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The ecological study of phytoplankton in Kyeonggi Bay, Yellow Sea
II. Light intensity, Transparency, Suspended substances

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西海 京畿湾 植物플랑크톤에 対한 生態学的 研究
Ⅱ. 光度, 透明度, 浮游物質

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Abstract

To clarify the light condition which influence on phytoplankton ecology in Kyeonggi Bay, light intensity, compensation depth, extinction coefficient, transparency and suspended substances are studied from May 1981 to September 1982.

Light intensities lie within adequate values for the phytoplankton growth from spring to autumn. However, in the winter season the light intensities show less than 4.8 mw/cm^2 on the surface resulting lower than optimum irradiance. Light intensity could be a limiting factor for phytoplankton growth in winter.

Compensation depths seasonally varied over an annual period in this study. Especially, in winter, compensation depths are confined to only 1-2 m below the surface. Extinction coefficient (K) values are relatively high over an year cycle. K values is highest in winter and lowest in summer. Transparency shows seasonal variation. Transparency is high in summer and low in winter.

Thus low light intensity, low compensation depth, low transparency and high extinction coefficient in winter are due to the high turbidity and high concentrations of suspended substances. High concentrations of S.S. in winter result from the sediments and detritus resuspended by the winter turbulence induced by the strong winter winds and the convectional mixing. In summer, good light condition and low turbidity may result from the thermal stability of water mass preventing the resuspension of sediment particles.

요약 : 경기만 식물플랑크톤 생태에 영향을 미치는 광조건을 알기 위하여 광도, 보상깊이, 소광계수, 투명도, 부유물질등이 조사 연구되었다.

봄부터 가을까지는 식물플랑크톤 성장에 적절한 광도를 유지하였으나 가을에는 플랑크톤 성장을 제한할 정도의 낮은 광도를 보였다.

투명도 및 보상깊이도 계절적인 변화를 보여 동계에는 표층하 1～2m내에 국한되었다. 소광계수는 만 전체에 전반적으로 높은 양상을 보이고 뚜렷한 계절변화를 보였다.

이와같은 낮은 광도, 낮은 보상깊이, 낮은 투명도, 높은 소광계수는 경기만 내 특징인 높은 탁도와 높은 부유물질 농도에 기인된다. 특히 겨울철의 나쁜 광조건은 조류와 북서계절풍에 의한 심한 수괴의 혼합으로 미세 퇴적물의 재 부유 현상에 기인된 것으로 보인다.

INTRODUCTION

The growth and development of phytoplankton ultimately depends upon the distribution of the light field in estuarine waters (Hitchcock & Smayda, 1977). In most esturine waters, nearly all the penetrating light is absorbed below the surface 1-3 m depth, and the estuarine phytoplankton receives sufficient light for photosynthesis in the surface layers only. The shallow penetration of light into estuarine waters depends largely on the turbidity which is much greater than that of the open sea. This turbidity is due to suspended substances. Suspended substances determine the optical characteristics of the water, such as its color and transparency. The relationship of the quantity of suspended substances in water to its color, turbidity and transparency has long been known (Jerlov, 1968).

Kyeonggi Bay and adjacent coastal areas are characterized by macrotidal range up to about 9-10 m having maximum tidal current with 3.4 knots (Yi, 1972). Thus strong tidal currents resuspend sediment particles and construct variable sedimentary structure on the tidal flats. Kyeonggi Bay receives large freshwater from the Han River together with run off from the Imjin River. From these river discharges, large suspended substances are also transported into this bay. Seasonally, strong winter monsoon sweeps over this bay and induces high concentration of suspended materials in the Yellow Sea (Huh, 1982). By above three reasons, suspended substances in Kyeonggi Bay show high concentrations and large seasonal variations. By the turbidity and suspended substances, light penetration and transparency may be limited in the shallow depth and show seasonal variation.

The main objective of this study is to explain the light condition which effect on phytoplankton ecology, and to clarify the relationship between the transparency and suspended substance through the analysis about the seasonal variation of S.S in the Kyeonggi Bay.

MATERIALS AND METHODS

Samples and data in this study area were collected from two surveys for each purpose. The first survey was carried out monthly during the periods from October 1981 to September 1982 at seven stations in the Incheon Bay and the second survey was carried out 9 times during the periods from May 1981 to April 1982 at five stations located in major tidal channels of the Kyeonggi Bay (Choi and Shim, 1986).

Monthly illumination data in Incheon Harbour was obtained from Incheon meteorological station. Light intensity was measured by KAHLSICO model 268 WA310 radiometric underwater irradiameter. The partial energy values were calculated using the appropriate factors and the values rounded off from the mathematical results. Measuring band width is 238 nm, and spectral measuring range is from 430 nm to 650 nm.

For compensation depth, the underwater cell is lowered until the value of its measurement is 1 % of that of the ambient intensity.

The reduction of light in the water column can be expressed in terms of the extinction coefficient (K). By Beer-Bouger law, K is generally defined (Bougis, 1976): $K_{1-2} = -\frac{\ln I_2 - \ln I_1}{Z_2 - Z_1}$, when I_1 and I_2 are irradiance at the levels Z_1 and Z_2.

Transparency was measured by Secchi disc.

For the determination of total suspended particulate matter, 1 liter of water samples were filtered on glass fiber filters of 47 mm diameter with 0.8 μm pore size under the pressure of about 1/2 atm. The filtered samples were then taken with aluminium foil made petri-dishes and dried in silica gel contained dessicators at room temperature for 48 hours or more. After drying, total suspended matter values were determined as the differences between original filter weight and

Table 1. Monthly variations of light intensity in Incheon Harbour (Incheon meteorological observatory)

(g cal/cm²/h)

Station	1981						1982		
	May	Jun.	Jul.	Aug.	Oct.	Dec.	Feb.	Mar.	Apr.
St. 1	18.0	37.6	37.3	31.3	28.9	9.6	9.2	22.9	18.9
St. 2	20.0	28.4	54.2	49.4	31.3	16.9	17.5	26.2	26.3
St. 3	37.3	34.9	59.0	51.8	34.9	24.1	20.5	27.4	24.0
St. 4	45.8	32.5	63.7	47.0	26.5	21.7	18.5	25.9	23.6
St. 5	42.1	19.3	34.9	38.5	20.7	16.9	14.4	21.9	15.5
Daily light Intensity (ly/day)	268.4	269.6	476.7	386.8	256.4	132.5	130.1	215.5	204.8

after filtering weight of the filter.

RESULTS AND DISCUSSION

Light intensity

Monthly light intensity in Incheon Harbour recorded by Incheon meteorological observatory was shown in Table 1. The average values of light intensity varied from 476.7 g cal/cm²/day in July to 130.1 g cal/cm²/day in early February. The average values at each station are much lower than the maximum energy available for photosynthesis at sea level, with not exceeding 42 to 48 g cal/cm²/hour (Bougis, 1976).

In the second survey area, the calculated energy values were shown in Table 2. Light energy at the surface ranged from 0.38 mw/cm² at station D in June, under the heavy clouds, to 12 mw/cm² at station C in August. Over the survey area, there are no significant inhibitions for the growth of phytoplankton in summer with the light intensity of less than 35 mw/cm² (Strickland, 1958). Except the winter season, other seasons lie within optimum irradiance for the maximum growth of phytoplankton, with a range of 4.8-10 mw/cm² (Ryther, 1956). However, in the winter season the irradiance, ranged from 1.84 mw/cm² to 4.66 mw/cm² at the surface, is lower than optimum irradiance. Therefore,

Table 2. The variation of light intensity measured on board in the second survey

(mw/cm²)

Station	Depth	Feb.	May	Jun.	Jul.	Aug.	Oct.	Dec.
St. A	Deck	6.00	4.66	12.00	12:00	14.33	11.33	4.33
	0 m	3.67	1.54	4.61	6.66	10.00	10.00	4.00
	1 m	0.01	0.42	0.08	1.33	0.92	1.33	0.41
	2 m		0.41		0.10	0.10	0.10	0.04
	3 m		0.04		0.03			
St. B	Deck	10.66	10.33	10.00	14.99	14.99	11.33	7.66
	0 m	4.33	3.33	4.61	7.33	11.00	10.00	4.66
	1 m	0.20	1.02	0.17	0.77	3.33	1.67	0.92
	2 m	0.05	0.33	0.04	0.31	1.23	0.82	0.09
	3 m		0.10		0.10	0.23	0.12	0.01
	4 m		0.03		0.05	0.09		
St. C	Deck	6.66	16.99	9.66	16.66	15.99	9.00	9.33
	0 m	4.33	11.00	3.82	8.33	12.00	7.66	4.66
	1 m	1.17	3.00	0.80	0.72	9.33	4.66	1.23
	2 m	0.23	0.50	0.33	0.51	6.00	3.33	0.13
	3 m	0.04	0.08	0.20	0.40	3.67	2.00	0.06
	4 m		0.02	0.09	0.33	2.67	1.17	
	5 m				0.23	1.84	0.82	
	6 m				0.13	0.15(8 m)	0.38	
	7 m				0.09		0.10	
St. D	Deck	4.61	15.99	2.00	15.33	13.66	6.00	7.06
	0 m	2.82	8.00	0.38	7.33	10.66	4.66	3.00
	1 m	0.38	6.14	0.11	4.09	6.66	3.00	0.46
	2 m	0.07	2.25	0.04	2.05	4.33	2.05	0.09
	3 m	0.02	0.73	0.03	1.43	2.46	1.02	0.03
	4 m		0.37	0.02	1.02	1.43	0.70	
	5 m		0.12		0.51	0.72	0.17	
	6 m				0.33	0.31	0.08	
	7 m				0.15	0.12	0.03	
St. E	Deck	4.00	12.99	6.00	9.33	11.00	6.66	5.33
	0 m	1.84	6.66	1.00	1.02	9.33	4.66	4.00
	1 m	0.68	2.76	0.50	0.73	5.66	2.08	2.56
	2 m	0.12	1.07	0.37	0.36	3.67	1.01	0.31
	3 m	0.02	0.70	0.07	0.22	2.46	0.11	0.05
	4 m		0.50	0.03	0.11	1.64	0.10	
	5 m		0.26		0.08	1.13	0.07	
	6 m		0.16			0.52	0.01	
	7 m		0.12			0.11		

the irradiance could be a limiting factor for phytoplankton photosynthesis in winter.

In the second survey area, compensation depths show monthly variations and spatial differences (Fig. 1). Maximum compensation depth is 7.9 m at station C in August and minimum depth is 0.8 m at station A in December. In summer, generally, compensation depths are deepest being due to the decrease of the turbidity, while minimum depth is shown in winter, being due to the high turbidity by winter mixing (Fig. 4). In winter, compensation depths are confined to only 1-2 m below the surface. The suspended materials in winter absorb the penetrating light within the depth of 1-2 m.

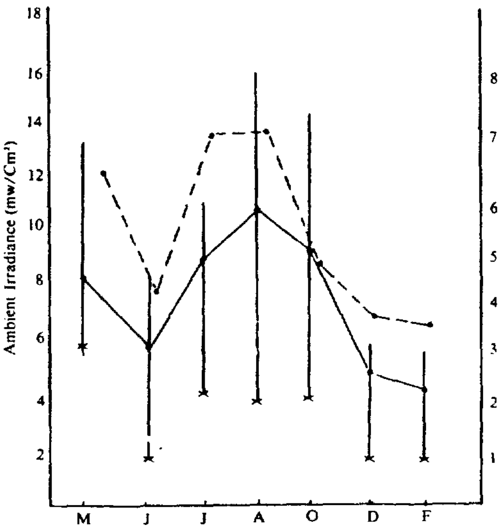

Fig. 1. Ambient irradiance (A.I.) and compensation depth (C.D) in the second survey area.

In comparing average compensation depth at each station, minimum depth is shown at station A, and maximum depth is shown at station E. The compensation depth increases toward the outer bay, increasing the depth of light penetration.

The reduction of light in the water columns of this study area is relatively great because of high turbidity. Average values of extinction coefficient (K) are shown high with 1.42 (Table 3). K values vary greatly with month and station in the range of 0.42-5.70. The values of extinction coefficient are high, and the values are minimum in July. K values at station A are the highest, while K values at station E are the lowest. K values decrease from the upper bay towards the offshore water. K values at the surface are less than that at the lower depth. K values show the increase toward the bottom being due to the suspension of bottom sediments.

In addition to the relationship between Secchi disc depth and light attenuation, Poole and Atkins (1929) formula is $K = \frac{1.7}{Ds}$ for water in the English Channel. This formula is used extensively by workers who are unable to measure K directly and it is given regularly in oceanography (Parsons et al., 1977). Recently, a number of investigators have proposed alternative equations relating K to Ds in different regional areas. Off the coast of southern california by Holmes (1970), a better fit is given by $K = \frac{1.4}{Ds}$: in very clear water by

Table 3. The distribution of extinction coefficients (K) in the second survey area

Station		1981						1982	Mean
		May	Jun.	Jul.	Aug.	Oct.	Dec.	Feb.	
St. A	s	1.14	3.42	1.80	2.39	2.30	2.30	5.90	2.75
	b	1.19	4.68	1.90	3.07	2.59	2.32	5.72	3.16
St. B	s	1.16	3.30	1.25	1.20	1.47	2.05	2.23	1.80
	b	1.16	1.45	0.91	1.20	1.32	2.26	1.38	1.38
St. C	s	1.58	0.80	0.69	0.55	0.62	1.45	1.56	1.04
	b	1.64	0.80	0.84	0.59	0.64	1.51	1.69	1.10
St. D	s	0.77	0.54	0.44	0.64	0.72	1.53	1.65	0.90
	b	0.94	0.57	0.42	0.67	0.77	1.37	1.47	0.89
St. E	s	0.65	0.50	0.42	0.63	0.84	1.46	1.51	0.85
	b	0.59	0.66	0.44	0.66	0.85	1.97	1.76	0.99
Average		1.08	1.81	0.76	1.16	1.14	1.82	2.12	1.42

Strickland (1958), $K = \frac{1.9}{Ds}$ and in the turbid water of the Cochin estuary by Quasim et al. (1968), $K = \frac{1.5}{Ds}$. However, Walker (1980) insisted that the most useful formula be $K = \frac{1.45}{Ds}$, correcting Atkins formula. In this study area, the relationships between Secchi disc depth and light attenuation formula show large variations from $K = \frac{0.91}{Ds}$ to $K = \frac{2.95}{Ds}$. Therefore, the using of these formula should be considered with seasons and regions.

Transparency

In the first survey area, a Secchi disc was used to determine transparency at all stations (Fig. 2). Shallower Secchi disc depths were recorded in winter, reflecting the greater turbidity of the bay during the winter mixing. Hahn (1968) indicated that the major factor in the change of water color and transparency is a suspended material, especially suspended clay, in the Yellow Sea. The transparency in summer is high in spite of the large fresh water runoff carring quantities of suspended materials (Fig. 4). This is probably due to the thermal stability of the water mass preventing the resuspension of sediment particles, or the runoff is limited at the upper part of the bay. And also, in the case of Garolim Bay which connects with the mouth of Kyeonggi Bay, the transparency shows relatively low values from 0.5 m to 3.8 m, with maximum of 2.5 - 3.8 m in August, minimum in the winter (KORDI, 1980). Transparency generally increases toward the mouth of bay where the influx of low turbid offshore water is greater.

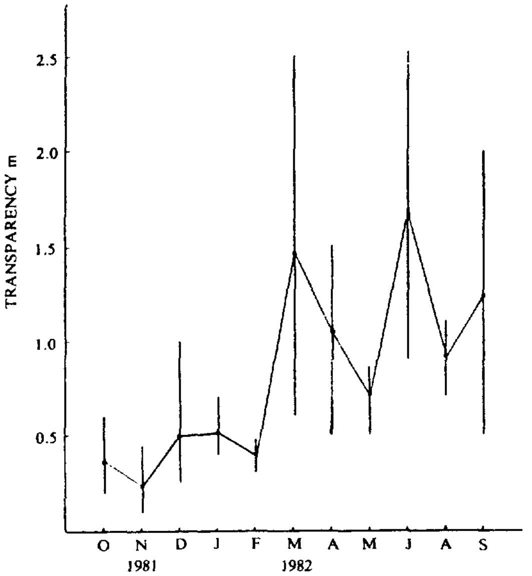

Fig. 2. The seasonal variations of Secchi disc depth in the first survey area.

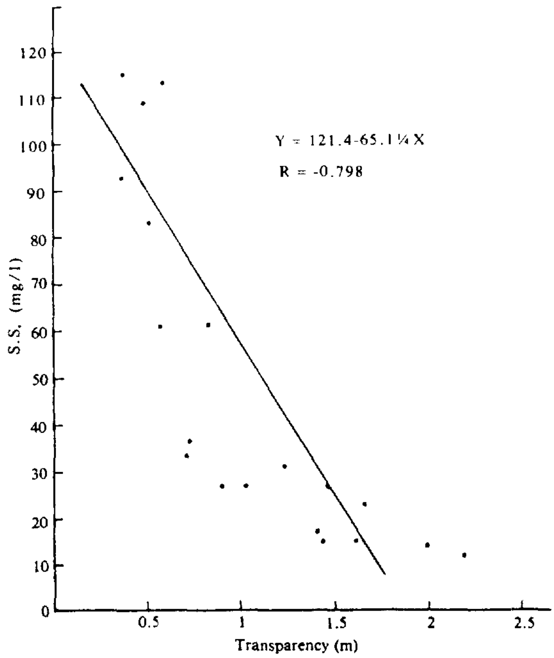

Fig. 3. Relation between the secchi depth and the concentration of S.S.

During a sampling period, the lower values of the transparent depths correspond to the higher concentrations of suspended substances (Fig. 3). The correlation coefficient between S.S. and transparency is -0.798. The relationship is only approximate but shows marked inverse relationship. There is also a linear relationship between attenuation coefficient and the concentrations of suspensions.

Suspended substances and turbidity

In the first survey area, the concentrations of S.S. at the surface varied with times and stations in the range of 15.0 -332.4 mg/l, having mean value of 68.5 mg/l (Fig. 4). This value is higher than that at Garolim Bay connected with Kyeonggi Bay (KORDI, 1980), but relatively lower than that at the Kum River estuary located in the south part of the Yellow Sea

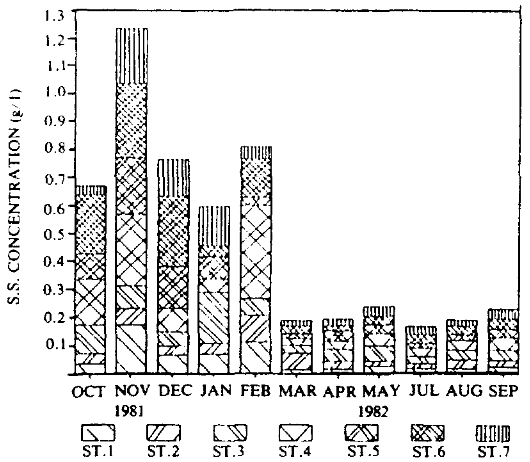

Fig. 4. The seasonal variation of S.S.concentrations in the first survey area.

with ranging from 65.8 mg/l to 935.6 mg/l (Kim, 1982). The average value of the concentrations varied with times from 22.7 mg/l in June to 115.7 mg/l in February. The high concentrations were shown in winter, autumn, spring and summer in order. The average concentrations also varied with stations. Relatively high concentrations were shown at station 6, inflowing of the runoff, and at station 4, being directly influenced by waste discharge. Minimum concentrations were shown at station 2, located in the harbour, having less resuspension of the bottom sediments. The total suspended concentrations show a general seaward decrease. Total S.S. concentrations seem to be influenced by salinity variations. Salinity variations cause rapid settling of suspended particulate by forming floccules at the time of mixing of freshwater with saline sea water during downstream transport (Postma, 1967).

In the first survey area, the differences of the suspended concentrations among the stations are less than that in seasonal variations. This means that the water masses, not being influenced directly by runoff or waste discharge, are relatively uniform, and that the variations of tidal currents and the tidal cycle in a day can not significantly influence total suspended concentrations, and turbidity level. Therefore, this short term factor, such as tidal cycle is minor factor influencing the TSM variations. These results are coincident with that of LANDSAT analysis by KORDI (1981).

The seasonal variations in the concentration of the average S.S. seem to be due to some physical processes such as wave action and thermal convection by seasonal winds. Meade and Sachs (1975) insisted that storm conditions lead to high concentrations of inorganic matter in suspension over the inner shelf south of Chespeake Bay. KORDI (1981) analyzed that one of two major factors influencing the turbidity level in the Kyeonggi Bay can be wind velocity. After three or four days with steady flowing of the strong winds of more than 7 m/sec, the surface turbidity may be rapidly increased by the resuspension of the bottom sediments. Kang and Choi (1984) indicated that sediments in the Yellow Sea basin are appreciably resuspended for shear stresses greater than 1 dyne/cm^2 and at stresses of approximately 1 to 2 dyne/cm^2. Fine particles on the order of 8ϕ are resuspended at such stresses.

The river discharges don't influence significantly on the turbidity over the bay. The influences are limited only to the river mouth. In spite of large fresh water runoff carring quantities of suspended materials after the heavy precipitation in summer, the transparency is the highest and S.S.concentrations and turbidity are shown the lowest in summer (Fig. 2 and 4). These conditions in summer seem to be due to the thermal stability of the water mass preventing the resuspension of sediment particles.

In general, the waters are seasonally most turbid in winter and transparent in summer over the Yellow Sea (Nakao, 1977; KORDI, 1981; Kim,1982). This might be resulted from the stirred up muds near the bottom in addition to the convectional mixing in winter. According to Pingree et al. (1976), winter mixing in the Celtic Sea is effected by tides from below and by wind and convection at the surface.

As winter advances, and as cold strong wind sweeps over the Yellow Sea, significant losses of heat take place. In winter by cooling and destratification due to the strong cold and dry northerly winds, the cold-air outbreaks cause intense, episodic, negative oceanic heat fluxes (Huh, 1982). According to Nakao (1977)'s calculation for the average amount of evaporation using Jacobs' equation, the amount of evaporation (E) is about 3.0 - 6.7

Table 4. Monthly means of total heat exchange (H; Cal/cm² day) in the Yellow Sea

(In. Bong, 1976)

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Incheon	-197	69	310	501	679	722	663	644	132	-126	-237	-364
Gunsan	-161	-68	137	417	487	527	580	272	-122	-306	-339	-208
Mokpo	-208	-17	250	435	565	600	664	492	235	34	-148	-259

mm/day in the Yellow Sea. Water temperature may be cooled from the surface to the bottom layers at the rate of about 0.3 -1.0 °C/day. Such a heat loss seems to explain the decrease of heat content in the vertical water column. He also calculated that the heat of evaporation (Qe), the exchanged heat between sea and atmosphere through conduction (Qc) and the total energy exchange between sea and atmosphere (Qa). In the winter, the values of Qe, Qa, Qc and E are the highest, being due to the strong winter winds. As a result, convectional mixing largely additions to the winter mixing, causing the resuspension and duration of S.S. In summer, by the low values water masses maintain maximum stability lacking convectional mixing.

In this study area, the heat exchanged from the air (Table 4) correlates high negatively with S.S. The correlation coefficient, R= -0.80. This means that convectional mixing, being due to the heat exchange, influences the resuspension of sediments. Bong (1976) indicated that through heat exchange, the surface waters are warmed by accepting heat from the atmosphere during March to September in west coastal area. After September the heat balance at the surface becomes a heat loss. The excess surface heat stored during the summer is removed from mid-October. The evaporation rate is the highest from October to next January with the distribution of 5 -12 mm/day. Strong convectional mixing could be generated by the heat exchange and evaporation from October to February. Therefore, severe winter mixing of water masses are induced by strong wave action and convectional mixing. High concentration of S.S.during late fall to winter are resulted from the resuspension of sediments by the tidal mixing and winter mixing due to the strong north-west winds and cooling temperatures.

Detritus and turbidity

In the second survey area, total numbers of non-living particulate matter which include sediment particle and detritus of the size with more than 30μm are counted under the microscope (Table 5). Average values at the surface

Table 5. Total number of detritus particles in the second survey area

(No/ml)

Station		1981						1982		
		May	Jun.	Jul.	Aug.	Oct.	Dec.	Feb.	Mar.	Apr.
St. A	s	232	1510	399	545	703	913	4910	1421	3472
	m	658	1459	933		636	987	3055	1650	
	b	198	781	1299	350	954	978	711	2335	3864
St. B	s	165	1163	490	121	635	1066	1807	1386	1017
	m	722	1559	816		914	954	1296	2650	
	b	1045	415	702	155	244	1572	1475		1451
St. C	s	516	278	260	126	275	1140	832	1579	269
	m	626	1416	274	139	427	850	1391	2744	2354
	b	1191	972		247	372	1442	2747	1645	1766
St. D	s	880	561	167		245	1271	1056	188	2216
	m	911		172	184	183	931	1560	2542	2872
	b	435	233	249	543	314	1918	1096	2371	2225
St. E	s	474	292	298	92			1475	2651	2627
	m	225	837	174	105		1299	1077		2963
	b	543	1472	283	50		1524	2099	4505	2493

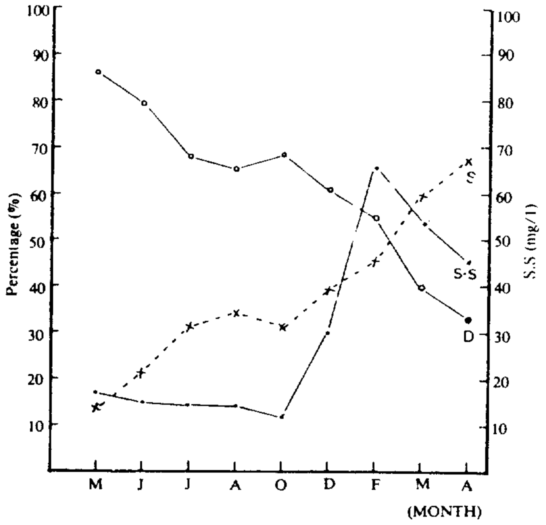

Fig. 5. The distribution of detritus and sediment particles in the second survey area.

varied with stations seasonally. Maximum values are shown in February and minimum values in August. In general, the high values were shown in winter and low values in summer. This variations seem to be associated with runoff, tidal range, wave mixing and summer stability. In summer and spring, average values at the upper part of the bay are relatively higher than that at the outer bay, being due to the high river discharges. While in winter, average values increased toward the outer bay. This may be due to the low river discharge and winter mixing, causing the resuspension of the bottom detritus.

The percentage of the detritus in non-living particulate matters ranged from 7.6% in April to 91.7% in May. In general, average percentage are high in summer and low in winter (Fig. 5). This may be due to the low percentage of sediment particles in summer and high percentage of those in winter. In comparing with sediment particles, high percentage of detritus in summer seems to be associated with the hydro-stabilities which prevent the resuspention of heavy particles of bottom sediment and have a possibility to resuspend lighter detritus on the bottom surface. As a result, detritus particles seem to influence on turbidity less than sediment particles. Sediment materials from both suspended praticles seem to be more important factor to reduce light penetrations.

CONCLUSION

Except in winter season, the irradiances in the surface layer of the Kyeonggi Bay lie within optimum range for the maximum growth of phytoplankton. However, in winter the irradiance is lower than optimum values. Therefore, light could be a limiting factor for phytoplankton growth in winter.

In all seasons, except summer, there are shallow compensation depths. Especially, in winter the average compensation depths were extremely low and shallow. This may be due to the high turbidity by winter mixing. Therefore, the phytoplankton can only survive in the surface layers and can contribute a little to primary production in this turbid estuary.

Extinction coefficient(K) values are relatively high. Especially, in winter, the values of extinction coefficient is the highest, being due to the suspension of bottom sediment particles.

High concentration of S.S. in this study area could limit the light attenuation as an inhibition factor for the growth of the phytoplankton. High concentrations of S.S. during late fall and winter result from the sediments and detritus resuspended by the tidal action and winter turbulence induced by the strong winds, and from the long duration by the convectional mixing. However, in summer, high transparency and low turbidity may result from the thermal stability of water mass preventing the resuspension of sediment particles, in spite of large river runoff. By the river runoff, high turbidity and low transparency are limited in the upper part of the bay.

In the Kyeonggi Bay, as a reducing factor of light penetration, sediment materials seem to be more important factor than detritus particles.

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