm, 3 µm and 20 µm size fractions respectively.

Nine sites were chosen to carry PP incubation in two cruises, 4 sites in 2007 cruise and 5 sites in 2008 cruise. PP was measured by the ¹⁴C assimilation method, and estimated by a method on the base of JGOFS protocol[10]. Seawater at the depth of 100%, 50%, 32.5%, 10%, 1% of surface irradiance were collected, each water sample was transferred to 500 mL bottles (Nelgene), 2 of them as light bottles and one as dark bottle. All bottles were filled into 4 µCi NaH¹⁴CO₃, and incubated for 4–6 h in a shade free area on the deck with the running surface seawater for temperature control. The cells were filtered onto a GF/F filter after the incubations, then immediately frozen and stored at −20 °C for later analysis. The incorporated radiocarbon was detected using a Beckman L6500 liquid scintillation counter.

2.3. Statistic

The correlation between variables was established using SPSS 12.0 software.

3. Results

3.1. 2007 Cruise

In 2007, surface sea temperature (SST) ranged from 25.29 to 29.46 °C, SST was lower than 27 °C in the coast and upwelling regions (Fig. 2), and increased from inshore to offshore. Low SST centre located in eastern Guangdong coast and Taiwan bank, and minimum was observed at E302. Surface sea surface salinity (SSS) ranged from 30 to 34, low SSS centre located outside of the mouth of the Pearl River estuary (PRE).

Fig. 1. Sampling map in northern South China Sea. Oval 2007: sampling region of 2007 cruise; Oval 2008: sampling region of 2008 cruise.

Fig. 2. Spatial distribution of temperature, salinity and chl a in nSCS in 2007. A: temperature (°C); B: salinity; C: chl a (mg m⁻³).

Fig. 3. Vertical distribution of temperature, salinity and chl a in E7 transect in 2007. A: temperature (°C); B: salinity; C: chl a (mg m⁻³).
Low saline water covers the upper layer of coast waters (Fig. 3), and two blooms were found in the upper water. Surface nitrate concentration ranged from 1.26 to 2.12 µmol L⁻¹, and high nitrate concentration occurred outside of PRE mouth. Phosphate concentration ranged from 0.36 to 0.42 µmol L⁻¹, and no significant change was found. Chl a concentration ranged from 0.06 to 3.73 mg m⁻³. Elevated chl a concentration appear along the coast (Fig. 2), and maximum was found at E709. High chl a concentration was mostly confined to upper layer (<10 m) at most of the coastal stations. Column integrated chl a (IB) ranged from 11.11 to 64.11 mg m⁻². High IB value occurred in the coast and upwelling area, maximum value occurred at E709. Microplankton dominated total chl a in the coast (Fig. 4), while picoplankton replace microplankton dominating total chl a in the shelf (E205).

Coast waters was more productive than the offshore waters (Table 1). Surface PP ranged from 0.23 to 6.32 mg m⁻³ h⁻¹, maximum value occurred at A3. Integrated primary production (IPP) ranged from 189.3 to 976.2 mg m⁻² d⁻¹, maximum value was found at E302, which was located in Yuedong upwelling region.

3.2. 2008 Cruise

SST in the upwelling region ranged from 24.78 to 30.25 °C, SST increased from the inshore to offshore areas and the low SST centre was located in Shantou coast (Fig. 5). SSS in the upwelling region ranged from 25.90 to 33.78. Low SSS centre was found west of 118°E (Fig. 5B), reflecting the mixing of freshwater from Pearl River with oceanic seawater.

Cold water intruded from northeast to southwest at the subsurface layer parallel to seashore (Fig. 6), which can be considered as the evidence of upwelling phenomena in Yuedong area.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Relevant parameters at PP incubation site in nSCS.</th>
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<tbody>
<tr>
<td>Parameters</td>
<td>2007</td>
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<tr>
<td></td>
<td>A3</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>52</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>27.18</td>
</tr>
<tr>
<td>Salinity</td>
<td>31.3</td>
</tr>
<tr>
<td>Chl a (mg m⁻³)</td>
<td>3.54</td>
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<tr>
<td>PP₅₅ (mg m⁻³ h⁻¹)</td>
<td>6.32</td>
</tr>
<tr>
<td>IB (mg m⁻²)</td>
<td>58.14</td>
</tr>
<tr>
<td>IPP (mg C m⁻² d⁻¹)</td>
<td>474</td>
</tr>
</tbody>
</table>

Fig. 4. Proportion of size fractionated chl a in 2007 (right) and 2008 (left) cruise in nSCS.

Fig. 5. Spatial distribution of temperature, salinity and chl a in nSCS in 2008. A: temperature (°C); B: salinity; C: chl a (mg m⁻³).

Fig. 6. Vertical distribution of temperature and salinity in nearshore parallelled to the coastline in 2008.
Surface nitrate concentration ranged from 1.34 to 13.25 μmol L\(^{-1}\). Phosphate concentration ranged from 0.48 to 0.87 μmol L\(^{-1}\). Nutrients concentration was abundant in upwelling region in 2008, can be interpreted as upwelled water carried nutrients to the upper layer. Surface chl a concentration was lower than 1 mg m\(^{-3}\) (0.12–0.73 mg m\(^{-3}\)) in upwelling region. IB ranged from 6.83 to 72.7 mg m\(^{-2}\), and maximum value was found at C2.

In D transect, microplankton contributes 63% of total chl a and picoplankton contribute 19%; while in A transect, microplankton contributes 32% of total chl a and picoplankton contribute 53% (Fig. 4). Different proportion of size fractionated chl a showed phytoplankton community response to the change of hydrographic and chemical environment. Surface PP ranged from 7.9 to 44.2 mg m\(^{-2}\) h\(^{-1}\), and maximum value occurred at S1. IPP ranged from 652.1 to 6601 mg m\(^{-2}\) d\(^{-1}\), high value was found in the upwelling region (S1, D1).

4. Discussion

Physical factors (such as upwelling, river discharge, Kuroshio intrusion, tidal effect and typhoons) have important impacts on biogeochemical dynamics in the pelagic zone in nSCS [5]. Upwelling and Pearl River discharge was most common phenomena in nSCS, so we focus on the impact on PP by Pearl River discharge and Yuedong upwelling.

4.1. Pearl River discharge

Discharge from a river or from an estuary can form a buoyant and nutrient-rich freshwater plume in the sea, the fate and characteristics of the plume, as well as the currents, are controlled by the interaction between the plume and wind-driven circulation [8]. Pearl River discharge often flow eastward to 116\(^\circ\)E in summer, the upper layer of west of 116\(^\circ\)E was covered by Pearl River freshwater, which showed low temperature and salinity phenomena [5,11]. Yin et al. [6] pointed that river discharge carried a lot of nutrients, stimulate the phytoplankton growth, high value occurred in coast, while nitrate deficit occurred in basin. Low temperature and salinity seawater cover the upper layer of west of 116\(^\circ\)E in 2007 (Fig. 2). Maximum value of chl a and nitrate were found outside of Pearl River mouth (E709). Microplankton dominates phytoplankton biomass in the coast, while picoplankton dominates in the offshore in 2007 (Fig. 4), showed phytoplankton community was influenced by freshwater discharge. IPP value in discharge influenced area (A3) was higher than offshore (E107, E308), which can explain that Pearl River discharge sustained high PP.

4.2. Yuedong upwelling

The appearance of abnormal low temperature and high salinity in the surface- and subsurface-layer could be regard as a good indicator of the upwelling [12]. High salinity (>34) and cold water (<24 \(^\circ\)C) intrude the subsurface in upwelling region (Fig. 6), indicating the emergence of Yuedong upwelling. In 2008, the cold water with high salinity and abundant nutrients raised from the deep layers stimulated the phytoplankton growth. Algae blooms caused by *Thalassionema nitzschioides* was found at the subsurface of upwelling regions (D2, C2), where phytoplankton abundance reached 1.58 × 10^6 ind L\(^{-1}\). High PP was found in 2007 (E302) and 2008 (S1, D1), all located in upwelling region. PP in upwelling region was enhanced by raised cold water, which played important role in the carbon fixation in nSCS.

PP showed positive relationship with IPP (p < 0.01) and negative relationship with SST (p < 0.05). Low temperature water, including upwelled water and freshwater, carried abundant nutrients, can sustain high PP. The relationship between PP and IPP reflected that surface water in coast and upwelling region was productive.

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