*Acta Oceanol. Sin.*, 2015, Vol. 34, No. 10, P. 132–146
DOI: 10.1007/s13131-015-0712-x
http://www.hyxb.org.cn
E-mail: hyxbe@263.net

# Spring and autumn living coccolithophores in the Bohai Sea and Yellow Sea, China

JIN Hualong[1, 2], FENG Yuanyuan[1, 2], LI Xiaoqian[1, 2], ZHAI Weidong[3], SUN Jun[1, 2*]

[1] College of Marine and Environmental Sciences, Tianjin University of Science and Technology, Tianjin 300457, China

[2] Tianjin Key Laboratory of Marine Resources and Chemistry, Tianjin University of Science and Technology, Tianjin 300457, China

[3] National Marine Environmental Monitoring Center, State Oceanic Administration, Dalian 116023, China

Received 23 January 2014; accepted 1 April 2014



**Abstract**

The living coccolithophores (LCs) are an important class of calcified taxa of phytoplankton functional groups, and major producers of marine biogenic inorganic carbon, playing an important role in the marine carbon cycle. In this study, we report the two-demensional abundance, composition of LCs and its correlation with the environmental parameters in spring and autumn, in order to understand the ecological role of LCs in the Yellow Sea and the Bohai Sea. In spring, totally 9 taxa belonging to coccolithophyceae were identified using a polarized microscope at the 1 000× magnification. The dominant species were *Emiliania huxleyi*, *Gephyrocapsa oceanica*, *Helicosphaera carteri*, and *Calcidiscus leptoporus*. The abundance of coccosphores and coccoliths ranged 0–7.72 cells/mL, and 0–216.09 coccoliths/mL, with the average values of 0.21 cells/mL, and 11.36 coccoliths/mL, respectively. The *Emiliania huxleyi* distribution was similar to *Gephyrocapsa oceanica*. The highest abundance of coccoliths was observed in the east of Shandong Peninsula in northern Yellow Sea, whereas *Helicosphaera carteri* distributed more widely. *Emiliania huxleyi* and *Gephyrocapsa oceanica* were the two predominant species in LCs with higher abundances. The distribution of LCs was similar to that of coccoliths. In autumn, 14 taxa belonging to coccolithophyceae were identified with dominant species as *Emiliania huxleyi*, *Gephyrocapsa oceanica*, *Helicosphaera carteri*, *Calcidiscus leptoporus* and *Oolithotus fragilis*. The abundance of coccosphores and coccoliths ranged 0–24.69 cells/mL, and 0–507.15 coccoliths/mL, with the average values of 1.47 cells/mL, and 55.89 coccoliths/mL, respectively. The highest abundance of coccoliths was located in Qingdao coastal waters and south of the survey area. The distribution of LCs was similar to the coccoliths; in addition, LCs presented large abundance in the east of the central Yellow Sea area.

**Key words:** living coccolithophores, Bohai Sea, Yellow Sea, spring, autumn

**Citation:** Jin Hualong, Feng Yuanyuan, Li Xiaoqian, Zhai Weidong, Sun Jun. 2015. Spring and autumn living coccolithophores in the Bohai Sea and Yellow Sea, China. Acta Oceanologica Sinica, 34(10): 132–146, doi: 10.1007/s13131-015-0712-x

## 1 Introduction

Living coccolithophores (LCs) is one of the major groups of marine phytoplankton in the ocean. LCs originated in the late 200 million years ago in the Triassic, flourished in the Cretaceous and almost all over the global ocean. LCs are giving in pavlova gyrans taxonomy, with more than 380 species identified. LCs play an important role in the marine carbon cycle. Coccolithophores with its protective shell of calcium carbonate, are considered to be more complete preservation of the fossils in the ocean (Brownlee and Taylor, 2004). Therefore, the study of its biostratigraphy has an important significance for the research of and Mesozoic and Cenozoic paleoceanography and global climate change. At the same time, LCs are important primary producers in the ocean, producing organic carbon through photosynthesis (Balch, 2004; Field et al., 1998).

Global survey on LCs started in the early 1960s. In China, the surveies of offshore LC species diversity and distribution have been conducted since the 1970s (Okada and Honjo, 1975). The first survey was conducted in the East China Sea area, and later on expanded in the South China Sea and the Yellow Sea. However, there were very few studies in the Bohai Sea, which is the innermost gulf on the North China and serves as one of the important fishery bases in China. Therefore the current research on the Bohai Sea and Yellow Sea coccolithophore diversities and distributions will help us to fill some research gaps, providing useful information for understanding the contribution in the carbon cycle of this ecologically important group in these areas.

## 2 Materials and methods

### 2.1 *Survey area and sampling methods*

We carried out a series of multidisciplinary investigations including hydrodynamics, chemical and biological oceanography in the Yellow Sea and the Bohai Sea (31.9°–39.3°N, 119.0°–124.5°E)

Foundation item: The Program for New Century Excellent Talents in University under contract No. NCET-12-1065; the National Natural Science Foundation of China under contract Nos 41176136, 41276124, 40776093 and 40676089 to Sun Jun; the National Natural Science Foundation of China under contract No. 41306118 to Feng Yuanyuan.
*Corresponding author, E-mail: phytoplankton@163.com

from May 2–20 in 2012 and November 2–20 in 2012 respectively. A total of 65 stations in spring and 67 stations in autumn were investigated (Fig. 1).

Water samples from each station were taken using a sampler with attached CTD (conductivity temperature depth) device. For each sample, 300 milliliter to one liter of seawater was filtered onto polycarbonate filters (25 mm diameter, 0.22 μm pore size) under less than 30 mm Hg filtration pressure. The filters were then transferred onto plastic Petri dishes for air-drying. The dried filters were clipped and then immobilized on glass slides using Neutral balsam for laboratory microscopic analysis (Sun et al., 2014). Species identification and nomenclature was refer to literatures (Sun and Jin, 2011).

**Fig. 1.** Sampling stations of living coccolithophores in the Yellow Sea and the Bohai Sea in spring and autumn, 2012. Transections show in redline. a. In spring and b. in autumn.

### 2.2 *Coccolith data analyses and statistical methods*

The samples were investigated using a Motic Inverted microscope (PM, BA300) under 1 000× magnification with more than 300 coccoliths or 100 coccospheres being identified and counted per filter according to Bollmann et al. (2002).

Coccolith/coccosphore abundance was calculated following the methodology described in Sun et al. (2011) as the following equation:

$$A = \frac{a \times S}{N \times b \times s},$$

where $A$ is the abundance of the species, $N$ is the number of fields counted in each filter, $a$ is the number of total cells of a species in the whole viewing fields of a filter, $b$ is the volume of the water filtered (mL), $S$ is the effective filtration area, and $s$ is the area of per field under 1 000× magnification.

coccolith/coccosphore dominance index ($Y$), relative abundance ($P$) calculation was calculated respectively following the methodology of Sun et al. (2003, 2011):

$$Y = \frac{n_i}{N} f_i,$$

$$P = \frac{n_i}{N},$$

where $Y$ is the dominance index, $N$ is the total number of cells of all species counted, $n_i$ is the number of cells of the species, $P$ is the relative abundance, and $f_i$ is the frequency of occurrence of the species in each sample.

## 3 Results

### 3.1 *Environmental factors*

The surface temperature and salinity distribution are shown in Fig. 2. Both salinity and temperature in the Yellow Sea area was in general higher than the Bohai Sea. The salinity along the coast was relatively low in spring. The sea surface temperature in autumn was higher than spring and the salinity was roughly the same in the two seasons. Temperature presented a trend of increasing from north to south and from nearshore to offshore.

The temperature and salinity vertical distribution of three major sections in the two seasons are shown in Figs 3 and 4, respectively. In spring, the distribution of the temperature presented an obvious stratification phenomenon except for Section B4. The temperature gradually decreased from surface to bottom, while there was no obvious stratification of salinity, but increased gradually from inshore to offshore. In the depth between 20 and 40 m south of Section H1, the Yellow Sea Cold Water Mass was formed with relatively low temperature and high salinity ($T$<8°C, $S$>32) (Fig. 3). In autumn, in the vertical direction the water mass was mixed evenly with stable temperature and salinity. Horizontally, temperature and salinity increased from inshore to offshore. The distribution of the temperature and salinity presented an obvious stratification phenomenon in Section H1. There was an obvious region with high temperature and low salinity below 20 m depth in the offshore area of Section H4 (Fig. 4).

### 3.2 *LC species in survey area*

In spring, a total of 9 taxa were identified (not including undetermined species) in this survey area. The common taxa observed

**Fig. 2.** The distribution of temperature and salinity in the surface layer in spring and autumn. a. Temperature distribution in spring (°C), b. salinity distribution in spring, c. temperature distribution in autumn (°C), and d. salinity distribution in autumn.

**Fig. 3.** Vertical distribution of temperature and salinity along the three sections in spring. a. Temperature distribution along Section B4 (°C), b. salinity distribution along Section B4, c. temperature distribution along Section H1 (°C), d. salinity distribution along Section H1, e. temperature distribution along Section H4 (°C), and f. salinity distribution along Section H4.

**Fig. 4.** Vertical distribution of temperature and salinity along the three sections in autumn. a. Temperature distribution along Section B4 (°C), b. salinity distribution along Section B4, c. temperature distribution along Section H1 (°C), d. salinity distribution along Section H1, e. temperature distribution along Section H4 (°C), and f. salinity distribution along Section H4.

were as followed: *Emiliania huxleyi*, *Gephyrocapsa oceanica*, *Helicosphaera carteri* and *Calcidiscus leptoporus*. For coccoliths, *Emiliania huxleyi* and *Gephyrocapsa oceanica* were absolutely dominant with the high frequency of 99.02% and 93.17% respectively; the sum relative abundance was 99.12%. *Emiliania huxleyi* and *Gephyrocapsa oceanica* were the dominant coccosphore species, with high frequencies of 24.39% and 13.66%, respectively (Table 1).

In autumn, 14 taxa were identified totally and the common taxa were the same as those in spring. *Emiliania huxleyi* and *Gephyrocapsa oceanica* were also the dominant species. Other common taxa observed were *Helicosphaera carteri*, *Calcidiscus leptoporus* and *Oolithotus fragilis*. For coccoliths, *Emiliania huxleyi* and *Gephyrocapsa oceanica* were absolutely dominant with high frequencies of 98.51% and 91.54%, and sum relative abundance of 99.5%. Several other common species frequency was about 10%, and their relative abundances were very low at about 1%. *Emiliania huxleyi* and *Gephyrocapsa oceanica* coccosphore were the dominant species, with high frequencies of 39.80% and 28.36%, respectively (Table 2).

### 3.3 *Horizontal distribution of common species*

In spring the abundance of coccoliths and cells ranged 0–216.09 coccoliths/mL, and 0–42.56 cells/mL, with average values of 11.36 coccoliths/mL and 0.21 cells/mL, respectively. The abundance of *Emiliania huxleyi* coccoliths ranged 0–198.00 coccoliths/mL, with an average value of 9.05 coccoliths/mL; the abundance of *Gephyrocapsa oceanica* coccoliths ranged 0–25.58 coccoliths/mL, with an average value of 2.09 coccoliths/mL; and the abundance of *Helicosphaera carteri* coccoliths was 0–0.44 coccoliths/mL, with an average of 0.03 coccoliths/mL. As for the cell abundances, *Emiliania huxleyi* ranged 0–6.39 cells/mL, with an average value of 0.15 cells/mL; the abundance of *Gephyrocapsa oceanica* cells ranged 0–1.32 cells/mL, with an average of 0.05 cells/mL.

In autumn, the abundance of coccoliths and cells ranged 0–507.15 coccoliths/mL and 0–24.69 cells/mL, with the average values of 55.89 coccoliths/mL and 1.47 cells/mL, respectively. The abundance of *Emiliania huxleyi* coccoliths ranged 0–366.91 coccoliths/mL, with the average of 40.40 coccoliths/mL; the abundance of *Gephyrocapsa oceanica* coccoliths ranged 0–185.22 coccoliths/mL, with the average value of 15.21 coccoliths/mL; and the abundance of *Helicosphaera carteri* coccoliths was 0–2.65 coccoliths/mL, with the average of 0.08 coccoliths/mL. As for the cell abundances, *Emiliania huxleyi* ranged 0–14.99 cells/mL, with the average value of 1.01 cells/mL; and the abundance of *Gephyrocapsa oceanica* cells ranged 0–10.58 cells/mL, with the average of 0.43 cells/mL.

As for the surface layer, in spring, the abundance of *Emiliania huxleyi* coccoliths ranged 0–156.99 coccoliths/mL, with the average abundance of 8.76 coccoliths/mL; the abundance of *Gephyrocapsa oceanica* coccoliths ranged 0–25.58 coccoliths/mL, and the average value was 2.36 coccoliths/mL. Highest abundances of *Emiliania huxleyi* and *Gephyrocapsa oceanica* were observed in stations east of Shandong Peninsula and north of the Yellow Sea; furthermore, high abundance of *Gephyrocapsa*

**Table 1.** Living coccolithophore species composition of the Yellow Sea and the Bohai Sea in spring, 2012

| Species | Frequency of occurrence (*fi*)/% | Relative abundance (*P*)/% | Dominance index (*Y*) |
|---|---|---|---|
| Coccolith dominant species | | | |
| *Emiliania huxleyi* | 99.02 | 80.46 | 0.796 723 |
| *Gephyrocapsa oceanica* | 93.17 | 18.66 | 0.173 882 |
| *Helicosphaera carteri* | 10.73 | 0.29 | 0.000 308 |
| *Calcidiscus leptoporus* | 9.76 | 0.28 | 0.000 271 |
| *Oolithotus fragilis* | 5.37 | 0.13 | 0.000 072 |
| *Braarudosphaera bigelowii* | 2.93 | 0.08 | 0.000 022 |
| *Rhabdosphaera clavigera* | 0.49 | 0.01 | 0.000 000 |
| *Cocolithus braarudii* | 1.46 | 0.06 | 0.000 008 |
| *Umbilicosphaera sibogae* | 0.98 | 0.03 | 0.000 003 |
| Coccolithophore dominant species | | | |
| *Emiliania huxleyi* | 24.39 | 74.61 | 0.181 979 |
| *Gephyrocapsa oceanica* | 13.66 | 23.32 | 0.031 846 |
| *Helicosphaera carteri* | 0.49 | 0.52 | 0.000 025 |
| *Calcidiscus leptoporus* | 0.49 | 0.52 | 0.000 025 |
| *Oolithotus fragilis* | 0.49 | 0.52 | 0.000 025 |
| *Braarudosphaera bigelowii* | 0.49 | 0.52 | 0.000 025 |

**Table 2.** Living coccolithophore species composition of the Yellow Sea and the Bohai Sea in autumn, 2012

| Species | Frequency of occurrence (*fi*)/% | Relative abundance (*P*)/% | Dominance index (*Y*) |
|---|---|---|---|
| Coccolith dominant species | | | |
| *Emiliania huxleyi* | 98.51 | 72.29 | 0.712 071 9 |
| *Gephyrocapsa oceanica* | 91.54 | 27.21 | 0.249 082 0 |
| *Helicosphaera carteri* | 10.45 | 0.14 | 0.000 147 6 |
| *Calcidiscus leptoporus* | 7.96 | 0.08 | 0.000 060 9 |
| *Oolithotus fragilis* | 12.94 | 0.08 | 0.000 106 6 |
| *Braarudosphaera bigelowii* | 5.47 | 0.04 | 0.000 021 5 |
| *Cocolithus braarudii* | 5.97 | 0.08 | 0.000 048 0 |
| *Umbilicosphaera sibogae* | 4.48 | 0.04 | 0.000 019 3 |
| *Scyphosphaera apsteinii* | 1.00 | 0.01 | 0.000 000 8 |
| *Reticulofenestra sessilis* | 1.00 | 0.00 | 0.000 000 4 |
| *Syracosphaera pulchra* | 0.50 | 0.01 | 0.000 000 4 |
| *Pleurochrysis placolithoides* | 0.50 | 0.00 | 0.000 000 2 |
| *Florisphaera profunda* | 0.50 | 0.00 | 0.000 000 2 |
| *Algirosphaera robusta* | 0.50 | 0.00 | 0.000 000 1 |
| Coccolithophore dominant species | | | |
| *Emiliania huxleyi* | 39.80 | 68.93 | 0.274 350 |
| *Gephyrocapsa oceanica* | 28.36 | 29.43 | 0.083 452 |
| *Calcidiscus leptoporus* | 1.99 | 0.45 | 0.000 089 |
| *Braarudosphaera bigelowii* | 1.49 | 0.30 | 0.000 045 |
| *Helicosphaera carteri* | 1.00 | 0.30 | 0.000 030 |
| *Oolithotus fragilis* | 1.00 | 0.22 | 0.000 022 |
| *Umbilicosphaera sibogae* | 0.50 | 0.15 | 0.000 007 |
| *Scyphosphaera apsteinii* | 0.50 | 0.15 | 0.000 007 |
| *Cocolithus braarudii* | 0.50 | 0.07 | 0.000 004 |

*oceanica* was found in the southern survey area. The abundance of *Helicosphaera carteri* was low, but a wide distribution of this species was observed (Fig. 5). The abundance of dominant species *Emiliania huxleyi* cells ranged 0–2.65 cells/mL, with an average value of 0.14 cells/mL; the abundance of the other dominant species *Gephyrocapsa oceanica* cells ranged 0–0.44 cells/mL, with the average of 0.03 cells/mL (Fig. 6). Higher values were mainly observed in the east of Shandong Peninsula and north of the Yellow Sea. The coccoliths distribution of the two dominant species showed similar trends to the cells.

**Fig. 5.** The horizontal distribution of coccolith abundance (coccoliths/mL) in surface layer in spring. a. *Emiliania huxleyi*, b. *Gephyrocapsa oceanic*, c. *Helicosphaera carteri*, and d. sum.

For the horizontal distribution of coccoliths in water column integral in spring, the sum abundance of coccoliths ranged $(1.05–79.55)\times10^6$ coccoliths/m$^2$, with the average abundance of $9.72\times10^6$ coccoliths/m$^2$, the abundance of dominant species *Emiliania huxleyi* coccoliths ranged $(0.79–75.34)\times10^6$ coccoliths/m$^2$, with the average abundance of $7.83\times10^6$ coccoliths/m$^2$, the abundance of *Gephyrocapsa oceanica* coccoliths ranged $(0.26–9.84)\times10^6$ coccoliths/m$^2$, and the average abundance was $1.86\times10^6$ coccoliths/m$^2$. The highest abundance of coccoliths was observed in the east of Shandong Peninsula in northern Yellow Sea and in Qingdao coastal waters (Fig. 7). For the horizontal distribution of integral coccosphore abundance in the water column, the sum abundance of coccosphores ranged $(0–3.86)\times10^6$ cells/m$^2$, with the average abundance of $0.21\times10^6$ cells/m$^2$, *Emiliania huxleyi* and *Gephyrocapsa oceanica* were the dominating species with abundances ranging $(0–3.19)\times10^6$ cells/m$^2$ and $(0–0.66)\times10^6$ cells/m$^2$ respectively, and average values of $0.16\times10^6$ cells/m$^2$ and $0.05\times10^6$ cells/m$^2$, respectively. The highest abundance of coccosphores was located in Qingdao coastal waters (Fig. 8).

In autumn, the surface layer abundance of *Emiliania huxleyi* coccoliths ranged from 0–292.38 coccoliths/mL, with the average abundance of 40.69 coccoliths/mL; the abundance of *Gephyrocapsa oceanica* coccoliths in the surface ranged 0–148.18 coccoliths/mL, and the average value was 15.20 coccoliths/mL. The distribution of *Emiliania huxleyi* was similar to the *Gephyrocapsa oceanica*. The higher values were observed in coastal waters of southern Shandong Peninsula and along 123°E in the southern investigation area. For *Calcidiscus leptoporus*, high abundances also presented along 123°E in southern area of southern investigation sea (Fig. 9). The abundance of dominant species *Emiliania huxleyi* cells ranged 0–11.47 cells/mL, with the average value of 0.99 cells/mL; the abundance the other dominant species *Gephyrocapsa oceanica* cells ranged 0–6.17 cells/mL, with the average of 0.37 cells/mL (Fig. 10). The cell distribution of the two dominant species showed similar to the coccoliths.

**Fig. 6.** The horizontal distribution of coccosphore abundance (cells/mL) in surface layer in spring. a. *Emiliania huxleyi*, b. *Gephyrocapsa oceanic*, and c. sum.

**Fig. 7.** The water column vertically integrated distribution of coccolith abundance ($10^6$ coccoliths/m$^2$) in spring. a. *Emiliania huxleyi*, b. *Gephyrocapsa oceanic*, c. *Helicosphaera carteri*, and d. sum.

For the horizontal distribution of integral coccolith abundance in autumn, the sum abundance of coccoliths ranged $(2.19–475.96)\times10^6$ coccoliths/m$^2$, with the average abundance of $55.89\times10^6$ coccoliths/m$^2$, the abundance of dominant species *Emiliania huxleyi* coccoliths ranged $(1.09–327.65)\times10^6$ coccoliths/m$^2$, with the average abundance of $40.70\times10^6$ coccoliths/m$^2$; the abundance of *Gephyrocapsa oceanica* coccoliths ranged $(0.17–148.31)\times10^6$ coccoliths/m$^2$, and the average abundance was $15.14\times10^6$ coccoliths/m$^2$. The highest abundance of coccoliths was observed in Qingdao coastal waters and south of the survey area (Fig. 11). For the horizontal distribution of coccosphore in water column integrally, the sum abundance of coccosphores ranged $(0–17.12)\times10^6$ cells/m$^2$, with the average abundance of $1.58\times10^6$ cells/m$^2$. *Emiliania huxleyi* and *Gephyrocapsa oceanica* were the dominating species with abundances ranging $(0–11.59)\times10^6$ cells/m$^2$ and $(0–5.66)\times10^6$ cells/m$^2$, and average values of $1.11\times10^6$ cells/m$^2$ and $0.47\times10^6$ cells/m$^2$, respectively. The area with the highest abundance of coccosphores was located in the coastal waters of Shandong Peninsula. Compared to the spring, there was a big change in the scope of high abundance (Fig. 12).

**Fig. 8.** The water column vertically integrated distribution of coccosphore abundance ($10^6$ cells/m$^2$) in spring. a. *Emiliania huxleyi*, b. *Gephyrocapsa oceanic*, c. *Helicosphaera carteri*, and d. sum.

**Fig. 9.** The horizontal distribution of coccolith abundance (coccoliths/mL) in surface layer in autumn. a. *Emiliania huxleyi*, b. *Gephyrocapsa oceanica*, c. *Calcidiscus leptoporus*, and d. sum.

**Fig. 10.** The horizontal distribution of coccosphore abundance (cells/mL) in surface layer in autumn. a. *Emiliania huxleyi*, b. *Gephyrocapsa oceanica*, c. *Calcidiscus leptoporus*, and d. sum.

**Fig. 11.** The water column vertically integrated distribution of coccolith abundance ($10^6$ coccoliths/m$^2$) in autumn. a. *Emiliania huxleyi*, b. *Gephyrocapsa oceanic*, c. *Calcidiscus leptoporus*, and d. sum.

**Fig. 12.** The water column vertically integrated distribution of coccosphore abundance ($10^6$ cells/m$^2$) in autumn. a. *Emiliania huxleyi*, b. *Gephyrocapsa oceanic*, c. *Calcidiscus leptoporus*, and d. sum.

### 3.4 *Vertical distribution of LCs at different sections*

#### 3.4.1 *Vertical distribution of coccolith in spring*

Section B4 located in the Bohai central shallow sea basin. In spring, the abundance of coccoliths ranged 1.32–53.58 coccoliths/mL, with the average of 8.64 coccoliths/mL. *Emiliania huxleyi* and *Gephyrocapsa oceanica* were the two dominant species. The relative higher values were found in central Bohai shallow sea basin. Section H1 went across the central Yellow Sea. In spring, the abundance of coccoliths ranged 0.88–13.89 coccoliths/mL, with the average value of 5.38 coccoliths/mL. *Emiliania huxleyi* and *Gephyrocapsa oceanica* were the dominating species with the abundance ranging 0.22–10.36 coccoliths/mL and 0.44–3.09 coccoliths/mL, with the average value of 4.07 coccoliths/mL and 1.18 coccoliths/mL, respectively. High abundances were mainly observed on the east side of the section. There were a large number of accumulations in the bottom layer of other stations, and *Helicosphaera carteri* abundance presented a wide distribution. Section H4 is located in the south area of investigation. In spring, the abundance of coccoliths ranged 2.21–19.62 coccoliths/mL, with the average of 6.04 coccoliths/mL. *Emiliania huxleyi* and *Gephyrocapsa oceanica* were the dominating species with the abundance ranging from 1.32–12.13 coccoliths/mL and 0.44–6.62 coccoliths/mL, with the average value of 3.84 coccoliths/mL and 2.01 coccoliths/mL, respectively. The abundance showed a trend of increasing and then decreasing with the increase of depth, resulting in a high value mainly observed in the central section (Fig. 13).

In the CCA diagram of coccoliths in spring (Fig. 14), Axis 1 mainly relates to ammonium concentration, while Axis 2 mainly relates to depth and salinity. Based on Fig. 14, the advantage of *Emiliania huxleyi* and *Gephyrocapsa oceanica* distribution is obvious; the two species was found in almost all the surveyed areas and water layers, indicating the species flexible adaptability, similar to most of the previous studies (Sun et al., 2014). *Calcidiscus leptoporus* had a positive correlation with ammonium concentration. *Braarudosphaera bigelowii* expressed a preference of deep water and rather oligotrophic conditions.

#### 3.4.2 *Vertical distribution of coccosphore in spring*

In Section B4, the coccosphore abundances ranged 0–0.88 cells/mL, with the average of 0.15 cells/mL, the coccosphore abundance was low in this section. *Emiliania huxleyi* and *Gephyrocapsa oceanica* were the only two species observed. Unlike the trend of coccoliths, coccosphore was mainly distributed in the lower water depth. In Section H1, the abundance of coccosphore ranged 0–1.76 cells/mL, with the average of 0.24 cells/mL. *Emiliania huxleyi* and *Gephyrocapsa oceanica* were the dominating species with the abundances ranging from 0–1.10 cells/mL and 0–0.66 cells/mL, and average values of 0.18 cells/mL and 0.05 cells/mL, respectively. In Section H4, the abundance of coccosphore ranged 0–0.44 cells/mL, with the average of 0.04 cells/mL. *Gephyrocapsa oceanica* and *Emiliania huxleyi* were the dominating species with the abundances ranging from 0–0.22 cells/mL and 0–0.22 cells/mL, with the average value of 0.03 cells/mL and 0.01 cells/mL, respectively. The abundance distribution of coccosphore cells was mainly affected by distribution of *Emiliania huxleyi* and *Gephyrocapsa oceanica*, similar to coccoliths (Fig. 15).

In the coccosphore CCA diagram (Fig. 16), Axis 1 relates to depth and Axis 2 relates to silicate concentrstion. For the dominant species of *Emiliania huxleyi* and *Gephyrocapsa oceanica*, the correlation between the main species and the environmental factors were similar to those of the coccoliths, except that *Helicosphaera carteri* had obvious positive correlation with depth, possibly caused by the sample station arrangements or sample numbers.

**Fig. 13.** Transection distribution (coccoliths/mL) of coccolith in spring. a. *Emiliania huxleyi* in Section B4, b. *Gephyrocapsa oceanica* in Section B4, c. *Helicosphaera carteri* in Section B4, d. sum in Section B4, e. *Emiliania huxleyi* in Section H1, f. *Gephyrocapsa oceanica* in Section H1, g. *Helicosphaera carteri* in Section H1, h. sum in Section H1, i. *Emiliania huxleyi* in Section H4, j. *Gephyrocapsa oceanica* in Section H4, k. *Calcidiscus leptoporus* in Section H4, and l. sum in Section H4.

**Fig. 14.** Results of the CCA of coccolith abundance vs. environmental factors in spring. $NO_2$ represents nitrite, $NO_3$ nitrate, $NH_3$ ammonium, Si silicate, P phosphate; E.huxleyi *Emiliania huxleyi*, G.oceanic *Gephyrocapsa oceanic*, H.carteri *Helicosphaera carteri*, B.bigelowii *Braarudosphaera bigelowii*, O.fragilis *Oolithotus fragilis*, C.leptoporus *Calcidiscus leptoporus*, C.braarudii *Coccolithus braarudii*, and U.sibogae *Umbilicosphaera sibogae*.

**Fig. 15.** Transection distribution (cells/mL) of coccosphore in spring. a. *Emiliania huxleyi* in Section B4, b. *Gephyrocapsa oceanica* in Section B4, c. sum in Section B4, d. *Emiliania huxleyi* in Section H1, e. *Gephyrocapsa oceanica* in Section H1, f. sum in Section H1, g. *Emiliania huxleyi* in Section H4, h. *Gephyrocapsa oceanica* in Section H4, and i. sum in Section H4.

**Fig. 16.** Results of the CCA of coccosphore abundance vs. environmental factors in spring. $NO_2$ represents nitrite, $NO_3$ nitrate, $NH_3$ ammonium, Si silicate, P phosphate, E.huxleyi *Emiliania huxleyi*, G.oceanica *Gephyrocapsa oceanic*, H.carteri *Helicosphaera carteri*, B.bigelowii *Braarudosphaera bigelowii*, C.leptoporus *Calcidiscus leptoporus*, and O.fragilis *Oolithotus fragilis*.

3.4.3 *Vertical distribution of coccolith in autumn*

In Section B4, the abundance of coccoliths ranged 6.39–279.59 coccoliths/mL, with the average of 80.39 coccoliths/mL. *Emiliania huxleyi* and *Gephyrocapsa oceanica* were the dominating species with the abundance ranging from 3.09 to 167.80 coccoliths/mL and 1.10–111.35 coccoliths/mL, with the average value of 46.95 coccoliths/mL and 33.30 coccoliths/mL, respectively. The abundance distribution showed a decreasing trend from coastal area towards offshore. The relative higher values were found in the shallow water stations; higher *Helicosphaera carteri* abundance appeared in the middle layer in the central section. In Section H1, the abundance of coccoliths ranged 3.31–340.01 coccoliths/mL, with the average of 75.29 coccoliths/mL. *Emiliania huxleyi* was the absolutely dominating species with the abundance ranging from 2.86 to 274.74 coccoliths/mL, and the average value was 65.09 coccoliths/mL. The abundance distribution of coccoliths was mainly affected by the distribution of *Emiliania huxleyi* and with an increasing trend towards offshore. In Section H4, the abundance of coccoliths ranged 5.29–418.51 coccoliths/mL, with the average value of 60.36 coccoliths/mL. *Emiliania huxleyi* was the absolutely dominating species with the abundance ranging from 4.19 to 292.38 coccoliths/mL, and the average value was 44.11 coccoliths/mL; higher abundances were mainly observed in coastal area (Fig. 17).

In autumn, in the coccolith CCA diagram (Fig. 18), Axis 1 mainly relates to depth and temperature and Axis 2 mainly relates to phosphate concentration. The abundance of coccoliths mainly was affected by the phosphate concentration, temperature and depth. *Emiliania huxleyi* and *Gephyrocapsa oceanica* presented high frequencies, and widely survived in the survey area; *Calcidiscus leptoporus* and *Braarudosphaera bigelowii* had a positive correlation with salinity and silicate concentration respectively.

3.4.4 *Vertical distribution of coccosphore in autumn*

In Section B4, the coccosphore abundances ranged 0–3.09 cells/mL, with the average of 0.75 cells/mL. *Emiliania huxleyi* and *Gephyrocapsa oceanica* were the dominating species with abundances ranging from 0–1.76 cells/mL and 0–1.10 cells/mL, and average values of 0.42 cells/mL and 0.32 cells/mL, respectively. The sum abundance had similar trend with coccoliths. High *Gephyrocapsa oceanica* cell abundance appeared in two areas different from the coccoliths distribution. In Section H1, the abundance of coccosphore ranged 0–7.06 cells/mL, with the average of 1.94 cells/mL. *Emiliania huxleyi* was the absolutely dominating species with abundance ranging from 0 to 6.62 cells/mL, and the average value was 1.67 cells/mL. The high values of coccosphore cells were distributed in the upper layer of east side of the section. *Helicosphaera carteri* coccosphore cells accumulated in the 30-m water depth of the central section. At Section H4, the abundance of coccospheres ranged 0–13.23 cells/mL, with an average of 1.49 cells/mL. *Emiliania huxleyi* and *Gephyrocapsa oceanica* were the dominating species with the abundance ranging from 0–7.06 cells/mL and 0–6.17 cells/mL, with average values of 0.81 cells/mL and 0.66 cells/mL, respectively. The distribution of coccosphore cells was similar to that of coccoliths, higher coccosphore abundances were mainly observed in coastal waters and there was no obvious change of the vertical distribution (Fig. 19).

And in the coccosphore CCA diagram (Fig. 20), Axis 1 relates to nitrite and ammonium while Axis 2 relates to temperature. *Emiliania huxleyi* and *Gephyrocapsa oceanica* were bound up with most environmental factors in the some degree while *Calcidiscus leptoporus* showed obvious positive correlation with ammonium concentration.

**Fig. 17.** Transection distribution (coccoliths/mL) of coccolith in autumn. a. *Emiliania huxleyi* in Section B4, b. *Gephyrocapsa oceanica* in Section B4, c. *Helicosphaera carteri* in Section B4, d. sum in Section B4, e. *Emiliania huxleyi* in Section H1, f. *Gephyrocapsa oceanica* in Section H1, g. *Calcidiscus leptoporus* in Section H1, h. sum in Section H1, i. *Emiliania huxleyi* in Section H4, j. *Gephyrocapsa oceanica* in Section H4, k. *Helicosphaera carteri* in Section H4, and l. sum in Section H4.

**Fig. 18.** Results of the CCA of coccolith abundance vs. environmental factors in autumn. $NO_2$ represents nitrite, $NO_3$ nitrate, $NH_3$ ammonium, Si silicate, P phosphate, E.huxleyi *Emiliania huxleyi*, G.oceanica *Gephyrocapsa oceanic*, H.carteri *Helicosphaera carteri*, B.bigelowii *Braarudosphaera bigelowii*, O.fragilis *Oolithotus fragilis*, C.leptoporus *Calcidiscus leptoporus*, C.braarudii *Coccolithus braarudii*, and U.sibogae *Umbilicosphaera sibogae*.

**Fig. 19.** Transection distribution (cells/mL) of coccosphore in autumn. a. *Emiliania huxleyi* in Section B4, b. *Gephyrocapsa oceanica* in Section B4, c. *Calcidiscus leptoporus* in Section B4, d. sum in Section B4, e. *Emiliania huxleyi* in Section H1, f. *Gephyrocapsa oceanica* in Section H1, g. *Helicosphaera carteri* in Section H1, h. sum in Section H1, i. *Emiliania huxleyi* in Section H4, j. *Gephyrocapsa oceanica* in Section H4, k. *Oolithotus fragilis* in Section H4, and l. sum in Section H4.

**Fig. 20.** Results of the CCA of coccosphore abundance vs. environmental factors in autumn. $NO_2$ represents nitrite, $NO_3$ nitrate, $NH_3$ ammonium, Si silicate, P phosphate, E.huxleyi *Emiliania huxleyi*, G.oceanica *Gephyrocapsa oceanic*, H.carteri *Helicosphaera carteri*, B.bigelowii *Braarudosphaera bigelowii*, C.leptoporus *Calcidiscus leptoporus*, and O.fragilis *Oolithotus fragilis*.

## 4 Discussion

By contrast the abundance of the two seasons, the coccolithophore abundance in the Bohai Sea survey area was very low and the abundance in the Yellow Sea is generally higher than that of the Bohai Sea. Higher coccolithophore abundance observed in eastern and southern Yellow Sea. These results of the Yellow Sea and the Bohai Sea have a certain correlation with the environmental characteristics, including temperature, salinity and nutrient concentrations. In the eastern Yellow Sea area, waters flowing from west coast of North Korea with high nutrient abundance have provided a better environment for coccolithophore growth. Whereas the Bohai Sea and central Yellow Sea are featured of low temperature, low salinity and nutrient limitation, therefore the bulk of the coccolithophore survival is limited. In the Yellow Sea and the Bohai Sea survey area, coccolithophore abundance in the vertical direction showed no obvious changes, with high value generally appearing in the middle and bottom water layer.

The distribution of coccolithophores is generally considered to be affected by the following possible factors. Yang et al. (2004) suggested that the distribution of LCs was mainly affected by the temperature and salinity; Winter et al. (2002) found the high abundance of LCs on the surface, above the nitrate halocline and in the photic zone under the DCM (deep chlorophyll maximum) in the Caribbean Sea; Andruleit et al. (2003) believed that the mixing layer depth was the decisive factor to the abundance of LCs and the competition with diatoms in the northern Arabian Sea; the study of Chen et al. (2007) in the South China Sea area indicated that coccolithophores were positively correlated with the chlorophyll *a* and mixed layer, but negatively correlated with temperature, nitrate concentration, and had obvious seasonal characteristic and regional difference; the study of Mohan et al. (2008) reported that the abundance and species of LCs was inversely linked to the silicate concentration in the Indian sector of the Southern Ocean.

In spring, temperature is low in the Bohai Sea and Yellow Sea Cold Water Mass area, limiting the production of most coccolithophores; in the southeast of the Yellow Sea, seawater salinity is higher and there was no obvious stratification of the water column, so the vertical distribution of the coccolithophore abundance showed no obvious change.

In autumn, the temperature was significantly higher than that of spring, with relatively higher temperature observed in the central and southern Yellow Sea areas, and higher salinity mainly distributed in the southern Yellow Sea waters. The coccolithophore distribution was basically consistent with the distribution of the thermohaline. Due to the effect of vertical mixing of the water column, the high value area of the coccolithophore abundance had a marked trend of upward movement in the vertical direction.

The nutrients concentration played a significant role on the Yellow Sea and the Bohai Sea coccolithophore distribution during the survey time. The abundance of coccoliths and the coccosphore cells in autumn were in general higher than those in spring.

*Emiliania huxleyi* and *Gephyrocapsa oceanica* were the absolutely dominating LC species in both of the seasons, and other common species were *Helicosphaera carteri*, *Calcidiscus leptoporus* and *Oolithotus fragilis*. The high coccolithophore abundance presented in significantly different areas in spring and autumn. The abundance in spring is very low and there was an increasing trend in coccolithophore abundance and species in autumn.

The studies on large-scale different quarter coccolithophore diversity and distribution in Bohai Sea and the Yellow Sea are still rare, especially in the Bohai Sea. The further studies on coccolithophores play the roles in the global carbon cycle and its feedback on global climate changes and ocean acidification is needed.

***Acknowledgements***

The authors would like to thank the crew and captain of the R/V *Dongfanghong II* for the logistic support during the cruise.

**References**

Andruleit H, Stäger S, Rogalla U, et al. 2003. Living coccolithophores in the northern Arabian Sea: ecological tolerances and environmental control. Mar Micropaleontol, 49(1–2): 157–181

Balch W M. 2004. Re-evaluation of the physiological ecology of coccolithophores. In: Thierstein H R, Young J R, eds. Coccolithophores. Berlin: Springer-Verlag, 165–190

Bollmann J, Cortés M Y, Haidar A T, et al. 2002. Techniques for quantitative analyses of calcareous marine phytoplankton. Marine Micropaleontology, 44(3–4): 163–185

Brownlee C, Taylor A2004. Calcification in coccolithophores. In: Theirstein H R, Young J R, eds. Coccolithophore from Molecular Process to Global Impacts. Berlin: Springer-Verlag, 31–50

Chen Y-L L, Chen H-Y, Chung C-W. 2007. Seasonal variability of coccolithophore abundance and assemblage in the northern South China Sea. Deep-Sea Res Pt II, 54(14–15): 1617–1633

Field C B, Behrenfeld M J, Randerson J T, et al. 1998. Primary production of the biosphere: integrating terrestrial and oceanic components. Science, 281(5374): 237–240

Mohan R, Mergulhao L P, Guptha M V S, et al. 2008. Ecology of coccolithophores in the Indian sector of the Southern Ocean. Mar Micropaleontol, 67(1–2): 30–45

Okada H, Honjo S. 1975. Distribution of coccolithophores in Marginal Seas along the Western Pacific Ocean and in Red Sea. Mar Biol, 31(3): 271–285

Sun Jun, An Baizheng, Dai Minhan, et al. 2011. Living coccolithophores in the Western South China Sea in Summer 2007. Oceanologia et Limnologia Sinica (in Chinese), 42(2): 170–178

Sun Jun, Gu Xiaoyao, Feng Yuanyuan, et al. 2014. Summer and winter living coccolithophores in the Yellow Sea and the East China Sea. Biogeosciences, 11(3): 779–806

Sun Jun, Jin Shaofei. 2011. Species diversity of living coccolithophores in Chinese sea waters. Biodiversity Science (in Chinese), 19(6): 787–797

Sun Jun, Liu Dongyan, Ning Xiuren. 2003. Phytoplankton in the Prydz Bay and the adjacent indian sector of the Southern Ocean during the Austral Summer 2001/2002. Oceanologia et Limnologia Sinica (in Chinese), 34(5): 519–532

Wen Tingting. 2010. Nutrient distribution characteristics in the East China Sea and the Yellow Sea and the preliminary study of upwelling cold vortex in northeastern Taiwan (in Chinese) [dissertation]. Qingdao: Ocean University of China

Winter A, Rost B, Hilbrecht H, et al. 2002. Vertical and horizontal dis-

tribution of coccolithophores in the Caribbean Sea. Geo-Mar Lett, 22(3): 150–161
Yang T-N, Wei K-Y, Chen M-P, et al. 2004. Summer and winter distribution and malformation of coccolithophores in the East China Sea. Micropaleontology, 50(S1): 157–170