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# The Ecological Study of Phytoplankton in Kyeonggi Bay, Yellow Sea

## I. Environmental Characteristics

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# 西海 京畿灣 植物플랑크톤에 對한 生態學的 研究

## I. 京畿灣의 環境特性

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**Abstract:** In order to clarify the influence of environmental factors on the phytoplankton community in Kyeonggi Bay, the hydrological and water quality data were obtained from 20 cruises from May, 1981, to September, 1982 in this bay.

Physical conditions at the mouth of the bay are more stable than those at the head of the bay. Temperatures and salinities of the upper part of the bay show great seasonal fluctuations due to the river discharge. By the extending effects of freshwater, a weak two-layer flow system is formed from the upper part of the bay to Palmi Island. In summer thermal stratification are formed in the middle and outer parts of the bay. In winter, However, the temperature shows no vertical temperature gradient. The inner bay and the vicinity area of Incheon Harbour are relatively polluted and eutrophicated due to both the runoff of freshwater from the Han River and the waste discharge from Incheon industrial complex. However, except the polluted area, the study areas are well oxygenated with more than 90% saturation.

**要約:** 京畿灣 植物플랑크톤의 群集生態에 영향을 미치는 環境特性을 알기 위하여 物理化學的 환경요인에 대한 분석이 1981년 5월부터 1982년 9월까지 20회에 걸쳐 채취된 시료를 토대로 행하여 졌다.

物理的 조건은 灣의 入口쪽이 河口쪽보다 안정된 상태를 보인다. 灣안쪽은 江水의 유입으로 水溫과 鹽分의 계절변화가 크게 나타난다. 염화수로에서 팔미도까지는 담수의 영향으로 상하로 약한 두층의 흐름이 형성된다. 팔미도 부근과 灣바깥쪽은 하계에 수온의 층상분포가 나타나나 동계에는 수온의 수직경사가 안 나타난다.

灣의 안쪽과 仁川港부근 수역은 담수의 유입과 인천공단에서 유입된 폐수의 영향으로 오염되고 富營養化된 상태를 보인다. 대체로 낮은 수소이온 농도, 높은 생화학적 산소요구량과 높은 영양염 분포를 보인다. 그러나 灣의 바깥쪽은 낮은 BOD와 높은 산소 포화도로 外海의 영향을 많이 받는 것으로 사료된다.

## INTRODUCTION

Kyeonggi Bay is a shallow coastal plain estuary about 10-40m depth, located in the middle part of the Korean west coast. This area is one of the typical drowned riverine valleys with rias coastline, including many islands, extensive tidal flats and tidal channels (KORDI, 1981).

The shallowness of coastal plain estuaries allows wind action and turbulent current generated by the tide and river flow to influence the water circulation. Evaporation by wind and sun light exceedingly influence heat exchange that give rise to a rapid fluctuation of water temperature over a wide coastal plain (Perkins, 1974).

It is characteristic that this bay is dominated by macrotidal range up to about 9-10m having maximum flood current of 2.7 knots and ebb current velocity of 3.4 knots respectively (Yi, 1972). Tremendous freshwater inflow from the Han River together with the run-off from the Imjin River cause extreme fluctuation of salinity in northern part of this bay. By the inflow of nutrients and trace elements from the Han River and Incheon industrial complex, the study area is polluted and eutrophicated occasionally.

In estuarine systems, numerous physico-chemical and biological factors may be responsible for phytoplankton distribution. The variation in salinity, temperature and often environmental factors determines characteristic species composition, distribution, productivity and successional pattern in estuarine ecosystems. This study lay emphasis on the spatial and temporal change of the various environmental factors in this estuarine ecosystem.

## METHODS AND MATERIALS

Samples for this study were collected in two survey areas. The first survey area is directly influenced by the runoff of Han River and the waste discharge from Incheon city. Physico-chemical environmental factors were measured at 7 sampling stations for 12 months from October, 1981 to September, 1982. The Second survey area includes 5 major tidal channels in Kyeonggi Bay. Samples were collected 9 times at 5 stations in each channel from May, 1981 to April, 1982 (Fig. 1). Station A in Yeomha Channel is located at the mouth of Han River, Station B in Incheon Channel is located near the Incheon Harbor, Station C is located at Palmi Channel in the middle part of Kyeongi Bay. Station D and E are located at the mouth of the Bay.

### Collection of physico-chemical data.

The weather data of air temperature, precipitation and wind velocity were referred to the report of meteorological observatory (1981). Water temperatures were measured by protected reversing thermometer attached to the Van-Dorn water sampler. Water samples were collected by Van-Dorn water sampler for measuring salinity, chemical oxygen demand, biological oxygen demand and nutrients. The salinities were measured by digital salinometer (Autosal model 8400) in the laboratory. Dissolved oxygens were measured with portable dissolved oxygen-temperature employed for D.O calibration. The solubility of oxygen in saline water can be expressed by the equation; $Cs = 14.161 - 0.3943T + 0.0077T^2 - 0.0000646T^3 - S\ (0.0841 - 0.00256T + 0.0000374T^2)$ mg/l, where S is salinity and T is temperature (Perkins, 1974). Water samples for hydrogen ion concentration (pH) were measured by portable pH meter (Chemcadet) on board. In the laboratory COD were measured by the p-Alkaline $KMnO_4$ consumption method, BOD were incubated for 5 days and measured according to Standard method (1976). Nutrient concentrations were measured by Technicon Autoanalyzer AA2, following to the methods of Strickland and Parsons (1972).

## RESULTS AND DISCUSSION

### A. Physical Characteristics

1. Air temperature, precipitation and wind.

Incheon city and its vicinity area have a more

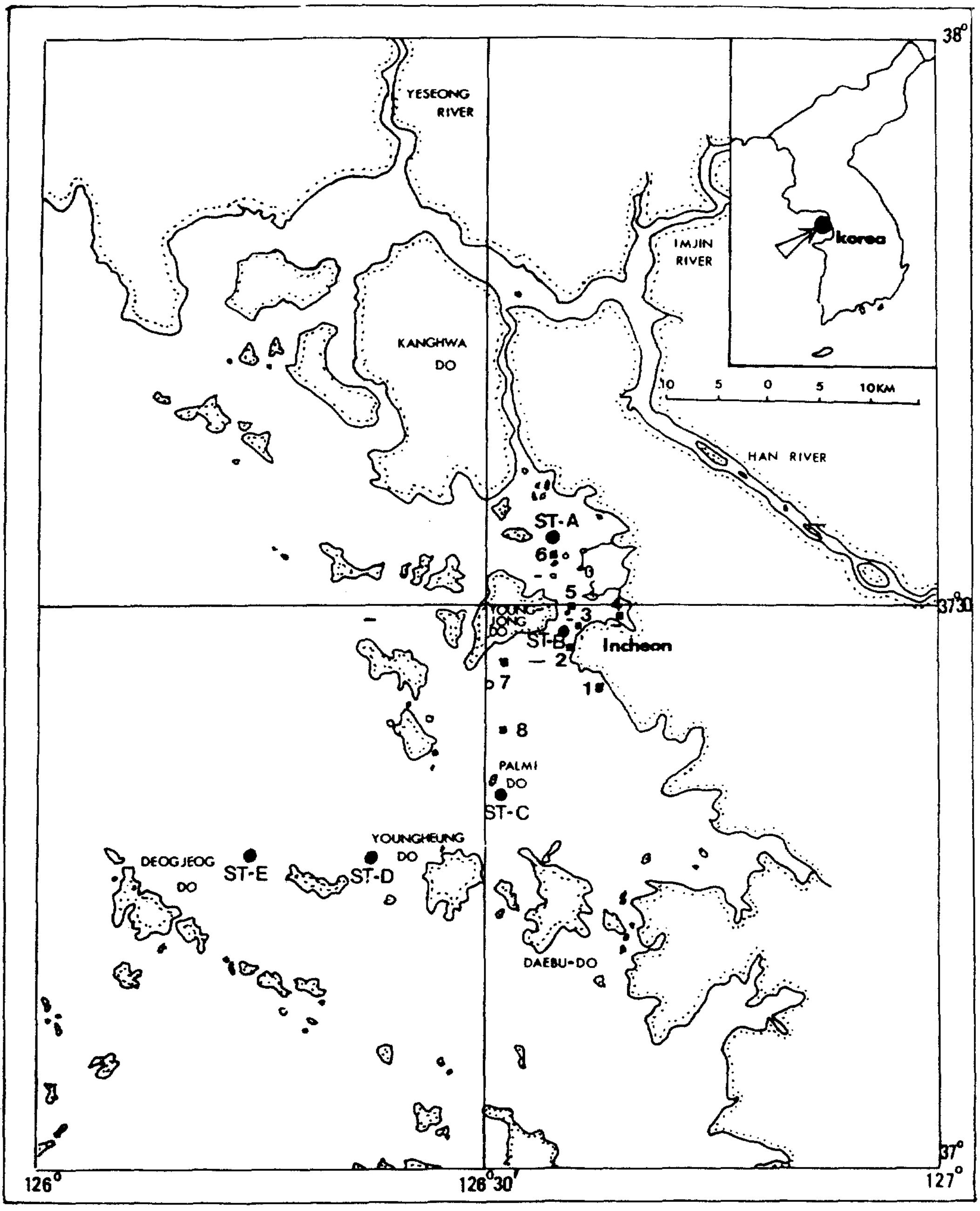

Fig. 1. Location map of Kyeonggi Bay.

mild weather than inland of the middle part of Korea. The mean annual temperature in Incheon city is 10.7°C, with the coldest month in January, averaging –6.3°C and the warmest month in July, averaging 24.4°C. Periods of below freezing temperatures are two months. The seasonal variation in air temperature is presented in Fig. 2.

The annual precipitation for the area averages 118 cm with the heaviest rainfall, maximum of 39.9 cm normally occurring in July. The times of least rainfall are occurred in the winter with minimum of 12.7 cm in December. The summer

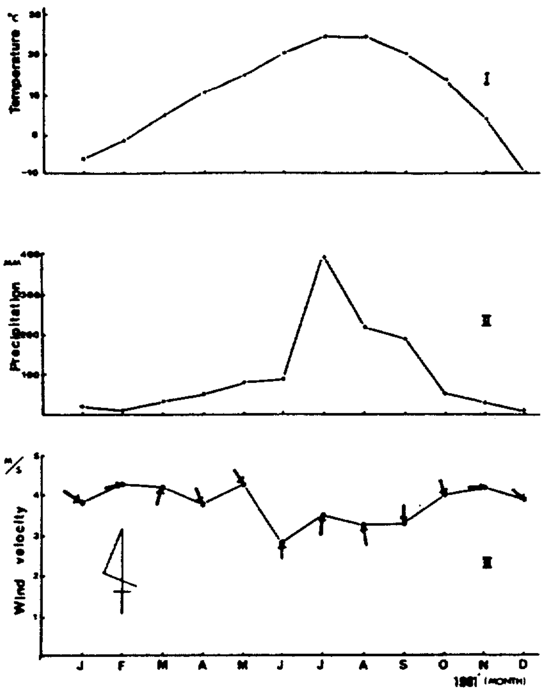

Fig. 2. The seasonal variations of air temperatures(I), precipitations(II), wind velocity and direction (III), in 1981 at Incheon Harbour. (by the data of meteological laboratory)

rains are largely in the form of a long spell of rainy weather to influence salinity fluctuations in the survey area (Fig. 5). The seasonal distribution of precipitation is presented in Fig. 2. The annual mean wind velocity is 3.7 m/sec, average for 24 hours. The prevailing winds blow from the north west in October, December, January, April and May, from the west in November, February and March and from the south in summer. Generally, from October to May, the northwest monsoon prevails and in summer winds blow from the south and southwest. Wind velocities are higher than those found in land, and often have strong effects on water level, heat exchange and current. The seasonal variation in the wind velocity and direction is presented in Fig.2.

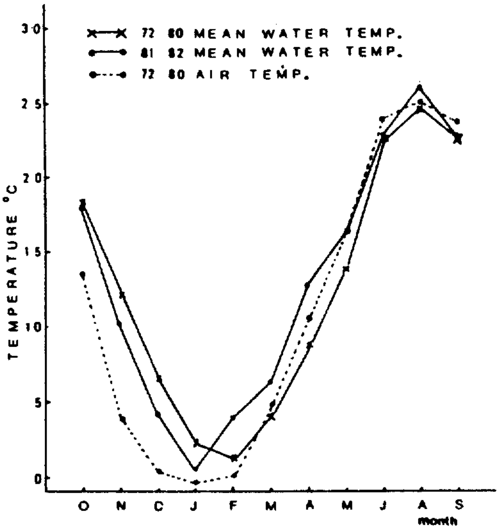

Fig. 3. Monthly variations of air temperatures and water temperatures from 1972 to 1980 in Incheon Harbour. (by the data of Hydrological office)

## 2. Water temperature

Water temperature data observed by Hydrographic Office at Incheon Harbor from 1972 to 1980 were lowest in February and highest in August, ranging from 1.35°C to 24.68°C with a mean of 13.04°C. The shallowness of the Bay combines with wind and tide-generated currents to promote rapid heat exchange (Riley, 1967). Seasonal variation patterns of water temperatures were similar to those of monthly mean air temperatures. In spring and summer water temperature was lower than air temperature while in autumn and winter the relation was reversed (Fig. 3). In the inner bay, annual range of water temperature was similar to that of air temperature. Such a fact seems to be due to the shallowness of water depth having small heat budget. Annual mean temperatures were ranged from 12.78°C at station 7 to 13.32°C at station 4, with a mean of 13.09°C in 1981 similar to above result from 1972 to 1980. Such little differences in the temperature between stations are due to the great tidal mixing over the survey area. Though there are little differences, temperatures

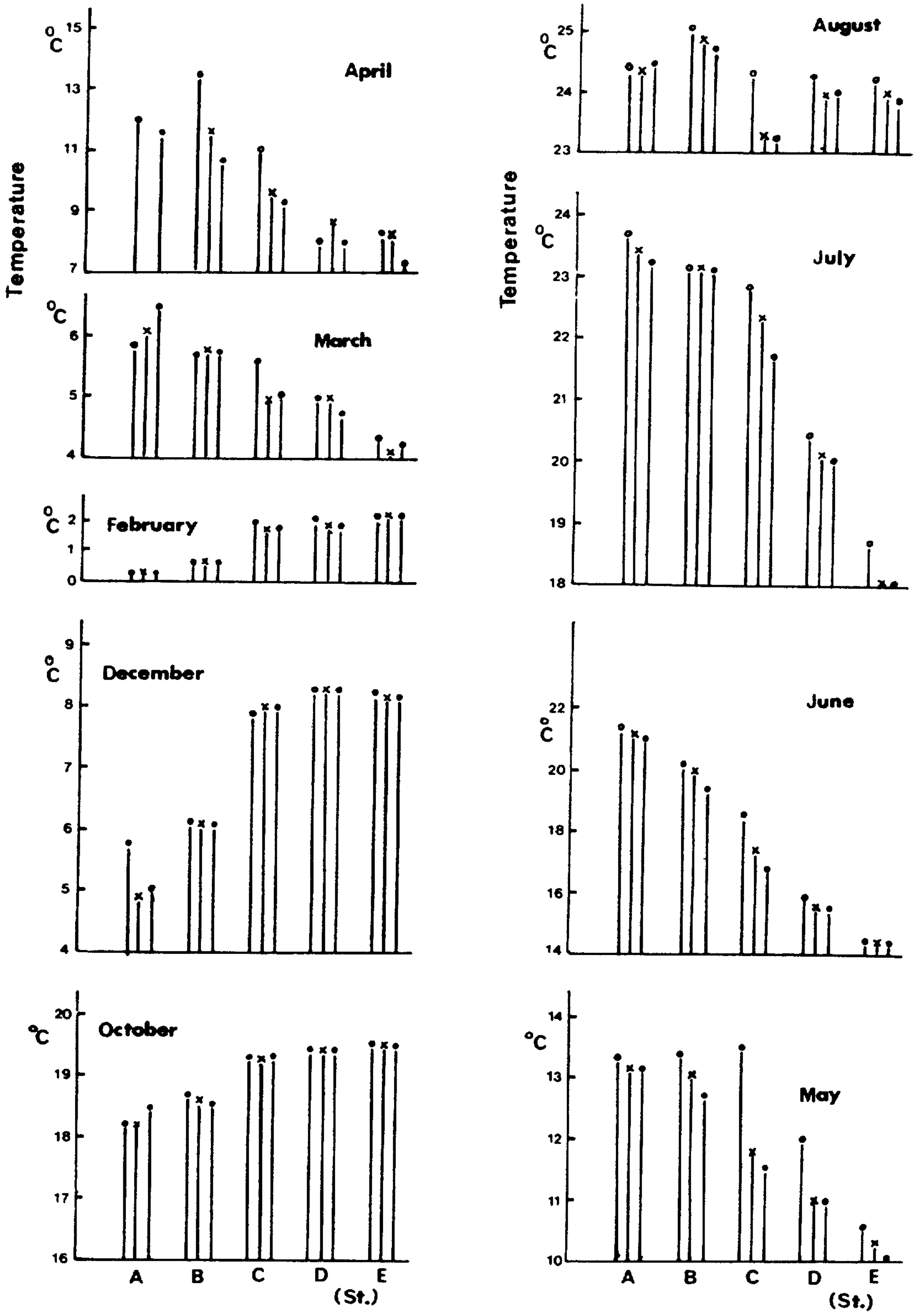

Fig. 4. The distribution of water temperatures in the second survey area.

at station 1 and station 4 show a little higher than at other stations by the inflow of waste water.

The temperature results measured at 5 channels are shown in Fig. 4. From March to July, the temperature decreases toward the outer bay. From October to February the gradient is reversed. Especially in summer the temperature usually decreases from the inner bay to the sea. These facts are due to the input of warm freshwater and the absorption of solar radiation by exposed mud flats which transfer accumulated heat to the overlying waters. Therefore temperature conditions at the mouth of bay are more stable than those at the head of bay. But from August to September temperature gradients were not shown due to the incursions of offshore waters.

In vertical profiles, during the spring and the summer, the surface water usually is much warmer than the deeper water. The largest vertical temperature gradients are shown at station C from April to September with about 1.5°C between the surface and bottom. From October to March, however, there is, no vertical temperature gradients. This fact may be due to the surface cooling caused by the cold air temperatures. Water masses in winter are more unstable than those in summer. If the mixing is especially vigorous, the phytoplankton may be carried down to deep layer and spend most of their time below the compensation depth and there will be no net production.

### 3. Salinity

The salinity of the Kyeonggi Bay is relatively lower than that of offshore area, due to the river discharges. Chung and Shim (1969) indicated that the salinity was changed directly by tidal effect in the Kyeonggi Bay, and that as a whole, the upper part of Kyeonggi Bay is mixohaline according to venice system. Because of mixing area between the freshwater and the saltwater, Kyeonggi Bay show estuarine characteristics. The salinities of the surface layer show great seasonal fluctuations due to the river discharge (Fig. 5). Salinities are low from summer to autumn and high from winter to spring. The high salinities in winter are due to the reduced discharge of rivers and partially heavy evaporation by the strong winds (Nakao, 1977).

The horizontal distribution of salinity increases towards the mouth of bay, which has a free connection with the offshore waters. Also, because of reducing effect of river discharge, the fluctuation of salinity are reduced towards the mouth of the bay. At station A, the salinity ranges from 19.16% to 31.43%. But at station E the ranges are between 30.89% and 32.40%.

At station A, the vertical distributions of mean salinity are shown from 26.88% at the surface to 27.82% at the bottom. Salinity profiles at station A, B and C show a little increase from surface to bottom. Therefore, a weak two-layer flow system is formed by the extending effects of freshwater from the upper bay to the station C. But at station D and E the vertical profiles of salinity show constant. At stations D and E, the tides are very strong in compare to the river flow. The vertical mixing becomes so intense that there is no variation in salinity from surface to bottom at stations D and E. From August to October, the horizontal distribution of salinity at station D and E is relatively uniform. This fact may be considered due to the incursion of the offshore water.

## B. Chemical characteristics.

### 1. pH

In the first survey area the pH values lie within the range of 4.30-8.20 with a mean of 7.67 (Table 1). The pH values vary extensively with stations and seasons. In comparison with the normal condition, these values are relatively low.

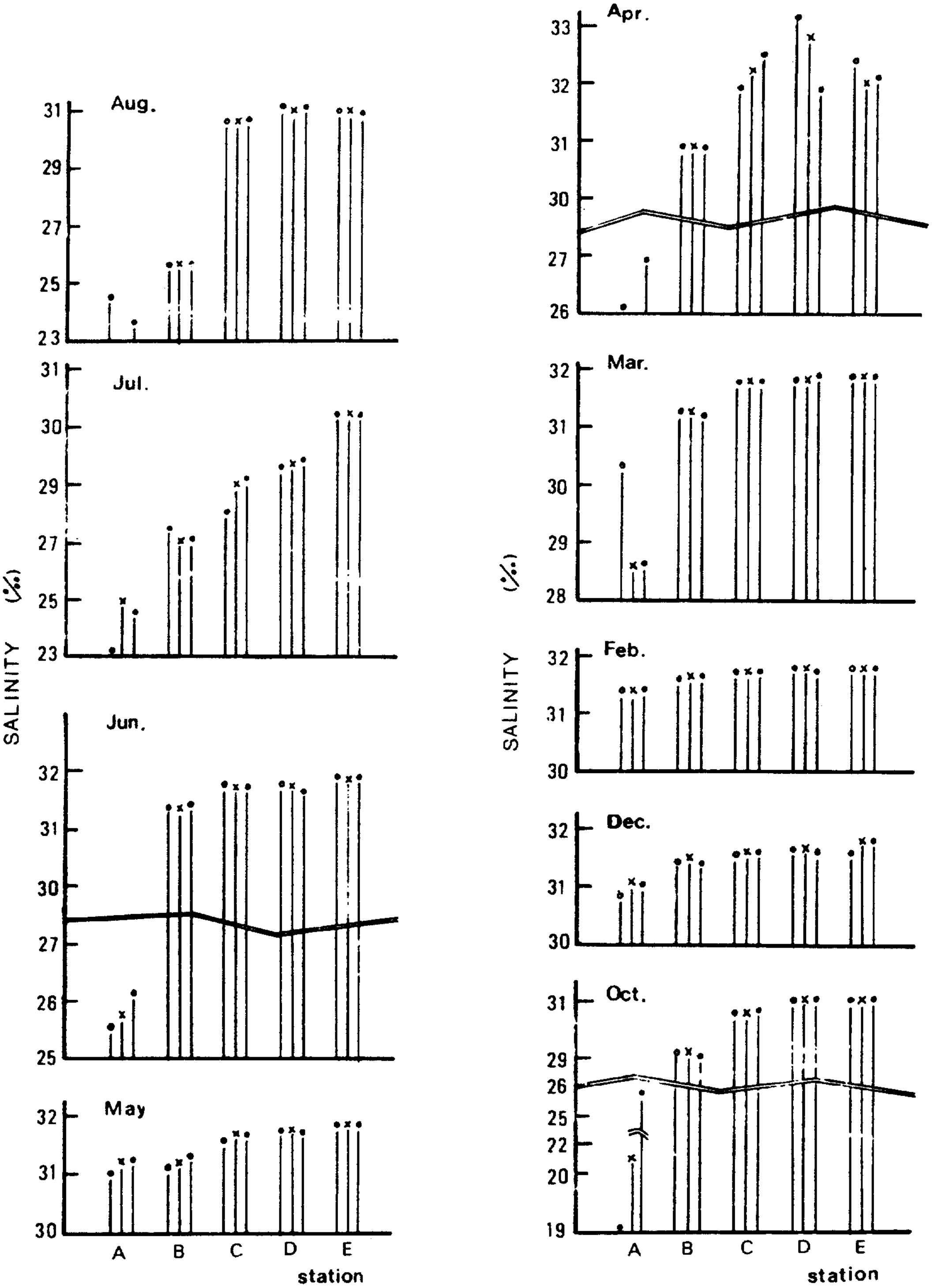

Fig. 5. The distribution of salinities in the second survey area.

**Table 1.** The seasonal variations of pH value in the first survey area

Unit : pH

| Station | 1981 | | | 1982 | | | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jul. | Aug. | Sep. | |
| St. 1 | 7.95 | 7.80 | 7.88 | 7.89 | 7.70 | 7.90 | 8.10 | 8.10 | 8.20 | 8.10 | 8.04 | 7.97 |
| St. 2 | 7.90 | 8.00 | 8.10 | 7.90 | 7.70 | 7.90 | 7.90 | 7.90 | 8.10 | 8.00 | 7.97 | 7.94 |
| St. 3 | 7.71 | 4.30 | 7.11 | 7.70 | 7.50 | 7.90 | 7.90 | 8.00 | 7.25 | 7.80 | 6.77 | 7.27 |
| St. 4 | 7.00 | 5.95 | 6.48 | 7.25 | 5.60 | 7.40 | 7.50 | 8.00 | 6.85 | 6.20 | 6.52 | 6.80 |
| St. 5 | 7.85 | 7.85 | 7.90 | 7.90 | 7.70 | 7.90 | 7.90 | 8.10 | 8.10 | 7.80 | 8.00 | 7.91 |
| St. 6 | 7.80 | 7.80 | 7.83 | 7.80 | 7.60 | 7.80 | 7.90 | 8.00 | 8.05 | 7.70 | 7.89 | 7.83 |
| St. 7 | 7.92 | 8.02 | 8.00 | 7.95 | 7.60 | 7.90 | 8.00 | 8.10 | 8.20 | 8.20 | 8.14 | 8.00 |
| Average | 7.73 | 7.10 | 7.61 | 7.77 | 7.34 | 7.81 | 7.89 | 8.03 | 7.82 | 7.68 | 7.62 | |

These low values could be due to the input of freshwater and waste discharge from the Han River and the Incheon industrial complex (Table 7). At stations 1,2,5 and 7, pH values are rather constant with the range of 7.7-8.20. These are similar to the results reported by KORDI (1978). But station 3 and 4 show especially low pH value with a mean of 7.27 and 6.80 respectively. Also, pH values at these stations very extensively with the range of 4.30-8.88 and 5.60-8.00, respectively. This suggests that station 3 and 4 are severely contaminated by acid waste discharging from Incheon industrial complex through Incheon Bridge tributary. At the Station 4, waters are polluted by strong acid release from Incheon industrial complex in the low tide, showing the extreme low values below the pH 3.0 occasionally. At high tide, the pH value is nearly normal condition showing about 8.0. This could be due to the buffering action and the dilution of the sea water. As shown in Fig. 6, at station 8, the pH values are relatively uniform. At station 8, the waters seem to be not affected by waste discharge with tidal cycle. At station 6, the pH values are relatively low. This may be due to the input of less buffered brackish water and unbuffered freshwater of slightly acid runoff. The seasonal variations of the average pH value are shown in Table 1. Although the pH values are usually highest in the summer and a minimum value occurs in the winter (Murray, 1966), maximum values in the study area occur in May and minimum value in November. Such a highest value in the spring may be due to the strong photosynthetic activity of the phytoplankton. At station 4, high values are especially concurrent with higher phytoplankton biomass (1,753,458 cells/l) in the spring. It is also usual to find high concentrations of oxygen and high pH values in the areas of high photosynthesis (Parsons et al. 1977). In spite of high water temperature in the summer, pH values are lower than that in the spring. This can be due to the effect of freshwater after the heavy precipitation and the input of waste water in the upper part of station 4. The lowest value in the winter seems to be due to the low temperature, high salinity and low photosynthesis of phytoplankton.

### 2. Dissolved Oxygen

Oxygen concentrations vary from a maximum of 13.8 mg/l at station 6 in February to a minimum of 2.4 mg/l at station 3 in September. Except station 3 and 4, all stations show relatively high oxygen concentrations with a mean of

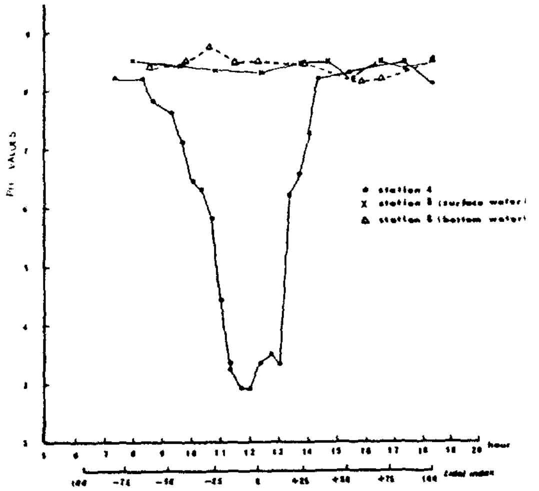

Fig. 6. The variation of PH values with tidal cycle at the spring tide.

above 8.0 mg/l (Table 2). These results agree with those obtained from the open coastal waters of the Yellow Sea (KORDI, 1982), but tends to be higher than those found in Incheon Dock (Yoo, 1982).

The percentage of dissolved oxygen saturation also varies extensively by months and stations ranging from 37.76% at station 3 to 121.41% at station 6. Except at station 3 and 4, the percentages of oxygen saturation at the rest stations are nearly more than 90%, and relatively high (Table 3).

Unpolluted stations are well-oxygenated from surface to bottom by turbulence, being due to tidal currents. Also, it is generally assumed that shallow water affected by wind or surf are fully oxygenated (Perkins, 1974). However, at stations 3 and 4, the saturation of dissolved oxygen are less than 70%. These levels are much lower than the standard saturation (80%) of water quality for fisheries and aquaculture (N.O.E, 1982). These low conditions may be due to the decomposition of organic matter, and the oxidation of sewage and industrial wastewater, since both domestic and industrial wastes contain surfactants which reduce the D.O concentration of the water (Perkins, 1974). The maximum percentage of dissolved oxygen are occurred in early February and minimum percentage are occurred in August. The saturation percentages are high in winter, spring, early spring, autumn and summer in order. This indicates that seasonal fluctuations of oxygen concentration in Kyeonggi Bay are affected by the stability of water mass and by phytoplankton growth. High percentage of oxygen in winter can be brought about by strong turbulence due to the winter monsoon winds (Nakao, 1977). High percentage in May could be caused by the photosynthetic activity of phytoplankton during spring bloom. Regeneration of oxygen in estuaries is brough about by mixing with well oxygenated water from river or the sea, direct reaeration from the air and by the photosynthetic activity of plants (Day and Balkema, 1981).

The vertical distributions of dissolved oxygen are similar at each depth in many cases. These constant distribution may be due to the mixing by tidal action or wind action. It is common that below the euphotic zone, the oxygen content decreases with depth as a result of oxidation of organic matter. However, unpolluted estuaries are normally well oxygenated from surface to bottom by the mixing due to tidal action (Day, 1981).

### 3. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

In the first survey area, the BOD ranges from 1.0 mg/l to 14.0 mg/l with a mean of 4.1 mg/l (Table 4). These concentrations are much higher than those in Incheon Dock (Yoo, 1982). Guthrie and Perry (1980) mentioned that an aquatic environment can have BOD of 5 mg/l (5ppm) and be polluted. If the BOD reaches the point where aerobic micro-organisms cannot survive, anaerobic forms become predominant, producing materials that are unpleasant to smell such as hydrogen sulfide ($H_2S$) or methange gas ($CH_4$).

**Table 2.** Distribution of Dissolved Oxygen in the first survey area.

(mg/ℓ)

| Station | 1981 | | | 1982 | | | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jul. | Aug. | Sep. | |
| St. 1 | 7.2 | 8.1 | 10.4 | 13.7 | 10.6 | 8.8 | 8.8 | 8.1 | 6.8 | 6.5 | 6.9 | 8.72 |
| St. 2 | 6.6 | 7.9 | 10.7 | 13.0 | 10.5 | 9.5 | 9.1 | 8.2 | 6.6 | 5.8 | 6.5 | 8.58 |
| St. 3 | 6.4 | 8.0 | 10.5 | 13.5 | 10.7 | 9.6 | 9.2 | 8.0 | 5.3 | 5.3 | 2.4 | 8.08 |
| St. 4 | 5.2 | 7.9 | 10.3 | 13.7 | 7.8 | 9.2 | 8.9 | 7.8 | 5.0 | 4.2 | 4.3 | 7.66 |
| St. 5 | 5.7 | 8.0 | 10.6 | 13.2 | 10.5 | 9.4 | 8.8 | 8.4 | 6.0 | 5.0 | 6.5 | 8.37 |
| St. 6 | 5.8 | 8.2 | 10.8 | 13.8 | 10.6 | 9.5 | 9.5 | 8.1 | 6.2 | 5.0 | 6.5 | 8.37 |
| St. 7 | 7.2 | 8.2 | 10.9 | 13.5 | 10.6 | 9.5 | 9.3 | 8.8 | 6.8 | 6.0 | 7.2 | 8.91 |
| Average | 6.3 | 8.1 | 10.6 | 13.7 | 10.7 | 9.6 | 9.3 | 8.8 | 6.8 | 6.5 | 6.8 | 8.39 |

**Table 3.** The percentage of Dissolved Oxygen Saturation in the first survey area

Unit: % Saturation

| Station | 1981 | | | | 1982 | | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jul. | Aug. | Sep. | |
| St. 1 | 93.40 | 92.46 | 101.21 | 120.97 | 102.53 | 90.87 | 105.25 | 104.38 | 98.02 | 98.50 | 99.97 | 100.69 |
| St. 2 | 85.59 | 87.78 | 104.53 | 114.90 | 101.95 | 96.88 | 110.22 | 105,84 | 94.43 | 86.07 | 92.92 | 98.28 |
| St. 3 | 81.55 | 87.80 | 100.94 | 117.93 | 105.23 | 98.09 | 108.86 | 100.64 | 75.56 | 72.72 | 37.76 | 89.76 |
| St. 4 | 65.87 | 85.50 | 98.74 | 121.03 | 73.24 | 97.22 | 105.94 | 101.12 | 71.55 | 60.85 | 56.26 | 85.21 |
| St. 5 | 71.56 | 86.11 | 102.98 | 116.62 | 102.53 | 95.16 | 104.69 | 106.49 | 86.71 | 67.94 | 88.43 | 93.57 |
| St. 6 | 72.61 | 86.14 | 103.46 | 121.41 | 99.24 | 96.61 | 112.61 | 101.22 | 88.35 | 60.07 | 77.83 | 92.69 |
| St. 7 | 92.66 | 92.61 | 107.32 | 119.41 | 104.35 | 97.56 | 106.71 | 112.10 | 95.50 | 89.18 | 102.36 | 101.80 |
| Average | 80.46 | 88.34 | 102.74 | 118.90 | 98.44 | 96.06 | 109.75 | 104.54 | 87.19 | 76.48 | 79.36 | |

As a result, water quality is decreased.

Among the stations, at station 4 BOD is highest, with a mean of 8.8 mg/l. This high BOD is due to the organic materials by the input of both domestic and industrial waste water from Incheon industrial complex. The BOD at station 6 are also relatively high. This may be due to the input of freshwater from Han River (Hong et al. 1978). Other stations have about 3 mg/l. These stations are less polluted by the dilutions of the sea water.

The BOD in summer is highest due to the large runoff from the Han River during the long precipitation periods and the high activity of biodegradation by high temperature. (Table 7) The BOD in the spring and autumn are relatively high. This is due largely to the large biomass of the phytoplankton. The winter have a minimum BOD value, due to the low temperature and the less input of freshwater and waste waters.

The COD ranges from 0.2 mg/l to 12.4 mg/l, with a mean of 3.7 mg/l (Table 5). Among the stations, station 4 has the highest COD, with a mean of 7.47 mg/l, and the COD at station 6 is relatively high. Yoshida (1973) defined that the seawater having a range of 3-10 mg/l COD corresponds the hypertrophic zone. Therefore, this study area is considerably polluted by the organic materials as show with BOD.

The COD varies with season. As a rule, the COD values are higher in summer. This may be due to the high oxidation with high temperature. The COD in winter is relatively high. This suggest the resuspension of organic matter from the bottom.

## 4. Plant nutrients.

### Nitrate-Nitrogen

In the first survey area, the concentrations of nitrate-nitrogen ranged from 2.25 ug-at N/l in May at station 7 to 40.00 ug-at N/l in November at station 6 with a mean of 11.29 ug-at N/l (Fig. 7). These results indicate that this study area are relatively eutrophicated by the input of freshwater and sewage.

Among the stations, station 6 shows the highest average concentrations, having of 20.73 ug-at N/l. This high value is due to the input of river discharge (Table 7). Station 3 and 4 also show high levels, being due to the effluent of the sewage and waste water from Incheon City. Level at stations 1,2 and 7, less influenced by freshwater and sewage, are relatively high. This may be due to the bottom regeneration. According to Boynton et al. (1980), it appears that nutrient fluxes across the sediment water interface represent an important source to the water column. Because stations mentioned above are located in extensive tidal flat, the regeneration from tidal flats may be occurred.

Seasonal variations of average nitrate-nitrogen values in the first survey area are presented (Fig. 7). Winter values are relatively high as usual in temperate areas. During winter, low rates of plant nutrient assimilation and the upward flux of nitrate from bottom by winter mixing keep high concentrations of nitrate until the onset of spring. Toward the spring, water stability reduces the vertical flux of nitrate and the increased utilization of nitrate by phytoplankton results in nitrate minimum in May. McCarthy et al. (1977) suggested that the cummulative phytoplankton utilization of nitrate were directly proportional to the increase in water temperature.

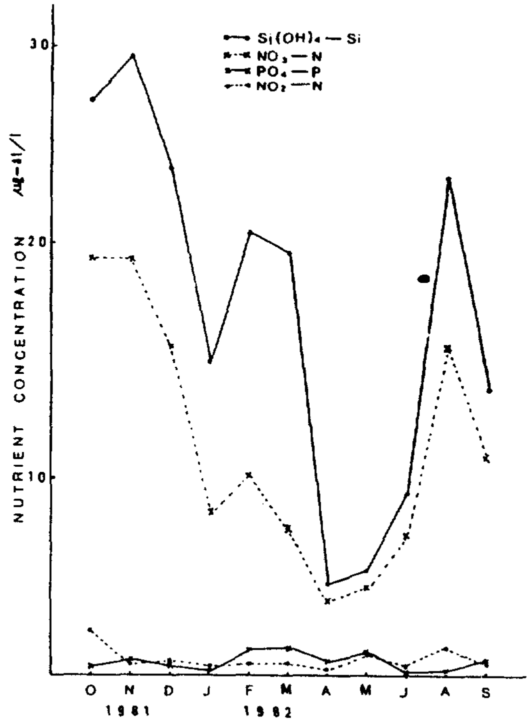

**Fig. 7.** Monthly variation of nutrient concentration in the first survey area.

High levels in August and September may be due to the large inputs of nitrate from runoff after summer heavy precipitation (Table 7). Especially, station 6 was high levels during this period. The highest levels in October and November may be due to both large inputs from freshwater and sewage, and vertical mixing by tide and wind. Thus in this study area, the distributions of nitrogen-nitrate usually show a predictable seasonal pattern.

In vertical distribution of nitrate, the surface concentrations at stations A and B are relatively higher than the bottom concentration (Table 6). At stations C, D and E, the surface values are

Table 4. The monthly variation of biochemical oxygen demand in the first survey area

Unit: mg/ℓ

| Station | 1981 | | | 1982 | | | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jul. | Aug. | Sep. | |
| St. 1 | 4.0 | 3.0 | 3.0 | 3.0 | 3.0 | 2.0 | 1.0 | 3.0 | 4.0 | 4.0 | 3.0 | 3.0 |
| St. 2 | 3.0 | 5.0 | 3.0 | 3.0 | 2.0 | 1.0 | 2.0 | 2.0 | 7.0 | 6.0 | 3.0 | 3.4 |
| St. 3 | 3.0 | 2.0 | 4.0 | 2.0 | 3.0 | 6.0 | 2.0 | 4.0 | 3.0 | 4.0 | 4.0 | 3.1 |
| St. 4 | 10.0 | 7.0 | 13.0 | 4.0 | 14.0 | 2.0 | 12.0 | 5.0 | 9.0 | 12.0 | 9.0 | 8.8 |
| St. 5 | 2.0 | 2.0 | 3.0 | 1.0 | 1.0 | 1.0 | 5.0 | 3.0 | 2.0 | 3.0 | 3.0 | 2.4 |
| St. 6 | 12.0 | 3.0 | 4.0 | 2.0 | 2.0 | 5.0 | 4.0 | 2.0 | 4.0 | 5.0 | 5.0 | 4.4 |
| St. 7 | 4.0 | 4.0 | 3.0 | 2.0 | 1.0 | 1.0 | 6.0 | 4.0 | 4.0 | 4.0 | 3.0 | 3.3 |
| Average | 5.4 | 3.7 | 4.7 | 2.4 | 3.7 | 2.6 | 4.6 | 3.3 | 4.7 | 5.4 | 4.3 | |

Table 5. The monthly variation of chemical oxygen demand in the first survery area

Unit: mg/ℓ

| Station | 1981 | | | 1982 | | | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jul. | Aug. | Sep. | |
| St. 1 | 4.40 | 6.80 | 2.80 | 2.40 | 2.20 | 1.20 | 1.40 | 1.30 | 6.30 | 7.70 | 1.00 | 3.41 |
| St. 2 | 3.20 | 2.40 | 3.60 | 1.60 | 2.40 | 0.20 | 0.80 | 1.00 | 8.20 | 7.90 | 1.00 | 2.94 |
| St. 3 | 3.20 | 4.60 | 2.80 | 1.00 | 0.80 | 1.60 | 1.70 | 2.10 | 3.90 | 4.30 | 2.90 | 2.63 |
| St. 4 | 6.60 | 6.40 | 7.80 | 1.60 | 9.60 | 1.80 | 12.40 | 8.10 | 12.10 | 10.90 | 4.90 | 7.47 |
| St. 5 | 3.20 | 3.60 | 3.20 | 2.20 | 1.20 | 1.40 | 4.00 | 4.10 | 4.00 | 5.10 | 3.20 | 3.20 |
| St. 6 | 4.20 | 5.40 | 3.20 | 2.00 | 0.20 | 2.20 | 6.50 | 0.80 | 4.70 | 4.90 | 0.70 | 3.16 |
| St. 7 | 1.60 | 4.00 | 4.80 | 1.20 | 8.00 | 0.80 | 1.70 | 1.90 | 6.10 | 4.90 | 0.70 | 3.25 |
| Average | 3.77 | 4.70 | 4.00 | 1.70 | 3.50 | 1.30 | 2.80 | 4.07 | 6.47 | 6.47 | 2.10 | |

lower than the bottom values. In summer, especially, the gradients are remarkable. According to Rhoads et al (1975), in Buzzards Bay, organic nitrate in the bottom water was found to be higher than at the surface throughout the summer. This may be due to the high bottom regeneration and water stability to prevent mixing. Density stratification markedly reduces the vertical flux of nitrate, and the increased utilization of nitrate by phytoplankton results in a summer nitrate minimum in surface waters (Ryther and Dunstan. 1971). In winter, however, the distributions at all depth are relatively constant being due to the winter mixing.

Nitrite-nitrogen

Average concentrations of nitrite are considerably high in the input area of freshwater (1.12 ug-at/1 at station 6) and waste water (1.07 ug-at/1 at station 4), like the nitrate distribution. However, stations 1, 2 and 7, relatively less polluted area, are shown low level concentrations and the concentrations decrease toward the outer bay.

The seasonal distributions of nitrite show different pattern from of nitrate (Fig. 7). Average values from November to early May are

Table 6. The distribution of $NO_3$-N in the second survey area

($\mu$g-at/ℓ)

| Station | | 1981 | | | | | 1982 | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | May | Jun. | Jul. | Aug. | Oct. | Dec. | Feb. | Mar. | Apr. | |
| | s | 9.58 | 5.55 | 8.09 | 18.45 | 16.51 | 12.72 | 10.05 | 10.14 | 52.55 | 17.07 |
| St. A | m | 1.19 | 2.02 | 3.56 | | 10.27 | 12.93 | 10.75 | 16.00 | | 8.10 |
| | b | 1.29 | 3.45 | 2.78 | 25.03 | 12.32 | 13.14 | 10.90 | 16.58 | 69.01 | 17.17 |
| | s | 6.38 | 6.26 | 5.00 | 8.50 | 9.25 | 9.22 | 8.33 | 7.18 | 8.56 | 7.63 |
| St. B | m | 2.98 | 5.18 | 5.12 | 7.42 | 6.20 | 9.02 | 8.17 | 6.71 | 6.80 | 6.40 |
| | b | 3.01 | 4.07 | 4.78 | 4.37 | 7.13 | 9.02 | 7.90 | 7.44 | 7.12 | 6.09 |
| | s | 0.88 | 1.78 | 3.24 | 0.69 | 0.21 | 8.19 | 3.25 | 5.77 | 2.82 | 2.98 |
| St. C | m | 1.51 | 1.82 | 2.72 | 0.68 | 0.43 | 7.57 | 3.48 | 5.68 | 3.00 | 2.99 |
| | b | 2.12 | 1.58 | 3.05 | 2.28 | 1.32 | 7.16 | 6.84 | 5.47 | 3.31 | 3.68 |
| | s | 0.50 | 1.37 | 2.78 | 1.09 | 0.19 | 7.78 | 4.89 | 5.46 | 5.07 | 3.24 |
| St. D | m | 0.62 | 1.42 | 2.88 | 1.21 | 0.87 | 7.78 | 6.05 | 4.95 | 5.16 | 3.44 |
| | b | 0.98 | 1.54 | 2.65 | 0.99 | 1.21 | 11.08 | 6.58 | 5.55 | 6.02 | 4.07 |
| | s | 0.51 | 0.68 | 1.57 | 1.26 | 1.51 | 7.99 | 6.53 | 6.01 | 5.33 | 3.49 |
| St. E | m | 0.70 | 1.27 | 1.89 | 1.71 | 2.01 | 7.96 | 6.72 | 3.69 | 6.96 | 3.66 |
| | b | 0.87 | 1.39 | 2.01 | 1.54 | 2.34 | 10.12 | 6.78 | 5.72 | 5.71 | 4.05 |
| Average | | 2.21 | 2.63 | 3.47 | 5.37 | 5.45 | 9.45 | 7.15 | 7.49 | 13.39 | |

relatively low and average concentrations in early May are lowest. This lowest value in May is probably due to the heavy uptake by phytoplankton. In comparing with high nitrate distribution, nitrite levels in winter are considerably low below mean value. Despite of winter mixing, low values in winter may be due to the nitrification of nitrite to nitrate in oxygen-rich waters. In winter high oxygen saturation caused by low temperature and strong winds oxidize nitrite to nitrate (French et al. 1983). The highest average values up to 2.30 ug-at N/1 in October may be due to the high nitrate concentration and low oxygen saturation. The highest values in late summer may be due to the input of freshwater and low oxygen saturations. Average concentrations in late May are relatively high. This may be due to the heavy regeneration of nitrogen after spring bloom.

### Phosphate-phosphorus.

In the first survey area, average concentration of phosphate is 0.78 ug-at P/l. The horizontal distributions of phosphate are different from the distribution of nitrogen (Fig. 8). The variations among the stations are not shown, but considerably constant distributions. This means that the input of phosphate phosphorus from waste waters at station 4 are much less than that of nitrogen. However, the average concentrations of phosphate phosphorus at station 6 are relatively high. This may be due to the inputs of freshwater.

Seasonal variations of phosphate are relatively remarkable (Fig. 7). From spring to summer, the concentrations gradually decrease. Minimum concentrations are occurred in August. These low concentrations seems to be correlated with water stability in summer season. The reason may be that water stability in summer prevents flux of

Table 7. Average values of water quality parameters in the mouth of Han River.

(in KORDI Report, 1978)

| Station | DO (%) | pH | COD (mg/l) | $NO_3$-N (ug-at/l) | $NO_2$-N (ug-at/l) | $PO_4$-B (ug-at/l) | $SiO_2$-S (ug-at/l) |
|---|---|---|---|---|---|---|---|
| Jechon | 43.00 | 7.21 | 15.95 | 49.43 | 3.93 | 1.20 | 58.00 |
| Ganghwa-Bridge | 75.00 | 7.50 | 19.59 | 66.43 | 3.82 | 0.86 | 59.49 |

phosphate from bottom sediments. From late summer to early spring through the winter, the concentration gradually increase, up to average concentrations of 1.44 ug-at P/l. Despite of low inputs at stations 4 and 6, high values prevaile in winter. This may be due to the large flux of phosphate by winter mixing. At spring blooms, the concentrations of phosphate are relatively low, but after bloom, the concentrations rapidly increases. In summer season, the vertical gradient in phosphate distribution is distinctly shown in the lower part of the bay. However, in winter these gradients are not occurred. This may be due to the winter mixing of water mass.

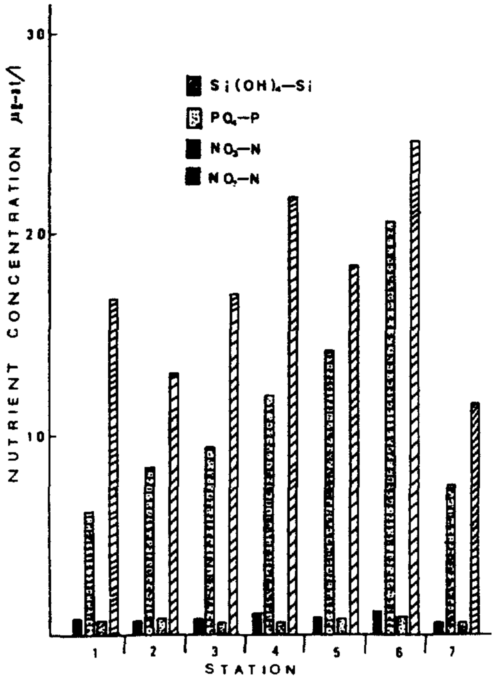

Fig. 8. The distribution of average nutrient concentration at each station in the first survey area.

Silicate-Silicon

In the first survey area, the concentrations of silicate-silicon ranges from 2.54 $\mu$g-at Si/l in May to 42.50 $\mu$g-at Si/l in November. The highest concentration occurrs in the upper area of the bay receiving freshwater input. The concentrations in the input area of waste water are also high, while those in the outer areas were relatively low. This indicates that the study area was enriched in silicate by both input of freshwater and waste water (Table 7).

The seasonal variations of silicate-silicon are predominant in this area (Fig. 7). From October to May, average concentrations are maintained high level. During spring, average concentrations decrease, reaching a minimum concentrations in accordance with spring bloom in May. After heavy rain in August, average concentration increases rapidly. Especially the concentrations at station 6, receiving freshwater input, are extremely high. But during the same period the concentrations at the outer bay are low. This means that the silicate supply by river increases rapidly after heavy rains and are mainly limited to the upper part of the bay. In general, silicate concentrations may be raised at times of larger river discharge, while low values coincide with spring and autumn blooms (Paasche. 1980).

The vertical distribution of silicate-silicon are shown typical gradient, increasing with depth. This may be due to the transport of silicate, mineralized in the surface sediment, from interstitial water by tidal current or wind waves (Vanbennkom. et al. 1974).

## SUMMARY AND CONCLUSION

Kyeonggi Bay and adjacent coastal areas characterized with macrotidal range are affected by both the input of freshwater from Han River together with adjacent rivers and the waste discharge from Incheon industrial area. These complicated estuarine systems show a large fluctuation of environmental factors and result in the characteristic phytoplankton ecology.

The large seasonal variations of water temperature are similar to those of air-temperature, mainly due to the shallowness of water depth. Temperature conditions at the mouth of the bay are more stable than those at the head of the bay. In summer, seasonal thermal stratification are formed. However, in winter, there is no vertical temperature gradients, due to the winter vertical mixing caused by winds, thermal convection, and tidal action.

The low salinities in summer and autumn are due to the increased river discharges by heavy precipitation. The high salinities in winter and spring result from the reduced discharge of rivers and partially heavy evaporation by the strong winds. According to the salinity profiles, a weak two-layer flow system is formed by the extending effects of freshwater from the upper of the bay to the Palmi Island. But in the outer bay, the vertical profiles of salinity show relatively constant.

The inner bay and the vicinity area of Incheon City are polluted and eutrophicated by the inputs of freshwater together with waste discharge both from Han River and from Incheon industrial complex. These areas are characterized by low pH values, high COD and BOD values, and the high nutrient concentrations. However, except the polluted area, the outer study areas are well oxygenated with more than 90% saturation. These high oxygen contents may be resulted from continous tidal action and strong turbulence.

During the winter, low rates of plant nutrient assimilation and the upward flux of nitrate and phosphate from bottom by winter mixing keep high nutrient levels until the onset of spring. Toward the spring, the increased utilization of nutrient by phytoplankton results in nutrient minimum in May. In summer, the low concentrations of nutrient at the surface waters may be resulted from the water stability preventing the vertical flux of nutrient regenerated. The major source of nitrogen and silicon may be river discharge and waste discharges but, that of phosphorous seems to be the autochthonous regeneration rather than external inputs. The distribution of plant nutrients seems to be greatly related with the physical properties of water mass in this bay.

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