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Species Composition and Spatial Distribution of Euphausiids of the Yellow Sea and Relationships with Environmental Factors

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Abstract – We investigated species composition and spatial distribution of the euphausiid community in the Yellow Sea and identified the relationship with environmental factors (temperature, salinity, chlorophyll *a*, nitrate, phosphate, and silicate) using bimonthly data from June, 1997 to April, 1998. The environment varied during the sampling period. In warm seasons, thermocline was well developed rendering lower temperature and higher salinity and nutrient concentrations in the bottom layer. During cold seasons the water column was well mixed and no such vertical stratification was noted. Horizontal distribution of temperature, however, differed slightly between near-coast and offshore areas because of the shallow depth of the Yellow Sea, and between southern and northern areas because of the intrusion of water masses such as Yellow Sea Warm Current and Changjiang River Diluted Water. Four euphausiid species were identified: *Euphausia pacifica*, *E. sanzoi*, *Pseudeuphausia* sp. and *Stylocheron affine*. *E. sanzoi* and *S. affine* were collected, just one juvenile each, from the southern area in June and December, respectively. *Pseudeuphausia* sp. were collected in the eastern area all the year round except June. *E. pacifica* occurred at the whole study area and were the predominant species, representing at least 97.6% of the euphausiid abundance. Further, the distribution pattern of the species was varied in regards to developmental stages (adult, furcilia, calyptopis, egg). From spring to fall, *E. pacifica* adults were abundant in the central area where the Yellow Sea Bottom Cold Water prevailed. Furcilia and calyptopis extended their distribution into nearly all the study area during the same period. From late fall to winter, adults were found at the near-coastal area with similar pattern for furcilia and calyptopis. The distribution pattern of *E. pacifica* was consistent regarding temperature, salinity, and three nutrients during the sampling period, whereas chlorophyll *a* showed a different pattern according to the developmental stages. The nutrients should indirectly affect via chlorophyll *a* and phytoplankton concentration. With respect to these results, we presented a scenario about how the environmental factors along with the water current affect the distribution of *E. pacifica* in the Yellow Sea.

Key words – *Eupahusia pacifica*, Yellow Sea, Seasonal spatial distribution, Yellow Sea Bottom Cold Water

1. Introduction

The Yellow Sea is an epicontinental marginal sea located between the Korean peninsula and the Chinese mainland. It is connected to the Bohai Sea to the north and to the East China Sea to the south. Its marine environment is seasonally variable depending on wind direction and heat exchange through sea surface. The heat exchange through sea surface takes place very quickly due to the shallow depth (mean=44 m). As a consequence, cold and relatively saline bottom water (the Yellow Sea Bottom Cold Water, YSBCW) develops along the deeper part of the Yellow Sea (>50 m). When it reaches its maximal intensity in summer, the vertical temperature difference could be more than 20°C. The YSBCW disappears in winter due to convectional mixing generated by the monsoonal wind, which prevails toward the north in summer and south in winter. The wind pattern influences

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also the current system in and out of the Yellow Sea. The major water masses of the Yellow Sea are YSBCW, the Yellow Sea Warm Current (YSWC), the West Korean Coastal Current and the Chinese Coastal Currents flowing southerly, and the Changjiang River Diluted Water (CRDW) which is a mixed water between the Changjinag River discharge and East China Sea water manifesting in summer (Lie 1984; Guan 1994; Feng 1998). Their boundary and intensity change with season (Lie 1984). In the Yellow Sea, with these radical changes in environment, one of the micronektonic animals, *Euphausia pacifica*, propagates and represents one of the major zooplanktonic groups (Yoon *et al.* 2000).

E. pacifica are the dominant species of euphausiids in the North Pacific (Boden *et al.* 1955; Mauchline and Fisher 1969; Brinton 1976) being an important component of marine pelagic food webs, and are one of the main prey organisms for commercial fishes, such as hair-tail, salmon, herring, sardine, mackerel, and baleen whales (Ponomareva 1963; Ito 1964; Komaki 1967; Mauchline and Fisher 1969; Mauchline 1980). For the Yellow Sea, studies on euphausiids were scarce and restricted to species composition. Among others, Hong (1969) reported two species of euphausiids, *E. pacifica* and *Pseudeuphausia latifrons* and Suh (1990) for *P. sinica*. Chen (1991) reported the distribution of *E. nana* and *P. sinica*, and Lee *et al.* (1998) for *E. pacifica* and *P. sinica*. Recently Yoon *et al.* (2000) investigated the spatial distribution of *E. pacifica* in terms of their developmental stages in relation to environmental factors. However, their study was limited in sampling period and was obscure in determining the major influencing factors on distribution.

In the present study, combining with the data of Yoon *et al.* (2000), we report detailed results on species composition and spatial distribution of euphausiids of the Yellow Sea, as well as the relationships with environmental factors. We attempted to make a hypothesis in regard to the variation in distribution with the environmental changes.

2. Materials and Methods

The central and eastern Yellow Sea (34-37°N and 124-126°30'E) was regularly visited (bimonthly) for an Oceanographic Survey Program since 1961 by National Fisheries Research and Development Institute, Korea (Fig. 1). Physical, chemical and biological data were simultaneously gathered. During the surveys from June, 1997 to April, 1998, euphausiids were collected and the results are presented in this paper.

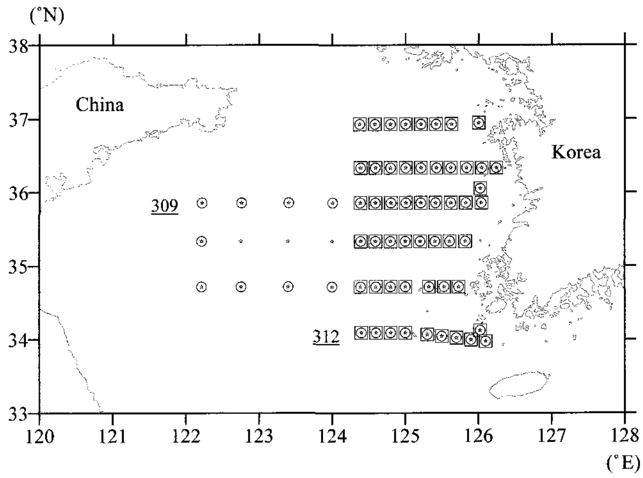


Fig. 1. Study area showing the sampling stations. The square denotes stations visited in February, June and December, the circle in April and October, and the star in August. Two lines, 309 and 312, are for the vertical section of environmental variables.

Temperature and salinity were measured at every station (Fig. 1) with a CTD (SeaBird model 19 or 25). At every other station, samples for chlorophyll *a* and nutrients (silicate, phosphate, nitrate) were taken at 0, 10, 20, 30, 50 and 75 m depths. In laboratory, chlorophyll *a* concentration was measured with spectrophotometer (Varian, Cary 1E) and nutrients with nutrient auto-analyzer (Bran+Luebbe, Traacs 800+) after methods described in Parsons *et al.* (1984). At the same stations for chlorophyll *a* and nutrients, euphausiids were collected using a conical net (mouth size 1 m, mesh size 500 μm) hauled vertically from bottom to surface and the samples were immediately fixed and preserved in buffered formaldehyde solution (10% V/V). Euphausiid eggs were sampled with NORPAC net (mouth size 0.45 m, mesh size 330 μm) and preserved also in buffered formaldehyde solution (10% V/V). In laboratory, euphausiids were counted and identified to species level, and for the most numerous one, *Euphausia pacifica*, identification was made up to the developmental stages (adult without distinction of sex, furcilia, calyptopis) under dissecting microscope (Olympus, SZX 12) according to the descriptions given in Brinton (1975), Ross (1981) and Baker *et al.* (1990).

Spatial distribution patterns of euphausiids were analyzed in relation to the environmental factors using Spearman's correlation.

3. Results

Temperature

Mean temperatures and ranges at the standard depths from June 1997 to April 1998 are presented in Table 1. It was noted that temperatures of the surface layer varied greatly during the study period with the highest value in August and the lowest in February, and those of lower layer (the 50-75 m depth) were relatively stable. The vertical difference was considerable during June-October and negligible during December-April, indicating development and disappearance of a thermocline.

Temperatures of the 10 and 50 m depth were selected to show the horizontal distribution (Fig. 2). At the 10 m depth from June to October, relatively cold water was found in the northeastern (near the Taean peninsula) and the southeastern areas (around Heuksan Is.), which was formed by tidal mixing with YSBCW (Lie 1989). During December-April, the temperature was relatively uniform throughout the water column with low values in the north and high in the south areas. At the 50 m depth from June to October, the coastal area was warmer than the offshore area because of its vicinity to the land. It was also apparent that the temperature gradient from coastal to central area became steeper during this period. The highest temperature at this depth was observed in October, indicating deepening of thermocline. From December to April, the horizontal distributions were similar with those of the 10 m depth.

Temperatures of the Lines 309 and 312 in August and February were selected to show the vertical sections in the study area (Fig. 3). As shown in Table 1, thermocline began to develop in April, reaching its maximal intensity

Table 1. Average and range of temperatures (°C), salinities, chlorophyll *a* (μg l^{-1}) and nutrient concentration (μM) of the study area. Averages were calculated from standard depths (0, 10, 20, 30, 50, and 75 m depth). Temperature and salinity data for Dec. 1997 were not available, and an average of 30 years was presented.

	Jun. 1997			Aug. 1997		
Parameter	aver±sd	range	n	aver±sd	range	N
Temperature	13.3±4.6	6.1-26.3	259	18.9±7.4	6.3-28.8	348
Salinity	32.68±0.48	31.86-34.09	240	32.48±0.65	28.90-33.67	347
Chlorophyll *a*	0.81±0.79	0.09-5.53	104	0.81±0.81	0.16-4.40	182
Nitrate	2.95±2.83	0.51-10.25	108	2.84±3.01	0.12-17.35	180
Phosphate	0.17±0.05	0.06-0.45	108	0.17±0.14	0.01-1.19	182
Silicate	5.92±3.28	0.93-14.96	108	8.03±4.89	1.67-20.88	182
	Oct. 1997			Dec. 1997		
Parameter	aver±sd	range	n	aver±sd	range	N
Temperature	16.7±4.0	7.1-21.5	326	10.6±0.9	8.1-12.9	266
Salinity	32.59±0.48	30.18-33.51	326	32.62±0.25	32.04-33.22	266
Chlorophyll *a*	0.62±0.51	0.01-2.69	153	0.73±0.33	0.15-2.21	135
Nitrate	3.22±3.27	0.01-10.60	152	2.37±0.85	0.15-4.78	133
Phosphate	0.09±0.09	0.03-0.86	157	0.11±0.09	0.01-0.55	133
Silicate	7.86±4.77	0.51-17.14	154	10.86±3.02	4.77-19.52	133
	Feb. 1998			Apr. 1998		
Parameter	aver±sd	range	n	aver±sd	range	N
Temperature	7.4±1.6	3.9-12.2	284	8.3±1.3	5.7-11.3	333
Salinity	32.92±0.24	32.26-33.84	284	32.87±0.26	31.75-33.76	333
Chlorophyll *a*	0.68±0.52	0.05-3.38	127	2.02±2.27	0.05-16.79	189
Nitrate	5.40±1.91	1.88-14.03	130	3.30±3.39	nd-15.65	191
Phosphate	0.56±0.09	0.20-0.81	130	0.19±0.16	0.01-1.74	191
Silicate	10.71±3.65	1.53-19.07	130	4.19±2.06	0.66-11.32	191

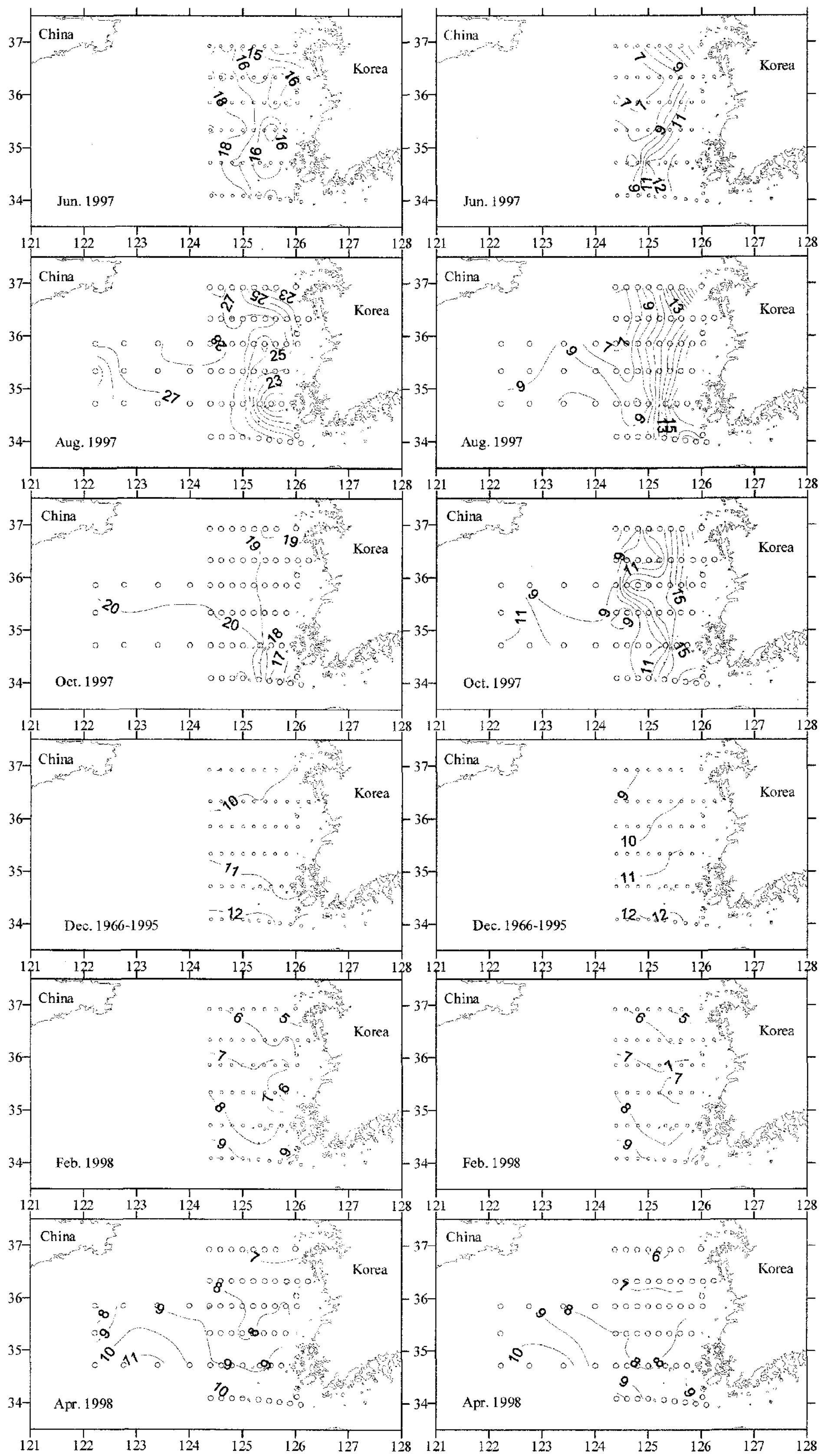


Fig. 2. Horizontal distribution of temperature at 10 (left) and 50 m depth (right) during the study period.

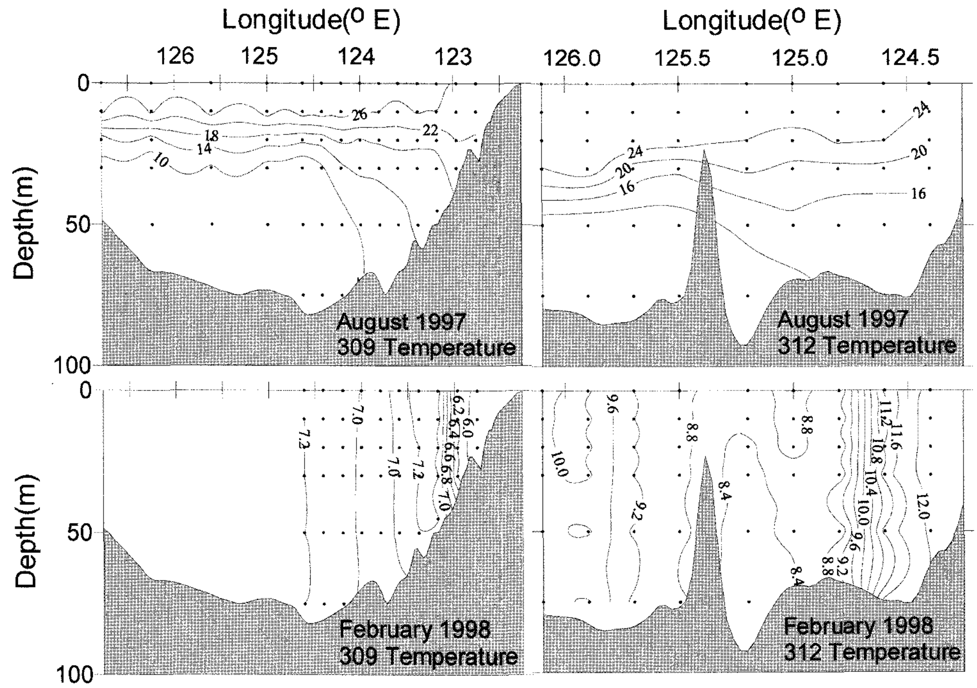


Fig. 3. Vertical section of temperature along the 309 and 312 lines in August 1997 and February 1998.

in August and disappearing in December. In August, thermocline was around 20 m depth in the Line 309 and 40 m depth in the Line 312. Temperatures in the bottom layer of the Line 309 was colder than that of the Line 312 (Fig. 3), indicating mixing of YSBCW with YSWC in the southern area. In February the water column was well mixed by surface cooling and strong monsoonal wind in both lines. In the Line 309 in both periods, relatively sharp gradients were noted between coastal and offshore areas. In the Line 312, however, weak gradient was detected in August probably because of the gentle slope of bottom, and in February both ends were warmer than the central part because of the YSWC intrusion.

Salinity

Salinity was highest in February and lowest in August (Table 1). Vertical variation of salinity was larger during June-October than during December-April. Salinities of the 50-75m depth were always higher than those of upper layers. In all the depths, salinities were low in the northeastern and central western areas, and high in the southern area (Fig. 4). Less saline water was found at the surface layer in the south-central area in August and persisted until October due to the CRDW influence. Water with high salinity at the surface around Heuksan Is. in August was formed by tidal mixing of the YSBCW.

The vertical sections of salinity showed variations not only between surface and bottom layers, and between coastal and offshore areas (Fig. 5), but also between survey lines. In August, halocline of about 2 psu was recorded at the 10-30 m depth in the Line 309 with less saline surface water in the western offshore area. In the Line 312, more diluted water was observed confirming existence of the CRDW. In February, the water column was well mixed and sharp gradient of salinity was observed between coastal and offshore areas. It was noted that coastal water of the Line 309 was more saline than the offshore one and the reverse for the Line 312 due to the intrusion of the saline YSWC.

Chlorophyll *a*

Chlorophyll *a* concentration showed two-fold variation during the study period (Table 1), highest in April and lowest in October. Maximum chlorophyll *a* layer was in the middle or bottom layer and never found in the surface layer. High chlorophyll *a* concentration was observed at stations near the coastal area. In April, the highest concentration was recorded in the central offshore area at 10 and 50 m (Fig. 6).

The vertical profile of chlorophyll *a* concentration in August and February in the Line 309 showed that it was

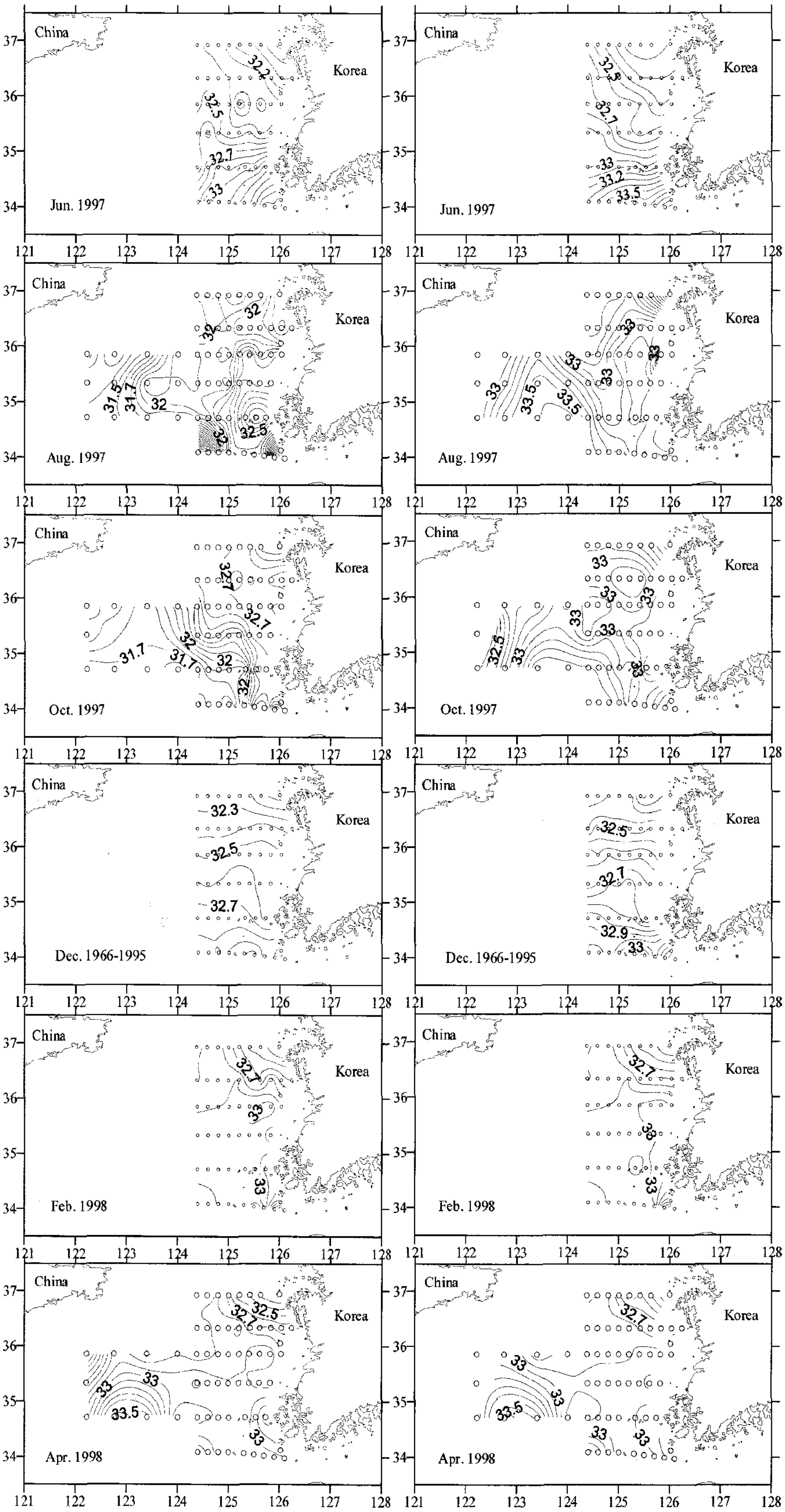


Fig. 4. Horizontal distribution of salinity at 10 (left) and 50 m depth (right) during the study period.

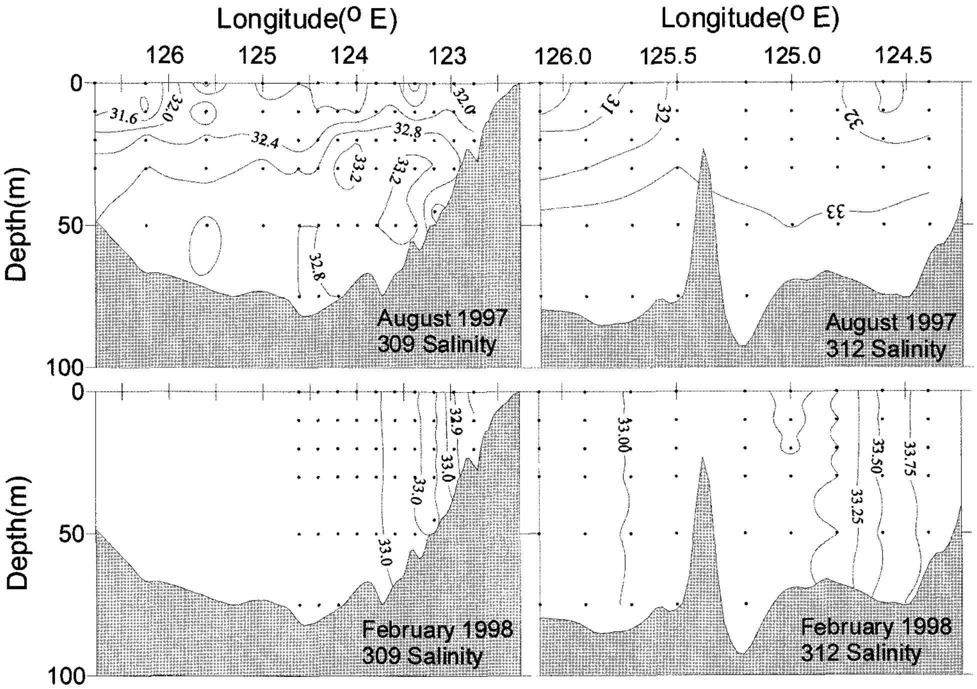


Fig. 5. Vertical section of salinity along the 309 and 312 lines in August 1997 and February 1998.

high in coastal areas with maximum concentration at 10 m in August and 50 m depth in February (Fig. 7). In the Line 312, however, concentration was high in the middle or in the bottom layers in August, and in the middle layer in February.

Nutrients

Nitrate concentration was high in February and low in August (Table 1). During June-October, nitrate concentrations in the upper layer were higher at stations near the coastal area than those of offshore areas, whereas in December-April, the difference between two areas was not evident. Distribution pattern of nitrate of the bottom layer was different from that of the upper layer; higher concentrations were found in the central offshore or in the southern central areas (Fig. 8). Phosphate concentration was highest in February and lowest in October (Table 1). Spatial distribution was relatively homogenous with slightly higher concentration in the southern area (Fig. 9). Silicate concentration was highest in December and lowest in April (Table 1). The values were high in the coastal or southern area for the upper layer, and central or southern areas for the bottom layer (Fig. 10). Vertical stratification of nutrients started in April, reached its maximum intensity in August, and disappeared in December.

Euphausiid community structure

In the study area, 4 species of euphausiids were identified: *Euphausia pacifica*, *Pseudeuphausia* sp., *Stylocheiron affine*, *E. sanzoi* (Table 2). Among them *E. pacifica* represented 99.5% of abundance on an annual basis with the least proportion recorded in June (97.6 %). The proportion and dominance of each developmental stage varied with time; adults were the most abundant in August and the least in December, furcilia the most abundant in June and the least in October, and calyptopis the most abundant in April and the least in October. Egg numbers were highest in April (average=131.9 eggs m^{-3}), dropped sharply in June (14.6 eggs m^{-3}) and were at their lowest in December (1.2 eggs m^{-3}). Daytime abundance of adult, furcilia, and calyptopis represented 35, 77, and 81% of night-time abundance, respectively, indicating intrinsic sampling error, notably for adults. *Pseudeuphausia* sp. was the second most abundant species but the abundance was considerably small compared to *E. pacifica* (Table 2). Their maximal abundance was in August. The other two species, *S. affine* and *E. sanzoi*, were observed only once during the study period: *S. affine* in December and *E. sanzoi* in June (Table 2).

The horizontal distribution of euphausiids varied with time. In April-October, *E. pacifica* adults were abundant

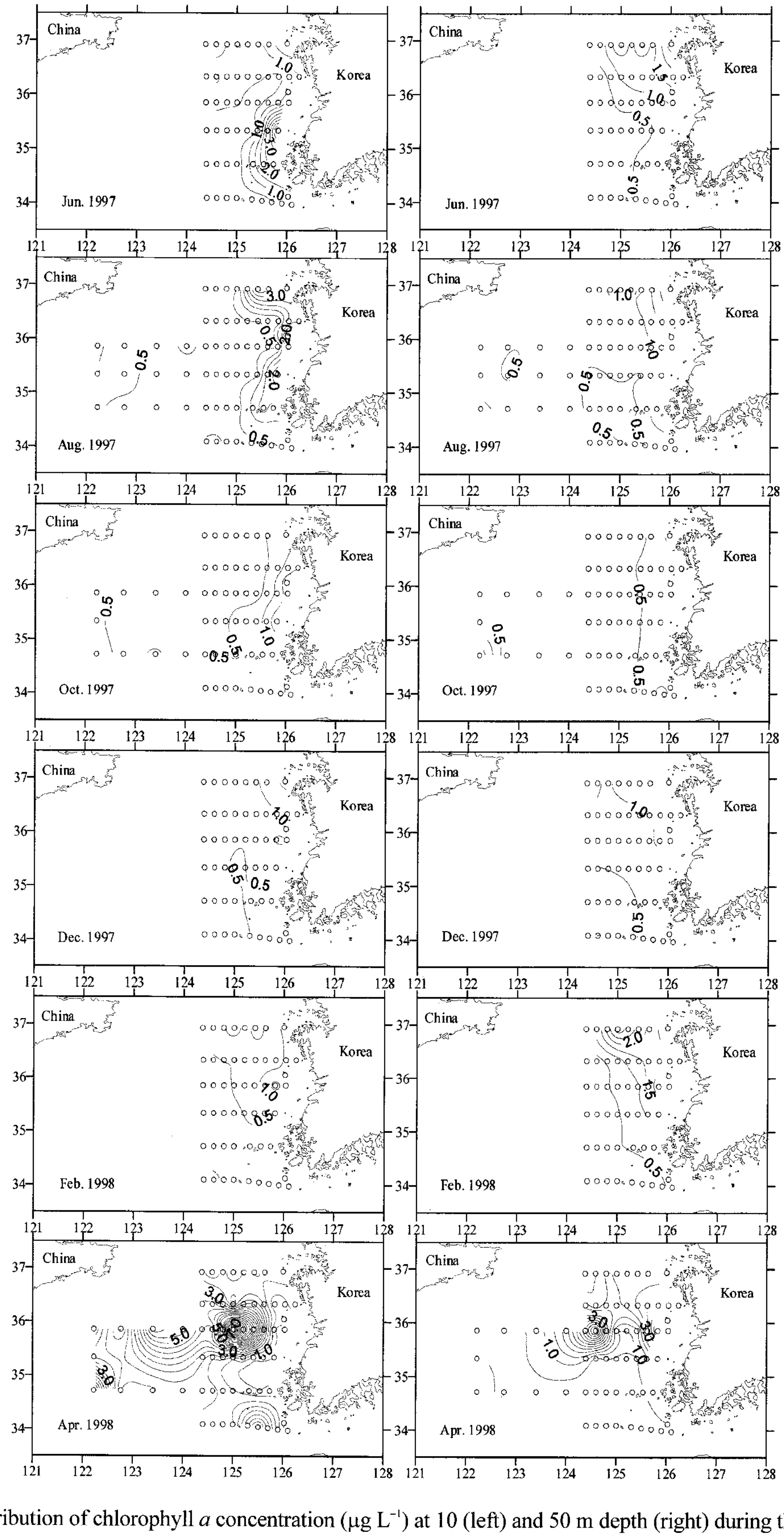


Fig. 6. Horizontal distribution of chlorophyll *a* concentration (μg L^{-1}) at 10 (left) and 50 m depth (right) during the study period.

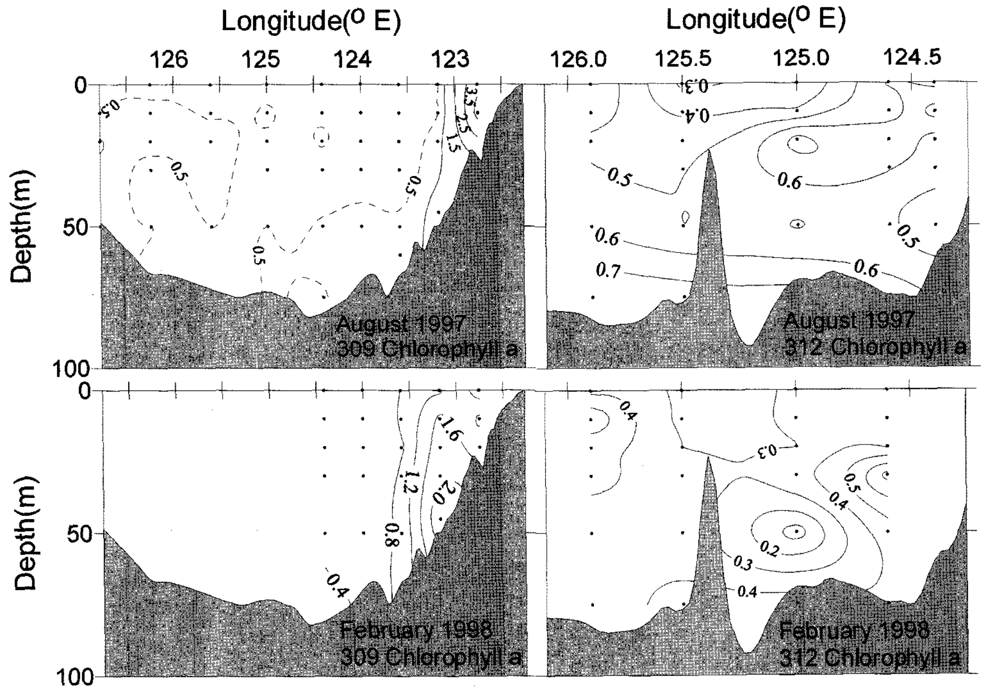


Fig. 7. Vertical section of chlorophyll *a* concentration (μg L^{-1}) along the 309 and 312 lines in August 1997 and February 1998.

in the central area around the diagonal axis of northwest to southeast, with none or small abundance at stations near the eastern and western coastal areas, where, however, a relatively large number of adults was recorded in December-February (Fig. 11a). Distributions of furcilia and calyptopis were very similar with those of adults and extended into nearly all of the study area (Fig. 11b, 11c). In August-October, they were not found in the northeastern coastal area and were rare in the central area, and their abundance was larger in the northern or central area than in the southern one, notably during December-April. The eggs were found nearly throughout the study area in April-June (Fig. 11d), and thereafter, their appearance was limited to the northern and central areas.

Pseudeuphausia sp. was observed only in the southeastern area in small quantities (Fig. 11e). It was absent in June. *S. affine* and *E. sanzoi* were observed only once in the southern area in June and December, respectively.

Statistical analysis

Spearman's correlation was used to identify the relationship between the distribution pattern of *E. pacifica* and the environmental variables, using the bimonthly data.

Among the 6 environmental factors tested for correlation, 5 of them followed similar variation along the sampling time and developmental stages. They were temperature, salinity, nitrate, silicate, and phosphate concentration: positive relationship for adult, and negative for furcilia and calyptopis. Only one factor, chlorophyll *a* concentration, showed a changing trend according to the developmental stages: all negative relationships for adult, equally positive and negative for furcilia, and all positive for calyptopis. The nutrient influence on euphausiid distribution should be indirect via chlorophyll *a* and phytoplankton concentration.

4. Discussion

Due to the shallow depth of the Yellow Sea, the water column responds rapidly to any weather change, and the water mass exchange is fairly limited due to the semi-enclosure between two lands (turnover rate: 5-6 years, Lee *et al.* 2002). So the air temperature strongly influences the seawater temperature with lag of less than one month, then the stratification and de-stratification of the water column. Kang *et al.* (1994) reported that even with large variations in salinity and temperature in the Yellow Sea, isotopic composition of seawater in summer and winter did not indicate significant seasonal difference, showing a

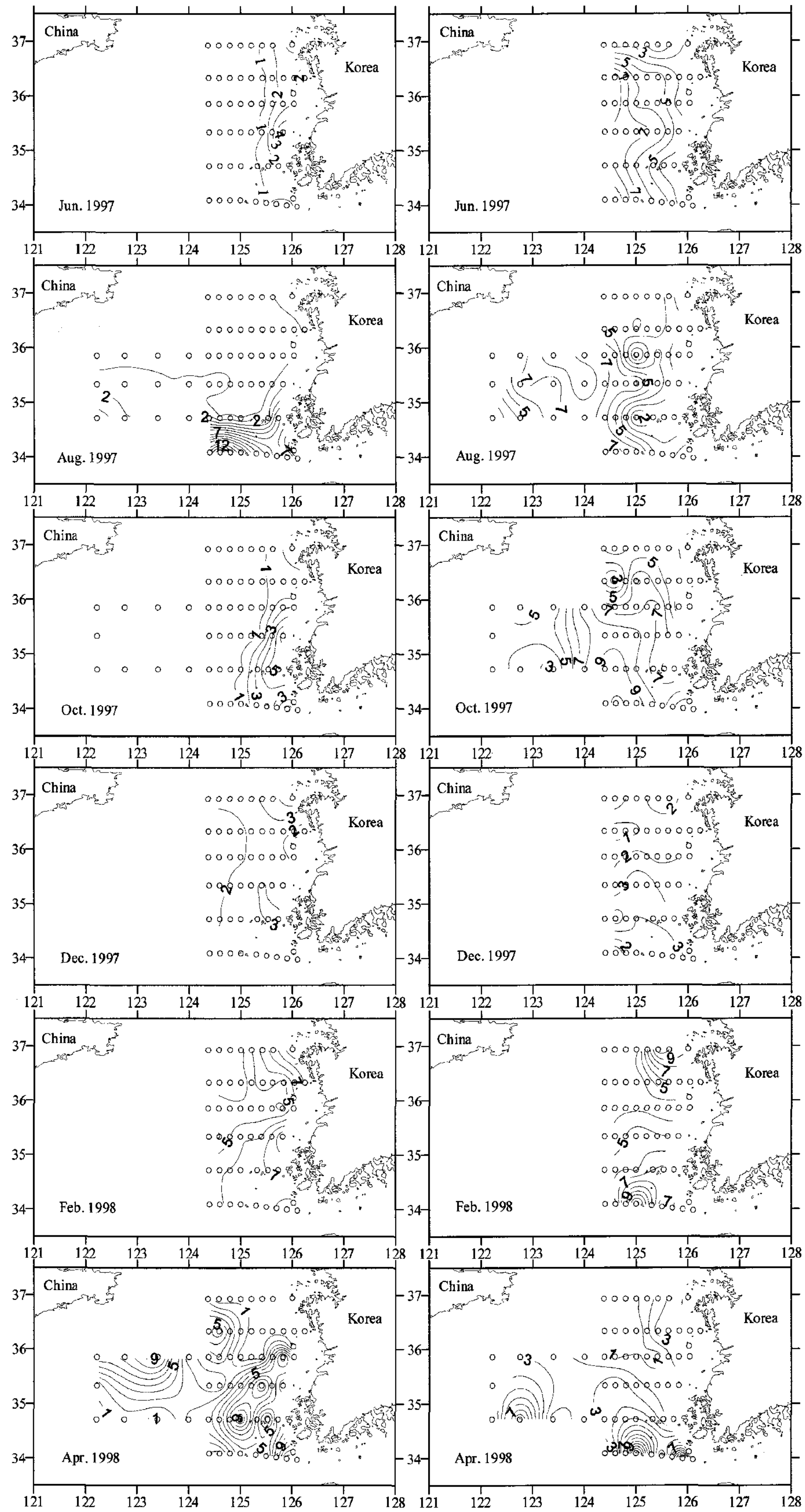


Fig. 8. Horizontal distribution of nitrate concentration (μM) at 10 (left) and 50m depth (right) during the study period.

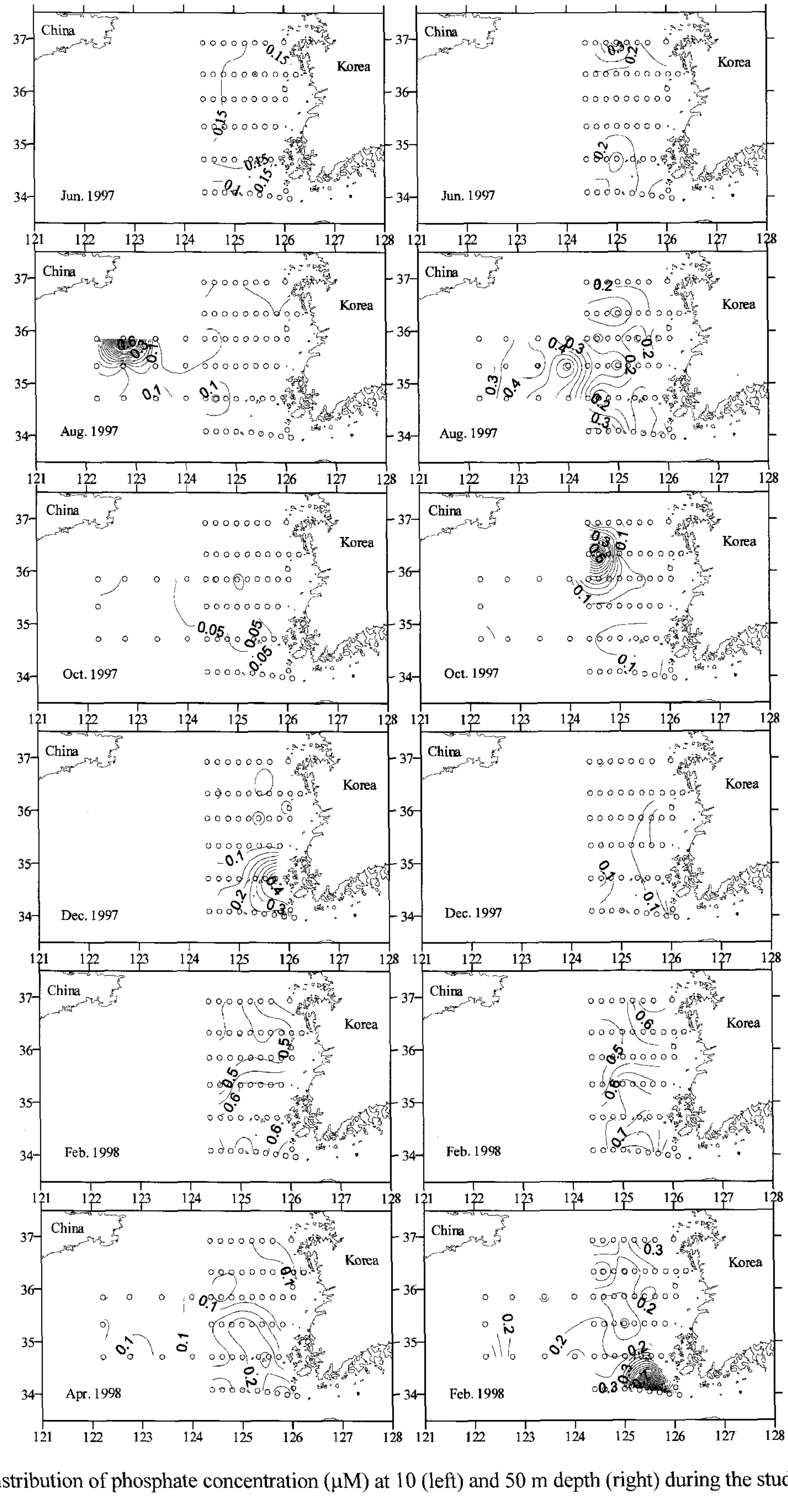


Fig. 9. Horizontal distribution of phosphate concentration (μM) at 10 (left) and 50 m depth (right) during the study period.

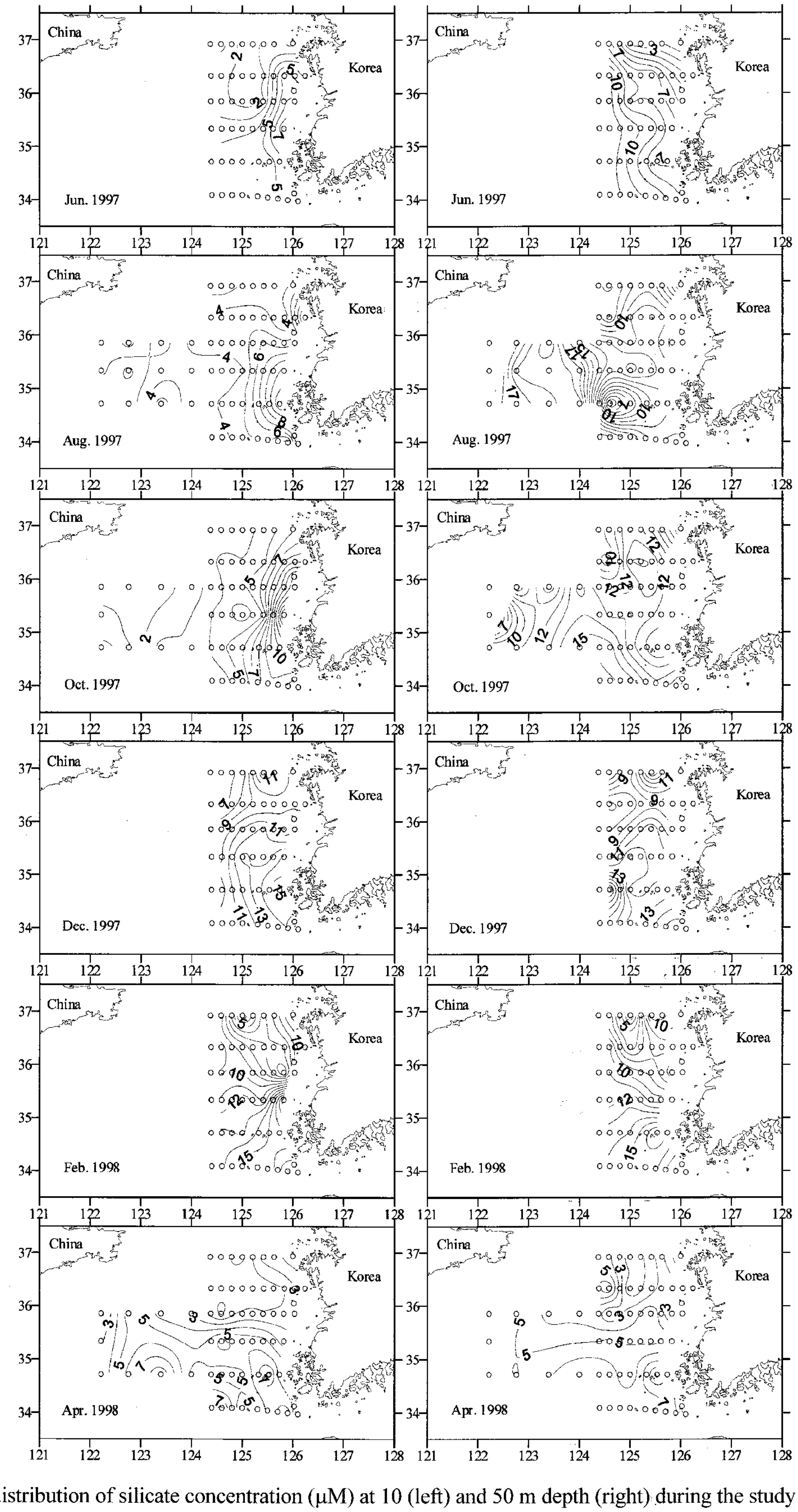
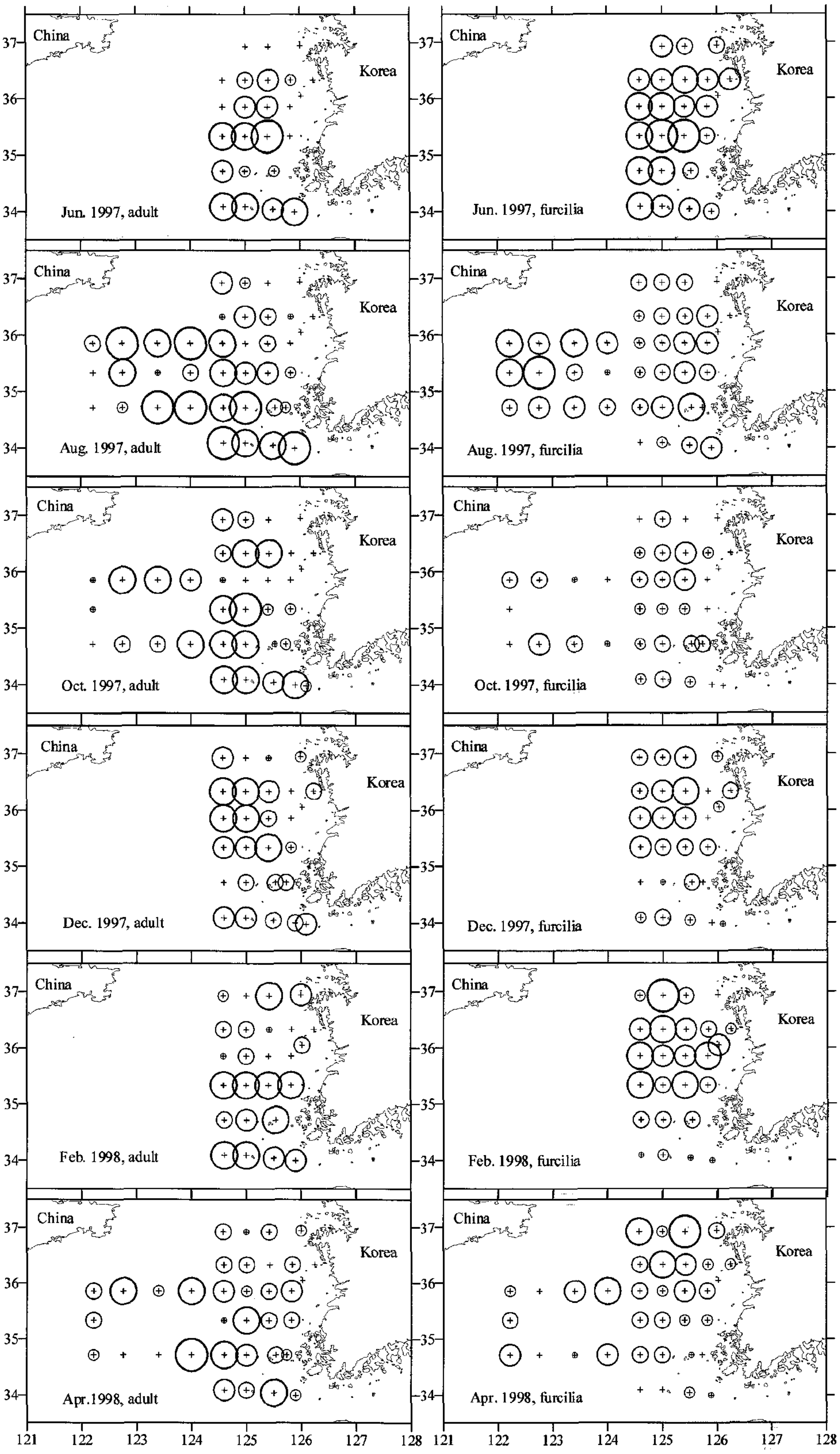


Fig. 10. Horizontal distribution of silicate concentration (μM) at 10 (left) and 50 m depth (right) during the study period.

Table 2. Abundance and proportion (%) of euphausiids collected in the study area

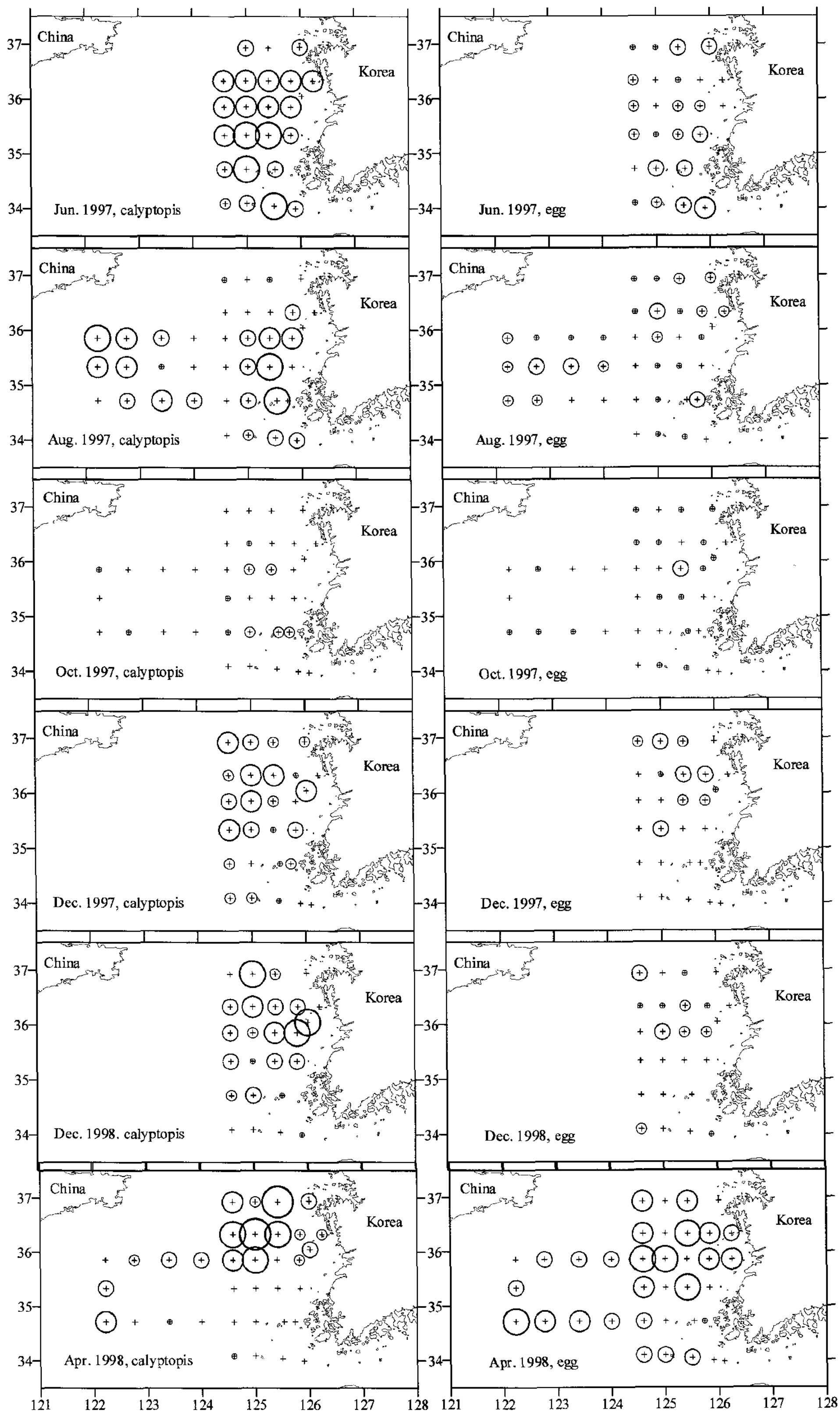
		Abundance (inds 100 m^{-3})			% in euphausiids Community
		Average	sd	Highest	
Jun. 1997	*Euphausia pacifica* adult	171	276	1156	26.5
	furcilia	331	395	1464	51.4
	calyptopis	142	210	1011	22.1
	Pseudeuphausia sp.	-	-	-	-
	Stylocheiron affine	-	-	-	-
	Euphausia sanzoi	0.1	0.3	1.4	0.01
Aug. 1997	*Euphausia pacifica* adult	454	828	3907	70.1
	furcilia	129	225	1292	19.9
	calyptopis	60	117	533	9.2
	Pseudeuphausia sp.	5	25	153	0.8
	Stylocheiron affine	-	-	-	-
	Euphausia sanzoi	-	-	-	-
Oct. 1997	*Euphausia pacifica* adult	306	669	3781	94.7
	furcilia	21	31	144	4.3
	calyptopis	2	4	15	0.4
	Pseudeuphausia sp.	3	10	41	0.6
	Stylocheiron affine	-	-	-	-
	Euphausia sanzoi	-	-	-	-
Dec. 1997	*Euphausia pacifica* adult	110	150	513	55.5
	furcilia	55	81	322	27.9
	calyptopis	28	40	146	14.2
	Pseudeuphausia sp.	5	13	57	2.3
	Stylocheiron affine	0.2	1	5	0.1
	Euphausia sanzoi	-	-	-	-
Feb. 1998	*Euphausia pacifica* adult	205	274	838	40.7
	furcilia	212	294	999	42.1
	calyptopis	86	218	1008	17.0
	Pseudeuphausia sp.	1	4	19	0.2
	Stylocheiron affine	-	-	-	-
	Euphausia sanzoi	-	-	-	-
Apr. 1998	*Euphausia pacifica* adult	143	255	1120	30.3
	furcilia	131	408	2355	27.8
	calyptopis	196	565	2953	41.8
	Pseudeuphausia sp.	0.4	1	6	0.1
	Stylocheiron affine	-	-	-	-
	Euphausia sanzoi	-	-	-	-

simple mixing trend resulting from solar heating at the sea-air interface. The T-S diagrams from our study confirm their findings (Fig. 12): water masses were homogenous throughout the study period except in August. Since April, the offshore upper layer of the study area warmed up and thermocline began to be formed, and with air temperature still increasing, the stratification intensified and reached its maximum intensity in August. Due to the presence of thermocline the water column was clearly separated into upper and bottom layers. The upper layer had higher temperature, lower salinity, lower chlorophyll *a* concentration, and lower nutrient concentration. The bottom layer preserving water characteristics of the last cold season (December-February) had lower temperatures (<12°C) and higher salinities (>32.5 psu). This YSBCW (Lie 1984) persisted until December and disappeared with



a) *E. pacifica* adult b) *E. pacifica* furcilia

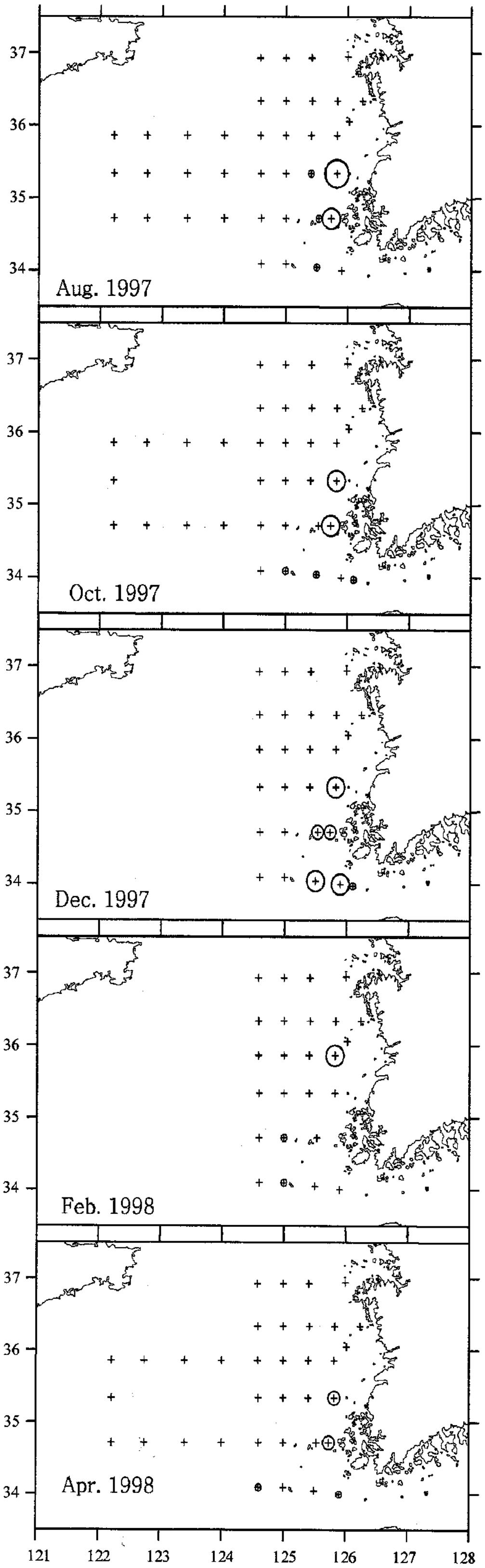
Fig. 11. Horizontal distribution of euphausiids in the study area.



c) *E. pacifica* calyptopis

d) *E. pacifica* egg

(Fig. 11. Continued.)



e) *Pseudeuphausia* sp.

(**Fig. 11.** Continued.)

water mixing. This water mass could be characterized by its high concentration of nutrients: in August, 1997, nitrate concentration of the 75 m depth was about 15 times higher, phosphate 5 times higher, and silicate 3.2 times higher than those of the surface, whereas in February, 1998, the concentrations were markedly similar. The accumulation of these nutrients in the bottom layer was of course due to the presence of the intensified thermocline. This thermocline indeed acts as a real physical barrier, allowing the passage from the upper to the bottom, but not from the bottom to the surface. Then, owing to the low concentration of nutrients, chlorophyll *a* concentration was low in the upper layer of strong thermocline. Subsurface chlorophyll *a* maximum layer was in the 10-30 m depth during the warm season, and nano- and pico-sized phytoplankton contributed a high proportion of the chlorophyll *a* and primary production in this offshore area (Choi 1991). The zooplankton community was composed mainly of large copepods such as *Calanus sinicus* (Lim *et al.* 2003) and euphausiids (Yoon *et al.* 2000).

The coastal area, on the other hand, was always well mixed all year-round by strong tidal currents, and thermocline was not found at all. The chlorophyll *a* and nutrient concentrations were high. Son *et al.* (1989) showed also high bacterial concentration in the coastal area compared to the offshore area of the Yellow Sea. In some areas tidal front was developed (Lie 1989) and high primary production based on diatom species was recorded (Choi 1991). The zooplankton community was composed of small copepods, such as *Acartia hongi*, and *Oithona similis* (Lim *et al.* 2003).

The composition of euphausiids of the Yellow Sea was extremely simple compared to the adjacent seas. Hong (1969) collected 10 species around the Korean peninsula, including the Yellow Sea with *E. pacifica*, *E. nana*, and *P. latifrons*. Yoon *et al.* (2000) reported the dominance of *E. pacifica* in the Yellow Sea. In the present study, we sampled *E. pacifica*, *Pseudeuphausia* sp., *Stylocheiron affine* and *E. sanzoi*. We consider, however, that *Pseudeuphausia* sp. should be *Pseudeuphausia sinica*, taking into account the previous reports in the Yellow Sea (Suh 1990; Chen 1991; Lee *et al.* 1998). *S. affine* and *E. sanzoi* were sampled just one specimen each, representing less than 0.01% of the euphausiid community of the study area. They were known as species of the Pacific central water mass and as a boundary or slope species of the tropical western sides of

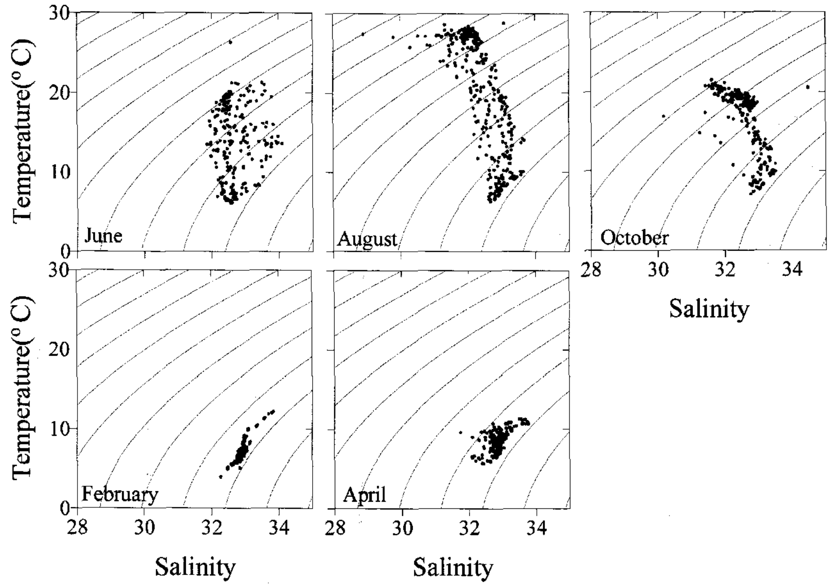


Fig. 12. T-S diagrams of the Yellow Sea from June 1997 to April 1998.

the Pacific and Indian oceans, respectively (Brinton 1975). Brinton (1975) reported also occurrence of these two species in the South China Sea. Hong (1969) sampled *S. affine* in the South Sea of Korea near Jeju Island, located on the route of Tsushima Current. The second most numerous euphausiid in the study area, *Pseudeuphausia* sp. (presumed *P. sinica*), represents, however, less than 1% of the euphausiid community. This species is known to be confined to the tropical western Pacific and Indian Oceans, and occurs in the eastern coastal regions of Japan, the East Sea of Korea, the East China Sea, and the South China Sea (Mauchline and Fisher 1969). According to Brinton (1975), *P. latifrons* was absent in areas where the surface salinity was less than 31 psu. In his study area (Gulf of Thailand), the suitable temperature and salinity range for larvae were 27-30°C and 31-34 psu, respectively, and their reproduction was during December-March. The present results confirms their occurrence in the Yellow Sea as reported by Hong (1969) and Yoon *et al.* (2000), and further, shows their seasonal distribution. The common characteristic of these 3 species is that they are resident in subtropical or tropical areas, for which the seasonal temperature and salinity variations are quite small compared to those of the Yellow Sea. In the present study, the first two species were just one juvenile specimen each, and *Pseudeuphausia* sp. were composed of juveniles collected mainly in the central eastern coastal area and adults collected in the southernmost areas. This southernmost area is the mixing area of YSWC, the East China Sea Water, CRDW, and YSBCW, each with its original physico-chemical properties that were easily distinguishable from each other (Lie 1984; Seung 1992; Su and Wong 1994; Pang and Oh 1995). In accordance with these physical and chemical studies' results, even though they did not show the seasonal flow intensity and direction, we speculate that the three euphausiids unfortunately intruded into and were not residents of the Yellow Sea. One of them, *Pseudeuphausia* sp. could survive (in summer, thanks for the high temperature) for a relatively long time but it could never be able to reproduce in the Yellow Sea.

The fourth, *E. pacifica*, is the dominant species in the Yellow Sea, representing more than 97.6% of the euphausiid community. This species is restricted to the North Pacific and occurs across the southern part of the Bering Sea, in the southern part of the Sea of Okhotsk, the East Sea of Korea southwards to about 30°N. The southern limit of its distribution is 9.5°C isotherm at 200 m depth (Mauchline and Fisher 1969). Hong (1969) sampled this species in the eastern area of the Yellow Sea in February-March, 1967. In the same area, and in summer and winter, Yoon *et al.* (2000) reported the predominance of this species and suggested that the temperature and chlorophyll *a* concentration would be the principal factors affecting the distribution pattern. In the present study we could confirm the predominance of *E. pacifica* in the Yellow Sea all year round and showed that the temperature and salinity are the main influencing factors of *E. pacifica* distribution, which differs slightly from the results of Yoon *et al.* (2000). We showed also the changing relationship of *E. pacifica*'s abundance with chlorophyll *a* concentration, for which we suggest that the egg and larval stages spread out passively to the coastal area of higher chlorophyll *a* concentration and that with growth they return to the water mass of poor chlorophyll *a* concentration, probably with a feeding regime shift from phytophagous to omnivorous.

Hypothetical scenario of seasonal variation of the spatial distribution of *E. pacifica* in the Yellow Sea

In this hypothetical scenario, some environmental factors take the main role, in particular the cooling and warming of the surface layer, and resultant intensification and weakening of thermocline. YSBCW and YSWC (Feng 1998) also affect the distribution pattern of *E. pacifica*. We also suppose that the vertical migration pattern varies with developmental stages: eggs and calyptopis are non-migrator, furcilia limited migrator, and adults fully vertical migrator.

In April, adults of *E. pacifica* stay in the coastal areas where food is abundant and spawn. Eggs and larvae are spread into the whole Yellow Sea but gathered in the northern Yellow Sea due to YSWC [direction and intensity of YSWC changes with the presence of YSBCW (Feng 1998) and with seasons (Pang and Oh 1995)]. Furcilia, capable of moving and migrating, extend further their distribution into the whole Yellow Sea. In June, thermocline is developed to a certain extent. Temperature is not limiting yet and distribution pattern of adults is similar to that of April. Some adults reproduce and similar pattern of distribution to those of April for eggs, calyptopis, and furcilia occurs. With continuous warming, in August, the thermocline is fully developed. Adults are totally regressed into the YSBCW or spread out into the northern and southern areas where the water depths are high enough to avoid the deleterious surface warming effect. Always migrating, some of the adults produce eggs. Non-migrating calyptopis, drifting into areas of high chlorophyll *a*, and furcilia can return to its distribution in the area near the YSBCW. Seawater temperature begins to descend in October. However, due to the still high temperature of the surface layer down to the thermocline, adults resided nearly in the same area as in August. Reproduction activity is very weak. Eggs, calyptopis, and furcilia show the distribution pattern forced by water mass movement and by their biological characteristics. With intensified surface cooling in December, adults can extend their distribution into the coastal area. In February, the water column is completely mixed, and adults spread out into the whole area, with limited extension into the northern area due to the low temperature (<8°C). This cycle of spatial distribution may occur annually.

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References

Baker, A. de C., B.P. Boden, and E. Brinton. 1990. A practical guide to the euphausiids of the world. Nat. History Mus. Pub., London. 96 p.

Boden, B.P., M.W. Johnson, and E. Brinton. 1955. The Euphausiacea (Crustacea) in the North Pacific. *Bull. Scrips Inst. Oceanogr.*, **8**, 287-400.

Brinton, E. 1975. Euphausiids of southeast asian waters. Naga Report Vol. 4, Part 5. 287 p.

Brinton, E. 1976. Population biology of *Euphausia pacifica* off Southern California. *Fish. Bull. U.S.*, **74**, 733-762.

Chen, G. 1991. Marine Atlas of Bohai Sea, Yellow Sea and East China Sea: Biology. China Ocean Press, Beijing. 250 p.

Choi, J.K. 1991. The influence of the tidal front on primary productivity and distribution of phytoplankton in the mid-eastern coast of Yellow Sea. *J. Oceanol. Soc. Kor.*, **26**, 223-241.

Feng, S. 1998. On circulation in Bohai Sea, Yellow Sea and East China Sea. p. 43-77. In: *Health of the Yellow Sea*, ed. by G.H. Hong, J. Zhang, and B.K. Park. The Earth Love Publication Association, Seoul.

Guan, B.-X. 1994. Patterns and structures of the currents in Bohai, Huanghai and East China Seas. p. 17-26. In: *Oceanology of China Seas,* Vol. 1., ed. by D. Zhou, Y.-B. Liang, and C.-K. Zeng. Kluwer Academic Publishers.

Hong, S.Y. 1969. The euphausiids crustacean of Korean waters. p. 291-300. In: *The Kuroshio (a symposium on the Japan Current)*, ed. by J.C. Marr. University of Hawaii Press.

Ito, J. 1964. Food and feeding habit of Pacific salmon (genus

Oncorhynchus) in their oceanic life. *Bull. Hokkaido Reg. Fish. Lab.*, **29**, 85-97.

Kang, D.-J., C.S. Chung, S.H. Kim, G.H. Hong, and K.R. Kim. 1994. Oxygen isotope characteristics of seawaters in the Yellow Sea. *La Mer*, **32**, 279-284.

Komaki, Y. 1967. On the surface swarming of euphausiid crustacean. *Pac. Sci.*, **21**, 433-448.

Lee, J.H., B.W. An, and G.H. Hong. 2002. Water residence time for the Bohai and Yellow seas. p. 385-401. In: *Impact of Interface Exchange on the Biogeochemical Processes of the Yellow and East China seas*, ed. by G.H. Hong, J. Zhang, and C.S. Chung. Bum Shin Press, Seoul.

Lee Y.C., Y.S. Qin, and R.Y. Liu. 1998. Yellow Sea Atlas. Ho Young Publishing Company, Seoul. 524 p.

Lie, H.-J. 1984. A note on water masses and general circulation in the Yellow Sea (Hwanghae). *J. Oceanol. Soc. Kor.*, **19**, 187-194.

Lie, H.-J. 1989. Tidal fronts in the southeastern Hwanghae (Yellow Sea). *Cont. Shelf Res.*, **9**, 527-546.

Lim, D., W.D. Yoon, S.H. Cho, and Y. Lee. 2003. Spatio-temporal distribution of zooplankton in the Yellow Sea. p. 159-169. In: *Biological Oceanography in Korea,* ed. by J.K. Choi. Dong-Hwa Press. (In Korean)

Mauchline, J. 1980. The biology of euphausiids. *Adv. Mar. Biol.*, **18**, 370-637.

Mauchline, J. and L. R. Fisher. 1969. The biology of euphausiids. *Adv. Mar. Biol.*, **7**, 454 p.

Pang, L.-C. and I.S. Oh. 1995. Warm water circulation and its origin by sea level fluctuation and bottom topography. *J. Kor. Fish. Soc.*, **28**, 677-697. (In Korean)

Parsons, T.R., Y. Maita, and C.M. Lalli. 1984. A manual of chemical and biological methods for seawater analysis. Pergamon, Oxford. 173 p.

Ponomareva, L.N. 1963. Euphausiids of the North Pacific, their distribution and ecology. Institut Okeanologii, Academiy a Nauk SSSR. (Translated by Israel Program for Scientific Translations, Jerusalem 1966, ISTP catalog no. 1368) 154 p.

Ross, R.M. 1981. Laboratory culture and development of *Euphausia pacifica. Limnol. Oceanogr.*, **26**, 235-246.

Seung, Y.H. 1992. Water masses and circulations around Korean peninsula. *J. Kor. Soc. Oceanogr.*, **27**, 324-331. (In Korean)

Son, S.K., K.H. Chung, J.S. Jo, and Y.C. Park. 1989. Seasonal variation of nutrients, total dissolved free amino acids and bacterial biomass in the Yellow Sea. *Yellow Sea Res.*, **2**, 1-12. (In Korean)

Su, Y.-S. and X.-C. Wong. 1994. Water masses in China Seas. p. 3-16. In: *Oceanography in the China Seas*, *v. 1.*, ed. by D. Zhou, Y.-B. Liang, and C.-K. Zeng. Kluwer Academic Publishers.

Suh, H.-L. 1990. *Pseudeuphausia sinica* (Euphausiacea, Crustacea): A new record from the Korean waters. *Bull. Kor. Fish. Soc.*, **23**, 65-67.

Yoon, W.D., S.H. Cho, D. Lim, Y.K. Choi, and Y. Lee. 2000. Spatial distribution of *Euphausia pacifica* (Euphausiacea: Crustacea) in the Yellow Sea. *J. Plankton Res.*, **22**, 939-949.