D-3.2.3 Distribution of chlorophyll-a and phytoplankton in the East China Sea

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Abstract To evaluate the influence on chlorophyll a (chl-a) distribution of the load from land discharges, a database of chl-a and related oceanographic parameters was constructed from 32 previous survey cruises in the East China Sea. The database consisted of chl-a, temperature and salinity for 32 cruises, transparency for 26 cruises and nutrients for 7 cruises. Also, Chl-a distribution and hydrography were observed in summer 1997 and in autumn 1998. The study area consisted of low-salinity waters from the Changjiang River and other continental shelf waters. The vertical profile of chl-a showed a peak in a subsurface layer throughout the study area. Chl-a concentration in surface waters in the Changjiang plume was higher than at the other sites. The highest chl-a concentrations were distributed in the subsurface layer between the low-salinity surface waters and the underlying Yellow Sea Bottom Cold Waters. The subsurface chl-a maximum was related to the thermocline. The depth of the subsurface chl-a maximum was calculated as one of the parameters in a function to represent the profile features. These depths showed a tendency to increase southeastward from the low-salinity waters, suggesting that the latter and vertical stratification might influence chl-a distribution in the East China Sea. The relationship between surface chl-a and salinity in summer 1997 and in the database showed that the surface chl-a levels in the low-salinity waters were higher in the Changjiang estuary than in the other shelf waters. Therefore, the majority of nutrients supplied from the River might be exhausted by phytoplankton in the Changjiang estuary in summer.

Key words: chlorophyll-a, East China Sea, database, hydrography.

1. Introduction

The recent remarkable acceleration in economic growth and consequent change in lifestyle in the Asian region has increased the discharge of various materials into adjacent seas. These materials could lead to eutrophication and finally to changes in the marine ecosystem. There is an urgent need to evaluate the influence of land discharges on the biological structure of the sea, through an understanding of chl-a distribution and its relationship with hydrographic structure.

The inflow of rivers from China into the East China Sea attains a maximum volume in summer[1]. Chl-a concentration and primary production at the sea surface fluctuate seasonally with a peak in summer in the Changjiang estuary[2),3)].

2. Research Objectives

The results of past cruises that observed chl-a concentration and related oceanographic parameters in the East China Sea were collated and arranged to ensure that all data are published. This study aimed to construct a database of chl-a and related parameters and to evaluate the relationship between chl-a distribution and hydrographic structure, using information from the database and observational results during the present study. This relationship is useful for determining the influence of land discharge on chl-a distribution in the East China Sea as fundamental information on long-term variation in chl-a distribution, the monitoring of hydrographic structures, and validation of data from ocean color sensors on satellites.

3. Research Method

We assembled data on chl-a and related oceanographic parameters by the Seikai National Fisheries Research Institute (NFRI) in the western waters of Kyushu, the East China Sea and offshore areas of the Nansei Islands, and by the Nansei NFRI in coastal waters of the Nansei Islands, during 32 cruises from 1973 to 1995. After excluding some erroneous values, data were input using a commercial database software and converted into text files.

Two cruises were conducted by the R/V Yoko-Maru, Seikai NFRI, from the Okinawa Trough to the central region of the continental shelf in the East China Sea (Figs. 1 and 2) on 25 July to 5 August 1997 and 30 September to 12 October 1998 to examine the relationship between chl-a distribution and hydrographic structure. Temperature, salinity and fluorescence were measured using a CTD (Formal Scientific Co. Ltd., ICTD) and an *in situ* fluorometer (Sea Tech Co. Ltd., FL-3000) on board an OCTOPUS (Octo-Parameter Underwater Sensor) at all stations. Water samples for salinity and chl-a were collected from the surface and various depths. The selected depths were determined as the center of the surface mixed layer, subsurface fluorescence maximum, highly turbid bottom layer, and near the bottom, based upon vertical profiles of fluorescence during lowering of the fluorometer. Chl-a concentrations were determined using a Turner Designs fluorometer after extracting the pigments in 90% acetone solution. The *in situ* fluorescence data for 1997 were converted to chl-a concentration using the relationship $Y = 2.05 + 1.17\log X$ ($R = 0.949$), and for 1998 were converted into chl-a concentration using two regression lines (Fig. 3).

4. Results and Discussion

(1) Construction of the database on chl-a distribution

Oceanographic parameters for the database consisted of chl-a, temperature, salinity, transparency and dissolved inorganic nutrients (Table 1). Data from the Oceanography Division of Seikai NFRI were collected in the East China Sea and the Yellow Sea during 25 cruises from 1973 to 1992. Chl-a concentrations were measured at standard depths to derive vertical profiles. Most chl-a concentrations were measured fluorometrically after extraction, but some were estimated using an *in situ* fluorometer after correction of the fluorometric measurements. Eighteen cruises were carried out over a 15-year period along latitude 31° 30'N from the Kyushu coast to the Changjiang estuary. Nine of these cruises were conducted in spring, five in summer, three in winter and one in autumn.

Six cruises by the Fisheries Division, Seikai NFRI, were carried out in the western waters of Kyushu from 1993 to 1995. These data, taken in winter to spring, were useful for understanding the spring bloom of phytoplankton. Dissolved inorganic nutrients were included. Sampling for chl-a and nutrients was limited to four depths to 100 m. The observations by the Oceanography Division, Nansei NFRI, were made within about 40 km of the coasts of the Tokara Islands, Amami Islands and Okinawa Island. Chl-a and nutrients were measured at standard depths. Consequently, the database constructed in the present study is useful for future studies of year-to-year fluctuations and spatial distribution of chl-a and the validation of ocean color from satellite observations.

(2) Vertical profiles of chl-a and hydrography from 1997 results

Peak depths in chl-a profiles were detected at all stations. The chl-a concentration at the peak depth was 0.5 to 5.6 $\mu g\ l^{-1}$ with a tendency to increase northwestward in the study area. The depth at the chl-a maximum fluctuated from 15 to 80 m and increased southward.

Figure 5 shows the vertical profiles of chl-a, temperature, salinity and density at Stns. A12, F12 and F9. The depths of the chl-a maximum were within the thermocline at a northwest station in a low-salinity plume, and below the thermocline on the continental shelf. These results suggested that chl-a profiles might be related to vertical stratification on the continental shelf. The chl-a subsurface maximum was at depths of 50 to 60 m in the marginal shelf to the Okinawa Trough, where the thermocline was not marked. In a past study[4)], we reported that in the East China Sea in summer, nutrients were exhausted in the surface waters but remained rich in the bottom layers. We concluded that the vertical distribution of phytoplankton was closely related to the nutrient supply from deeper layers in the study area.

(3) Horizontal distribution of the chl-a maximum from 1998 results

Distribution of temperature and salinity in surface waters showed the colder, low-salinity waters originating in the Changjiang River with small spatial variations in the other continental shelf waters. The surface chl-a was much higher in the low-salinity waters than in the other waters, suggesting correspondence with the plume of high chl-a expanding from the Changjiang estuary, shown in the SeaWiFS chl-a image on internet home page (http://seawifs.gsfc.nasa.gov//SEAWIFS.html).

Figure 8 shows the vertical structure of temperature, salinity, density, transmission and chl-a at line 11. The low-salinity waters around Stn. a11 had a thickness of about 30 m above the thermocline with the Yellow Sea Bottom Cold Water. The depth of the thermocline was 40 to 50 m at Stns. T3 to a11, deepening to about 60 m at the southernmost station. Transmission was highly uniform throughout the water column at Stns. T3 and T4 but higher above and in the thermocline than in the underlying layer at the other stations. This suggested that in autumn, highly turbid waters containing much suspended matter were limited to the bottom layer below the thermocline.

High chl-a concentrations were detected in low-salinity water from the Changjiang River with a subsurface peak in the thermocline. The maximum gradually deepened southward to about 60 m within the thermocline.

In situ fluorescence at 1-m intervals was used to evaluate the vertical profile of chl-a. The chl-a concentrations by OCTOPUS were found to be underestimated at the surface waters but overestimated in the highly turbid bottom waters. The vertical profiles of chl-a were characterized as having a subsurface maximum at most stations, although they were homogeneous in the surface mixed layer without peaks at Stns. T3 and T4. The vertical profile of chl-a at each station was fitted to a combination of Gaussian and exponential functions[5)] assuming that the chl-a profile should have a Gaussian peak in the water column. Where the water was sampled at several depths only, there were sometimes insufficient data to estimate the features of the profile in the whole water column. *In situ* fluorescence values of chl-a were fitted to calculate five parameters of the function, including the depth of the subsurface chl-a maximum. This depth was found to be at about 20 m in low-salinity waters, deepening to about 90 m at the southernmost station. We conclude that parameterization of the chl-a profile function is a useful tool for understanding the characteristics of chl-a vertical profiles in the East China Sea.

(4) Influence of riverine load on surface chl-a distribution

The chl-a concentrations were 0.1 to 0.4 μg l^{-1} in the surface waters at most stations, while slightly higher, more than 1.5 μg l^{-1}, in surface waters of salinity less than 30 PSU during the 1997 cruise. This shows that the influence of the riverine load extended to the offshore area more than 400 km away from the Changjiang estuary. Nagata *et al.*[6] reported a significant negative relationship between chl-a and salinity in the surface waters west of Kyushu. Figure 11 shows the plot of chl-a and salinity at the sea surface using data from past and present studies in the East China Sea[3),7),8)].

Ning *et al.*[8] reported that chl-a attained 6 to 7 μg l^{-1} in the area of salinity 25 to 30 PSU west of 124°E in the Changjiang estuary in summer. The chl-a concentration in the present study reached a maximum of 1.7 μg l^{-1} at the stations with salinity of 28-30 PSU. Past observations at 19 stations in the area 124-126°E showed that the chl-a concentrations in offshore waters of salinity 21-32 PSU were 0.1 to 2.3 μg l^{-1}, lower than those in the Changjiang estuary.

This evidence suggests that most nutrients supplied from the River were rapidly exhausted by phytoplankton in the Changjiang estuary west of 124°E in summer. However, Hama *et al.*[3] recorded chl-a of 14 μg l^{-1} in surface water of salinity 31.6 PSU about 100 km from the mouth of Changjiang estuary in August. We suggest that year-to-year fluctuation in chl-a concentration should be considered with reference to variation in riverine load and related anthropogenic matter.

5. **References**

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Table 1. Summary of the database contents.

Organization	Location	Period	Parameters
Oceanography Division Seikai NFRI	West of Kyushu and East China Sea	1973-1992	T, S, Tr, Chl-a
Fisheries Division Seikai NFRI	West of Kyushu	Mar.-Apr. 1993 Mar.-Apr. 1994 Feb.-Apr. 1995	T, S, Tr, Chl-a Nutrients
Oceanography Division Nansei NFRI	Coastal waters of Nansei Islands	Nov. 1992	T, S, Tr, Chl-a Nutrients

NFRI: National Fisheries Research Institute
T: Temperature, S: Salinity, Tr: Transparency, Chl-a: chlorophyll-a

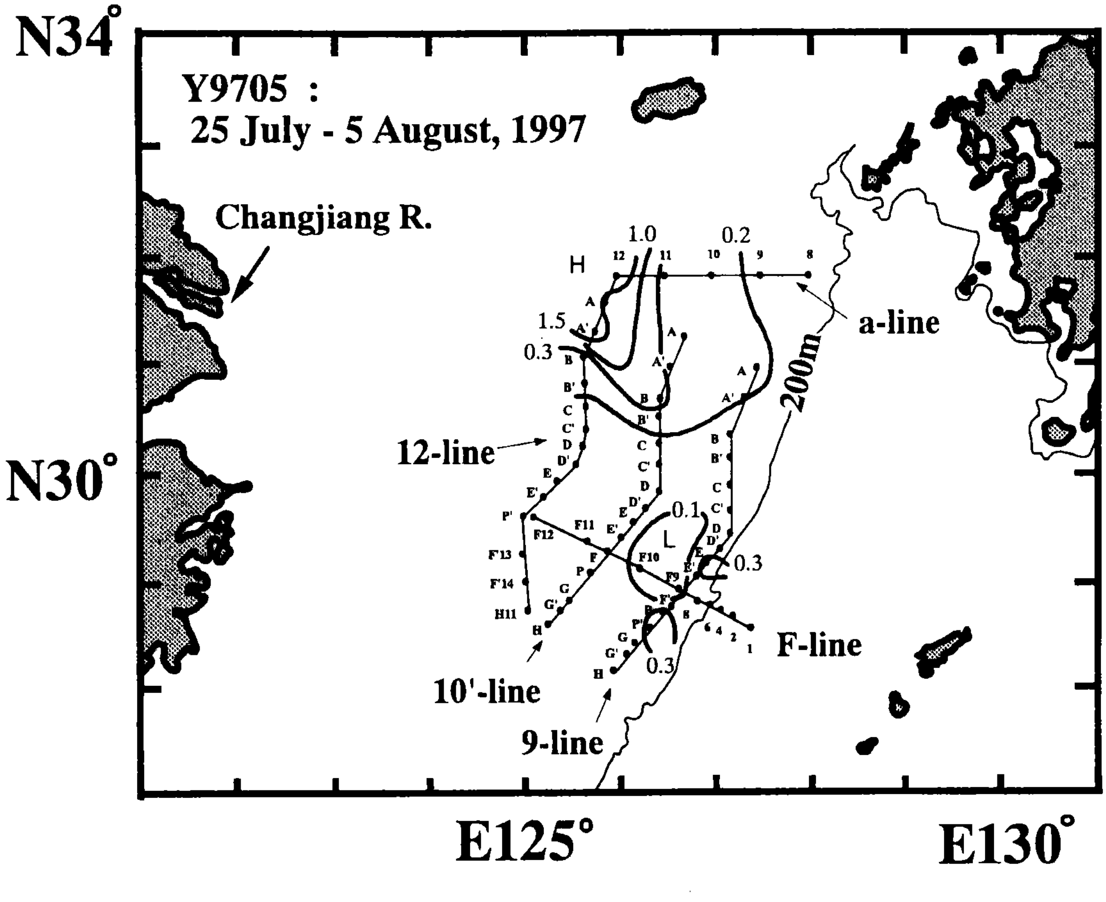

Figure 1. Observational sites in summer 1997, showing the contours of surface chlorophyll-a concentration.

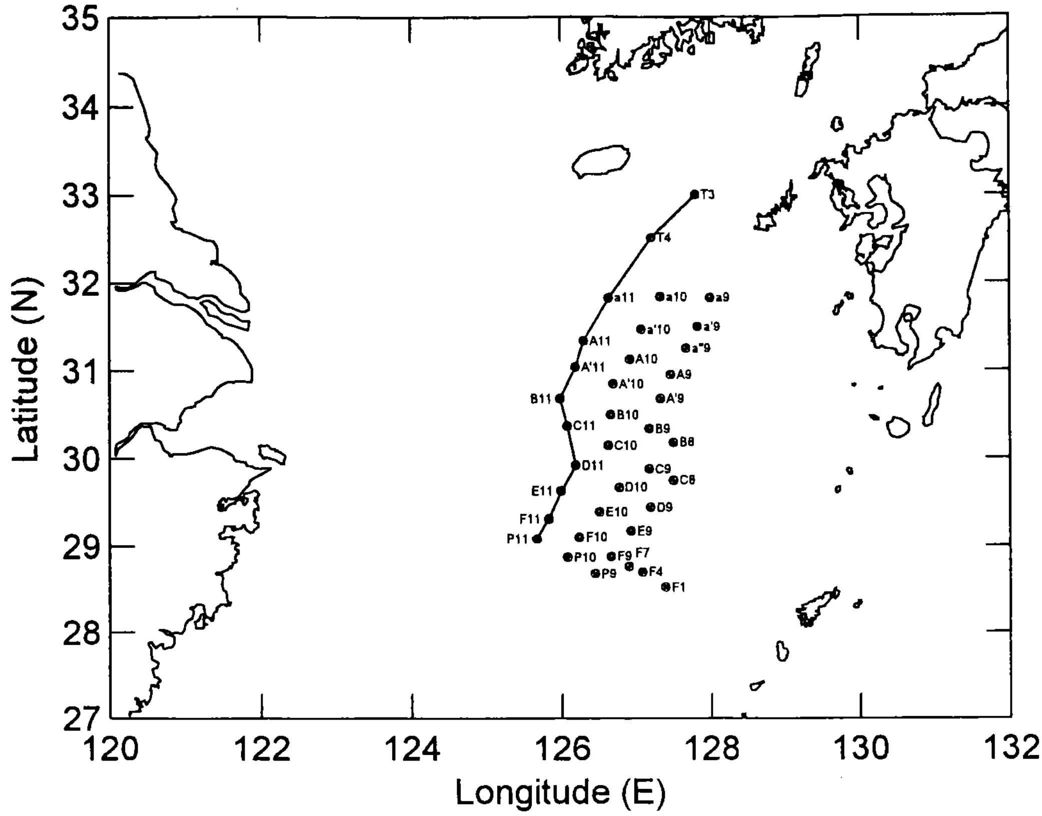

Figure 2. Observational sites in autumn 1998. The line denotes the locations of the vertical sections.

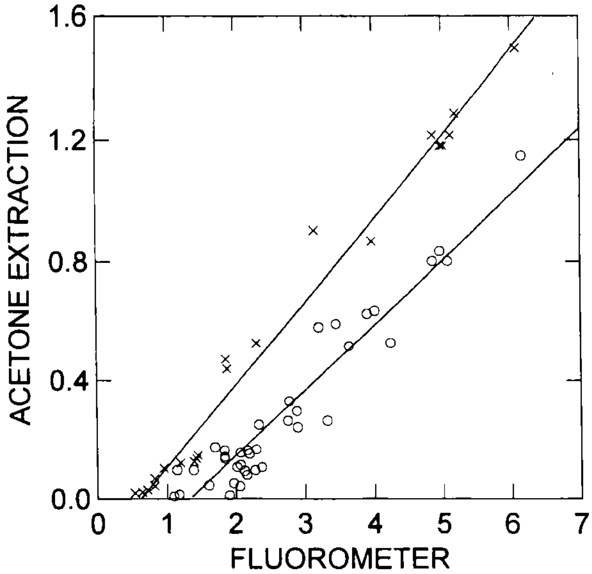

Figure 3. Plot of *in situ* fluorescence values and chlorophyll-a measured fluorometrically with acetone extraction in 1998. Crosses: low-salinity waters from the Changjiang River; circles: other shelf waters.

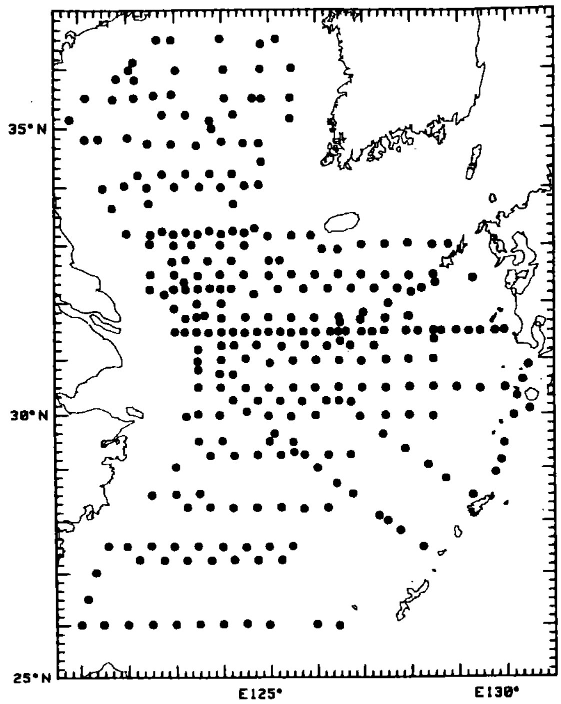

Figure 4. Location of observational sites of the Oceanographic Division, Seikai NFRI, used in the database.

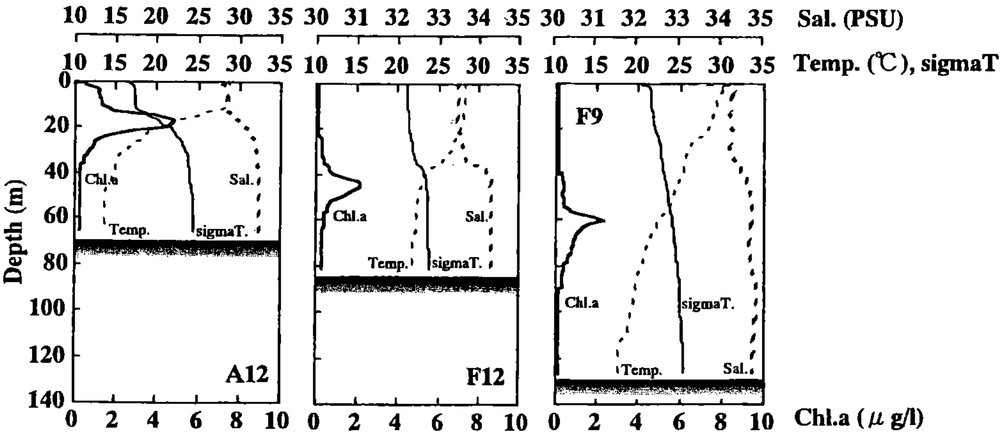

Figure 5. Vertical profiles of chlorophyll-a, temperature, salinity and density at Stns. A12, F12 and F9 in 1997.

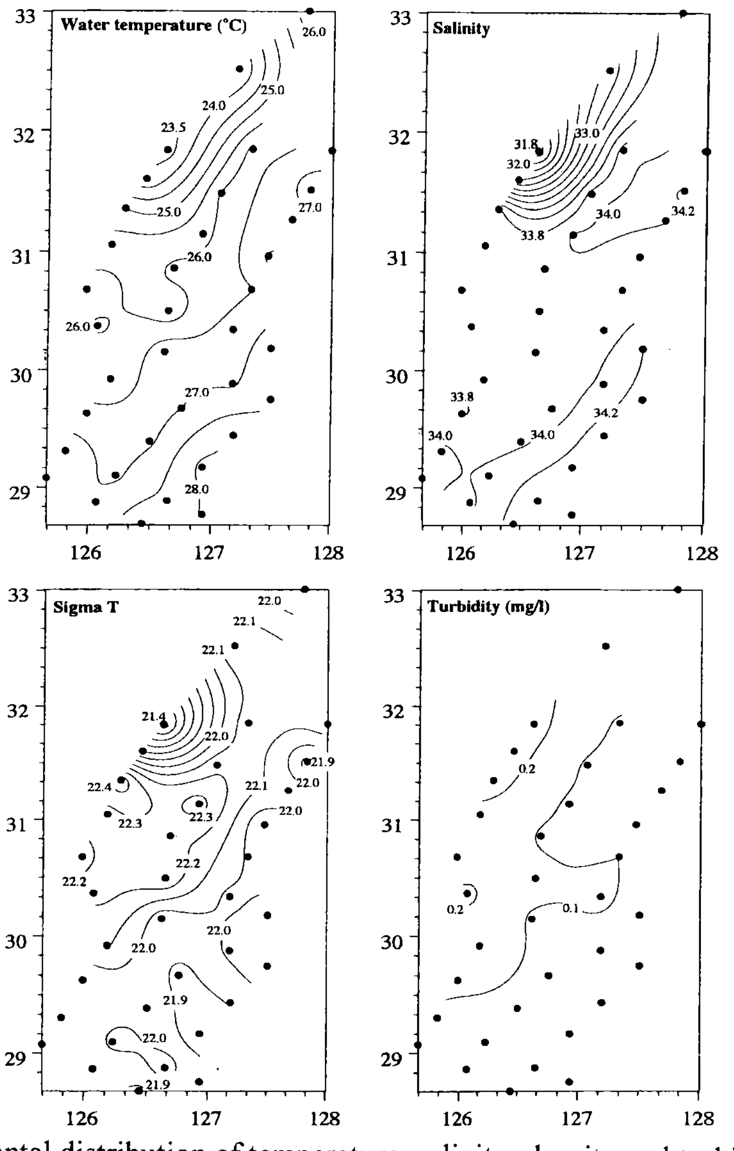

Figure 6. Horizontal distribution of temperature, salinity, density and turbidity in surface waters in 1998.

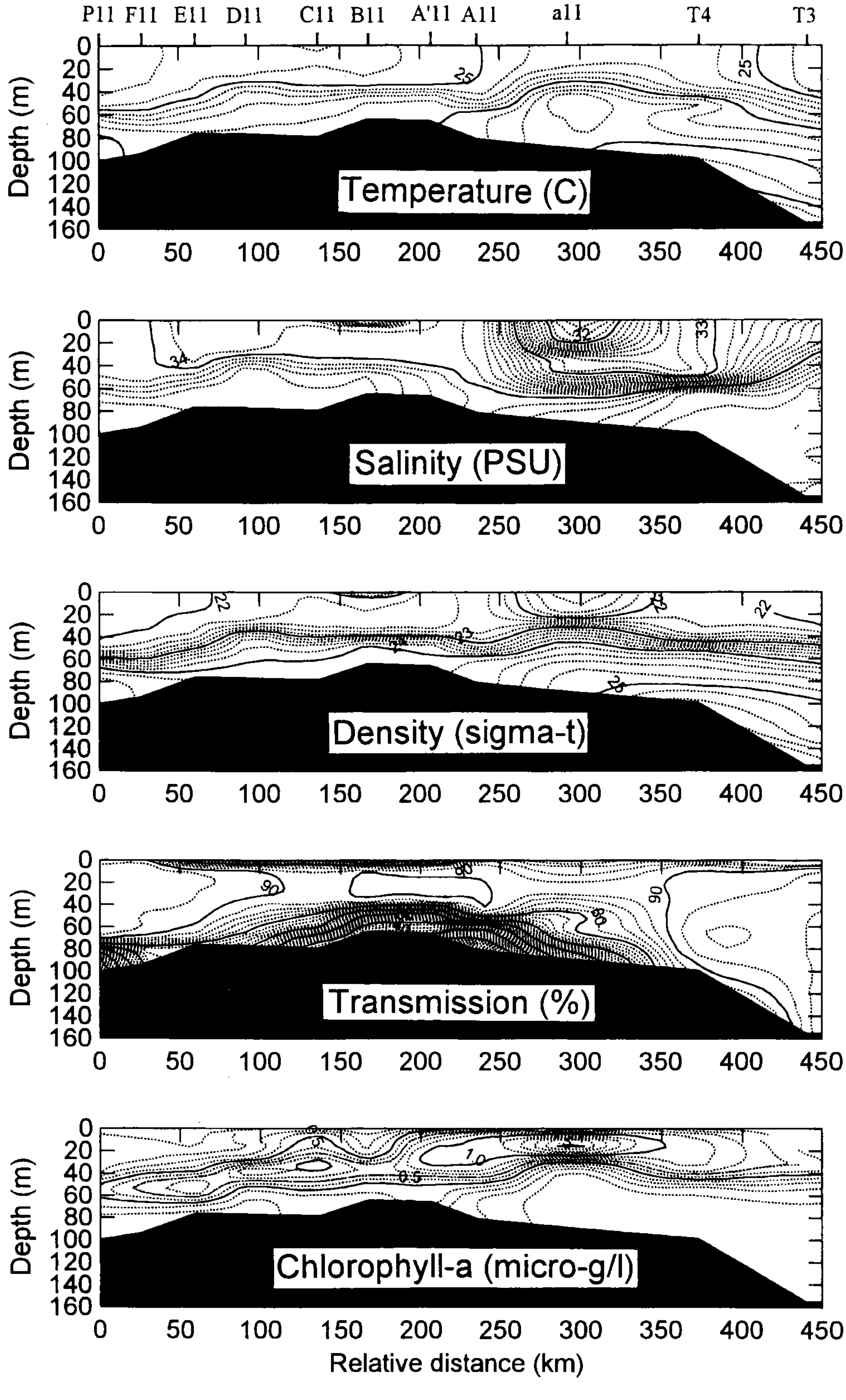

Figure 8. Vertical sections of temperature, salinity, density, transmission and chlorophyll-a along line 11 in 1998. X-axis denotes the distance (km) from the southernmost station, P11.

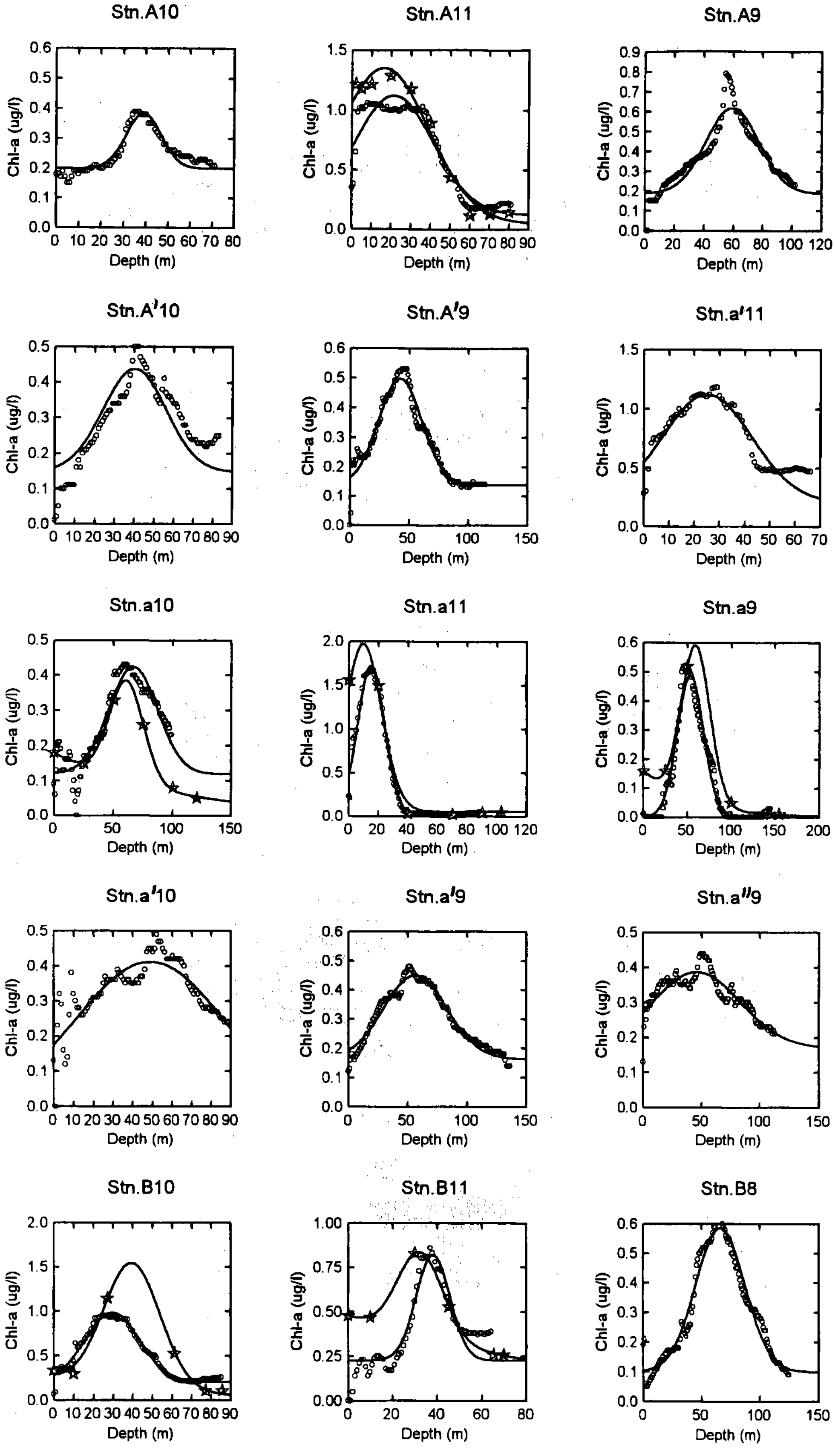

Figure 9. Vertical profiles of chlorophyll-a and the fitted curves for each station in 1998. Circles: *in situ* fluorescence as chlorophyll-a; stars: fluorometrically measured chlorophyll-a in water samples.

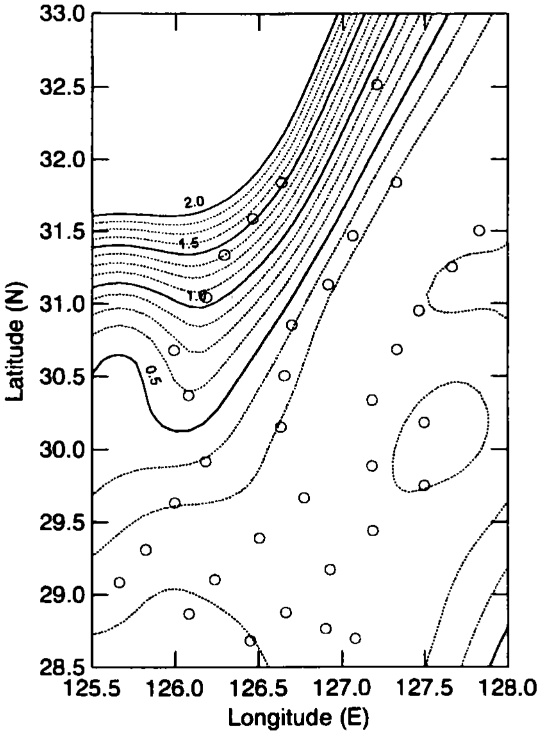

Figure 7. Chlorophyll-a distribution in Surface waters in 1998. Circles denote observational sites.

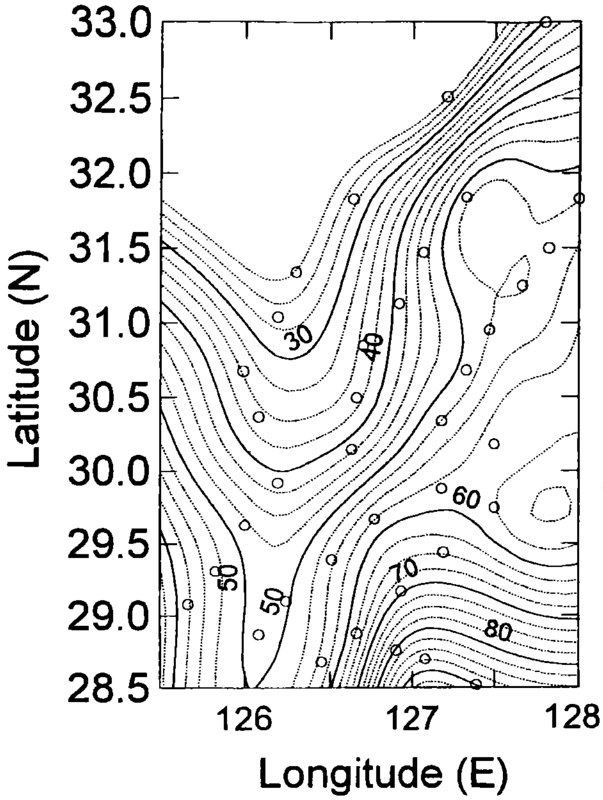

Figure 10. Horizontal distribution of the depth (m) of the subsurface chlorophyll-a maximum in 1998. Circles denote observational sites.

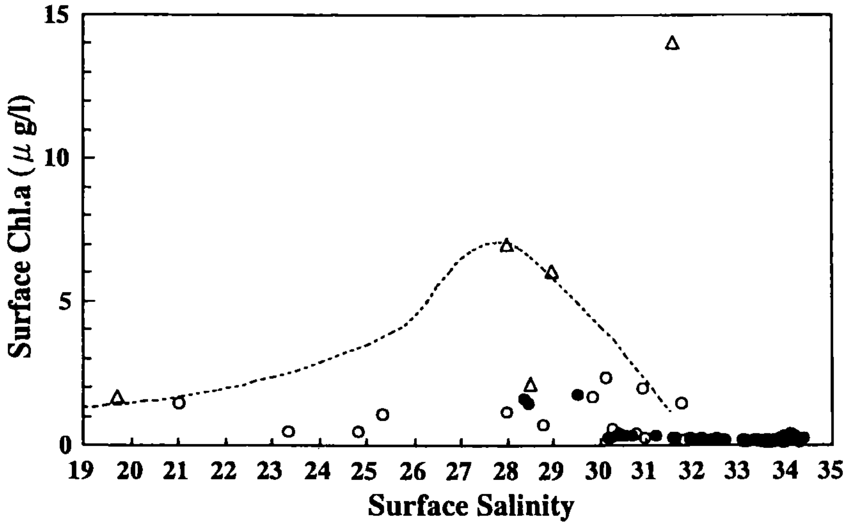

Figure 11. Plot of chlorophyll-a and salinity (PSU) in surface waters. Closed circles: the 1997 cruise results (east of 125°E); open circles: the past cruise results (124-126°E); triangles: the past cruise results (west of 124°E); dotted line denotes the chlorophyll-a maximum in the Changjiang estuary[8].