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Observation of thermohaline structure and phytoplankton biomass in the shelf front of East China Sea during early summer

Osamu MATSUDA, Yoshinori NISHII,
Yang-Ho YOON and Takuo ENDO

Faculty of Applied Biological Science, Hiroshima University
Higashi-Hiroshima 724, Japan

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Abstract Observations were carried out on oceanographic conditions and phytoplankton biomass in the shelf front region of the East China Sea during early summer in 1987 along the 31°40′N latitude line. As a result of water mass analysis on T-S diagram, two characteristic water masses were identified. Those were cold coastal water mass originated from Yellow Sea and warm water mass originated from Kuroshio water, between them internal discontinuous layer (thermocline and pycnocline) was formed at intermediate depth.

Phytoplankton biomass, phytoflagellates biomass in particular, and concentration of chlorophyll *a* were high in the vicinity of the discontinuous layer. Dissolved oxygen was supersaturated in the chlorophyll rich water which indicated active photosynthesis. Nutrient in terms of dissolved inorganic phosphorus was almost completely depleted in the surface water but still remained in the deeper water below the high chlorophyll layer. The possible reason for the high phytoplankton biomass present in the layer may be due to continuous supply of nutrients from bottom water, availability of underwater irradiance and density gradient formed in the layer.

INTRODUCTION

The East China Sea is geographically separated from Pacific Ocean by Ryukyu Island chain in the southeast and Yellow Sea in the northwest. The sea is also extended to the Japan Sea through Tsushima and Korea Strait. The basic oceanographic condition of the sea has been believed to be governed by the magnitude of freshwater supply from China and by the Kuroshio water. The recent study on heat budget suggests that an increase of salinity by evaporation from the sea surface also plays an important role in the formation of characteristic water mass (MAEDA, 1989). Therefore main oceanographic structure of the sea is, in brief, composed of two water masses which are low temperature low salinity water (Yellow Sea cold water) and high temperature high salinity water (Tsushima warm water) from Kuroshio. These two characteristic water masses form sharp thermohaline front in winter and distinct thermal stratification in summer, where internal discontinuous layer develops in the interface between two water masses (HUH, 1982). HU (1986) observed the thermocline every year in June from 1975 to 1984 at around 126°E along 32°N. This discontinuous layer is considered to be a part of the continental shelf front.

Partly because of topographical condition, shallow coastal area on the continental shelf

(<200 m) dominates the Sea and also partly because of oceanographic condition described above, the East China Sea provides productive fishing grounds for both warm water species and cold water species including both near shore and migratory groups (Aoyama and Hayashi, 1988). It is hence important to understand the mechanism of biological production in the frontal region, where relatively few works has been done on the biological processes compared with works on physical oceanography.

In the present study, chemical and biological parameters of the sea were observed as well as physical structure on a transect line of the East China Sea across the frontal region, where although some observations were reported on water masses and distribution of temperature and salinity few investigations on the biomass of phytoplankton and nutrient cycle have ever been carried out.

The T & R/V *Toyoshio Maru* of Hiroshima University performed a 9 days research cruise in the East China Sea across the Tsushima Current from June 19 to June 27, 1987. During the cruise, several oceanographic and marine biological studies were carried out on board with special reference to environmental condition, primary production, plankton ecology and food chain structure in the region. This paper presents a part of the result of the research cruise.

MATERIALS AND METHODS

Field observation was carried out on board T & R/V *Toyoshio Maru* at 11 stations along the 31°40′N latitude line in the East China Sea on June 21, 1987. Eleven stations were located from 128°E (Stn. E1) to 125°30′E (Stn. E11) at every 15′ intervals on the line (Fig. 1). At all stations, observations on water depth, transparency (Tr) by Secchi disk and salinity temperature profiles by STD monitor (Alec Co. AST-1000) were carried out. In addition to these, water samples were collected at stations of odd number using Van Dorn bottles at different depths [0, 10, 25, 50, 100 and 10 m above bottom (B-10)m]. After collecting water samples, sestonic chlorophyll *a* (Chl. *a*) and pheopigments (Pheo.) were determined by trichromatic absorptiometry (Strickland and Parsons, 1972). Number of phytoflagellates and diatoms were counted under an optical microscope. As nutrients, three forms of phosphorus in seawater, namely dissolved inorganic phosphorus (DIP), dissolved organic phosphorus (DOP) and particulate phosphorus (PP), were determined. Separation of PP from DIP and DOP was done with a Millipore filter (HA; pore diam. 0.45 μm). After filtration, DIP in the filtrate was determined by the method of Murphy and Riley (1962) as modified by Strickland

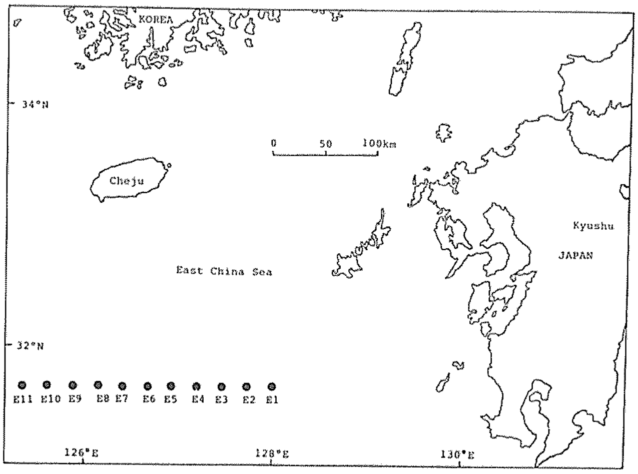

Fig. 1. Location of sampling stations.

and Parsons (1972). Organic phosphorus in the filtrate was converted to orthophosphate by the procedure of Menzel and Corwin (1965), and then the total phosphorus in the filtrate (dissolved total phosphorus; DTP) was determined. DOP was calculated by subtracting the initial phosphate in the filtrate (DIP) from DTP. Filter samples were served for PP analysis in which particulate material was digested in a Teflon container with perchloric acid and nitric acid at 150°C for 5 h, resulting phosphate was analyzed as analyzed for DIP.

RESULTS AND DISCUSSION

1. *Physical Structure*

Distribution of temperature on the transect shows that warmer water (>20°C) dominates surface or subsurface, while colder water (<14°C) prevailed in the bottom water of shallow area (Fig. 2). At the interface between warm and cold water, distinct thermocline was observed in subsurface where temperature variation with depth was so remarkable and the temperature gradient sometimes exceeded 0.5°C/m. In general, the nature of the thermocline became more distinct and the depth of thermocline became less in the western stations.

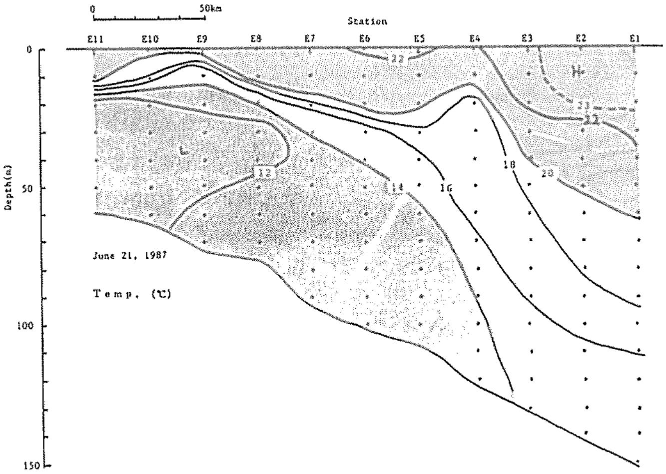

Fig. 2. Distribution of temperature across the transect in the East China Sea.

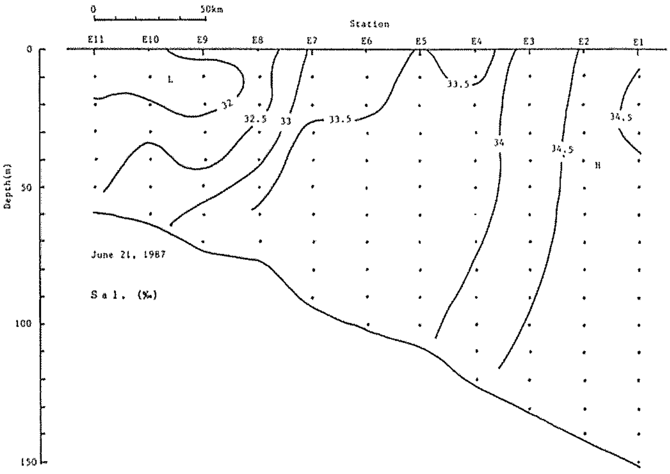

Fig. 3. Distribution of salinity across the transect in the East China Sea.

Results of salinity observations indicate that salinity was at its minimum (<32‰) in the surface or subsurface at Stn. E9 to Stn. E11 and gradually increased from west to east (Fig. 3). The T-S diagram showing the data of all stations (Fig. 4) indicates that salinity of seawater above thermocline are classified into three groups as the group of Stn. E1 to E3, Stn. E4 to E7, and Stn. E8 to E11. These results also indicate that horizontal salinity gradients in surface water are steep between Stn. E3 and Stn. E4, and also between Stn. E7 and Stn. E8. From the T-S diagram, it is clear that characteristics of two representative water masses, one dominating surface of Stn. E1 to E3 and other dominating the bottom water of Stn. E8 to E11, are entirely different. As a result of water mass analysis on T-S diagram using the published T, S values for specific water mass, it could be concluded that the representative water mass observed has originated from Kuroshio water and Yellow Sea cold water, respectively.

Distribution of density factor σt calculated from temperature and salinity showed the marked density stratification which was mainly due to thermal stratification reinforced with salinity gradient (Fig. 5). Marked density gradient (pycnocline) was observed at about 15-20 m depth from Stn. E7 to Stn. E11, where the density gradients expressed by $\Delta\sigma t \times 100/m$ exceeded 10. These values are found to be comparable to the values reported in summer by TOMIYAMA (1989) in the same region.

The observed values of Tr (m) ranged from 22 to

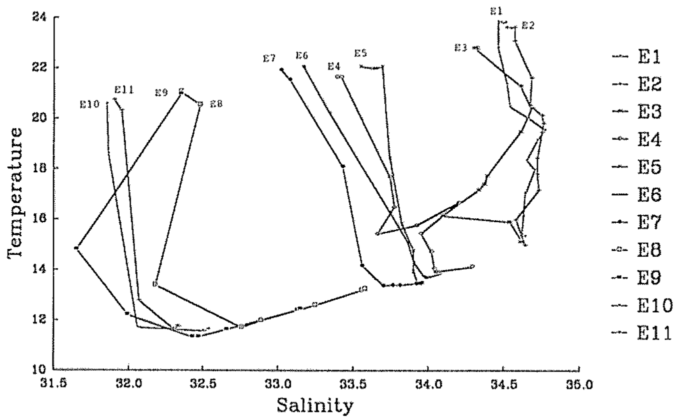

Fig. 4. T-S diagram showing the characteristics of temperature (°C) and salinity (‰) in different stations.

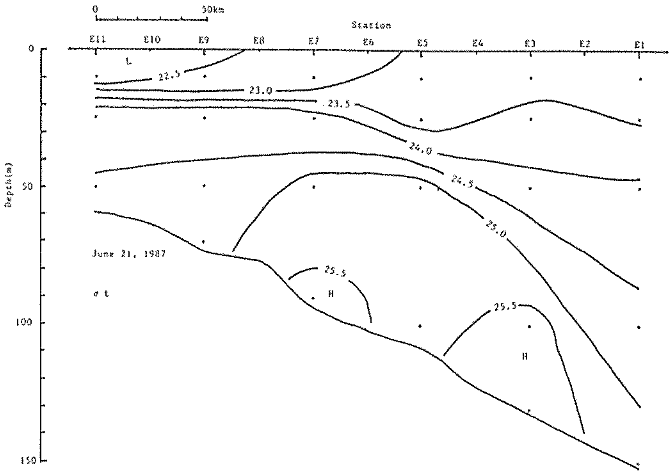

Fig. 5. Distribution of density factor σt across the transect in the East China Sea.

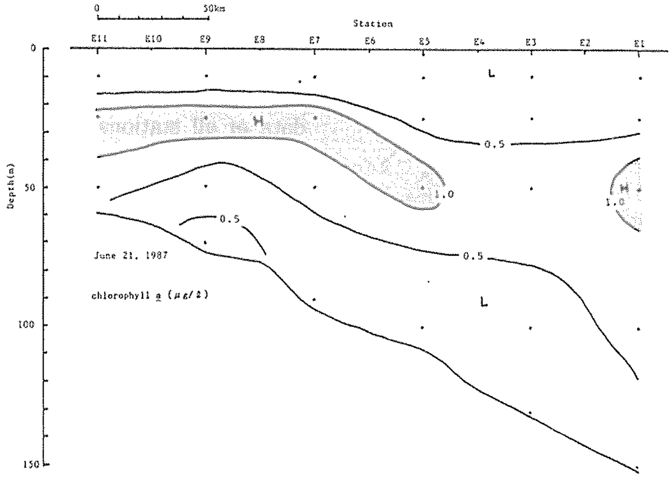

Fig. 6. Distribution of chlorophyll *a* across the transect in the East China Sea.

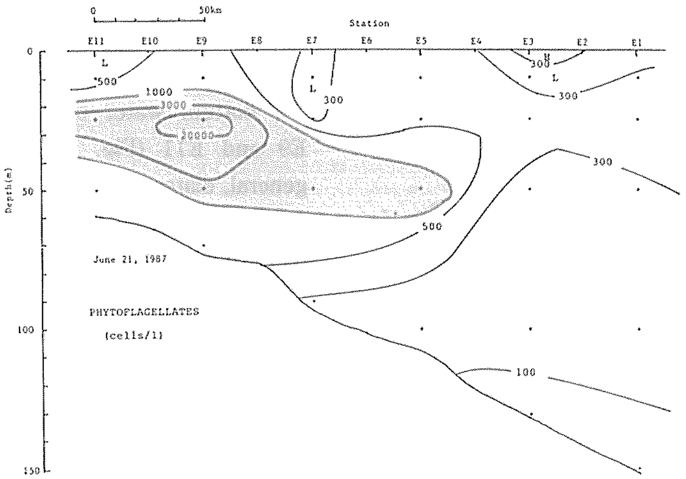

Fig. 7. Distribution of phytoflagellates biomass across the transect in the East China Sea.

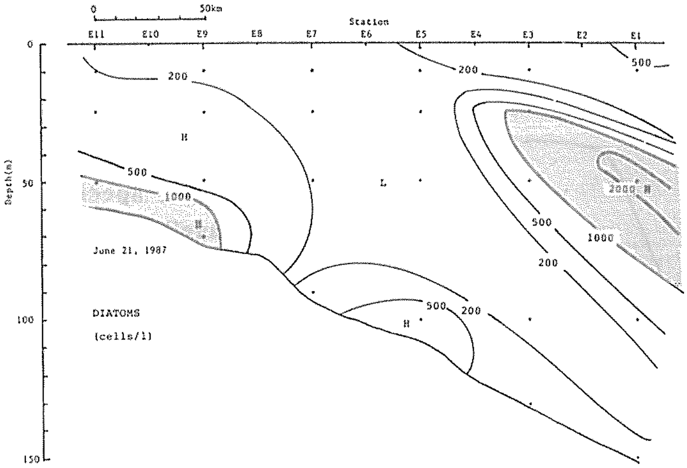

Fig. 8. Distribution of diatom biomass across the transect in the East China Sea.

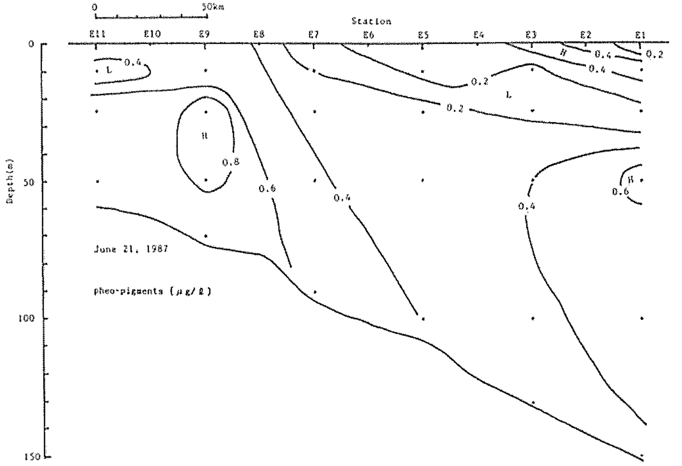

Fig. 9. Distribution of pheopigments across the transect in the East China Sea.

15 showing the tendency of decreasing from east to west. These results show that the depth of euphotic zone also decreased from east to west and that concentration of particulate matter in the upper part of the sea was relatively low compared with eutrophic region.

2. *Phytoplankton Biomass*

The result of Chl. *a* determination showed that high Chl. *a* concentration was observed just below the pycnocline along the internal discontinuous layer from Stn. E5 to Stn. E11 and also at 50 m depth of Stn. E1 (Fig. 6). Whereas, Chl. *a* concentration was only less than 0.5 μg/l both in surface and bottom water of the stations studied in present study.

Biomass of phytoflagellates was high only in the intermediate depth from Stn. E5 to Stn. E11 and this distribution was in agreement with the distribution of high Chl. *a* (Fig. 7). These results support the idea that Chl. *a* distribution was mainly influenced by the abundance of phytoflagellates. Maximum abundance attained 20000 cells/l at 25 m of Stn. E9. On the contrary, biomass of diatoms was relatively high in the in-

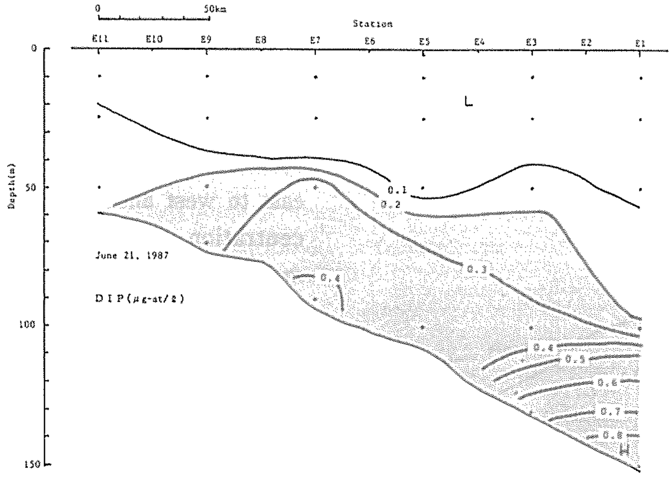

Fig. 10. Distribution of DIP across the transect in the East China Sea.

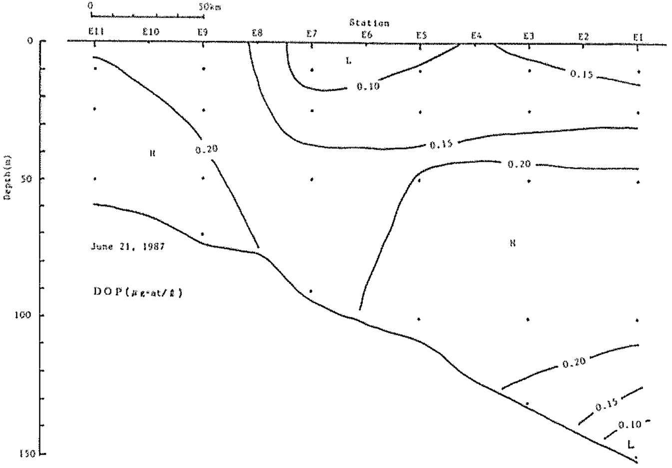

Fig. 11. Distribution of DOP across the transect in the East China Sea.

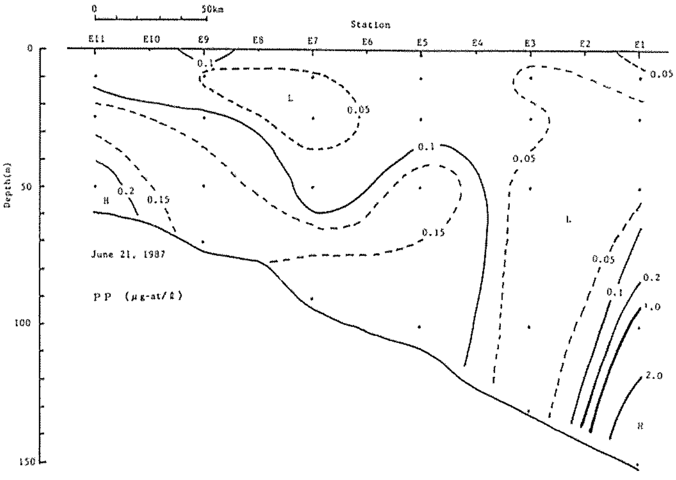

Fig. 12. Distribution of PP across the transect in the East China Sea.

termediate depth from Stn. E1 to Stn. E3 and in the bottom water of Stn. E9 and E11 (Fig. 8). In general, diatoms were abundant in warm water mass while phytoflagellates were abundant in cold coastal water mass showing the marked increase along the discontinuous layer between two water masses.

The reason for the difference in distribution between phytoflagellates and diatoms may be partly due to the physiological characteristics of these phytoplankton groups. Not a few species of phytoflagellates require vitamins and micro-nutrients for their growth (IWASAKI, 1979). On the other hand, growth of diatoms is often stimulated by macronutrients (TAKAHASHI and FUKAZAWA, 1982). In the studied area, availability of vitamins and micro-nutrients is probably higher in the coastal water mass than in the warm offshore water mass.

Concentration of pheopigments was high just below the water in which large amount of phytoplankton was observed (Fig. 9). As pheopigments are decomposition products of

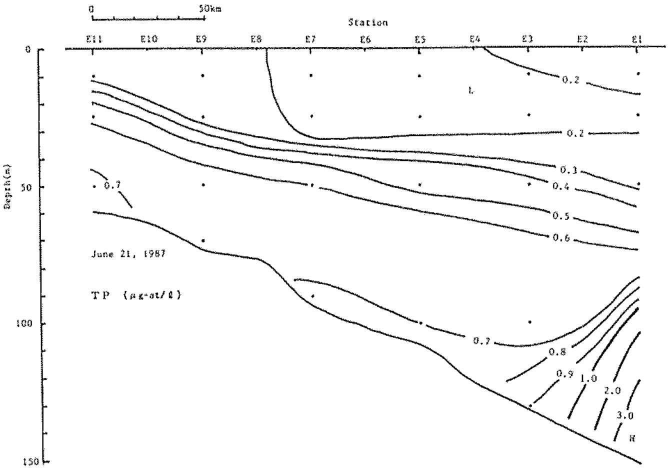

Fig. 13. Distribution of TP across the transect in the East China Sea.

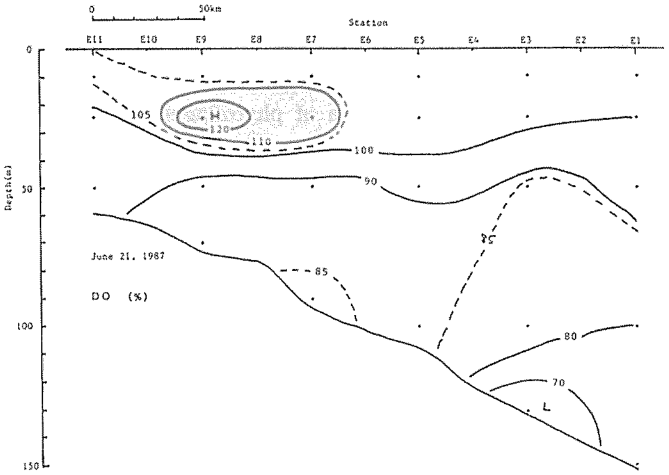

Fig. 14. Distribution of DO (%) across the transect in the East China Sea.

chlorophyll, the distribution of pheopigments suggests that the deteriorated material was abundant in the water.

3. *Nutrients*

Concentration of DIP, a typical inorganic nutrient, was below 0.1 μg-at/l in the water less than 25 m depth at all stations and then generally increased with depth (Fig. 10). These results indicate that DIP was almost completely depleted in the surface layer of all the stations, which is probably due to uptake by phytoplankton but high concentration of DIP still remained in deeper water.

Concentration of DOP was also very low in surface water but slightly increased in bottom water from Stn. E5 (Fig. 11). This distribution pattern of DOP agreed with the distribution of pheopigments, which suggest the fromation of DOP during the decomposition process of phytoplankton material.

Concentration of PP was generally low except the bottom water at Stn. E1. Slightly higher concentration of PP below the pycnocline possibly indicates accumulation of sinking particles originated from phytoplankton (Fig. 12).

Consequently, resultant concentration of TP (sum of three forms of phosphorus) was low in surface water but high in bottom water. Hence, distribution of TP showed strong stratification, in which steep gradient of TP concentration was observed in the intermediate layer (Fig. 13).

4. *Phytoplankton Activity and Biological Processes*

In order to understand photosynthetic activity of phytoplankton, relationship between Chl. *a* concentration and DO percentage was examined. Dissolved oxygen was generally high in the upper part of the sea, especially from 20 to 30 m depth of the stations E7 to

E10 (Fig. 14). This distribution of DO is well agreed with Chl. *a* distribution. As supersaturation of DO generally indicates the result of active photosynthesis, these results suggest that phytoplankton community indicated by high Chl. *a* concentration could be active in photosynthesis.

These results above also show that phytoplankton biomass and possibly photosynthetic activity were high at the internal discontinuous layer (interface) between two characteristic water masses which were already described. The possible reason for the high phytoplankton biomass present in the layer may be due to continuous supply of nutrients from bottom water and the availability of sufficient underwater irradiance during the study period. In the surface water above discontinuous layer, lack of nutrient supply due to strong stratification inactivates phytoplankton growth even though other conditions were favorable. On the contrary, phytoplankton is not able to grow in the deeper water because of insufficient solar energy although nutrients are rich in the water. Consequently, most appropriate phytoplankton growth could be attainable at only intermediate depth in the stratified region assuming that the depth of productive zone would be Tr×2.5. This idea is also supported by KOZASA (1989) who reported on the distribution of Chl. *a* in the East China Sea in summer. Pycnocline at the interface may also play an important role on accumulation of sinking particles and on influencing vertical migration of phytoflagellates.

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東シナ海陸棚フロント域における初夏の海洋構造と植物プンクトンの分布

松田　治・西井　祥則・尹　良湖・遠藤　拓郎

広島大学生物生産学部，東広島市 724

東シナ海陸棚域の横断面観測を1987年6月に北緯30°40′線に沿って実施した結果，黄海冷水系の低温沿岸水塊と対馬暖流系の高温高塩分水塊が形成する顕著な不連続構造を見出した。この不連続構造は温度躍層と同時に密度躍層を伴っており，躍層の深度は中国陸岸寄りで浅くなった。また，この躍層近傍では周辺よりも高いクロロフィルa濃度と植物プランクトン，特に鞭毛藻類の高いバイオマスが観測された。さらに，そこでは溶存酸素が過飽和であったことから活発な光合成作用が示唆された。溶存無機態リンの濃度は表層で非常に低く，一方底層では高かった。不連続面付近で植物プランクトンバイオマスが高い理由として，不連続面下部からの連続的な栄養塩の供給と，上層からの水中日射エネルギーの供給が同時に成立することおよび密度成層の存在があげられた。