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Phytoplankton growth and microzooplankton grazing in the continental shelf area of northeastern South China Sea after Typhoon Fengshen

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ABSTRACT

Dilution experiments were used to investigate the phytoplankton growth and microzooplankton grazing in the continental shelf area of northeastern South China Sea during 30 June and 7 July, 2008, occurring about a week after Typhoon Fengshen. We detected negative phytoplankton growth rates (-0.03 to $-2.02\,d^{-1}$) and measured grazing rates of microzooplankton on phytoplankton in size-fractionations of 20–200 μm ($1.25\pm0.44\,d^{-1}$), 3–20 μm ($1.48\pm0.63\,d^{-1}$) and <3 μm ($1.02\pm0.42\,d^{-1}$). Results showed significant correlations between phytoplankton growth and microzooplankton grazing rates, between phytoplankton and ciliate abundance, and between the dominant phytoplankton *Thalassionema nitzschioides* and the dominant ciliate *Helicostomella longa* ($p<0.05$). Phytoplankton decay, due to nutrient-limited conditions occurring with the fading of upwelling and spreading of freshwater plume after Typhoon Fengshen, may account for negative phytoplankton growth rates in this study. Synergism in the specific size-selective grazing of various species, including ciliates and heterotrophic dinoflagellates, may contribute to similar grazing rate on phytoplankton in different size-fractionations, at the integrated level. Interactions between phytoplankton and microzooplankton, including grazing selectivity, top-down and bottom-up control between phytoplankton and microzooplankton may contribute to these findings. Our results indicate that under conditions of negative phytoplankton growth microzooplankton grazing may reduce energy loss from the epipelagic waters by retrieving energy from the decaying phytoplankton community.

1. Introduction

Phytoplankton growth and zooplankton grazing are crucial processes in structuring the food web and regulating material and energy flow in epipelagic waters as phytoplankton is the base of classical herbivore food web and the microbial loop (Azam et al., 1983). Primary production is the main material and energy source of pelagic food web. Zooplankton then transfers phytoplankton biomass to a higher trophic level by grazing on phytoplankton and being preyed upon by higher trophic predators. Notably, zooplankton grazing removes, on average, 40% of coastal marine primary production (Duarte and Cebrian, 1996).

However, macro- and meso-zooplankton (larger than 200 μm) usually impose limited grazing pressure on phytoplankton (e.g. Landry et al., 1994; Zhang et al., 2007). By contrast, microzooplankton (<200 μm), an important component of the microbial loop consume a large proportion of the primary products (Landry and Calbet, 2004) and constitute a major trophic link between primary producers and larger consumers (like copepod). This, in turn, serves as prey for fish, birds, and mammals (Strom and Fredrickson, 2008). Thus, microzooplankton grazing plays a significant role in controlling phytoplankton community and food availability to higher trophic levels (Landry et al., 1997, 2000; Liu et al., 2002; Suzuki et al., 2002; Wetz and Paerl, 2008).

The dilution technique (Landry and Hassett, 1982) is widely used to estimate phytoplankton growth and synchronous microzooplankton grazing (Lessard and Murrell, 1998; Gifford, 1988), although increasing use has also brought scrutiny and critiques (e.g. Gallegos, 1989; Evans and Paranjape, 1992; Dolan and Mckeon, 2004). Several studies have used this technique to investigate microzooplankton grazing during phytoplankton blooms (e.g. James and Hall, 1998; Suzuki et al., 2002; Sun et al., 2003), coupling between phytoplankton growth and microzooplankton grazing (e.g. Burkill et al., 1987; Suzuki et al., 2002; Irigoien et al., 2005; Palomares-García et al., 2006; Chen et al., 2009), and size-selectivity of microzooplankton grazing (e.g. Burkill et al., 1987; Froneman and Perissinotto, 1996; Strom and Strom, 1996; Kuipers and Witte, 1999; Strom and Fredrickson, 2008). Collectively, these studies have provided great insight into understanding microzooplankton grazing and phytoplankton growth in this study.

So far, there are only few studies (Su et al., 2007; Zeng and Huang, 2007, 2008) investigating the continental shelf area of

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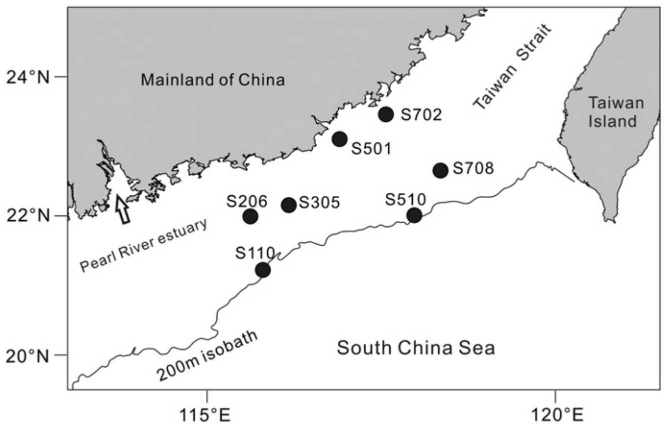

Fig. 1. Experimental sites.

northeastern South China Sea (Fig. 1), and few focus on the implications of upwelling, freshwater plume and typhoon/tropical storm on phytoplankton growth and microzooplankton grazing. Upwelling, freshwater plume and typhoon/tropical storms are common phenomena in this region in the summer and have aroused extensive concerns regarding the role of these phenomena in dissolved and particulate matter transport, and chemical or biological processes (Gan et al., 2009; Jing et al., 2009; Shu et al., 2011). These natural phenomena can significantly influence phytoplankton growth and microzooplankton grazing (e.g. Irigoien et al., 2005). So far, the grazing impact of microzooplankton on different sizes of phytoplankton in this region is not known.

This study aimed to investigate: (1) phytoplankton growth and mortality in size-fractionations of 20–200, 3–20 and $<3\,\mu m$ under the unique physical conditions after the passage of Typhoon Fengshen; and (2) from the first point we evaluated the role of microzooplankton in the energy flow in the waters studied.

2. Materials and methods

2.1. Study area

The areas studied covered the vast majority of the continental shelf off eastern Guangdong from the coast to the shelf break area (Fig. 1). Upwelling, freshwater plumes and typhoon/tropical storms are common phenomena in northeastern South China Sea in the summer. Upwelling forced by the prevalent southwesterly wind is known to occur in many waters in this area (Wu and Li, 2003; Su, 2004; Gan et al., 2009). The upwelled nutrient-rich deep water may support a large phytoplankton community or phytoplankton bloom (Mann, 1993). A large amount of run-off from the Pearl River and other coastal rivers usually create freshwater plumes in summer. The plumes spread eastward across the continental shelf, forced by southwesterly winds and currents, which occasionally reach up to the Taiwan Shoal (Su, 2004; Gan et al., 2009; Shu et al., 2011). Typhoon or tropical storms usually influence this region in summer as well. Therefore, physical conditions in this specific area are unique to the summer season.

Dilution experiments were conducted at 7 sites in the continental shelf of northeastern South China Sea during the cruise of the Northern South China Sea Coastal Oceanography Process Experiment (SCOPE), aboard the R/V *Shiyan 3* during 30 June and 7 July, 2008 (Fig. 1). Sites S501 and S702 were located in nearshore waters off eastern Guangdong, S708 was located at the Taiwan Shoal waters, S206 and S305 at the nearby the Pearl River estuary, and S110 and S510 in the shelf break area.

2.2. Dilution experiment treatments

Phytoplankton growth and microzooplankton grazing rates were estimated based on the dilution technique (Landry and Hassett, 1982) following Landry et al. (1995) and Liu et al. (2002). Before the cruise all of the experimental bottles, strainers, tubing and other containers were soaked in 10% (v/v) hydrochloric acid and deionized waters for more than 10 h, and then thoroughly rinsed with milli-Q water. About 30 L of surface seawater were collected and pre-screened with 200 μm nylon mesh to remove meso- and macroplankton. Part of the pre-screened water was gently filtered (less than 200 mbar) through a filter with 0.45 μm pore size. The first 2–3 L of particle-free water was discarded to avoid contamination. Particle-free seawater was used to rinse the experimental bottles. The particle-free water was first added to the experimental polycarbonate bottles, and afterwards these bottles were gently filled and mixed with unfiltered seawater from the same source. Replicates of dilution treatments (fraction of unfiltered seawater, i.e. dilution factor (DF)) of 0.25, 0.5, 0.75, and 1.0 were prepared in 8 polycarbonate bottles (2.4 L) without nutrient addition. One bottle was filled with particle-free water as control.

All of the experimental bottles were incubated for 24 h in perspex incubators with a screen (neutral density) on deck to simulate the natural light regime, and the temperature was controlled by running seawater pumped from the sea surface. A total of 8 dilution experiments were conducted at 7 stations.

2.3. Salinity and temperature

Salinity and temperature data was obtained by casting a CTD (Seabird).

2.4. Chlorophyll a determination and remote sensing of chlorophyll a

For the size-fractionated chlorophyll *a* of micro- (20–200 μm), nano- (3–20 μm) and pico-phytoplankton ($<3\,\mu m$), 500 or 1000 mL seawater from each treatment before and after incubation was filtered through a sequence of 20 and 3 μm polycarbonate filters (25 mm, Osmonics Inc.), and Whatman glass-fiber filters (GF/F). The filters were wrapped in aluminum foil and stored in $-20\,^{\circ}C$ until analysis. All laboratory analysis was finished within three weeks after sampling. Total chlorophyll *a* was estimated as the sum of the three size-fractionations. These filters were extracted in 90% acetone with magnesium carbonate, sonicated for 15 min in cold water, and stored at $-20\,^{\circ}C$ in darkness for 24 h. Then, the extractions were centrifuged before being analyzed by fluorometry using a Turner Designs Model 10 Fluorometer (Parsons et al., 1984). Cluster analysis among sites based on chlorophyll *a* of micro- ($>20\,\mu m$), nano- (3–20 μm) and pico-phytoplankton ($<3\,\mu m$) and their proportions was conducted with software Primer v6.

The dataset of remote sensing of chlorophyll *a* for comparison before and after the passage of Typhoon Fengshen was obtained from MODIS (http://modis.gsfc.nasa.gov/). The dataset included eight-day averages with 4 km spatial resolution. June 17–24, 2008, represents the period before the passage of the typhoon, and July 3–10, 2008 represents the time after typhoon.

2.5. Plankton identification and enumeration

For species analysis, phytoplankton samples were fixed with Lugol's solution according to Parsons et al. (1984). The subsample of 1000 mL was concentrated to 20 mL by settling for at least 24 h, the supernatant was siphoned, and qualitative and quantitative analyses were carried out using an inverted microscope according to the method of Utermöhl (1958).