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Spring distribution of diatom assemblages in the East China Sea

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ABSTRACT: The distribution of diatom assemblages in the East China Sea in late spring was investigated in relation to hydrographical characteristics. Using principal component analyses, 3 water types and 4 diatom assemblages were defined. The distribution pattern of water types showed a 2-layer structure. The nutrient-depleted Surface Water Type forms a layer above the nutrient-laden Mid-Layer Water Type. In addition, the low-salinity eutrophic Coastal Water Type was found near the Changjiang river plume. In general, the distribution of diatom assemblages matches that of water types. The Upwelled Assemblage and the Coastal Assemblage existed respectively in the upwelled Subsurface Kuroshio Water (the Mid-Layer Water Type) and the Changjiang river plume (the Coastal Water Type). A Background Assemblage with low standing stock was found over the entire study area in both the Surface Water Type (nutrient limited) and the Mid-Layer Water Type (light limited). The Shelf-Break Assemblage was observed near the shelf break, where variations in physical or chemical environments were insignificant. This probably resulted from an upwelling event that had not previously been observed. Our results indicate that a widespread Background Assemblage is the basic diatom distribution pattern in the East China Sea. At locations where a nutrient source becomes available, the Background Assemblage will change into a new assemblage such as the Upwelled Assemblage or the Coastal Assemblage.

KEY WORDS: Background assemblage · Diatom assemblage · East China Sea · Upwelling · Kuroshio

INTRODUCTION

The East China Sea (ECS) is the largest marginal sea in the western North Pacific and is distinctly characterized by its broad continental shelf. Hydrography of ECS is basically controlled by several current systems. The Kuroshio Current flows northeastward along the shelf margin and forms the western border of the ECS. Across from the Kuroshio, the Yellow Sea Coastal Current flows southward along the coast of mainland China. This current brings in enormous amounts of nutrients from Chiangjiang (Yangtze River) runoff, and becomes a major nutrient source for the ECS (Beardsley et al. 1985, Gong et al. 1996). On the southern end, the Taiwan Warm Current enters the ECS from the Taiwan Strait and flows northward, and can be detected as far as the Changjiang river mouth (Beardsley et al. 1985). Another hydrographic phenomenon in this region is a cold eddy in the southern ECS (Wong et al. 1991, Gong et al. 1995). The cold eddy is a persistent upwelling system that brings the subsurface nutrient-rich Kuroshio Water to the euphotic zone (Chen & Wang 1990, Liu et al. 1992).

Our understanding of the phytoplankton distribution in the ECS is rather limted. Furuya et al. (1996) investigated the geographic distribution of the phytoplankton assemblages in winter, and found that the entire continental shelf of the ECS was occupied by a Background Assemblage. In summer, a widespread Background Assemblage with several major species in common is also observed along a cross-shelf transect in the southern ECS (Chiang et al. 1997). However, along a nutricline where the oligotrophic surface water meets the underlying upwelling water, a different diatom assemblage with enhanced phytoplankton biomass is identified. This type of enhanced assemblage with high standing stock and unique species composition has

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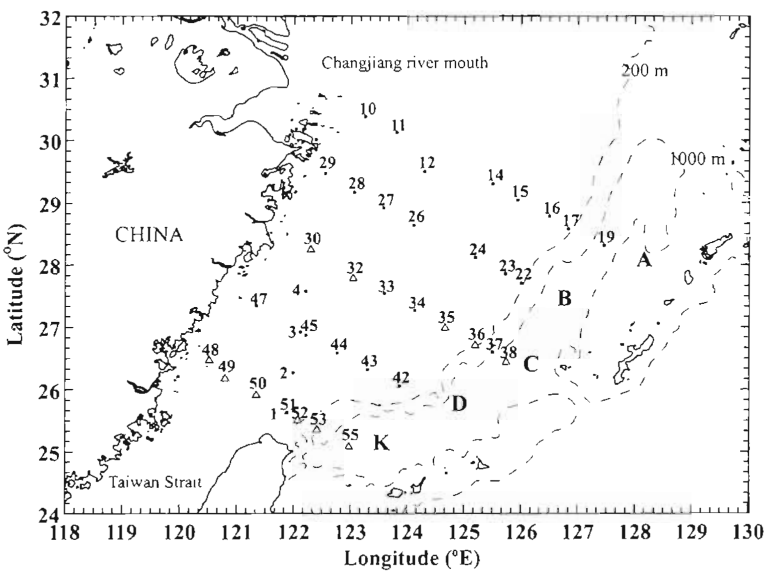

Fig. 1. Sampling stations occupied in May 1996 to investigate the diatom distribution in the East China Sea. Five cross-shelf transects were named, from north to south, Transects A, B, C, D, and K, respectively. At stations marked with a triangle (Δ) water samples were collected from multiple depths for diatom identification

been linked to the upwelling system in the southern ECS (Chen 1992, 1995)

As phytoplankton species composition is important to our understanding of carbon cycling and resource management in the ESC, we conducted a survey covering the entire ECS in May 1996. The primary goal is to understand if the Background Assemblage still exists in spring, and if the dominant species differ from those of the winter Background Assemblage. Second, we wish to establish a relationship between the enhanced diatom assemblages and the interactions among biological, physical, and chemical processes.

MATERIALS AND METHODS

Sampling and analysis. Samples were collected onboard RV 'Ocean Researcher I' from May 5 to 15, 1996. A total of 35 sampling stations was established to cover the entire continental shelf of the ECS (Fig. 1). Most of the stations were positioned along 5 cross-shelf transects (Transects A, B, C, D, and K), and an additional 4 stations (Stns 1 to 4) were arranged in a longitudinal direction. A CTD-Rosette assembly (General Oceanics) equipped with 20 l Go-Flo bottles was employed to record temperature and salinity as well as to collect water samples. Water samples for horizontal distribution were taken at 2 m depth. For stations along Transects C and K, water samples were collected at 3 to 12 depths throughout the water column. The maximum sampling depth was 150 m for deep stations. The maximum sampling depth of stations shallower than 150 m was 10 m above the bottom. In addition, the satellite image of sea surface temperature recorded by the NOAA-14 satellite was received at a ground station of the Department of Fishery Science of the National Taiwan Ocean University on May 13, 1996.

Diatom species composition. Diatom cells in a 100 ml sample were concentrated by the Utermöhl method, and were identified and counted using an inverted epifluorescence microscope (Nikon-Tmd 300) at 200× or 400× (Hasle 1978). The detailed procedure can be found in Chiang & Taniguchi (1993), and only cells with a size larger than 10 µm were enumerated.

Nutrient concentration. Water samples for the determination of nutrient concentrations were placed in 100 ml polypropylene bottles, frozen instantly in liquid nitrogen, and stored in a freezer. Nutrients were analyzed with a self-designed flow injection analyzer (Strickland & Parsons 1972, Gong et al. 1992). Nitrate was reduced to nitrite with cadmium wires activated with a copper sulfate solution, and the nitrite was converted to the pink azo dye for colorimetric determination. Concentrations of phosphate and silicate were measured using the molybdenum blue and the silicomolybdenum blue methods, respectively (Strickland & Parsons 1972, Pai et al. 1990).

Data analysis. The techniques of principal component analyses (PCAs) and cluster analyses (Pielou 1984) were employed to group stations with similar traits. The actual computation was performed with the aid of Statistical Analysis System (SAS) software. Two separate PCAs were carried out using an oceanographic data set (OD set) and a diatom data set (DD set), respectively. The OD set contained temperature, salinity, and concentrations of 4 nutrients measured at individual stations. The DD set contained the 40 most frequently observed diatom species (present in at least 20% of samples). In the PCA-OD result, the first and the second principal components (PC_1 and PC_2) were used to define the water types. In PCA-DD, the first 3 principal components, PC_1, PC_2 and PC_3, were used to define the diatom clusters. Subsequently, all stations were grouped based on their principal component values using the average linkage clustering method (Euclidean distance = 1.0, Pielou 1984). Within a diatom assemblage, the dominant species was defined as a species constituting more than 25% of the total diatom abundance and appearing in more than 50% of samples.

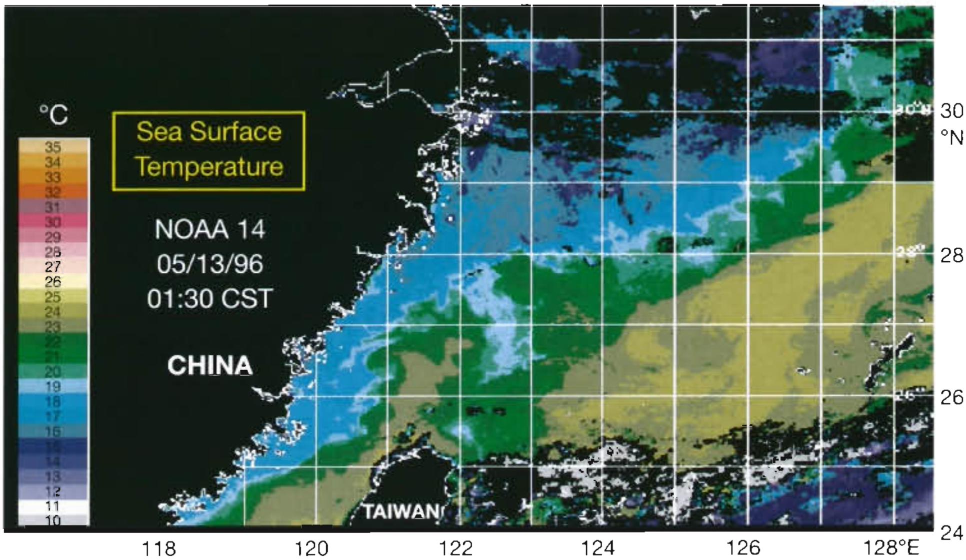

Fig. 2. Satellite image of the sea surface temperature of the East China Sea area on May 13, 1996

RESULTS

Hydrography

Based on NOAA satellite imagery (Fig. 2) taken on May 13, 1996 and CTD data at 2 m depth (Fig. 3A,B), hydrographic features of the study area can be summarized as follows. The Yellow Sea Coastal Current, low in both temperature and salinity (<18°C, <33 psu), flowed along the coast of the mainland. This current carries a high level of nitrate with concentrations always greater than 5 µM (Fig. 3C). On the outer shelf, warm, salty (>24°C, >34.5 psu) Kuroshio Water flowed along the shelf break, and active mixing between these 2 current systems was marked by numerous intrusion fingers and eddies on the shelf interior. A warm stream of the Taiwan Warm Current flowed northward from the Taiwan Strait which could be clearly seen as for north as 27° N. In addition, a cold eddy was present on the southern edge of the study area (Fig. 2).

This general mixing scheme was further supported by the vertical section of temperature and salinity along Transect C (Fig. 4). The low-temperature and low-salinity Yellow Sea Coastal Current occupied the 0 to 40 m depth at Stn 30, where the nitrate concentration was higher than 5 µM. The high-temperature and high-salinity Kuroshio Water was observed in the surface layer at Stns 35 to 38. On the other hand, a warm pocket (>20°C) existed in the 0 to 40 m depth at Stn 33. Two fronts were found along this transect: one existed at Stn 32, which was at the border between the coastal water and the warm pocket, and the other was located in between Stns 34 and 35, which formed the boundary between the warm pocket and the Kuroshio. In addition, an upward displacement of high-salinity and high-nitrate water was observed at the shelf break (Stn 36) at 20 m depth. This feature might be the result of an upwelling event, but an analogous feature was not observed in the temperature section (Fig. 4).

Further to the south on Transect K (Fig. 5), the low-temperature and low-salinity coastal water was still present at Stns 48 and 49, but nitrate concentration was below 1 µM. In addition, in the mid-shelf region, stratification of the water column was weak. A warm water mass with temperature above 23°C was found at Stn 50, which marked the center of the Taiwan Warm Current. The upwelling center at Stn 52 was identified according to its high salinity, low temperature, and high nitrate concentration. The vertical structure of the cold eddy in the southern ECS was clearly seen at Stns 51 to 53.

When PCA was used to analyze the oceanographic data (PCA-OD), PC_1 explained 56.98% of the total variance and positively correlated with nitrate and dissolved silicate (Table 1). PC_2 accounted for 24.26% of the variance and correlated positively with salinity but negatively with nitrite. By plotting the PC_2 of each

Table 1. Eigenvalues of PC_1 and PC_2 associated with each oceanographic parameter based on principal component analysis. Percentage of variance explained by PC_1 and PC_2 is indicated in the parentheses

Variable	PC_1 (56.98%)	PC_2 (24.26%)
Temperature	−0.445	0.316
Salinity	−0.088	0.719
Nitrate	0.522	0.128
Nitrite	0.111	−0.517
Phosphate	0.485	0.301
Dissolved silica	0.524	0.092

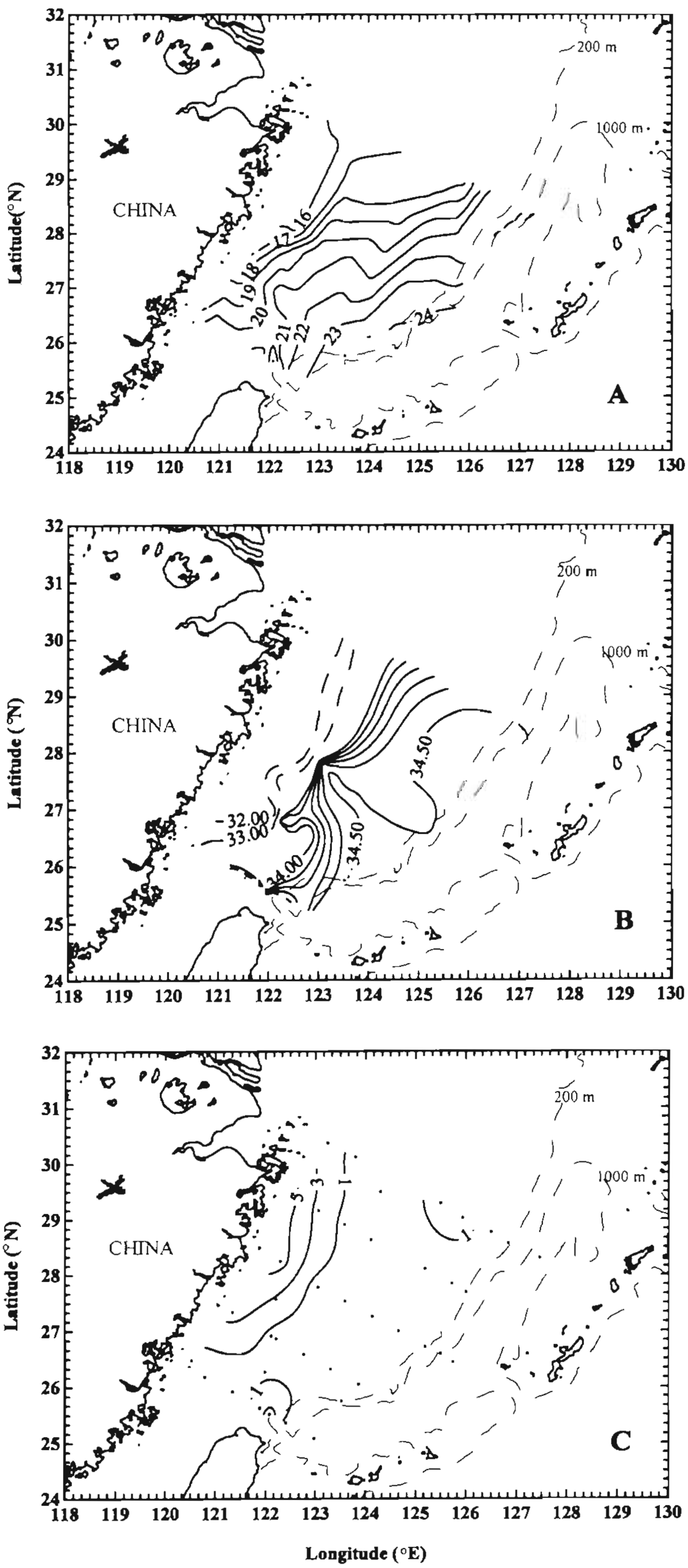

Fig. 3. Surface distribution of (A) temperature (°C), (B) salinity (psu), and (C) nitrate concentrations (μM) in the East China Sea

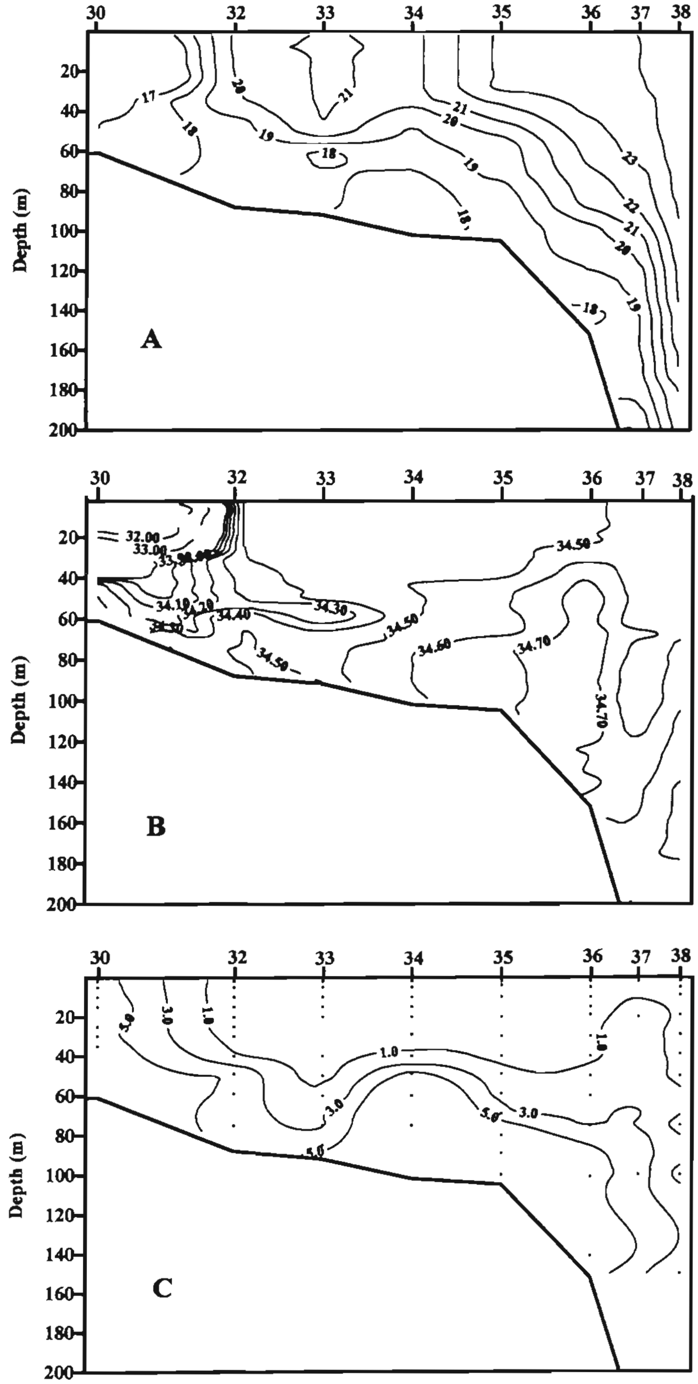

Fig. 4. Vertical profiles of (A) temperature (°C), (B) salinity (psu), and (C) nitrate concentrations (μM) along Transect C

station against PC_1, 4 clusters were identified (Fig. 6). The horizontal and vertical distributions of individual clusters are given in Fig. 7. Cluster A represents the low-nutrient Surface Water Type, Cluster B is the low-salinity Coastal Water Type, and Clusters C and D are the nutrient-rich Mid-Layer Water type. The Surface Water Type is an ubiquitous water type that occupied a

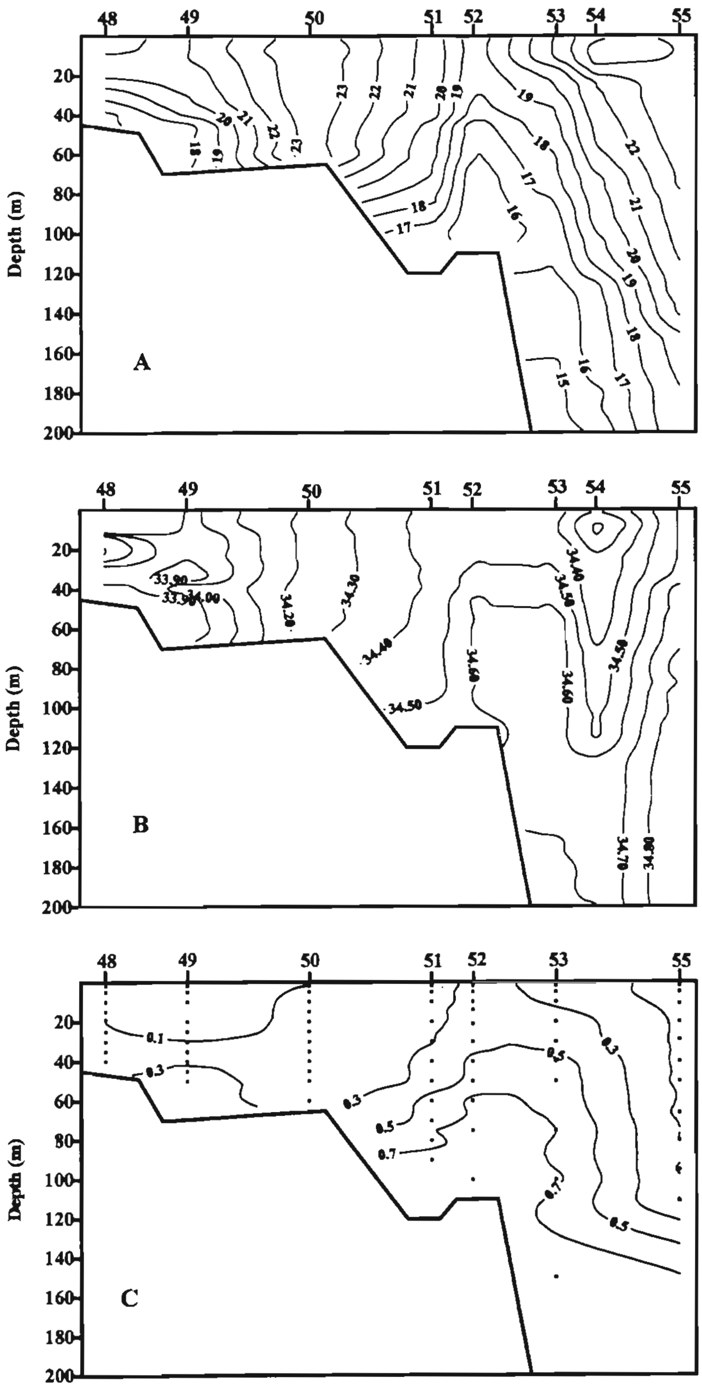

Fig. 5. Vertical profiles of (A) temperature (°C), (B) salinity (psu), and (C) nitrate concentrations (µM) along Transect K

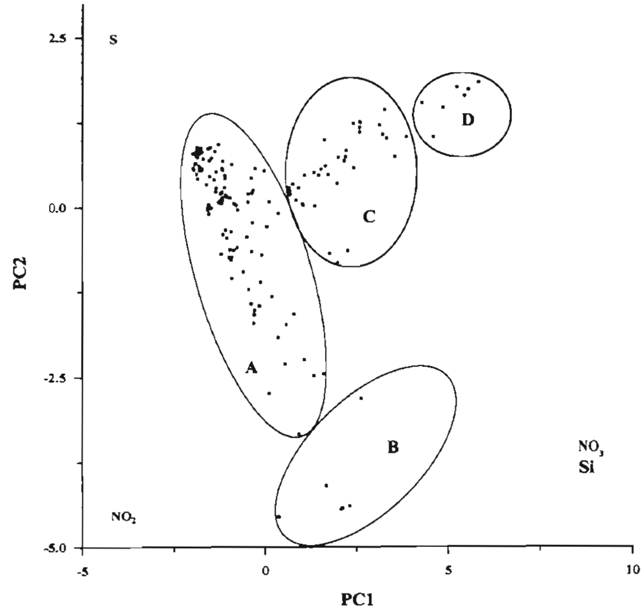

Fig. 6. Scatter diagram of PC_2 against PC_1 of the oceanographic data based on principal component analysis. Ovals denote 4 clusters identified by the average cluster analysis (Eucliden distance = 1.0)

large portion of the ECS at 2 m depth (Fig. 2A). On Transect C, it was observed that the Surface Water Type occupied the surface layer with a thickness from 40 to 60 m, and the Mid-Layer Water Type existed beneath the Surface Water Type (Fig. 7B). On Transect K, due to shallower bottom depths, the Surface Water Type extended all the way to the sea floor (Fig. 7C). The upwelling system centered at Stn 52 was the only place that the Mid-Layer Water Type was detected. The distribution of Coastal Water Type was restricted to the coastal stations in the northern ECS, and its distribution pattern was similar to that of nitrate (Figs. 3C & 7A).

Diatom assemblages

The horizontal distribution of diatom abundance did not entirely match that of chlorophyll *a* concentration (Fig. 8A,B). A good agreement of diatom and chlorophyll *a* distribution was observed near the Changjiang river plume with diatom abundance exceeding 10^5 cells l^{-1} and chlorophyll *a* concentrations exceeding 1.5 µg l^{-1} at Stn 10 and Stn 2. However, in the upwelling area on Transect K, a high diatom abundance (>5 × 10^4 cells l^{-1}) was observed, but the corresponding chlorophyll *a* concentration was not especially high (Fig. 8A,B).

The vertical distribution of diatoms and chlorophyll *a* revealed that phytoplankton patches observed at 2 m depth did not penetrate deep. The patch near the Chiangjiang river plume stayed in depths shallower than 20 m (Fig. 8C,D). Similarly, the patch near the upwelling system was shallower than 30 m (Fig. 8E). The vertical section along Transect C revealed an additional patch which was not detectable from the sea surface (Fig. 8D). This patch was found near the shelf

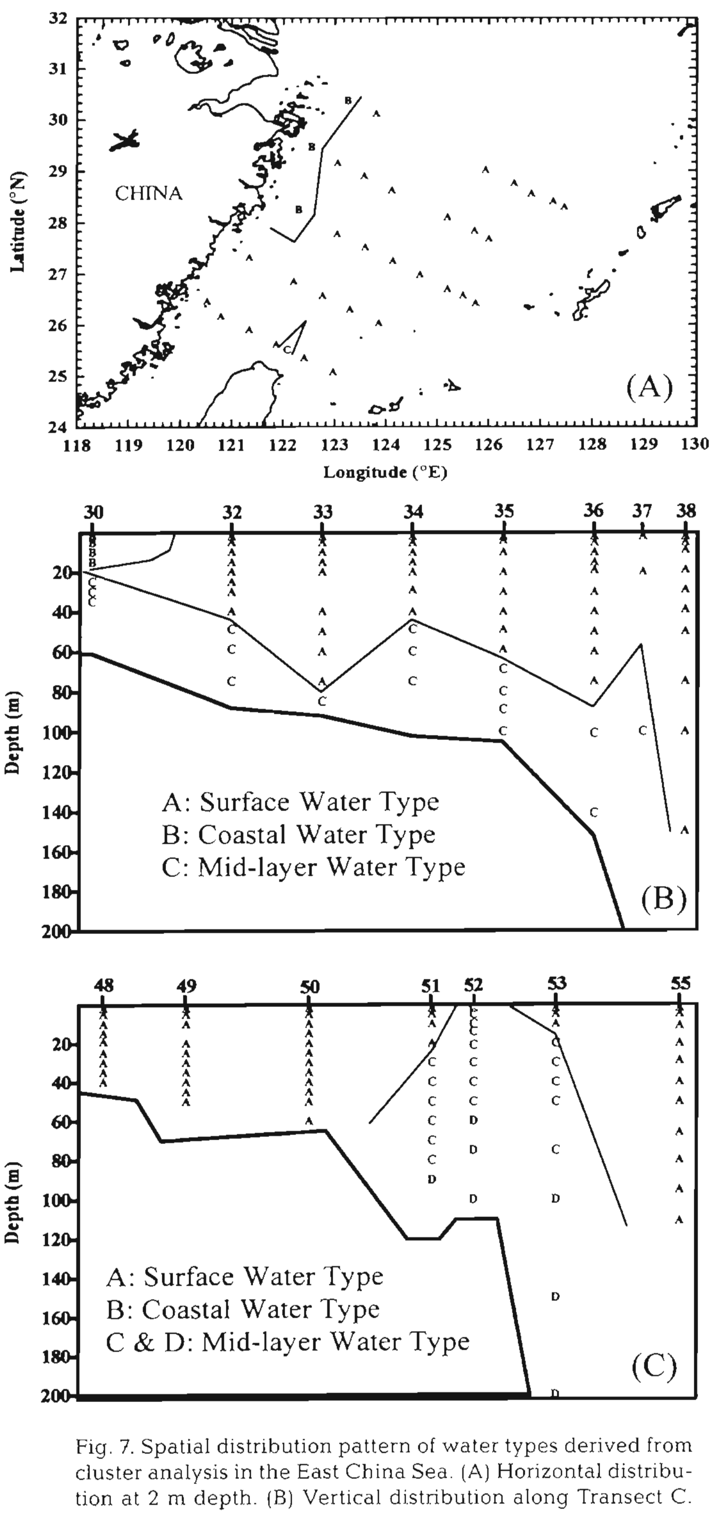

Fig. 7. Spatial distribution pattern of water types derived from cluster analysis in the East China Sea. (A) Horizontal distribution at 2 m depth. (B) Vertical distribution along Transect C. (C) Vertical distribution along Transect K. Cluster A: Surface Water Type; Cluster B: Coastal Water Type; Clusters C and D: Mid-Layer Water type

break (Stn 35) and was characterized by a high density of diatoms ($>5 \times 10^4$ cells l^{-1}) and chlorophyll *a* concentrations (>0.5 µg l^{-1}). When viewed using nitrate distribution, the patch was located on the shelf-side of the nitrate-rich water near Stn 37 (Fig. 4C).

Based on PCA using the diatom species data set (PCA-DD), about 40% of the total variance was explained by PC_1, PC_2, and PC_3 (Table 2). PC_1 primarily reflected the influence of *Bacteriastrum delicatulum, Chaetoceros diversus, C. lorenzianus, Guinardia striata, Hemiaulus hauckii, Leptocylindrus danicus*, and *Rhizosolenia hebetata* f. *semispina*; PC_2 reflected the influence of *Asterionellopsis glacialis, C. curvisetus,*

Table 2. Forty dominant diatom species, which occurred in more than 20% of samples, used as variables for the principal component analysis and their eigenvectors of PC_1, PC_2, and PC_3. Percentage of variance explained is indicated in parentheses

Variable	PC_1 (21.99%)	PC_2 (9.88%)	PC_3 (7.77%)
Asterionellopsis glacialis	0.039	0.302	0.312
Bacteriastrum comosum	0.294	−0.113	−0.021
Bacteriastrum delicatulum	0.160	−0.021	−0.028
Bacteriastrum hyalinum var. *princeps*	0.202	−0.090	0.049
Bacteriastrum minus	0.075	−0.072	−0.015
Cerataulina pelagica	0.043	0.181	−0.013
Chaetoceros compressus	0.170	0.117	−0.060
Chaetoceros curvisetus	0.036	0.306	−0.336
Chaetoceros danicus	0.059	0.089	−0.0245
Chaetoceros decipiens	0.006	0.024	0.026
Chaetoceros didymus	0.050	0.285	−0.038
Chaetoceros diversus	0.262	−0.079	−0.003
Chaetoceros lorenzianus	0.300	0.118	0.044
Corethron criophilum	0.200	−0.025	0.028
Coscinodiscus sp.	0.031	0.076	0.034
Dactyliosolen fragilissimus	−0.019	−0.001	0.064
Ditylum brightwellii	0.043	0.323	0.304
Eucampia cornuta	0.060	0.289	−0.367
Eucampia zodiacus	0.050	0.183	0.227
Guinardia flaccida	0.021	0.063	0.156
Guinardia striata	0.298	−0.106	0.008
Hemiaulus hauckii	0.286	−0.106	−0.001
Lauderia annulata	0.108	0.308	0.327
Leptocylindrus danicus	0.298	−0.004	−0.054
Leptocylindrus mediterraneus	0.166	−0.122	0.048
Navicula distans	0.102	−0.035	−0.134
Navicula sp.	0.036	−0.090	0.120
Nitzschia longissima	0.014	0.188	−0.296
Nitzschia sp.	0.179	0.174	0.220
Phaeodactylum tricornutum	0.040	0.135	−0.141
Pleurosigma sp.	0.196	−0.067	−0.112
Pseudo-nitzschia delicatissima	0.043	0.251	−0.039
Pseudo-nitzschia seriata	0.093	0.107	0.110
Rhizosolenia alata f. *gracillima*	0.176	−0.110	−0.038
Rhizosolenia hebetata f. *semispina*	0.280	−0.117	−0.001
Rhizosolenia imbricata	0.244	−0.111	0.017
Skeletonema costatum	0.066	0.147	−0.131
Thalassionema nitzschioides	0.086	−0.040	0.131
Thalassiosira rotula	−0.001	0.171	−0.180
Thalassiosira sp.	0.047	−0.071	0.115

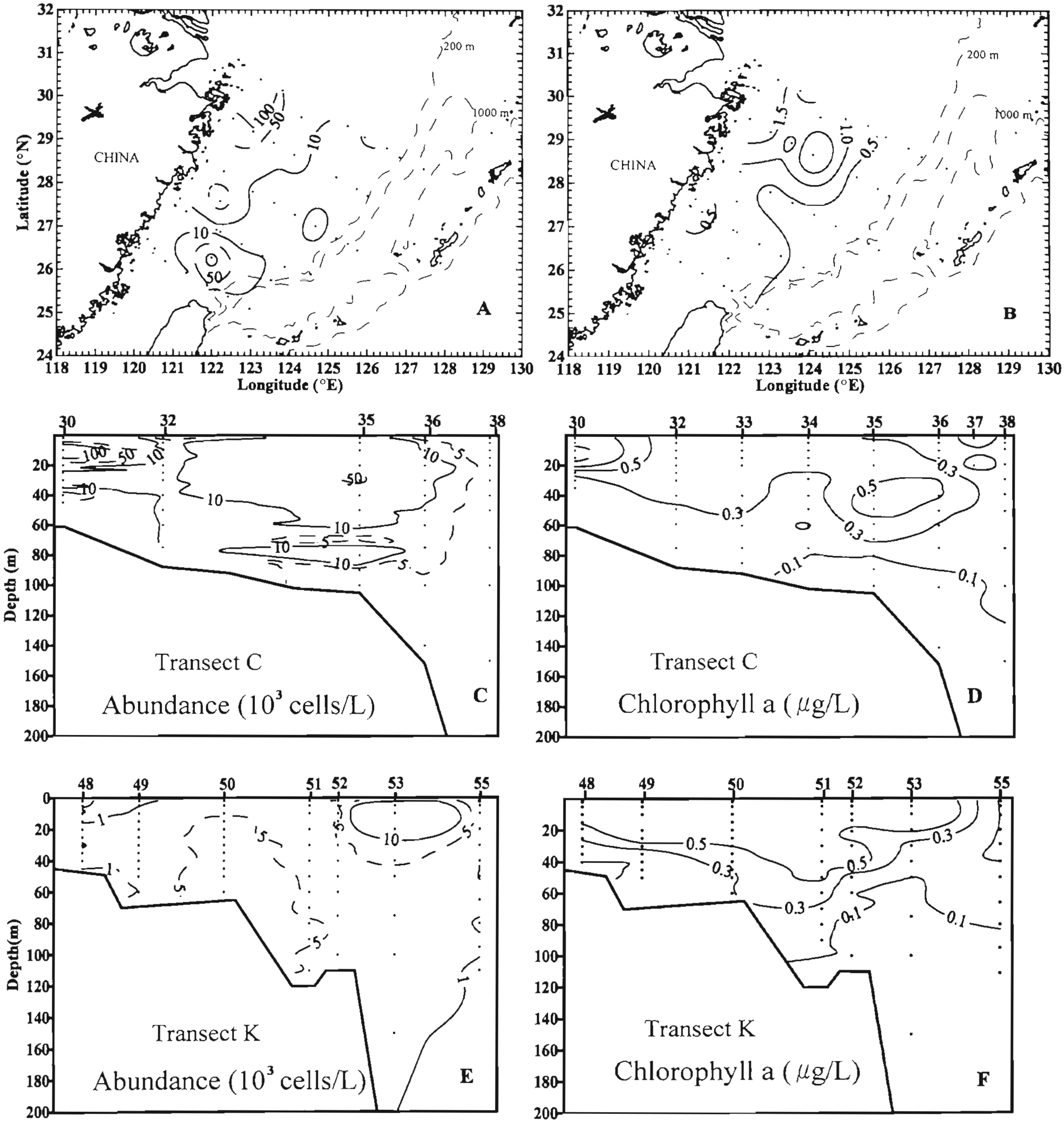

Fig. 8. Spatial distribution of diatom abundance (10^3 cells l^{-1}) and chlorophyll *a* (μg l^{-1}) in the East China Sea. Horizontal distribution; (A) diatom abundance and (B) chlorophyll *a* at 2 m depth. Vertical distribution along Transect C; (C) diatom abundance and (D) chlorophyll *a*. Vertical distribution along Transect K; (E) diatom abundance and (F) chlorophyll *a*

C. didymus, *Ditylum brightwellii*, *Eucampia cornuta*, *Lauderia annulata*, and *Pseudo-nitzschia delicatissima*; and PC_3 reflected the influence of *Asterionellopsis glacialis*, *C. curvisetus*, *Ditylum brightwellii*, *Eucampia cornuta*, *Lauderia annulata*, and *Nitzschia longissima*. Based on a scatter diagram of PC_1, PC_2, and PC_3, 5 clusters were identified (Fig. 9).

Cluster A was defined as the Background Assemblage because it was the most commonly encountered species composition in the sampling area. The dominant species in this assemblage were *Thalassionema nitzschioides* and *Pseudo-nitzschia delicatissima*, both belonging to neritic cosmopolitan species (Table 3). Water samples containing the Background Assem-

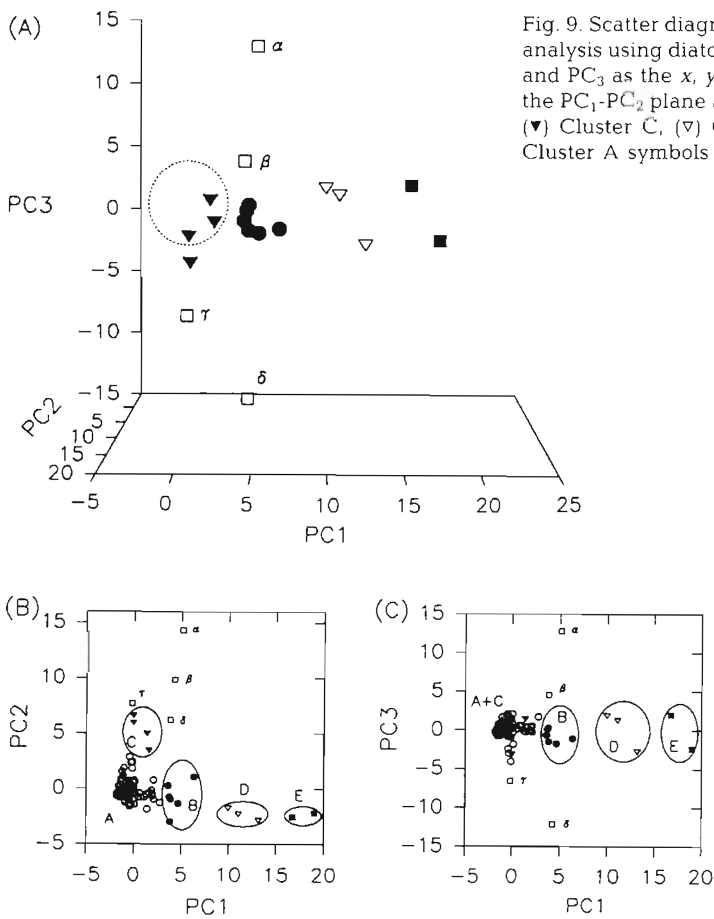

Fig. 9. Scatter diagram of PC_1, PC_2 and PC_3 based on the principal component analysis using diatom species data. (A) 3-dimensional diagrams with PC_1, PC_2 and PC_3 as the *x*, *y*, and *z*-axis, respectively. (B) Projection of data points on the PC_1-PC_2 plane and (C) on the PC_1-PC_3 plane. (○) Cluster A, (●) Cluster B, (▼) Cluster C, (▽) Cluster D, (■) Cluster E and (□) isolated minor clusters. Cluster A symbols were omitted in (A) to improve clarity, and the range of Cluster A is marked by a circle

blage were usually low in diatom abundance, with concentrations rarely exceeding 1×10^4 cells l^{-1}.

In contrast to Cluster A, other clusters and isolated points appeared at several specific locations in the ECS (Figs. 10, 11 & 12). In other words, stations containing these non-A Clusters aggregated into several 'islands' on a lawn of the Background Assemblage. Based on the geographical location of these 'islands', we were able to define 3 diatom assemblages.

(1) Coastal Assemblage: This assemblage was found at Stns 4, 10, 11, 28, and 30 near the mainland coast. Species composition at these stations belongs to Cluster C on the scatter diagram (Fig. 9), and the dominant species include *Chaetoceros curvisetus* and *Pseudo-nitzschia delicatissima*. At Stn 30, although the Background Assemblage was found at 2 m depth, a species composition with Cluster C characteristics was found at 15 m depth (Fig. 11). In addition, 2 isolated points with high PC_2 values on the scatter diagram, points γ and δ, are also included in the Coastal Assemblage because their distribution was closely related to that of Cluster C stations. The range of the Coastal Assemblage overlapped with that of the Coastal Water Type (Figs. 7 & 10), and diatom abundance within this assemblage ranged from 5×10^5 to 5×10^4 cells l^{-1}.

(2) Shelf-Break Assemblage: This assemblage was observed in the surface layer at Stns 23, 35, and 36 near the shelf break, where the water depth was less than 20 m (Fig. 12). The species composition in this assemblage includes Clusters B, D, and E (Fig. 9,

Table 3. Distribution and dominant species of individual diatom assemblages defined by principal component analysis in the East China Sea. #: isolated point

Assemblage	Coastal	Upwelling	Shelf-Break	Background
Diatom cluster	C, #	B, #	B, D, E	A
Distribution				
Stn (depth, m)	Stn 4 (2) Stn 10 (2) Stn 11 (2) Stn 28 (2) Stn 30 (10–15)	Stn 1 (2) Stn 2 (2) Stn 53 (5–10)	Stn 23 (2) Stn 35 (2–40) Stn 36 (15–20)	All the rest
Dominant species	*Chaetoceros curvisetus* *Pseudo-nitzschia delicatissima*	*Pseudo-nitzschia delicatissima* (Stn 1) *Asterionellosis glacialis* (Stn 2) *Chaetoceros compressus* (Stn 53)	*Chaetoceros compressus* *Guiinarida striata* *Pseudo-nitzschia delicatissima*	*Pseudo-nitzschia delicatissima* *Thalassionema nitzschiodes*

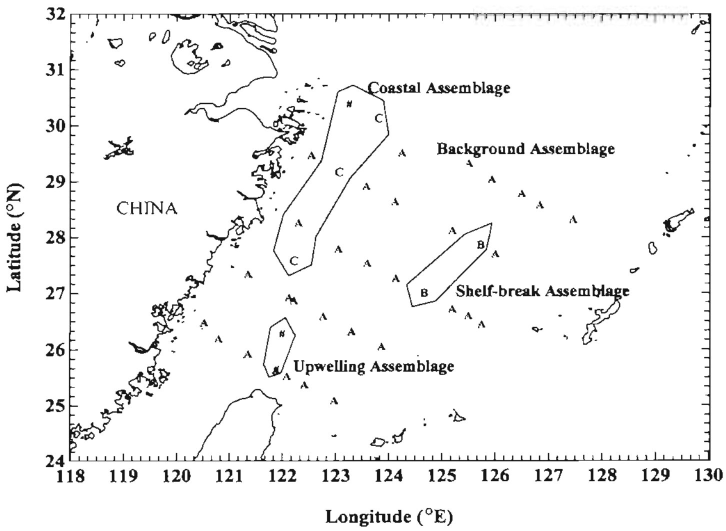

Fig. 10. Horizontal distribution pattern of diatom assemblages derived from cluster analysis in the East China Sea. Capital letters indicate the cluster types at 2 m depth, and # indicates isolated points

Table 3). Clusters D and E are closely related to Cluster B since all 3 clusters are indistinguishable in PC_2 and PC_3 values. The vertical distribution of this assemblage indicates that diatom composition near the sea surface belongs to Cluster B. As the depth increased, the diatom community became richer in PC_1 species, and the cluster type gradually changed from B and D, to E (Fig. 11). Population density within this assemblage was intermediate, typically between (1 and 5 × 10^4 cells l^{-1} (Fig. 8). Dominant species are neritic cosmopolitan species including *Chaetoceros compressus*, *Pseudo-nitzschia delicatissima*, and *Guinardia striata*.

(3) Upwelling Assemblage: Stations that contained Upwelling Assemblage aggregated on either side of the upwelling system in the southern ECS (Figs. 10 & 12).

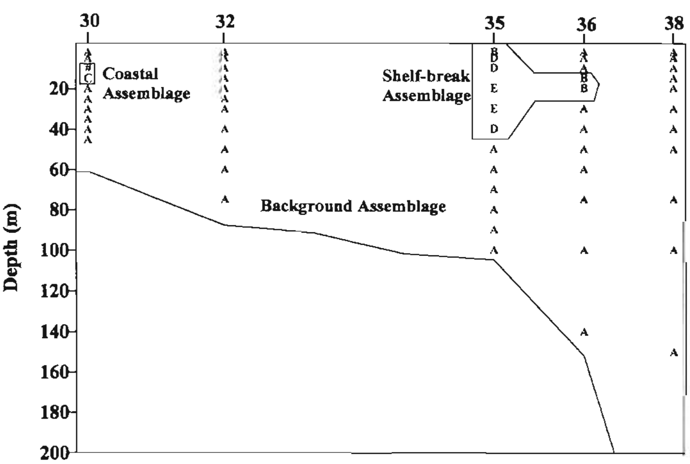

Fig. 11. Vertical distribution pattern of diatom assemblages along Transect C. Symbols as in Fig. 10

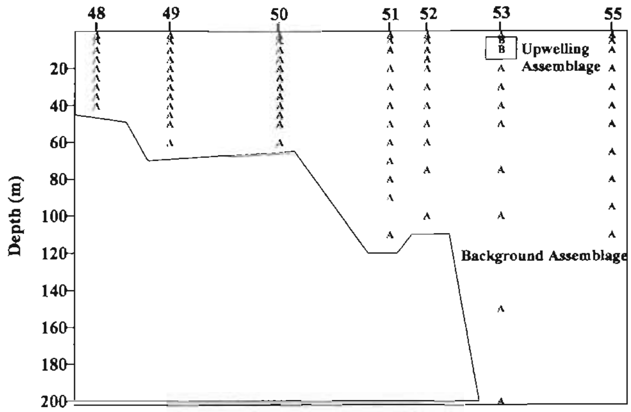

Fig. 12. Vertical distribution pattern of diatom assemblages along Transect K. Symbols as in Fig. 10

On the oceanic side of the upwelling, species composition between 5 and 10 m deep at Stn 53 was classified as Cluster B, similar to that found in the Shelf-Break Assemblage. The dominant species was *Chaetoceros compressus*. On the other side of the upwelling at Stns 1 and 2, the species composition was not associated with any of the 5 clusters. Instead it formed isolated points α and β with PC_3 values greater than 0 on the scatter diagram. The diatom abundance at Stn 1 was 10^4 cells l^{-1}, and the dominant species was *Asterionellopsis glacialis*. At Stn 2, diatom abundance abruptly increased more than 10 times to 1.2×10^5 cells l^{-1}, and the dominant species changed to *Pseudo-nitzschia delicatissima* (Table 3).

DISCUSSION

According to the result of PCA-OD (Fig. 7), 3 water types, which create different living environments for phytoplankton, exist in the ECS. The general distribution pattern is a 2-layered structure with the oligotrophic Surface Water Type on top of the nutrient-laden Mid-Layer Water Type. The Mid-Layer Water Type can be brought to the surface by upwelling processes, as observed in the upwelling system on Transect K. On the other hand, the Coastal Water Type is observed only at the inner-shelf stations of Transects A, B, and C. The characteristics of this water type are high nutrients and low salinity. Apparently, as the Yellow Sea Coastal Current flows southward, it receives fresh water and nutrients from Changjiang runoff, and transforms into the eutrophic Coastal Water Type. However, the distribution of Coastal Water Type does not extend to southern stations on Transects D and K, where the existence of cold water is still evident (Fig. 7). This fact suggests that nutrients in the Coastal Water Type are gradually exhausted because of phyto-

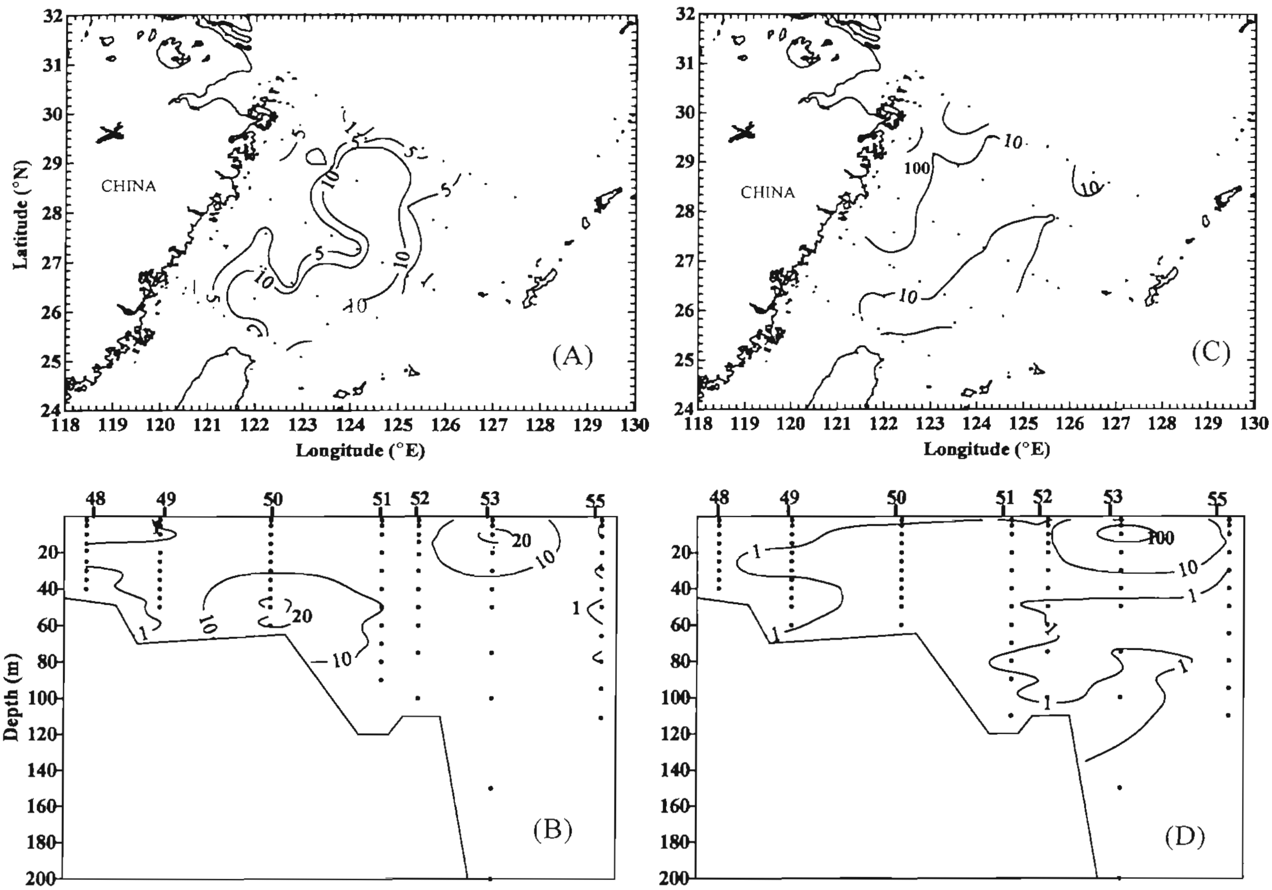

Fig. 13. The spatial distribution of *Thalassionema nitzschioides* (10^2 cells l^{-1}) and *Chaetoceros compressus* (10^2 cells l^{-1}, C) in the East China Sea. *T. nitzschioides* (A) horizontal distribution and (B) vertical distribution along Transect K. *C. compressus* (C) horizontal distribution and (D) vertical distribution along Transect K

plankton uptake or mixing with surrounding waters. Thus, it finally becomes the oligotrophic Surface Water Type when it flows away from the Changjiang river plume.

The distribution pattern of diatom assemblages is generally consistent with that of water types. Most surface water in the ECS is occupied by the oligotrophic Surface Water Type, in which we find a similar diatom composition defined as the Background Assemblage. This assemblage is characterized by small standing stock and neritic cosmopolitan species such as *Pseudo-nitzschia delicatissima* and *Thalassionema nitzschioides* (Chiang et. al. 1994, Marshall & Nesius 1996). The variation in abundance of these species is small. For example, the abundance of *T. nitzschioides* varies between 10^2 and 10^3 cells l^{-1} (Fig. 13A,B).

Although the ECS is occupied by the Surface Water Type and the Background Assemblage, several enhanced diatom assemblages were found in waters with higher nutrient content. The Coastal Assemblage was found in Coastal Water Type near the Changjiang river plume. The Upwelling Assemblage was observed in the upwelled Mid-Layer Water Type in the southern ECS. The dominant species on one side of the upwelling is different from the species on the other side (Table 3). This is not necessarily a result of different living conditions since there was a time delay of 10 d between the sampling dates of Stns 1 and 53.

The only enhanced assemblage that does not associate with a specific water type is the Shelf-Break Assemblage. When we compared distribution of Shelf-Break Assemblage (Fig. 11) with nutrients (i.e. nitrate), high-nitrate water was found at the subsurface of Stn 37 (Fig. 4C). Therefore, we propose that an upwelling event may have occurred near the shelf break, and the elevated nutrient level stimulated some species of phytoplankton to grow actively. This process caused the Background Assemblage to change into the Shelf-Break Assemblage (Marshall & Nesius 1996, Chiang et al. 1997). So far, this upwelling process has not been demonstrated by hydrographic data. Therefore, diatom assemblages occasionally can trace the distribution of different water masses or some physical and chemical processes (Chiang et al. 1994 and citations therein).

The formation of the Background Assemblage may come from the winter convection of water (Chiang & Taniguchi 1993). In winter, the entire continental shelf is occupied by nutrient-rich water (Gong et al. 1995), but the strong mixing and low irradiance level are unfavorable for phytoplankton growth. Only some tolerant species can survive these bad living conditions and maintain a low standing stock in the ECS. The dominant species of the Background Assemblage are the benthic diatom *Paralia sulcata* in the inner shelf area and *Thalassionema nitzschioides* in the outer shelf (Furuya at al. 1996). In spring and summer, the water column becomes stratifed (Gong et al. 1996). However, *T. nitzschioides* remains a dominant species and the Background Assemblage with similar species composition is found in both the nutrient-depleted surface layer and the nutrient-laden subsurface layer (Figs. 11, 12 & 13, Chiang et al. 1997). On the other hand, some subtle differences in species composition do exist between seasons. A dominant species in the winter Background Assemblage, *Paralia sulcata*, disappears in spring. Also, a spring dominant species, *Pseudo-nitzschia delicitassima*, ceases to appear in the summer Background Assemblage. The seasonal variation in dominant species may represent a general pattern of seasonal succession of the Background Assemblage in the ECS (Smayda 1980).

In conclusion, nutrient availability affects the spatial distribution pattern of the diatom assemblages on the continental shelf of the ECS. The Background Assemblage is widely distributed in areas where light (aphotic zone) or nutrients (euphotic zone) are limited. In the euphotic zone at certain locations, when a nutrient supply from river runoff or upwelling is received, some diatom species, which are a minor part of the Background Assemblage, grow prosperously and then transform the species composition to a new enhanced assemblage (the Coastal Assemblage or the Upwelling Assemblage). This phenomenon of phytoplankton composition change resulting from nutrient-stimulated phytoplankton growth has been proposed by Ishizaka et al. (1983), Yamamoto et al. (1988), Hayward & Mantyla (1990), and Chiang et al. (1997). When the nutrients are depleted, the diatom assemblage will sustain itself for a short period (Shelf-Break Assemblage), but eventually it will change back to the Background Assemblage (Chiang et al. 1997).

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