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STUDIES ON THE SEASONAL VARIATIONS OF PLANKTON ORGANISMS AND SUSPENDED PARTICULATE MATTER IN THE COASTAL AREA OF KO-RI*

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ABSTRACT

Densities and composition of phytoplankton and zooplankton, concentrations of particulate organic carbon, particulate organic nitrogen, and particulate inorganic matter were determined in the coastal area of Ko-ri during one year. There are peaks of densities of plankton organisms in summer, autumn, and spring. Concentrations of particulate organic carbon ranged from 35 to 3,785 mg/m^3 (averaging 868 mg/m^3), particulate organic nitrogen ranged from 4.4 to 158 mg/m^3 (averaging 45 mg/m^3), inorganic suspended matter ranged from 0.6 to 11.6 mg/L (averaging 5.7 mg/L), and the carbon-nitrogen ratios of the suspended matter were varied from 0.5 to 231 (averaging 35), with each seasonal cycle. The phytoplankton density and particulate organic carbon were possitively correlated from March to November, negatively from December to February, and the zooplankton density and particulate organic nitrogen were well correlated.

INTRODUCTION

In recent year, a considerable knowledge on the suspended particulate matter in the sea has been accumulated by many authors (Armstrong and Atkins, 1950; Jerlov, 1951 and 1953; Hanaoka, 1952; Riley, 1959; McAllister et al., 1960; Krey, 1961; Parsons and Strickland, 1962; Dal Pont and Newell, 1963; Parsons, 1963; Menzel and Goering, 1966; Nishizawa, 1966; Buchan et al., 1967; Menzel, 1967; Saijo, 1969 etc.). However, all of these studies are concerned with the offshore and ocean waters, little is known with the inshore and coastal waters. Plankton and suspended organic matter of marine environments are both important in view of their fundamental position in the marine food chain. The food potential of a given area is estimated by analyzing the temporal variation of the amount and type of marine plankton and detritus present in the standing crop. Studies on the ecology of shallow water plankton have shown there is a seasonal cycle in production correlated with the hydrographical conditions of the area, and the concentration and distribution of the suspended particulate matter depend on the whole entrance of terrigenous materials, regional biotic fauna and flora, and hydrodynamical conditions. Therefore regional and seasonal incidences of the suspended particulate matter in the shallow water are apparently more complexed than our expectation.

Choe and Chung (1966) studied the primary production of the coastal water of Korea, and Choe (1967 and 1969) also studied the phyto-

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plankton production in inshore and offshore waters of Korea. However, nothing has been reported on the plankton and suspended particulate matter of the coastal area of Ko-ri. The overall objective of this study is an evaluation of the nature and extent of the suspended particulates including plankton organisms in the open coastal water of the Sea of Japan. In addition at Ko-ri, a nuclear power plant is to be located in near future. This study will provide data on the plankton standing crops, seasonal succession and variation of suspended particulates which existed before operation of the power plant, and serve as a comparison for future plankton and suspended matter investigations that may be carried out after the power plant is completed and operating.

DESCRIPTION OF STUDY AREA

Ko-ri (129°17′ E, 35°19′ N) is located on the south-eastern coast of Korea bordering the Sea of Japan, about 20 miles northeast of Busan and 16 miles south of Ulsan (Fig. 1). Average tidal current is relatively high (Choe and Chung, 1970). and the average tidal amplitute is about 1.0 m. Much of the bay area is only a few meters deep at low tide and there are extensively developed *Zostera marina*, and other areas dominated by *Undaria pinnatifida* and other algae.

MATERIALS AND METHODS

Samples were collected monthly from May 1969 to April 1970, from 10 stations along 5 and 12 m contours (Fig. 1). Monthly phytoplankton samples (500 ml) were collected with Kitahara's water bottle from the middle layer of each station, and zooplankton samples were collected using a Kitahara's quantitative plankton net by the vertical haul from the bottom to the surface. These plankton samples were preserved in neutralized formalin, and cell and individual counts were made at the laboratory.

Samples of suspended particulate matter were collected with the Kitahara's water bottle, 4 liters capacity at each station. Suspended particulates were separated by filtering each one liter of sea water through Millipore filter (AA type,

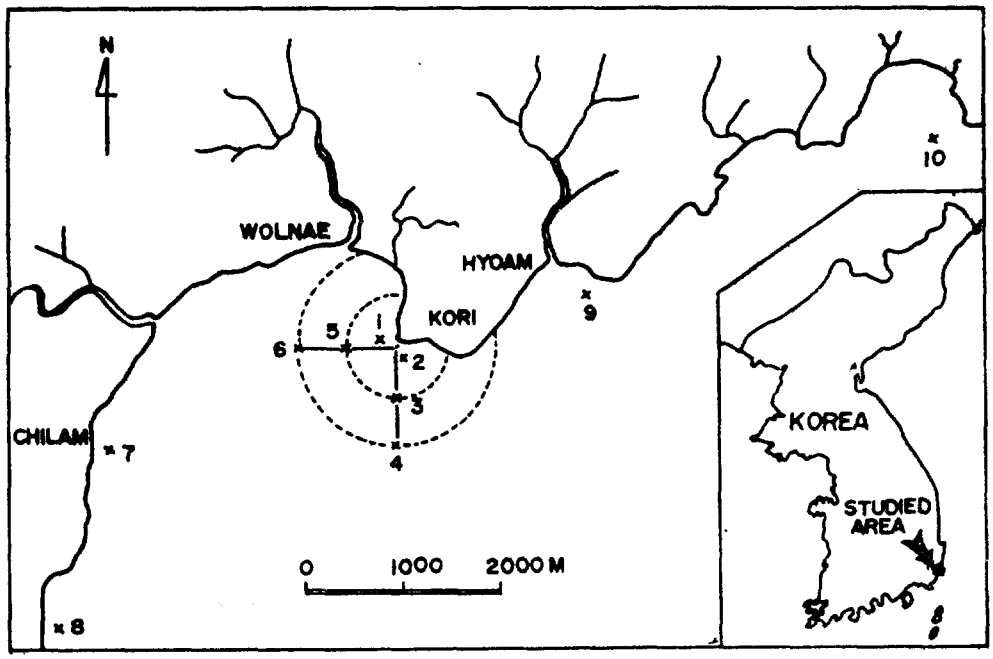

Fig. 1. Map of the Ko-ri sea area showing the location of sampling stations.

pore size 0.8μ) coated with magnesium carbonate except in the measuring of inorganic particulate matter. Particulate organic carbon and nitrogen analyses were performed by methods of Strickland and Parsons (1960), and the ash weight of inorganic fraction was obtained by ashing the filterate in a muffle furnace for 5 hr at 450°C, cooling in a desiccator, and weighing. In these case, water samples for analyzing organic and inorganic materials were prefiltered with 300 to 500μ plankton netting to remove the large plankton and debris.

Data from the surveys were analyzed by regions: region A (Station 7 and 8), region B (Station 1-6), and region C (Station 9 and 10), respectively.

RESULTS

General Hydrographical Conditions in the Area

General hydrographic conditions of the Ko-ri sea area had been described by Choe and Chung (1970). In brief, regional averages of surface and bottom water temperatures in the Ko-ri sea area during the experimental period are given in Fig. 2. Water temperature had a pronounced seasonal cycle. The average ranged from 11.1°C during February to 22.8°C during September.

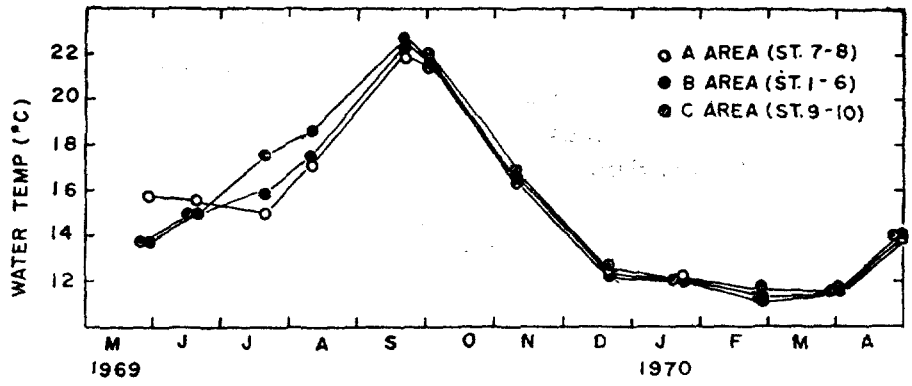

Fig. 2. The seasonal pattern of average sea water temperatures in the Ko-ri sea area.

The range in water temperature was almost same tendency in each region. In June, July and especially in August, the difference in water temperature between the surface and bottom waters was as much as 3 to 6°C, but from October to May the difference was much reduced.

Averages of regional salinities of surface and bottom water are given in Table 1. The average ranged from 28.50 to 33.79 ‰, generally lower during May to November, higher during December to April. From December through April, the average salinity had always in excess of 33 ‰.

Regional Secchi disc readings for the Ko-ri sea area were shown in Table 2. Regional average Secchi disc readings varied from 2.3 to 6.8, lower in the rainy season (May to October), and higher in the dry season (November to

Table 1. Regional average salinity (‰) for the Ko-ri sea area.

Region	1969 May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	1970 Jan.	Feb.	Mar.	Apr.
A	31.82	32.96	32.66	32.78	31.97	31.12	32.98	33.53	33.71	33.71	33.58	33.40
B	32.99	33.43	28.50	31.15	30.78	30.50	32.32	33.60	33.48	33.76	33.66	33.11
C	32.45	33.40	31.81	32.21	31.75	30.95	31.77	33.50	33.78	33.75	33.68	33.79

April).

Region B, located in the bay area, generally showed large turbidities during the summer and fall months. The maximum Secchi disc reading was noted in November with the value of exceeding 6.0. In February, Secchi disc readings of region A and B were considerably lower, but this reason is not apparent.

Table 2. Regional average Secchi disc readings (m) for the Ko-ri sea area.

Region	1969 May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	1970 Jan.	Feb.	Mar.	Apr.
A	3.4	3.0	3.0	3.2	2.9	3.0	6.8	4.2	4.0	2.4	4.5	5.9
B	3.5	3.2	2.3	2.4	3.4	2.6	6.3	4.7	5.1	2.6	5.8	6.3
C	4.6	3.6	3.3	2.7	3.8	2.4	6.0	5.2	4.5	4.3	5.8	5.5

Phytoplankton

Monthly phytoplankton standing crops, succession and regional phytoplankton abundance of this study are summarized in Table 3 and Fig. 3. A total of 86 species of phytoplanktonic organisms were detected in the Ko-ri sea area. These included 54 diatoms, 8 dinoflagellates, 2 silicodinoflagellates, and 22 tintinnides.

In general, diatoms dominated the algal population throughout the year, especially *Skeletonema costatum*, *Nitzschia seriata*, *Chaetoceros curvisetus*, *Eucampia zoodiacus*, *Chaetoceros affinis*, *Thalassionema nitzschioides* and *Lauderia borealis* were the most abundant diatoms, which consisting the major phytoplankters in the Ko-ri sea area.

Flagellates and tintinnides represented only a small proportion in number of the total phytoplankton standing crop, and these species were generally limited the period from June to November of the year. However, *Ceratium fusus* appeared through the year with a considerable amount.

Regular seasonal progression of the phytoplankton standing crop was evident, but the regional change in phytoplankton abundance was not apparent. Relatively larger amount of phytoplankton occurred in March, July, August and November in order of exceeding 5,000 cells/L. On the other hand, for the months January, April, May, October and December, the regional densities of the phytoplankton were in order of under 1,000 cells/L. The maximum average of 25,825 cells/L was recorded at region C in August, and the minimum average of several cells/L was recorded at region A in May and January.

Table 3. Seasonal phytoplankton abundance in cells×10/L in the Ko-ri sea area.

Species	Jan. 21/70	Feb. 27/70	Mar. 31/70	Apr. 29/70	May 27/69	Jun. 18/69	Jul. 18/69	Aug. 8/69	Oct. 1/69	Nov. 8/69	Dec. 18/69
Bacillariophyceae											
Arachoidiscus ornatus								.1			
Asterionella japonica							15	4	5		
Bacteriastrum comosum									.2		
B. hyalinum										2	
B. varians									3		
Biddulphia sinensis		2	.9								
Chaetoceros affinis	.4		1	.6	2	19	19	25	3	124	.4
C. atlanticus							3	6	1		

Table 3. Continued.

Species	Jan. 21/70	Feb. 27/70	Mar. 31/70	Apr. 29/70	May 27/69	June 18/69	Jul. 18/69	Aug. 8/69	Oct. 1/69	Nov. 8/69	Dec. 18/69
C. Compressus			2							2	
C. curvisetus			15	12		109	173	59	6	183	
C. decipiens								2	2	4	
C. decipiens f. singularis								.2			
C. didymus		.8	33	2				5			
C. didymus v. anglica								4			
C. didymus v. protuberans						8					
C. distans							8	3	1		
C. lorenzianus										5	
C. pseudocrinitus										90	
C. weisflogi							2			1	
Climacodium biconcavum						.5					
Coscinodiscus astromphalus.						.1	2	.6	.8		
C. gigas					.3	.1	12	3	1		
C. granii			.1		.2		12	7	.3	.1	
C. janesianus									.1		
C. marginatus					.2		.9	.9	.7		.1
C. radiatus						.4	.2	.2		.1	
C. wailesii			.5	.2	.1		.2				
Ditylum brightwellii			1	.3					1	.7	
Eucampia zoodiacus		6	342	10		11		75		55	
Lauderia borealis	2	7	91	4							
Leptocylindrus danicus					2			1	4	88	
Licmophora abbreviata			.1			.5					
Nitzschia seriata			59	2	3	129	84	682	1	61	.8
N. longissima						.5	.5	4	.2		
Pleurosigma angulatum							.4				
P. elongatum							.4	.3		.1	
P. intermedium							.4				
P. normanii	.2	.5	1	.7		3	2	.2	.8	1	1
P. sp.					.6	8					
Rhizosolenia alata					.2	10			.3		
R. alata f. indica										.6	
R. calcar avis										.2	
R. hebetata f. semispina			26	2		.8			15	.2	
R. robusta			.1				.1			.1	
R. stolterfothii			2			14	2	17		4	
R. styliformis								.2		3	
Schröderella delicatula			2					63	.7	29	
Skeletonema costatum			3	6	11	24	730	393	1	78	

Table 3. Continued.

Species	Jan. 21/70	Feb. 27/70	Mar. 31/70	Apr. 29/70	May 27/69	June 18/69	Jul. 18/69	Aug. 8/69	Oct. 1/69	Nov. 8/69	Dec. 18/69
Stephanopyxis palmeriana		103	2					.4			
Synedra sp.							.1				
Thalassionema nitzschioides	.8	.6	6	5		13	21	125	.1	14	2
Thalassiosira hyalina				.6		.5	2	7	2		
T. rotula			14			2			.3		
Thalassiothrix frauenfeldii			.5	.5		2	5	28	8	22	.7
Chromonadae											
Ceratium furca					.4		.4		.4	.2	
C. fusus	.1	.3	.2	.7	4	1	6	15	3	.9	.1
C. macroceros					.5	.3					
C. pennatum							.1				
C. tripos				.1						.2	
Dictyocha fibula								.2	.3		
Distephanus speculum									.5		
Peridinium curvipes								.6			
P. depressum										95	
Pyrophacus horologicum				.1	.1						
Ciliophora											
Amphorellopsis acuta									.2		
Amphorella brandti									1		
A. quadrilineata									1		
Codonellopsis morchella						.1			3		
Favella azorica								.1			
F. campanula								.1			
F. taraikaensis						.1			.1	.3	
Protorhabdonella striatura									.7		
Tintinnopsis angustior								.6			
T. beroidea								8	.2		
T. bütchlii									.2		
T. gracilis								2			
T. japonica								2			
T. mortensenii									.4		
T. pusilla									.2		
T. radix						.1		.8	.2	.5	
T. sufflata									.4		
T. tenuis						.1					
Tintinnus lusus-undae						.4			.6		
T. perminatus									.1		
T. stramentus									.4		
Undella claparedei									2		
Total	3.5	120.2	602.4	46.8	24.6	357.5	1101.7	1545.5	73.4	865.2	5.1

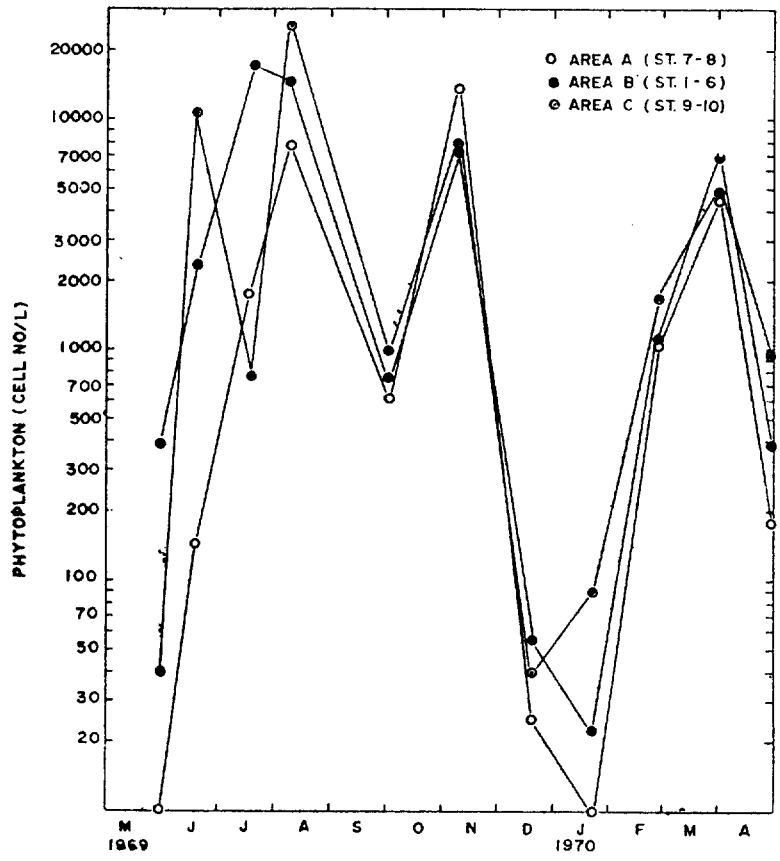

Fig. 3. The seasonal variation in cell numbers per liter of phytoplankton in the Ko-ri sea area.

Zooplankton

Monthly zooplankton standing crops, succession, and regional zooplankton abundance are summarized in Table 4 and Fig. 4. Collected zooplankton samples were classified into 16 species and groups. Copepoda and its larval forms, *Nactiluca*, *Pycnogonida* larva , *Oikopleura*, and *Balanus* larva are the predominant groups among them. Especially, Copepoda and its larval forms appeared consistently through the year, accounting for 25~95% of the total population counted. *Balanus* larva began to appear in March and its appearance reached a peak in June with 654 individuals/m^3 in average, and then gradually decreased to the lowest amount in December and thereafter. *Mytilus* larva was much smaller in quantity than *Balanus* larva, and its appearance was limited only during March and August. *Noctiluca* appeared almost the year round, but its number was not large. The other groups appeared with small quantities in a limited period. From June to November *Sagitta* appeared comparatively large amount.

The regional and seasonal changes in zooplankton abundance were not evident. However, a large amount of zooplankton occurred during February and April in order of 13,000 to 83,000 individuals/m^3 except region A in February. The maximum average of 83,000 individuals/m^3 was recorded at region C in February, and the minimum average of 2,700 individuals/m^3 was recorded at region A in December.

Table 4. Seasonal zooplankton abundance in individuals per m^3 in the Ko-ri sea area.

Groups	Jan. 21/70	Feb. 27/70	Mar. 31/70	Apr. 29/70	Jun. 18/69	Jul. 18/69	Aug. 8/69	Oct. 1/69	Nov. 8/69	Dec. 18/69
Balanus larva	20		50	51	654	406	372	220	288	18
Bivalve larva					267	11	23		131	133
Copepoda	3685	16243	8510	11120	3406	7783	4407	10365	8117	2646
Copepoda larva	2888	5896	3176	3820	1119	1291	850	1706	1746	676
Megalopa			67							
Echinopluteus		114			23	141	42	64	255	31
Evadne				50	59					
Fish eggs					149					
Gastropoda larva		48	418	33	77				54	68
Lucifer tipus							85			
Mytilus larva			22	21	34	12	11			
Noctiluca	366	1423	470	1327	988	201	39	254	613	33
Oikopleura	123	393	1206	99		83			1058	
Podon					41		44		1391	74
Pycnogonida larva	143	316	413	1111	388	179		347	134	189
Sagitta		102			211	116	132	298	77	
Total	7225	24535	14332	17632	7416	10223	6005	13254	13864	3868

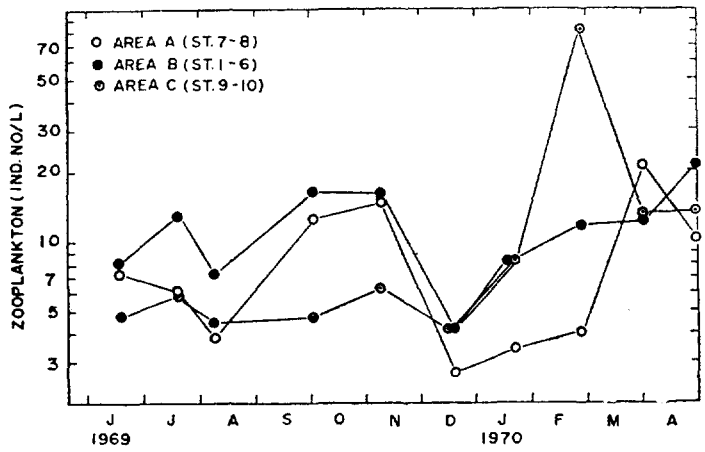

Fig. 4. The seasonal variation in individual numbers per liter of zooplankton in the Ko-ri sea area.

Suspended Particulate Matters

Amounts of particulate organic carbon, organic nitrogen, inorganic matter, and carbon-nitrogen ratios in the Ko-ri sea area are summarized in Table 5, and its seasonal and regional variations are shown in Fig. 5 and 6.

In general, suspended particulate matters of the Ko-ri water are relatively abundant. For the inshore water of the Ko-ri, the concentration of suspended particulates were greater than those of the open sea.

Little regional variation in the particulate organic carbon was observed, and the total amounts were in the range of 35 to 3,785 mg/m^3 (averaging 865 mg/m^3) at the surface, 35

to 3,505 mg/m³ (averaging 872 mg/m³) at the bottom, and total range of 35 to 3, 785 mg/m³ (averaging 868 mg/m³), respectively. This shows a pronounced seasonal variation in the particulate organic carbon which considerably correspond to the seasonal pattern in phytoplankton populations, except during May, December and January. The observations indicated seasonal peaks in the abundance of particulate organic carbon during summer (June~August) and early winter (December). The average of particulate organic carbon concentration in August was in order of over 2,000 mg/m³ for the entire area.

Table 5. Summarized data for suspended particulate matter and its carbon-nitrogen ratio in the coastal water of Ko-ri (May 1969—April 1970).

Region		Org.-C (mg/m³)		Org. -N (mg/m³)		Inorg. matter (mg/L)		C/N	
		Range	Mean	Range	Mean	Range	Mean	Range	Mean
A	Surface	70-1474	910	12-114	47	1.5-8.2	5.2	1.5-231	40
	Bottom	35-2305	887	10-106	48	1.1-10.9	6.4	0.7-172	32
B	Surface	35-3785	867	9-158	48	1.1-7.9	5.3	0.6-230	30
	Bottom	35-3505	868	4-123	50	1.2-11.6	6.9	0.6-226	29
C	Surface	35-2432	818	12-92	35	0.6-9.8	4.5	0.5-182	38
	Bottom	35-2305	860	12-123	39	0.9-9.7	5.9	1.0-173	36
	Surface	35-3785	865	9-158	43	0.6-9.8	5.0	0.5-231	37
	Bottom	35-3505	872	4-123	46	0.9-11.6	6.4	0.6-226	32
	Total	35-3785	863	4-158	45	0.6-11.6	5.7	0.5-231	35

The total amounts of particulate organic nitrogen were in the range of 9 to 158 mg/m³ (averaging 43 mg/m³) at the surface, 4 to 123 mg/m³ (averaging 46 mg/m³) at the bottom, and total range of 4 to 158 mg/m³ (averaging 45 mg/m³), also showing a pronounced seasonal cycle in the particulate organic nitrogen, which closely correspond to the seasonal pattern in zooplankton populations. However, there is no direct correlation between the particulate organic carbon and organic nitrogen concentrations observed. For the particulate organic nitrogen concentration, there is some variations with the region and season.

The total amounts of suspended inorganic matter were in the range of 0.6 to 9.8 mg/L (averaging 5.0 mg/L) at the surface, 0.9 to 11.6 mg/L (averaging 6.4 mg/L) at the bottom, and total range of 0.6 to 11.6 mg/L (averaging 5.7 mg/L) with little regional variation. During most of the year, the weight of inorganic particulate matter forms the major part of the total suspended matter ranging between 84—90% of the total. From the seasonal trend of particulate inorganic matter, it is clear that there is a pronounced seasonal effect.

The carbon-nitrogen ratios for the particulate matter in the coastal water of Ko-ri were varied remarkably with season. The values varied in the range of 0.5 to 231 (averaging 37) at the surface, 0.6 to 226 (averaging 32) at the bottom, and total range of 0.5 to 231 (averaging 35), respectively. These values were greater drastically than those particulate matter

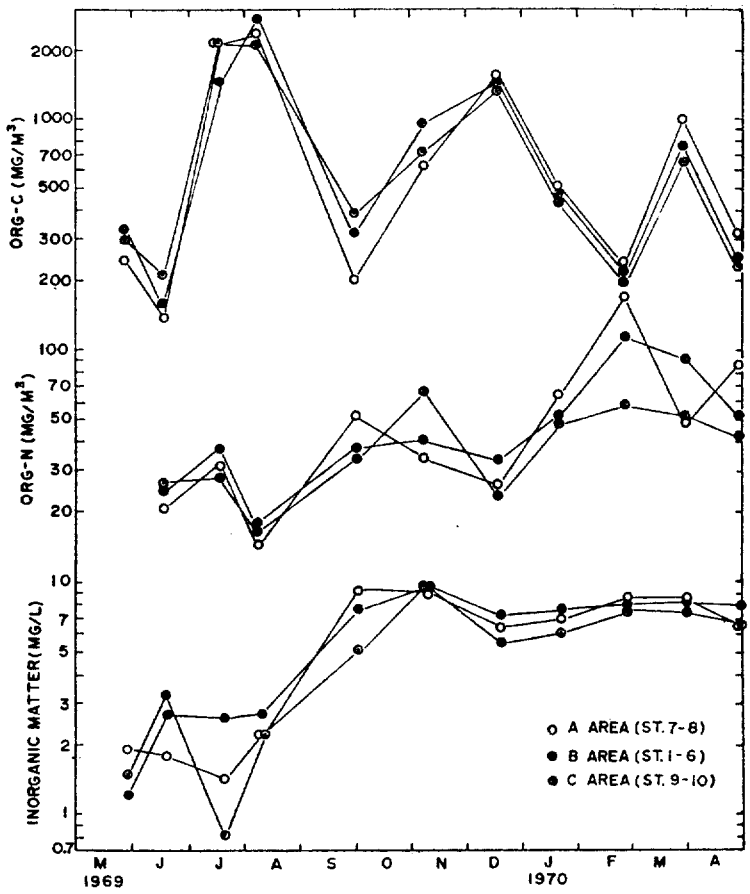

Fig. 5. Seasonal variations of the particulate organic carbon, organic nitrogen and inorganic matter in the Ko-ri sea area.

found in the open sea. There is little regional variation in the level of carbon-nitrogen ratio of the particulate matter. A greater value of the carbon-nitrogen ratio occurred in August with the level of exceeding 100, while the value of February was less than 2. The seasonal change in carbon-nitrogen ratio does also well correspond to the seasonal change in the particulate organic carbon. In July, August and December, the average carbon-nitrogen ratio of the particulate matter was comparatively higher for the entire area.

DISCUSSION

Plankton productions in the coastal water of Ko-ri varied with season, and little relationship was found between phytoplankton and zooplankton productions. In general, diatoms are the dominant species of algal population throughout the year. Diatoms of *Skeletonema costatum*, *Nitzschia seriata*, *Chaetoceros curvisetus*, *Eucampia zoodiacus*, *Chaetoceros affinis*, *Thalassionema nitzschioides* and *Lauderia borealis* were constituting the major phytoplankton in the Ko-ri sea area. However, phytoplankton production was considerably lower than open areas of the Sea of Japan (Choe, 1969). The monthly average cell numbers ranged from 35 to 15,455 cells/L, averaging 4,314 cells/L for the entire area, and the maximum cell number occurred in August

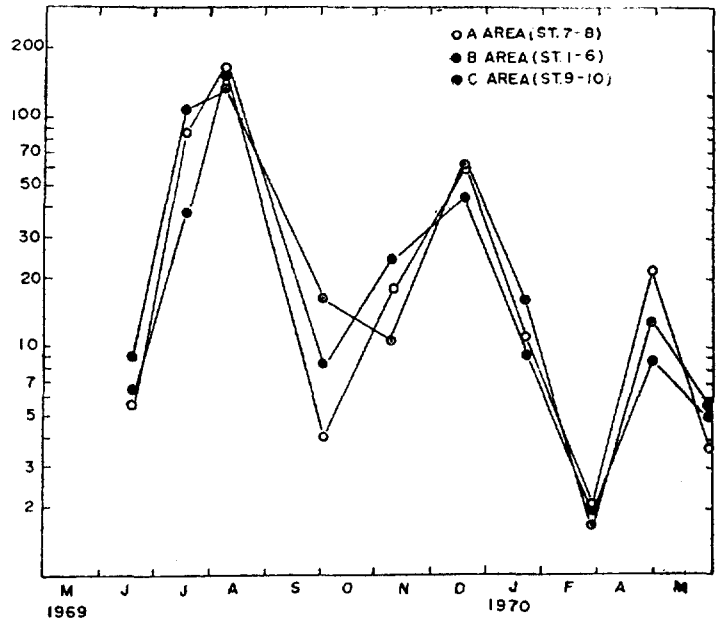

Fig. 6. Seasonal variation of the carbon-nitrogen ratio of suspended particulates in the Ko-ri sea area.

and the minimum number in January.

On the other hand, Copepoda and its larval forms were the dominant zooplankton accounting for 25~95% of the total population accounted at all regions through the year. The monthly average individual numbers ranged from 3,868 to 24,535/m^3, and the maximum number occurred in February and the minimum number in December. The water in the Ko-ri sea area is relatively high in suspended particulates, fluctuating over a wide range. The particulate organic carbon ranged from 35 to 3,785 mg/m^3, averaging 868 mg/m^3 for the entire area. The maximum concentration occurred in August, and the minimum concentration in June. The particulate organic nitrogen ranged from 4 to 158 mg/m^3, averaging 45 mg/m^3, for the entire area, and the maximum concentration occurred in February, the minimum in August.

On the other hand, the inorganic particulate matter ranged from 0.6 to 11.6 mg/L, averaging 5.7 mg/L with the maximum concentration occurred in November, the minimum in June. It is a characteristic of the Ko-ri sea during most of the year, of which the inorganic particulate matter forms the major part of the total suspended particulates in weight. Large values of the suspended particulate in the Ko-ri sea area may be encountered to relatively high turbulence and a rich algal flora in the coastal area.

At last, the carbon-nitrogen ratio for the suspended particulates varied in the range of 0.5 to 231, averaging 35 for the entire area. It is surprising to find such low and high carbon-nitrogen ratios. According to Parsons and Strickland (1962), and Saijo (1969), the carbon-nitrogen ratio of the particulate organic matter in oceanic waters is generally known to be in the order of 6-14. The high values of carbon nitrogen ratios were obtained in the season which the particulate organic nitrogen concentration were low as in August and December, and the low values of carbon-nitro-

gen ratios were recorded in the season which the maximum particulate organic nitrogen occurred in February. The bay area and its adjacent sea area have heavy stands of *Zostera marina* and other red and brown algal vegetations, which might be contributed large quantities of organic matter to the sea.

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