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Dynamics of heterotrophic dinoflagellates off the Pearl River Estuary, northern South China Sea

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ABSTRACT

Variations in abundance, biomass, vertical profile and cell size of heterotrophic dinoflagellates (HDFs) between summer and winter and its controlling factors were studied in the northern South China Sea (SCS). It was found that HDF abundance and carbon biomass were 4–102 × 10^3 cells L^{-1} and 0.34–12.3 mg C L^{-1} in winter (February 2004), respectively, while they were 2–142 × 10^3 cells L^{-1} and 0.22–31.4 μg C L^{-1} in summer (July, 2004), respectively, in the northern SCS. HDF abundance and carbon biomass decreased from the estuary to inshore and then offshore. Vertical profiles of HDF abundance were heterogeneous, which accorded well with that of chlorophyll a (Chl.*a*). Higher abundance of HDFs was often observed at a depth of 30–70 m offshore waters, matching well with the Chl.*a* maximum, while it showed high abundance at the surface in some coastal and estuary stations. Small HDFs (≤20 μm) dominated the assemblage in term of abundance accounting for more than 90%. However, large HDFs (>20 μm) generally contributed equally in terms of carbon biomass, accounting for 47% on average. HDFs showed different variation patterns for the different study regions; in the estuarine and continental shelf regions, abundance and biomass values were higher in summer than those in winter, while it was the reverse pattern for the slope waters. Hydrological factors (e.g. water mass, river outflow, monsoon and eddies) associated with biological factors, especially the size-fractionated Chl.*a*, seemed to play an important role in regulating HDF distribution and variations in the northern South China Sea.

1. Introduction

Heterotrophic dinoflagellates (HDFs) are a major component of the micro-zooplankton (<200 μm) size class, and as predators of various classes of plankton, and as prey for larger members of the zooplankton, they provide a key trophic linkage in the microbial food web (e.g. Jeong, 1999; Levinsen and Nielsen, 2002; Yang et al., 2004; Sherr and Sherr, 2007). Sherr and Sherr (2007) have summarized evidence showing that HDFs are a significant component of micro-zooplankton and they have the greatest potential to consume diatoms of the major groups of herbivores in pelagic systems. Since many species have an optimal size ratio between themselves and their prey of 1:1, HDFs can prey on organisms as large as, or larger than, themselves in size, while other categories of phagotrophic protists (heterotrophic flagellates and ciliates) in general feed on smaller sized prey (e.g. Jeong 1999; Sherr and Sherr, 2007). Consequently, small HDFs (<20 μm) can compete for prey with heterotrophic nanoflagellates and ciliates, and large HDFs (>20 μm) can compete with copepods for prey (Archer et al., 1996; Sherr and Sherr, 2007). A certain part of the phytoplankton standing stock is consumed by HDFs and so primary production is affected (Hall et al., 2004; Hlaili et al., 2006). Moreover, with their potential fast-growth rate, HDFs respond quickly to blooms and play a role as significant as the meso-zooplankton in consuming phytoplankton blooms (Archer et al., 1996; Assmy et al., 2007; Sherr and Sherr, 2007). Thus, it is certain that HDFs play a significant role in carbon-energy flow and material cycling in oceanic ecosystems (Lessard, 1991; Sherr and Sherr, 1994; Jeong 1999).

Although the important role of HDFs in pelagic microbial food web dynamics is documented in numerous equatorial to polar studies (e.g. Verity et al., 1996; Sherr et al., 1997; Levinsen and Nielsen, 2002; Yang et al., 2004; Henjes et al., 2007), many reports are still biased towards the ciliated component of the micro-

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zooplankton rather than HDFs (Nielsen and Andersen, 2002; Sherr and Sherr, 2007). In addition, misconceptions remain that the micro-zooplankton planktonic protists are mainly ciliates (Sherr and Sherr, 2007). Based on the important roles described above, the HDFs obviously deserve to be included in studies of micro-zooplankton community structure and food web dynamics (Sherr et al., 1997; Nielsen and Andersen, 2002; Sherr and Sherr, 2007). However, spatial distribution and temporal variations of these assemblages are not adequately addressed.

The northern South China Sea (SCS) off the Pearl River estuary, located mainly between 17 and 23 °N and from 110 to 118 °E, and characterized by tropical and subtropical climate is a marginal sea with wide continental shelves and complex hydrological environments. The northern SCS represents typical oligotrophic characteristics, with significant environmental gradients (e.g. temperature, salinity and nutrients) due to the influence of the Pearl River, the thirteenth largest river in the world. The northern SCS is also sensitive to many types of physical forcing on the different terms (e.g. meso-scale eddies, monsoon). Previous studies show that the oligotrophic offshore regions of the northern SCS are characterized by low biomass and special temporal variations with high biomass in winter while low in summer, which are quite different from the conditions in temperate and tropical waters (Tseng et al., 2005; Huang et al., 2008). Thus it is necessary to assess micro-zooplankton stocks in order to study the coupling of predator–prey in such a subtropical oligotrophic ocean. However, there has been little study concerning micro-zooplankton distribution and temporal variation in this area. Eddies are very active in the northern SCS (e.g. Wang et al., 2003; Jia et al., 2005). Ning et al. (2004) report that eddies affect phytoplankton and primary production in the SCS, indicating that the cold eddy shows rich nutrients, low dissolved oxygen (DO), and high Chl.*a* and primary productivity (PP), while the warm pool is associated with poor nutrients, high DO, and low Chl.*a* and PP. Unfortunately, very few studies have been made concerning the effects of eddies on HDF abundance and biomass in this area. Two anticyclonic (warm) eddies occurred during our cruise in February, 2004, and two transects were set across the two warm eddies to study coupling between meso-scale eddies and HDFs.

The aim of the present study was to examine temporal and spatial variations of HDFs and the factors influencing their distribution and temporal variations. The coupling between meso-scale eddies and HDFs, and the size-spectrum of HDFs were also addressed in the northern SCS.

2. Materials and methods

2.1. Study area

The study was carried out during two cruises, which were in February 2004 and July 2004, in the northern SCS off the Pearl River Estuary (17.5–23 °N, 110.5–118 °E). The study area involved subtropical waters with wide continental shelves and very complex hydrological conditions. Stratification existed almost throughout the year offshore, although the study area was influenced by the East Asian monsoon. Differences of wind velocity and other hydrological factors (e.g. meso-scale eddies and upwelling) cause changes in the vertical mixing layer nutricline depth (Tseng et al., 2005), influencing nutrient supply and availability in the upper water, and affecting plankton biomass and distribution in the study area concomitantly. The outflows of the Pearl River and the Hanjiang River also greatly influence this area, mostly in the wet season (March–September), and provide large amounts of nutrients into this area (Huang et al., 2008). Based on the water depth along the transects, we divided the area into three typical regions: coast, shelf, and slope.

The sampling stations are shown in Fig. 1. There were four transects (A, B, C and D), which went southeastward from the coast to the continental shelf and then to the slope (deep water). Transect A was from the Pearl River estuary to the southwest of Dongsha Island; transect B passed through the summer wind-driven upwelling off eastern Guangdong; transect C was from Modaomen, one branch of the Pearl River to the SCS, to the continental slope; while transect D was to the northeast of Hainan Island.

During the winter cruise in February, 2004, two anticyclonic (warm) eddies were observed (Fig. 1). Transect B partly cut through one warm eddy (WE1) near Dongsha Island, while transect D cut through another warm eddy (WE2) to the east of Hainan Island. WE1 was stronger and was formed by the Kuroshio intrusion while WE2 was in its weakening period and might have been of local origin from the northern SCS (Wang et al., 2008). Stn. B2 was at the edge of WE1, while Stn. D3 was at the edge of WE2.

2.2. Sampling

Water samples for biological and chemical analyses were collected using Niskin bottles from the Sea Bird 19 CTD-sampler (Oceanic Co., USA), at 3–8 selected depths for each station depending on the water depth. Biological and chemical analyses were carried out on water samples drawn from the same bottles.

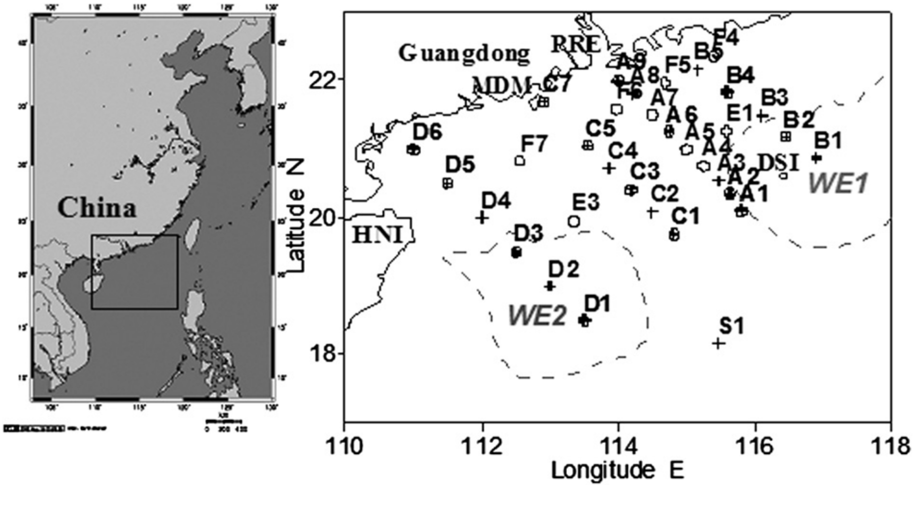

Fig. 1. Sampling stations in the northern South China Sea. + for July, 2004, and ○ for February, 2004. PRE, Pearl River Estuary; MDM, Modaomen; HNI, Hainan Island; DSI, Dongsha Island; WE1, warm eddy 1; WE2, warm eddy 2.