Distribution characteristic and variation trend of planktonic dinoflagellate in the Taiwan Strait from 2006 to 2007

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Abstract: Based on 4 cruise surveys from July 2006 to October 2007 in the Taiwan Strait, the species composition, community structure and spatio-temporal distribution of dinoflagellate were studied. A total of 131 dinoflagellates belonging to 18 genera were identified. The population was dominated by hyperthermal and hyperhaline species accounting for 72.52% of the total species. Eurythermal and euryhaline species were the second most common one accounting for 25.19% of the total species. It was only 2.29% for neritic species. The maximum species number occurred in summer, while the maximum cell density appeared in spring. The average dinoflagellate cell density was 404.96×10^4 cells/m^3. It showed that the dinoflagellate cell density increased from the nearshore waters to the open sea and from the north to the south. Compared with the results during 1984-1985, the horizontal distribution pattern and seasonal variation of the dinoflagellate have not changed significantly, but the dinoflagellate cell density increased by 3.01 times. Further analysis of the dinoflagellate abundance variations both in the spatial and temporal aspects, indicated that the abundance of dinoflagellate increased more significantly in cold seasons, and there was a larger increase in the north of the Taiwan Strait. Besides，the dinoflagellate community structure changed notably. It showed that the diversity and evenness index were relatively high, and the proportion of dinoflagellate cell density to the total phytoplankton increased.

Keywords: planktonic dinoflagellate, distribution characteristics, variation trend, Taiwan Strait

1 Introduction

Oceans play a major role in the global carbon cycle and so directly impact the space and extent of climate change. Plankton are particularly good indicators of climate change because they are free floating and can respond easily to changes in temperature and oceanic current systems by expanding and contracting their ranges (Hughes, 2000). There

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is strong evidence for systematic changes in plankton abundance, community structure, distribution and phenology over recent decades in many areas worldwide. Many members of the genus *Ceratium*, important primary producers in tropical and temperate waters, have expanded their range into warmer water (Edinburgh Oceanographic Laboratory, 1973; Barnard, 2004). For example, before 1970, *C. trichoceros* was only found at the south of the UK, but is now found off the west coast of Scotland and in the northern North Sea. In North Atlantic, over the past 45 years, the common dinoflagellate *Ceratium tripos* peaked in abundance 27 days earlier (Edwards and Richardson, 2004). In North Sea, the mid-1980s marked a shift from a predominance of cold-water to warm-water species, as the oceanic biogeographic boundary along the European continental shelf moved northward (Beaugrand, 2004). Also, Chinese scholars found that percentage of dinoflagellates had increased in Jiaozhou bay, Bohai bay and Daya bay (Jiao, 2001; Sun, 2002; Wang et al., 2004).

Although there have been extensive reports on phytoplankton in the Taiwan Strait, most of them focused on diatoms (Yang, 1995; Lin, 2007), very few concerned with dinoflagellate (Lin, 1988). In 2006, the Chinese Offshore Investigation and Assessment (National ‘908’) was conducted. So far, there were only studies on the water samples of phytoplankton collected from Fujian coastal waters in summer and winter, respectively (Wang, 2009, 2010). Based on the net samples of phytoplankton obtained from the Taiwan Strait during the survey, the present study analyzed the species composition, the distribution characteristics, the relationship of the dinoflagellate with ocean currents, and the variation trend of planktonic dinoflagellate in the surveyed sea.

2 Materials and methods

2.1 Sample collection

The samples were collected with vertical plankton haul (37 cm diameter opening and 280 cm long, with 0.077 mm mesh size) from 101 stations in the Taiwan Strait during July 2006 to October 2007 (115.2° - 121.5°E, 21.2° - 27°N) (Fig. 1). The dinoflagellate samples were preserved with 2% final concentration of formaldehyde and analyzed in the laboratory using a microscope.

2.2 Data analysis

The species diversity index （H′） and evenness index （J） were calculated using the following formula:

$$J = H'/\log_2 S \qquad \text{(Pielous, 1969)}$$

$$H' = -\sum_{i=1}^{s} p_i \log_2 p_i \quad \text{(Shannon-Wiever, 1963)}$$

where S is the total numbers of species in one sample, and Pi is defined as n/N, among which n is cell density of the i^{th} species and N is total density of the sample.

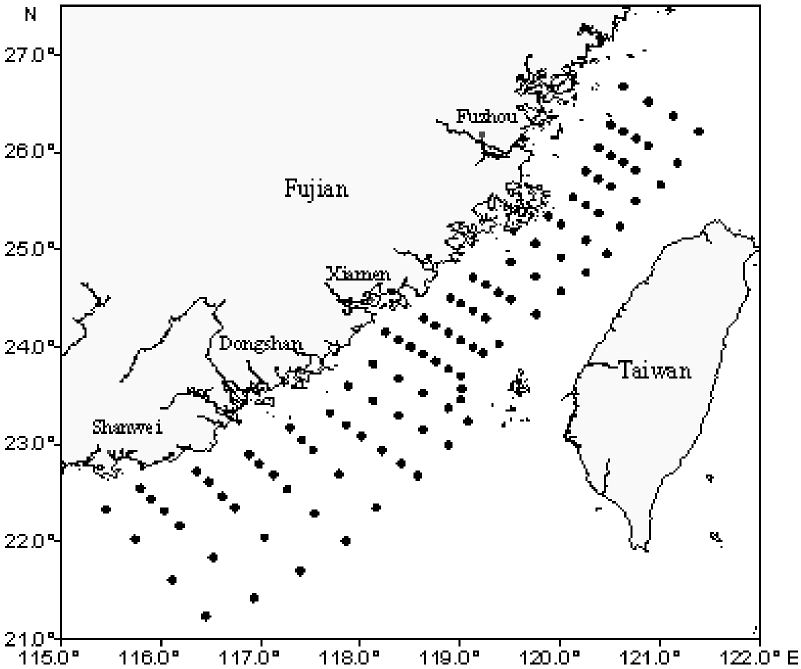

Fig. 1 Distribution of sampling stations in the Taiwan Strait

3 Result and discussion

3.1 Species composition

A total of 131 species belonging to 18 genera of dinoflagellate were recorded. Most of them were hyperthermal and hyperhaline species, which accounted for 72.52% of the total species. Among them, oceanic olig-warm species such as *Ornithocercus qudratus*, *Ornithocercus magnificus*, *Pyrocystis robusta*, *Pyrocystis fusiformis*, *Pyrocystis rhomboides*, *Ceratium gibberum*, et al., were carried to the Taiwan Strait by the Branch of the Kuroshio and the South China Sea water, and usually occurred in the southeast of Taiwan Strait in spring and summer. Eurythermal and euryhaline species were the second most common one accounting for 25.19% of the total species, such as *Ceratium furca*, *Ceratium fusus*, *Ceratium macroceros*, *Ceratium tripos*, *Protoperidinium divergens*, *Protoperidinium depressum*, *Protoperidinium oceanicum*, *Prorocentrum micans*, *Dinophysis candata*, et al. These species were the most important species in spring and autumn. Neritics species only accounted for 2.29% of the total species, such as *Noctiluca scintillans*, *Prorocentrum minimum*, *Scrippsiella trochoidea*, which mainly appeared in the coastal waters in spring and winter. The dominant species, as results, were *Ceratium fusus* and *Ceratium trichoceros* which accounted for 45.96% and 21.54% of the total abundance, respectively.

The seasonal variation of the dinoflagellate species by this study was similar with that during 1984 - 1985. As shown in Fig. 2, the maximum species number appeared in summer and then in spring, and the lowest in winter. Such consequence can be the results of geographical location of the surveyed sea. The Taiwan Strait is located in subtropical zone, which is the transition from the South China Sea to the East China Sea. In summer, the southwest monsoon prevails, and the South China Sea warm water and the branch of Kuroshio become the strongest and bring in a plenty of hyperthermal and hyperhaline species. In winter when the northeast monsoon is strong and under the influence of the southwestwards Min-Zhe coastal current, the water temperature and salinity decrease to the minimum of the year, therefore the hyperthermal and hyperhaline species decline from the north to the south.

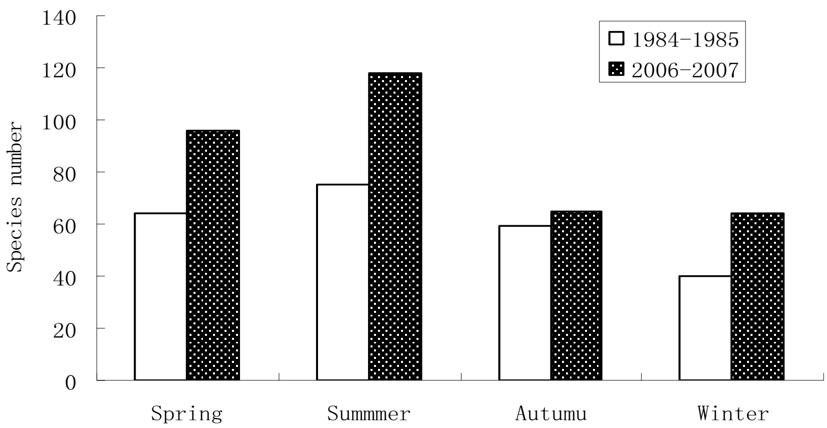

Fig. 2 Seasonal variation of species number of dinoflagellate in the Taiwan Strait

3.2 Horizontal distribution

The average abundance of dinoflagellate in spring was 671.10×10^2 cells/m^3, which presented the maximum of four seasons in the year. The fluctuation of dinoflagellate abundance among stations varied largely, ranging from 47.85×10^2 cells/m^3 to $3\,450\times10^2$ cells/m^3.

Influenced by the Min-Zhe coastal current of low temperature and low salinity, the dinoflagellate abundance in sea waters to the north of Xiamen was very low with less than 100.0×10^2 cells/m^3. Similarly, because of residuals from the Min-Zhe coastal current it exist a small area with density lower than 100.0×10^2 cells/m^3 in the middle area from Xiamen to Penghu. Except that the dinoflagellate abundances at a few stations were lower than 500.0×10^2 cells/m^3, the values of most stations in the south of Xiamen were higher than 1 000.0×10^2 cells/m^3. The maximum value, higher than 3 450×10^2 cells/m^3, was founded at the south of Taiwan shallow water. In general, the distribution trend of dinoflagellate abundance descended from south to north and from the open sea to the nearshore waters (Fig. 3a). In spring, with the raising temperature and the accumulation of nutrients during the winter, some eurythermal and euryhaline species bloomed. These species may included *Ceratium fusus*, *Ceratium tripos*, *Ceratium furca*, *Dinophysis candata*, *Ceratium macrocero*, *Protoperidinium conicum*, et al., which accounted for 23.83%, 10.05%, 5.96%, 4.77%, 2.48% and 2.27% of the total abundance, respectively. In addition, with the northeast monsoon gradually weakened, the Min-Zhe coastal current shrinked to the north of the Pingtan islands. At the same time, the warm water from South China Sea and the branch of Kuroshio currents that intruded to the Taiwan Strait became strengthened with the southwest monsoon. More hyperthermal and hyperhaline species were brought in. The density of species such as *Ceratium trichoceros*, *Ceratium massiliense* and *Diplopsalis lenticula* may account for 16.70%, 2.93% and 3.85% of the total abundance, respectively. These two factors could have led to the maximum dinoflagellate abundance of the year.

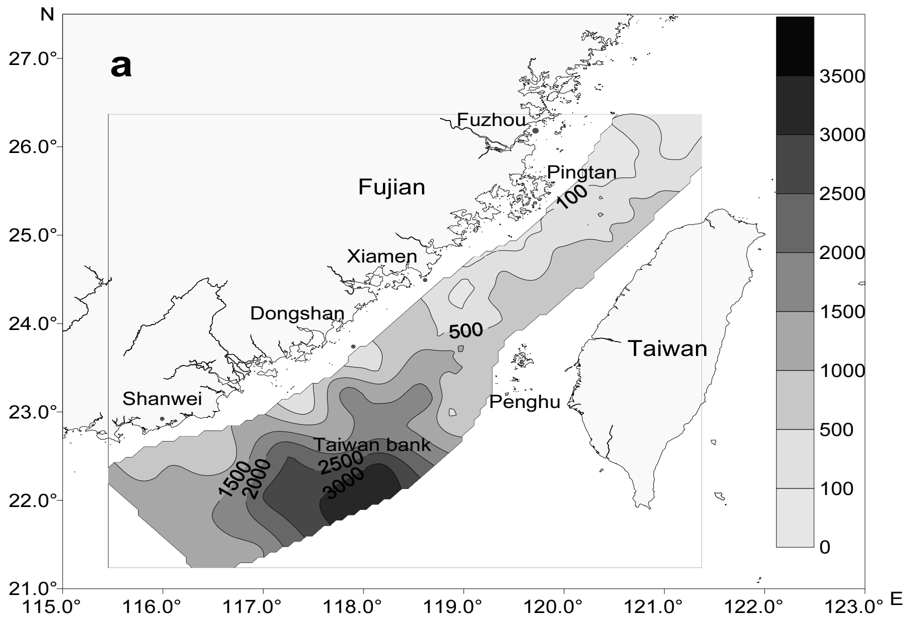

Fig. 3a Horizontal distribution of dinoflagellate abundance in spring (10^2 cells/m^3)

The average dinoflagellate abundance in summer was 532.72×10^2 cells/m^3, with the second maximum in the year. The dinoflagellate abundance among stations ranged from 77.25×10^2 cells/m^3 to 2036.88×10^2 cells/m^3, and it was high in the open sea to the south of Penghu which was more than 1 000.0×10^2 cells/m^3, and formed two high concentration areas where the abundance was more than 1 500.0×10^2 cells/m^3 in the southwest and north of the Taiwan shallow water. Due to the coastal upwelling and the diluted water from Zhujiang River, the water temperature and salinity of coastal waters between Dongshan and Shanwei were low, and the dinoflagellate abundance there was less than 500.0×10^2 cells/m^3. The dinoflagellate abundance in the northern stations of the surveyed sea was still relatively low. A denstiy less than 100.0×10^2 cells/m^3 occurred at a few stations in the east of Xiamen bay. It was the same as that in spring, and the horizontal distribution of the dinoflagellate abundance showed a descending from the south to the north and from the open sea to the nearshore waters. However, the scope of high value with more than 500.0×10^2 cells/m^3 expanded to the north and to the coast (Fig. 3b). This was because the southwest monsoon prevailed in summer, and the South China Sea warm water and the branch of Kuroshio came into the strongest stage. They could flow into the East China Sea through the Taiwan Strait, and consequently some oceanic olig-warm species significantly increased, so the dinoflagellate species became the richest throughout the year. The composition of dominant species were diversified in this season, and the proportion of eurythermal and euryhaline species declined, such as *Ceratium fusus, Protoperidinium oceanium, Protoperidinium conicum* accounting for 20.07%, 6.59% and 4.58% of the total abundance, respectively. However, the ratio of hyperthermal species and hyperhaline species increased significantly, such as *Ceratium trichoceros, Pyrocystis pseudonoctiluca, Ceratium massiliense, Pyrocystis fusiformis, Ceratium breve, Diplopsalis lenticula* accounting for 23.24%, 5.87%, 5.34%, 4.11%, 3.31% and 2.37% of the total abundance, respectively. The proportion of the oceanic olig-warm species *Pyrocystis* spp（excluding the species *Pyrocystis pseudonictiluca*）to the total abundance increased from 3.02% in spring to 5.47%.

In autumn, the dinoflagellate abundance continued to decline. The average of dinoflagellate abundance was 277.57×10^2 cells/m^3, varying from 23.81×10^2 cells/m^3 to 1 300.0×10^2 cells/m^3. It was the low value area in the north of Xiamen with the value less than 200.0×10^2 cells/m^3, and the minimum of less than 50.0×10^2 cells/m^3 occurred at the coastal area of the north. It ranged from 200.0×10^2 cells/m^3 to 400.0×10^2 cells/m^3 in the central sea area between Xiamen and Dongshan. The value of the dinoflagellate abundance in the southwest of Penghu was relatively high, and the highest value of over 1 000.0×10^2 cells/m^3 was founded at the southern end of the surveyed sea (Fig. 3c). In autumn, the southwest monsoon disappeared gradually, the northeast monsoon increased progressively. The South China Sea warm water began to weaken, and the Min-Zhe coastal current with low temperature and low salinity began to flow southward, and hence the embryonic form of “cold in the north and warm in the south” began to appear. In this way, areas of high density (> 600.0×10^2 cells/m^3) shrinked to the open sea of southern Penghu. The dominant species in this season were mainly eurythermal and euryhaline species, such as Ceratium furca、Ceratium fusus、Noctiluca scintillans and Ceratium tripos, accounting for 19.06%, 17.88%, 12.60% and 11.57% of the total abundance, respectively. The proportion of the hyperthermal and hyperhaline species Ceratium trichoceros reduced to 16.70%, and that of the oceanic olig-warm species Pyrocystis spp（excluding the species Pyrocystis pseudonictiluca）was only 0.43%.

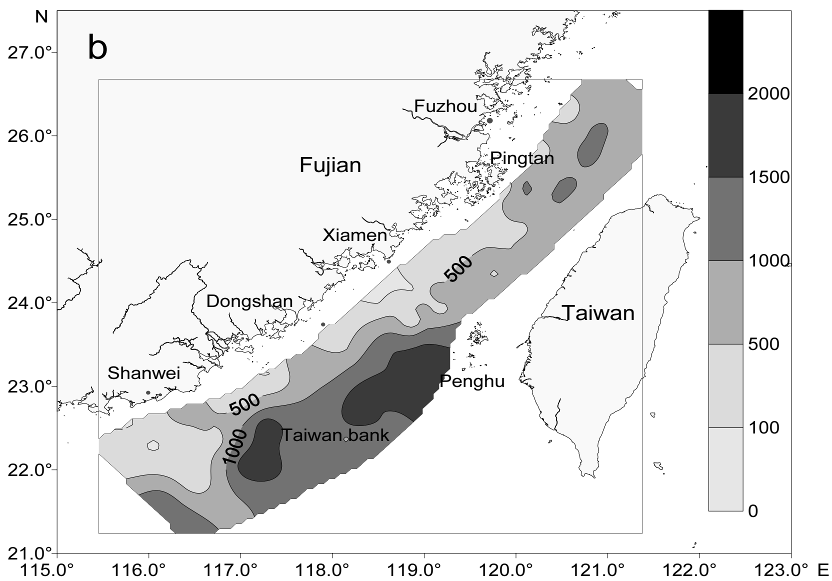

Fig. 3b Horizontal distribution of dinoflagellate abundance in summer (10^2 cells/m^3)

The dinoflagellate abundance was at the lowest level in winter. It varied from 3.65 ×10^2 cells/m^3 to 800.20 ×10^2 cells/m^3, with the average value of 138.45×10^2 cells/m^3. In this season, the prevailing northeast monsoon forced the Min-Zhe coastal current with low temperature and low salinity flow southward, reaching the adjacent water of Shantou along Fujian coast. Therefore, the abundance of most stations decreased to less than 100.0×10^2 cells/m^3, except for waters close to Shanwei where it presented a small-scale high value area contributed by a great densen nearshore hypohaline species such as Noctiluca scintillans and Scrippsiella trochoidea. Influenced by the hyperthermal and hyperhaline seawater, the abundance at a few stations near the Penghu islands was relatively high (more than 200.0×10^2 cells/m^3), and formed a high abundant area of more than 500.0×10^2 cells/m^3 in the southeast of Taiwan shallow water. The dominant species in this season were mainly eurythermal and euryhaline species, such as Ceratium fusus and Ceratium furca accounting for 56.33% and 13.57% of the total abundance, respectively. While the proportion of the hyperthermal and hyperhaline species Ceratium trichoceros reduced to 4.53%. The oceanic olig-warm species Ornithocercus spp and Pyrocystis spp were founded only at a few stations in the southern edge of the surveyed sea.

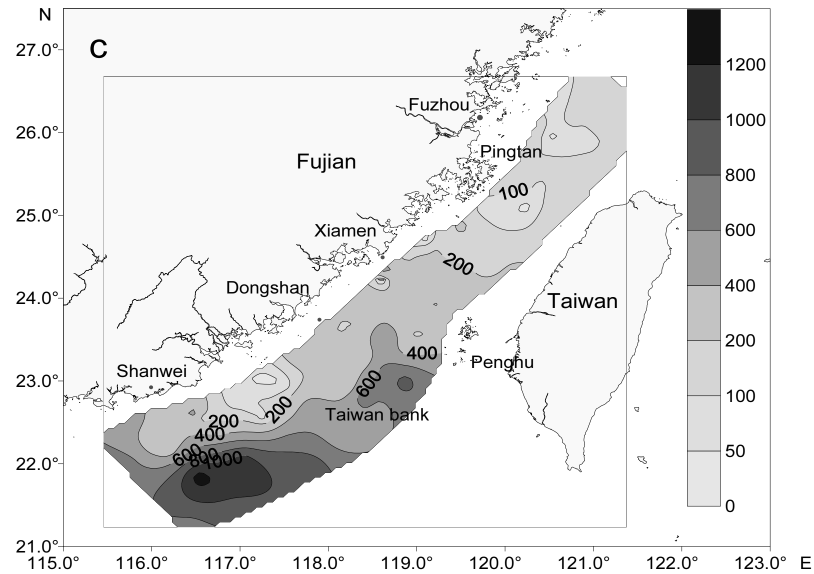

Fig. 3c Horizontal distribution of dinoflagellate abundance in autumn (10^2 cells/m^3)

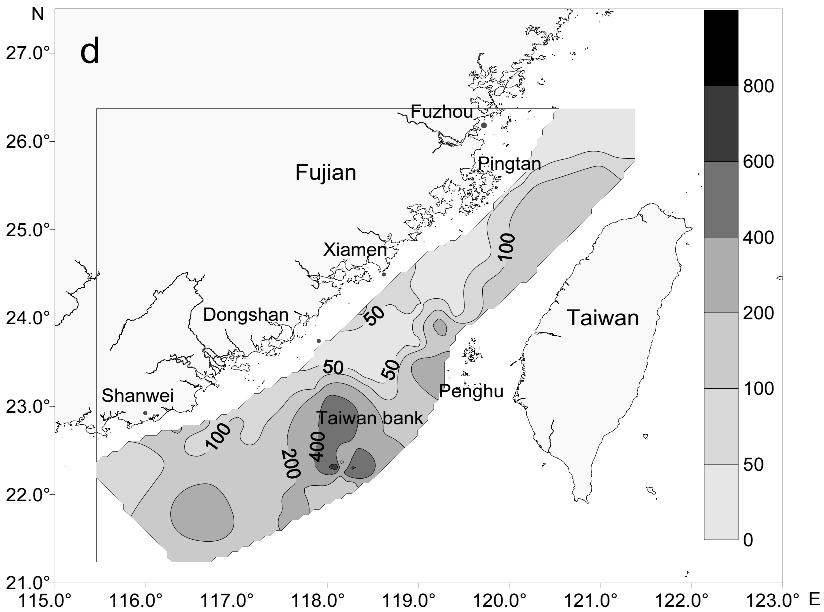

Fig. 3d Horizontal distribution of dinoflagellate abundance in winter (10^2 cells/m^3)

Comparing with the findings of 1984 - 1985 in the surveyed sea, the seasonal variation trend of the dinoflagellate abundance was in agreement with the results of 1984 - 1985. The maximum appeared in spring, and the second maximum occurred in summer, and the lowest in winter. In addition, the horizontal distribution pattern did not change evidently, which descended from the south to the north and from the open sea to the nearshore waters. However, the average dinoflagellate abundance in this survey was 3.01 times as that of 1984 - 1985. From both the spatial and seasonal aspects, further analysis of the dinoflagellate abundance variations in the surveyed sea was conducted. In the seasonal variation, the dinoflagellate abundance increased by 2.15 and 4.11 in warm seasons (spring and summer), while in cold seasons (autumn and winter) the dinoflagellate abundance increased more significantly. The incremental amplitude was 4.15 and 4.83 for autumn and winter, respectively. The dinoflagellate abundance in winter was less than one-tenth of that in spring in the findings of 1984-1985, while the dinoflagellate abundance in winter was more than one-fifth of that in spring in this survey (Tab. 1). In the horizontal distribution, the dinoflagellate abundance increased most significantly in the north than that in the center and south of the Taiwan Straits (Tab. 2). The global warming has changed the spatial and temporal distribution of sea surface temperature (SST) in China's coastal ocean during the past century. The area in East China Sea, from the Taiwan Strait to the estuary of the Yangtze River, experienced the largest increase in SST. The SST has increased by 1.4 ℃ in winter and 0.5 ℃ in summer comparing to that prior to 1976 (Cai et al., 2009). This might be one of the reasons why the incremental amplitude of dinoflagellate abundance in winter was significantly larger in the survey sea.

Tab. 1 Seasonal variations of dinoflagellates abundance in Taiwan Striat (×10^2cells/m^3)

Time	Spring	Summer	Autumn	Winter	average
May 1984 - February 1985	312.82	129.72	66.87	28.64	134.51
August 2006 - December 2007	671.10	532.72	277.57	138.45	404.96
Increment amplitude	2.15	4.11	4.15	4.83	3.01

Tab. 2 Range of dinoflagellates abundance along the latitude in Taiwan Strait (×10^2cells/m^3)

Areas	1984 - 1985	2006 - 2007	Incremental amplitude
Northern areas (25°30' - 26°50'N)	33.88×102	157.68×102	4.65
Central areas (23°30' - 25°30'N)	134.51×102	233.80×102	1.74
Southern areas (21°10' - 23°30'N)	254.04×102	261.12×102	1.03

In recent years, increasing eutrophication associated with global changes has varied the phytoplankton abundance, community structure and distribution. Long-term observations from 1958 - 1999 in the Bohai Sea showed that the replacement of diatom by dinoflagellates was the main feature of phytoplankton community changes in recent years. It indicated that the proportion of diatoms to the total phytoplankton declined, while that of dinoflagellate increased (Sun, 2002). The phytoplankton communities have been miniaturized and their biodiversities were simplified in Daya Bay during the last 20 years (Wang, 2004). In this survey, it also indicated that the proportion of dinoflagellate to the total phytoplankton has risen from 0.55% in 1984 - 1985 up to 1.02%. However, being different from the diatom community, the diversity index of dinoflagellate increased in the Taiwan Strait, indicating that dinoflagellate community structure was stable in the surveyed sea (Tab. 3). This is because the surveyed sea was influenced mainly by the South China Sea and the branch of Kuroshio, and the dinoflagellates were primarily consisting of oceanic warm water species, and accordingly the increase of the dinoflagellates abundance may be linked more closely to the climate change and the strength of warm currents, whereas the increase of the dinoflagellate in the coastal water was attributed to the outbreak of small toxic species caused by eutrophication.

Tab. 3 Annual variation of the characteristics of dinoflagellates community in Taiwan Strait

Survey time	Proportion of dinoflagellate abundance to the total phytoplankton	H,	J,
1984 - 1985	0.55%	1.64	0.59
2006 - 2007	1.02%	2.60	0.83

4 Conclusions

a) A total of 131 dinoflagellate species belonging to 18 genera were identified, including 72.5% hyperthermal and hyperhaline species, 25.19% eurythermic and euryhaline species and 2.29% neritic species. The seasonal variation trend of the species was consistent with the results in 1984 - 1985. The species was the most abundant in summer, followed by spring, autumn and winter. It was related to the South China Sea and the branch of Kuroshio with hyperthermal and hyperhaline in summer and the Min-Zhe coastal current with low temperature and low salinity in winter.

b) The average of dinoflagellate abundance was 404.96×10^4 cells/m^3. The seasonal variations and horizontal distribution pattern were consistent with the findings in 1984 - 1985. The maximum of the dinoflagellate abundance occurred in spring; the second appeared in summer, and the lowest in winter. The spatial distribution of dinoflagellate abundance descended from the south to the north and from the open sea to the nearshore waters.

c) The dinoflagellate abundance in 2006 - 2007 is 3.01 times as that of 1984 - 1985 in the Taiwan Strait. The increase amplitude in cold seasons and in north of the surveyed sea is highly significant.

d) Comparing with the finding of 1984 - 1985, the dinoflagellate community structure changed significantly in this survey. The proportion of the dinoflagellate abundance to the total phytoplankton increased and the diversity and evenness index were also higher.

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台湾海峡浮游甲藻的分布特征和变化趋势

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摘 要：根据2006-2007年“国家908”专项台湾海峡4个航次调查，分析该海域浮游甲藻的种类组成、群落结构和时空分布特征。共鉴定甲藻18属131种，其中高温高盐种为主体，占总种数的72.52%，其次为广温广盐种，占总种数的25.19%，近岸种仅占2.29%。夏季甲藻的种类最丰富，而春季甲藻的丰度最高。平均丰度为404.96×10^2 cells/m^3，其平面分布呈现从近岸向外海、从北向南递增的趋势。与1984-1985年的调查结果相比较，甲藻丰度的平面分布格局和季节变化趋势没有明显变化，但丰度增加3.01倍。从季节变化看，冷季甲藻丰度增加较为显著；从平面分布看，台湾海峡北部增加较多。此外，该海域甲藻群落结构也发生变化，种类多样性指数和均匀度上升，其丰度占浮游植物总丰度的比例由0.55%上升到1.02%。

关键词：浮游甲藻；分布特征；变化趋势；台湾海峡