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Phytoplankton community and environmental correlates in a coastal upwelling zone along western Taiwan Strait

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ABSTRACT

Upwelling system in western Taiwan Strait is important for facilitating the fishery production. This study investigated hydro-chemical properties, phytoplankton biomass, phytoplankton species composition, three-dimensional (horizontal, vertical and transect) distribution of phytoplankton abundance, as well as phytoplankton annual variation and the correlation of phytoplankton community with the upwelling of underlying current and nutrients according to samples of Fujian-Guangdong coastal upwelling zone in western Taiwan Strait from August 27 to September 8, 2009. The results manifest that the nutrient-rich cold and high salinity current on the continental shelf of South China Sea upwells to the Fujian-Guangdong coastal waters through Taiwan Bank and the surging strength to surface is weak while strong at 30-m layer. The thermohaline center of coastal upwelling shifts to the east of Dongshan Island and expanded to offshore waters in comparison with previous records. A total of 137 phytoplankton species belonging to 59 genera in 4 phyla are identified excluding the unidentified species. Diatom is the first major group and followed by dinoflagellate. Cyanobacteria mainly composed by three *Trichodesmium* species account for a certain proportions, while Chrysophyta are only found in offshore waters. The dominant species include *Thalassionema nitzschioides*, *Pseudo-nitzschia pungens*, *Thalassionema frauenfeldii*, *Pseudo-nitzschia delicatissima*, *Rhizosolenia styliformis*, *Chaetoceros curvisetus*, *Diplopsalis lenticula* and *Trichodesmium thiebautii*. Phytoplankton community mainly consists of eurythermal and eurytopic species, followed by warm-water species, tropic high-salinity species and oceanic eurythermic species in order. Phytoplankton abundance ranges from 1.00×10^2 ind./L ~ 437.22×10^2 ind./L with an average of 47.36×10^2 ind./L. For vertical distribution, maximum abundance is found at 30 m-depth and the surface comes second. Besides, the abundance below 30 m decreases with increasing water depth. The horizontal and transect distribution of phytoplankton abundance are both displayed in patchy size, and the peak area is the offshore waters from the east of Dongshan Island to the south of Zhangpu which is basically coincident with the thermohaline center of the upwelling, but the distribution range of phytoplankton high abundance is expanded out of the upwelling center. Phytoplankton abundances on 3 transects in offshore waters from the east of Dongshan Island to the south of Zhangpu are higher than that of nearshore waters and the other 5 transects. Moreover, the underlying current is accompanied by shade flora so as to offer a certain evidence for the presence of upwelling. Phytoplankton abundance at 30 m-depth and bottom both present low significant positive correlation with phosphate, while there are not significant correlations between the content of inorganic nitrogen and phytoplankton abundance in all water layers. The intensity and range of Fujian-guangdong coastal upwelling has a regulating effect on the species succession, abundance distribution and the location of phytoplankton peak area.

1. Introduction

Upwelling phenomena have been frequently observed in the coastal and marginal seas. The effects of upwelling on ecosystems vary depending on the intensity and frequency of such events (Chen et al., 2005; Wilkerson and Dugdale, 1987). Generally, in all cases, nutrient-rich cold and deep water rise to the shoal water column and enhances the primary productivity of the ecosystem. Among the most upwellings, coastal upwelling is a strong dynamic process accompanied by the changes of hydrology, nutrients and biology (Summerhayes et al., 1995). It is described as a conveyer belt of nutrients and carbon.

Taiwan Strait is a shallow shelf-channel linking the South China Sea (SCS) with the East China Sea (ECS). In the early 1960s, the oceanographers in China noticed that some sea areas in the western Taiwan Strait were characterized by low surface seawater temperature (SST) but high salinity during summer. They also considered that the phenomenon may be associated with upwelling (Cai, 1981; Chen et al., 1982). Since 1980s, many comprehensive investigations in the Taiwan Strait and the surrounding seas had been conducted in succession. Especially,

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the survey team led by Hong et al. (1991) comprehensively performed "Minnan-Taiwan Bank Fishing Ground Upwelling Ecosystem Study" with multidisciplinary researches from 1987 to 1988. A plentiful results from the investigation further prove that there are several upwelling systems in the western waters of Taiwan Strait, where the 3 regions are: Fujian-Guangdong coastal zone from the southeast of Dongshan Island to Shantou coastal waters, the southern Taiwan Bank and the middle active region in the east of Haitan Island (Chen et al., 1992; Hong et al., 1991; Huang, 1991; Xiao, 1988). Water mass rich in nutrients at the bottom are taken to euphotic layer for the growth and propagation of phytoplankton by upwelling so as to nourish a lot of zooplanktons and support the fishery production. Thereby, the change of upwelling strength directly influenced the stability of marine ecosystem and the production capacity of sea area (Estracha and Blasco, 1979; Hong et al., 1991; Schaefer et al., 1999).

The growth of marine phytoplankton meets the energy demand of life system in the ocean to support the normal operation of marine ecosystem. In general, its community structure and abundance changes directly reflect the comprehensive effect of habitat, which can feed back environment conditions (Pomeroy, 1974). At the early phase, the research on the phytoplankton of upwelling systems of the western Taiwan Strait mainly aimed to classify and explore the ecological properties and distribution of species (Chen, 1979; Jin, 1982; Ye et al., 1982). Besides, there had been some researches into phytoplankton biomass, the primary productivity, size-fraction structure (Li and Wang., 1991; Wang et al., 2002; Yang et al., 1991; Zhang and Yang, 1991). Meanwhile, the abundance distribution of phytoplankton of the upwelling zone in southern Taiwan Bank and their environmental correlates were discussed as well (Feng, 1991; Huang and Liu, 1991; Zhang et al., 1997). Furthermore, results verified the limitation of nutrients of upwelling system and its regulating roles on phytoplankton by *in situ* field tests in the western Taiwan Strait (Hong et al., 2011; Hu et al., 2008; Ou et al., 2006; Wang et al., 2008).

It is believed that the upwelling current in Fujian-Guangdong coast is induced by the movement of southwest monsoon in summer. Besides the center location, intensity and distribution range of the coastal upwelling change sharply and influence greatly the nutrient supplement of sea area resulting in the changes of ocean environment (Hong et al., 1991, 2005; Huang, 1991; Shang et al., 2005; Tang et al., 2002). Thereby, the components of phytoplankton, such as the community structure, abundance variation, distribution pattern, during the Fujian-Guangdong coastal upwelling were significant to reveal the strength as well as the forming and decline of upwelling current. Moreover, it is important to analyze the interactions between phytoplankton and environmental factors, such as nutrients, water mass and currents. Based on the samples obtained from water layers in Fujian-Guangdong costal upwelling zone in summer 2009, the species composition, abundance variation, distribution of phytoplankton are reported in this study. Moreover, we investigate the correlation of environmental factors, such as the upwelling of underlying current and nutrients for further understanding the ecological and biological properties of coastal upwelling system and the influencing factors.

In this study, 2 aims are set firstly the center location, intensity and range of the Fujian-Guangdong coastal upwelling in 2009 ascertained by hydro-chemical parameters and phytoplankton biomass, and secondly, variations of phytoplankton species and abundance with environmental correlates in the Fujian-Guangdong coastal upwelling zone.

2. Materials and methods

2.1. Phytoplankton and Chlorophyll a

Thirty stations of 8 transects for the phytoplankton sampling (Fig. 1) were deployed in the western Taiwan Strait in late summer and early autumn from August 27th, 2009 to September 8th, 2009. Landscope was from Zhangpu, Fujian to Huilai, Guangdong. Samples, each with an aliquot of 1000 mL water, were collected from 5 water layers (1, 10, 30, 50, and bottom) with a SeaBird Electronics (SBE911 Plus) CTD system. For the station with water depth less than 30 m, the water layer of 2 m above the seabed was regarded as bottom layer. The collected samples were preserved in 3% neutralized formalin for further analysis. For quantitative analysis, the settlement method described by Sukhanova (1978) was adopted. Numerical analysis was carried out using inverted plankton microscope. Phytoplankton was identified according to the identification guides of Tomas (1997) and, particularly, of Jin (1982) and Chen (1979). The phytoplankton analyzed was assigned to important species of diatoms, dinoflagellate, blue green algae and Chrysophyta. In addition, the closely similar species were observed by utilizing acidizing treatment introduced by Håkansson (1984) with respect to a few species of pinnularia (diatom) and dinoflagellate.

Chlorophyll *a* was collected by filtering another 500 mL of seawater through Whatman (25 mm) GF/F filters. The filters were kept frozen in the dark for 24 hours before they were extracted in 90% acetone. The chlorophyll *a* content was then measured by fluorometric method according to Yentsch and Menzel (1963) used a Turner Designs 10-Au Fluorometer.

2.2. Hydro-chemical parameters

At the period of phytoplankton sampling, hydrological and chemical investigation was carried out. Water temperature and salinity were recorded *in situ* used a CTD system. For the nutrients, 100 mL water subsamples were collected at the same layer of phytoplankton sampling and kept immediately at -20 °C after the sampling. In the Laboratory the water samples were filtered used a Millipore filtering system (MFS) and dissolved inorganic phosphate, nitrate, nitrite and reactive silicate were analyzed by means of SKALAR SAN++ (Netherlands) automatic analyzer according to the JGOFS (UNESCO, 1994). The detection limits of each nutrient is 0.1 μM for NO_3-N, 0.01 μM for NO_2-N, 0.01 μM for NH_4-N, 0.03 μM for PO_4-P and 0.1 μM for SiO_3-Si.

2.3. Data processing and analysis

Phytoplankton dominant index (Y) was calculated by $Y = \frac{n_i}{N} fi$, where. n_i is the abundance of the ith species, N is the total abundance of each species presents, and fi is the occurrence rate of the ith species of the sample.

Correlation coefficient (r) were calculated between phytoplankton abundance and physic-chemical parameters. All these statistical analyses were performed using SPSS statistical software (Version 11.5 for Windows, SPSS, Chicago, IL, USA). Maps and figures were performed with Golden software Surfer 8.0.

3. Results

3.1. Determining the center location, intensity and range of Fujian-Guangdong coastal- Upwelling zone

From June to August in summer, southwest monsoon cause the offshore movement of Fujian-Guangdong coastal water to induce the upwelling current of deep water from SCS so that the surface water showed hydrological features such as low SST, high salinity and rich nutrients (Cai, 1981; Chen et al., 1982; Hong et al., 1991; Huang, 1991; Xiao, 1988). Besides, the surface water was found with high phytoplankton biomass (Yang et al., 1991; Zhang et al., 1997). In this study, the overall properties of the surface seawater could be summarized as follows: the average SST and salinity were 28.7 °C and 32.7; the ranges were 25.5 ~ 30.3 °C and 30.2 ~ 33.9 (Fig. 2A, B). The range of the surface nitrate content was less than the detection limit of 1.12 μM with an average of 0.28 μM. Higher values were mainly found in the offshore