# Water Quality of the Yellow Sea in Summer

Sun-Jae YOU · Jong-Gu KIM and Gwang-Su KIM*
*Department of Marine Environment, Kunsan National University, Kunsan 573-400, Korea*
**Department of Environmental Engineering, National Fisheries University of Pusan, Pusan 608-737, Korea*

The distributions of temperature, salinity, dissolved oxygen, chemical oxygen demand, dissolved inorganic nitrogen and phosphate in the Yellow Sea are described from data collected in June and July, 1994. Based on the observations of water temperature and salinity, the fresh waters originated from the Changjiang River were found to affect the waters adjacent to Cheju Island. In the light of the distributions of dissolved oxygen and chemical oxygen demand, the western part of the Yellow Sea was worse in water quality than the eastern part. Based on data of nutrients, eutrophication indices of the western part were higher than those of the eastern part in summer. It is concluded that the western part of the Yellow Sea appeared to receive high pollution loads from rivers and was evaluated to have high potentiality of red tide occurrence.

## Introduction

The Yellow Sea is a semi-enclosed shallow waters surrounded by the Korean peninsula and the Chinese continent in the Pacific Northwest region, which is connected with the Bohai Sea in north and with the East China Sea in south. Its surface area is known to be 404,000$km^2$, total volume of water to be 17,620$km^3$, average depth to be 44$m$, and the maximum longitudinal and latitudinal lengths to be about 1000$km$ and 700$km$, respectively (Valencia, 1988).

The average annual amounts of fresh waters discharged into the Yellow Sea from major rivers along its coast are reported to be 950$km^3$ from the Changjiang River and 42$km^3$ from the Huanghe River of China, and to be 35$km^3$ from the Aprok (Yalu) River, 14.9$km^3$ from the Daedong River, 19.4$km^3$ from the Han River, 6.2$km^3$ from the Keum River and 2.6$km^3$ from the Yeongsan River of Korea(Yu *et al.*, 1988; Ministry of Environment ROK, 1993a; Yanagi, 1994).

In Korea, due to population increase and industrialization, the amounts of sewage and industrial wastewater flowing into the Yellow Sea have increased rapidly since 1960s, and the various reclamation and construction works to provide industrial complexes have been performed along Korean west coast. In addition, free trade areas and industrial belts are formed in China under the open door policies, and the population, thereby, is recently concentrated in large cities along China east coast. Total annual amounts of industrial drainage and sewage in China were reported to be 25.14 billion tons and 7.25 billion tons, respectively, in the year 1984. In view of the industrial development, the increase of population and the elevation of living standard, it is estimated that total annual amount of industrial drainage and sewage in China will be 42.5 billion tons and 18.9 billion tons, respectively, by the year 2000(UNEP, 1992; Ministry of Environment ROK, 1993b).

In recent decades, the environment of the Yellow Sea has been damaged severely by pollution, overfishing and coastal & ocean engineering. Accordingly, some phenomena such as the sudden deaths of organisms in a certain area due to the input of large amount of wastewater and/or the instabilities in food chains caused by eutrophication have happened on scale of several days or several months. As long term phenomena in the Yellow Sea, the sharp decline of production resources in quality and quantity and the elimination of ecological species have been occurred by pollution(She, 1993). Therefore, water quality is considered to be of special importance to the marine environment.

In Korea, The National Fisheries Research and Development Agency (1989) conducts bimonthly serial oceanographic observations and seawater analyses on 21 fixed lines in Korean waters including the eastern part of the Yellow Sea in February, April, June, August, October and December. The Korea Ocean Research and Development Institute (1992, 1993) also conducted actively oceanographic observations, seawater analyses, biological surveys, etc. in the Yellow Sea. In addition, Plenty of reports and papers concerning the Yellow Sea have been published in China since 1950's(Sun and Tang, 1993).

It is, however, difficult to find the data of seawater analyses which could be obtained through the surveys or observations performed over the entire area of the Yellow Sea in the same period of summer.

In this study, the characteristics of water quality for whole open area far from Korean and Chinese teritorial waters in the Yellow Sea are described, and the basic data are presented for further researches of marine ecosystem conservation and seawater quality management in the Yellow Sea.

## Materials and Methods

The water samples were collected with all-PVC Niskin samplers from six different depths viz. 1*m*, 10*m*, 20*m*, 30*m*, 50*m* and 75*m* at 10 stations on the side of Korea, and from three different depths viz. the water surface, mid-depth and about 1*m* above the bottom at 11 stations on the side of China (Fig. 1) from June 22 to July 22, 1994 on board T/S Haelim (1,057 GT) and T/S Haelim No.3(303 GT) of Kunsan National University. After the samples were freezed and stored, seawater analyses were conducted at laboratory. Water temperature, pH, salinity and dissolved oxygen were measured *in situ* using thermometer, pH meter (Orion 200 series), salinometer (E2-Tsurumi) and DO meter (YSI 58), respectively. For duplicate test, the dissolved oxygen was also measured by Winkler-Azide modification method for 100*ml* samples. COD, $NH_4^+$-N, $NO_2^-$-N, $NO_3^-$-N, and $PO_4^{3-}$-P were measured by $KMnO_4$ method on alkaline condition, Indophenol method(Ministry of Environment ROK, 1991), Colorimetric method, Cadmium Reduction method and Ascorbic Acid method, respectively (APHA, AWWA, WPCF, 1989). In this study, dissolved inorganic nitrogen (DIN) means the summation of $NH_4^+$-N, $NO_2^-$-N and $NO_3^-$-N.

The published data from the National Fisheries Research and Development Agency (1989) and the Korea Ocean Research and Development Institute (1992, 1993) were also used as references for the figures regarding the ditributions of water temperature, salinity, DO, COD and nutrients and for the comparison of data obtained in this study.

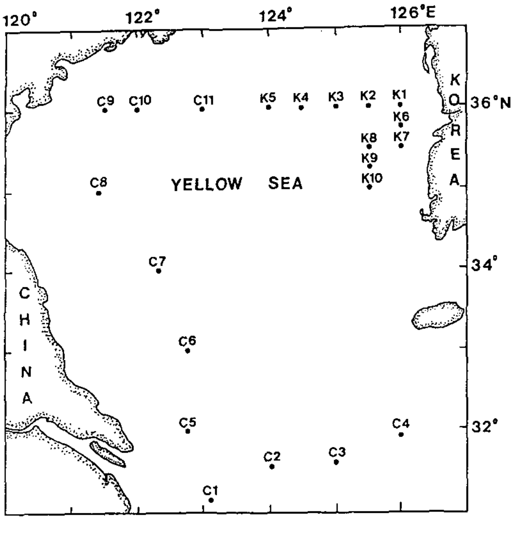

Fig. 1. Location of sampling stations in the Yellow Sea.

## Results and disscusion

For discussion, 21 stations in the Yellow Sea are divided into two parts; 10 stations (K1~K10) on the side of Korea(the eastern part of the Yellow Sea) and 11 stations (C1~C11) on the side of China(the western part of the Yellow Sea). The range and mean value of each chemical constituent in surface water are shown in Table 1. The results of seawater analyses at each depth on all sampling stations in the Yellow Sea are shown in Table2 and 3.

### 1. Water temperature and salinity

The distributions of temperature and salinity in surface water over the Yellow Sea are illustrated in Fig. 2 and Fig. 3, respectively, and the vertical profiles of water temperature and salinity on the cross-section along the latitude line of 36° N are shown in Fig. 4.

Table 1. The range and mean value of each chemical constituent in surface water of the Yellow Sea in summer

| items | Unit | Eastern Part | | Western Part | |
|---|---|---|---|---|---|
| | | Range | Mean | Range | Mean |
| Temp. | ℃ | 14.9~26.5 | 18.6 | 22.8~27.5 | 24.7 |
| pH | | 8.00~8.25 | 8.13 | 8.11~8.82 | 8.37 |
| Salinity | ‰ | 31.29~33.43 | 32.71 | 20.72~31.32 | 27.27 |
| DO | *mg/l* | 5.37~10.49 | 8.44 | 5.49~10.80 | 7.39 |
| COD | *mg/l* | 1.33~3.82 | 2.11 | 1.86~4.00 | 2.59 |
| $NH_4^+$ -N | *ug*-at/*l* | ND~0.57 | 0.16 | ND~3.64 | 0.81 |
| $NO_3^-$ -N | *ug*-at/*l* | 0.21~3.57 | 1.09 | 0.29~15.71 | 2.83 |
| $NO_2$ -N | *ug*-at/*l* | ND~0.20 | 0.05 | ND~0.51 | 0.21 |
| DIN | *ug*-at/*l* | 0.21~4.15 | 1.31 | 0.73~16.94 | 3.85 |
| $PO_4^3$ -P | *ug*-at/*l* | 0.13~1.13 | 0.30 | 0.18~4.28 | 0.70 |
| N/P | | 0.47~32.17 | 8.11 | 1.43~54.29 | 11.30 |

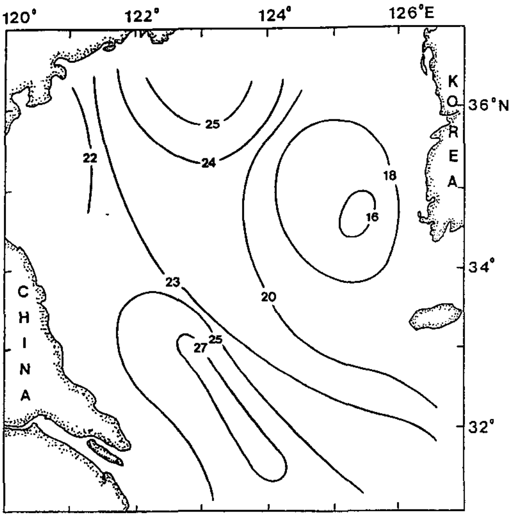

Fig. 2. Distribution of water temperature (℃) in surface water over the Yellow Sea.

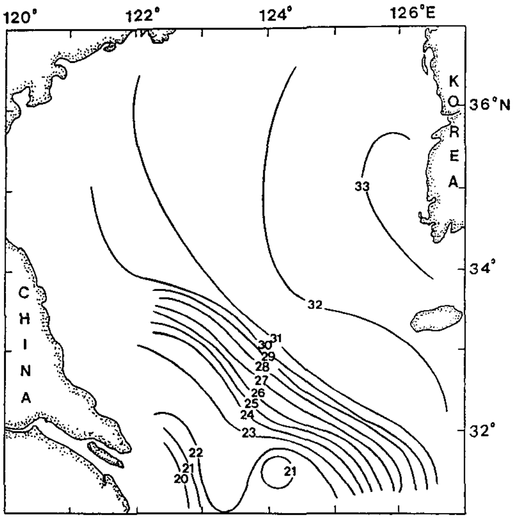

Fig. 3. Distribution of salinity (‰) in surface water over the Yellow Sea.

Table 2. The results of water quality analyses on the side of Korea eastern part in the Yellow Sea

| St. Dep. | Temp. | pH | Sal. | DO | COD | TSS | $NH_4^+$-N | $NO_2^-$-N | $NO_3^-$-N | DIN | $PO_4^{3-}$-P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No. (*m*) | (℃) | | (‰) | ( | *mg/l* | ) | ( | | *ug*-at/*l* | | ) |
| K1- 0 | 18.5 | 8.00 | 32.27 | 8.94 | 3.82 | 3.20 | 0.500 | 0.079 | 3.571 | 4.150 | 0.129 |
| K1-10 | 16.9 | 8.07 | 32.12 | 8.99 | 2.03 | 3.00 | 0.071 | ND | 0.857 | 0.929 | 0.161 |
| K1-20 | 12.4 | 8.02 | 32.79 | 8.63 | 1.48 | 3.20 | 0.857 | ND | 2.786 | 3.643 | 0.581 |
| K1-30 | 12.0 | 8.03 | 32.80 | 8.80 | 1.64 | 1.90 | 0.857 | ND | 0.857 | 1.714 | 0.613 |
| K2- 0 | 18.0 | 8.25 | 32.64 | 7.82 | 2.81 | 4.80 | 0.571 | ND | 0.857 | 1.429 | 0.387 |
| K2-10 | 18.0 | 8.19 | 32.63 | 6.99 | 2.26 | 2.60 | 0.857 | ND | 0.857 | 1.714 | 1.645 |
| K2-20 | 15.5 | 8.36 | 31.54 | 7.46 | 1.72 | 24.60 | 0.857 | ND | 2.214 | 2.357 | 6.258 |
| K2-30 | 8.5 | 8.24 | 32.98 | 8.55 | 1.56 | 4.70 | 0.714 | 0.079 | 1.643 | 2.436 | 0.677 |
| K2-50 | 9.0 | 7.93 | 32.93 | 9.71 | 1.64 | 4.50 | 0.714 | ND | 2.786 | 3.500 | 5.000 |
| K3- 0 | 19.0 | 8.10 | 32.58 | 7.48 | 2.19 | 2.90 | ND | ND | 0.857 | 0.857 | 1.129 |
| K3-10 | 18.8 | 8.19 | 32.66 | 8.86 | 1.33 | 2.80 | ND | ND | 1.143 | 1.143 | 1.645 |
| K3-20 | 18.0 | 8.13 | 32.69 | 8.18 | 1.25 | 4.80 | ND | ND | 0.286 | 0.286 | 0.226 |
| K3-30 | 10.5 | 8.03 | 33.04 | 9.60 | 1.40 | 5.80 | 1.286 | ND | 5.071 | 6.357 | 0.839 |
| K3-50 | 9.0 | 7.91 | 33.03 | 8.57 | 1.25 | 4.60 | 1.000 | 0.029 | 7.000 | 8.029 | 1.710 |
| K3-75 | 9.0 | 7.90 | 33.07 | 8.68 | 1.48 | 5.10 | 1.000 | 0.029 | 5.857 | 6.886 | 0.807 |
| K4- 0 | 19.2 | 8.10 | 32.70 | 8.03 | 1.48 | 2.10 | 0.357 | ND | 1.714 | 2.071 | 0.129 |
| K4-10 | 19.3 | 8.14 | 32.71 | 8.22 | 1.48 | 22.60 | ND | ND | 2.786 | 2.786 | 0.129 |
| K4-20 | 18.2 | 8.18 | 32.41 | 8.54 | 1.33 | 3.10 | 0.357 | ND | 1.143 | 1.500 | 1.258 |
| K4-30 | 14.6 | 8.21 | 32.61 | 9.72 | 1.25 | 3.00 | 0.929 | ND | 2.214 | 3.143 | 1.807 |
| K4-50 | 9.8 | 7.80 | 33.02 | 7.92 | 1.48 | 28.00 | 1.786 | ND | 3.643 | 5.429 | 3.056 |
| K4-75 | 11.1 | 8.23 | 32.94 | 9.60 | 1.33 | 4.00 | 0.071 | ND | 2.786 | 2.858 | 1.645 |
| K5- 0 | 26.5 | 8.25 | 31.29 | 5.37 | 2.64 | 3.19 | ND | 0.200 | 0.500 | 0.700 | 0.178 |
| K5-10 | 25.6 | 8.25 | 31.66 | 6.88 | 2.55 | 1.54 | ND | 0.143 | 0.571 | 0.714 | 0.045 |
| K5-20 | 17.4 | 8.18 | 32.18 | 8.66 | 2.72 | 2.57 | 0.286 | 0.114 | ND | 0.400 | 0.802 |
| K5-50 | 10.8 | 8.02 | 32.54 | 8.55 | 2.55 | 3.24 | ND | 0.228 | 0.929 | 1.157 | 0.802 |
| K5-70 | 11.0 | 7.96 | 32.02 | 8.98 | 2.55 | 8.00 | ND | ND | 11.643 | 11.643 | 1.158 |
| K6- 0 | 15.0 | 8.11 | 32.63 | 8.48 | 1.79 | 4.60 | 0.071 | ND | 0.643 | 0.714 | 0.129 |
| K6-10 | 14.0 | 8.04 | 32.73 | 9.39 | 2.11 | 3.90 | 0.071 | ND | 1.643 | 1.714 | 0.452 |
| K6-20 | 13.3 | 8.12 | 32.63 | 8.82 | 2.11 | 4.90 | ND | ND | 0.357 | 0.357 | 0.129 |
| K6-30 | 14.5 | 8.02 | 32.80 | 8.61 | 1.40 | 3.50 | 0.429 | ND | 2.714 | 3.143 | 0.516 |
| K7- 0 | 20.0 | 8.20 | 33.07 | 10.49 | 1.48 | 7.70 | ND | ND | 0.643 | 0.643 | 0.161 |
| K7-10 | 18.0 | 8.07 | 32.98 | 7.84 | 1.33 | 6.20 | ND | 0.186 | 11.286 | 11.471 | 0.581 |
| K7-20 | 20.0 | 8.20 | 33.15 | 9.68 | 2.03 | 6.50 | ND | ND | 2.071 | 0.271 | 0.226 |
| K8- 0 | 17.7 | 8.19 | 33.19 | 9.23 | 1.87 | 2.00 | 0.179 | 0.136 | 0.249 | 0.564 | 0.161 |
| K8-10 | 17.5 | 8.17 | 33.06 | 9.71 | 2.42 | 4.20 | ND | ND | 1.071 | 1.071 | 0.161 |
| K8-20 | 16.4 | 8.15 | 33.01 | 9.09 | 1.72 | 3.10 | ND | ND | 1.857 | 1.857 | 0.290 |
| K8-30 | 17.5 | 8.17 | 33.14 | 9.08 | 1.87 | 3.20 | 0.214 | 0.029 | 2.286 | 2.500 | 0.290 |
| K8-50 | 11.2 | 8.04 | 33.15 | 8.60 | 1.95 | 16.30 | ND | 0.136 | 4.429 | 2.529 | 0.677 |
| K9- 0 | 17.0 | 8.07 | 33.29 | 9.17 | 1.64 | 9.90 | ND | ND | 0.214 | 0.214 | 0.452 |
| K9-10 | 16.0 | 8.09 | 33.41 | 9.53 | 1.95 | 3.20 | ND | 0.029 | 0.214 | 0.214 | 0.226 |
| K9-20 | 15.0 | 7.98 | 33.30 | 8.99 | 1.64 | 9.20 | ND | 0.057 | 3.500 | 3.557 | 0.581 |
| K9-30 | 17.0 | 8.10 | 33.07 | 9.84 | 1.95 | 3.30 | 0.357 | ND | 0.857 | 1.214 | 0.161 |
| K9-50 | 13.0 | 7.98 | 33.24 | 8.84 | 1.79 | 24.50 | 0.286 | 0.079 | 0.143 | 0.507 | 0.581 |
| K10- 0 | 14.9 | 8.04 | 33.43 | 9.42 | 1.33 | 4.10 | 0.071 | 0.057 | 1.643 | 1.771 | 0.161 |
| K10-10 | 13.5 | 8.01 | 33.36 | 9,89 | 1.33 | 3.60 | ND | 0.079 | 4.500 | 4.579 | 0.516 |
| K10-20 | 13.0 | 7.97 | 33.06 | 8.84 | 1.25 | 10.10 | 0.357 | 0.107 | 6.357 | 6.821 | 0.581 |
| K10-30 | 14.5 | 8.03 | 33.12 | 9.29 | 1.09 | 3.30 | ND | 0.107 | 2.000 | 2.107 | 0.290 |
| K10-50 | 12.9 | 7.98 | 33.37 | 8.53 | 1.72 | 78.90 | ND | 0.136 | 5.071 | 5.207 | 0.613 |

Table 3. The results of water quality analyses on the side of China western part in the Yellow Sea

| St. Dep. No. (*m*) | Temp. (℃) | pH | Sal. (‰) | DO ( | COD mg/l | TSS ) | $NH_4^+$-N ( | $NO_2^-$-N | $NO_3^-$-N ug-at/l | DIN | $PO_4^{3}$ -P ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C1- 0 | 25.0 | 8.65 | 22.61 | 10.80 | 2.36 | 1.25 | ND | 0.513 | 4.500 | 5.013 | 0.267 |
| C2- 0 | 27.5 | 8.82 | 20.72 | 8.41 | 2.19 | 1.49 | 0.713 | 0.513 | 15.714 | 16.940 | 0.312 |
| C2-20 | 21.2 | 8.31 | 29.61 | 8.99 | 2.68 | 1.14 | 0.429 | 0.114 | 0.357 | 0.900 | 0.178 |
| C2-40 | 19.4 | 8.23 | 28.64 | 8.45 | 2.68 | 2.48 | 0.500 | 0.45 | 0.214 | 1.199 | 0.312 |
| C3- 0 | 23.6 | 8.31 | 27.97 | 9.13 | 2.19 | 2.96 | 0.429 | ND | 2.071 | 2.500 | 0.312 |
| C4- 0 | 23.0 | 8.33 | 28.46 | 9.23 | 1.86 | 2.14 | 1.286 | 0.029 | 0.429 | 1.744 | 0.356 |
| C4-20 | 17.8 | 8.27 | 29.18 | 9.45 | 2.11 | 3.00 | ND | ND | 1.357 | 1.357 | 0.267 |
| C4-70 | 14.0 | 8.08 | 30.59 | 8.01 | 2.36 | 4.57 | ND | 0.029 | 12.286 | 12.315 | 0.713 |
| C5- 0 | 25.6 | 8.43 | 22.16 | 5.49 | 4.00 | 5.75 | 3.643 | 0.485 | 2.000 | 6.128 | 4.276 |
| C5-20 | 21.1 | 8.07 | 31.54 | 4.09 | 2.85 | 13.49 | 0.286 | 0.257 | 20.071 | 20.614 | 1.203 |
| C5-30 | 20.5 | 8.03 | 32.12 | 3.74 | 5.40 | 36.05 | 8.214 | 0.285 | 44.857 | 53.356 | 9.710 |
| C6- 0 | 27.4 | 8.56 | 23.86 | 7.35 | 2.47 | 3.76 | 0.500 | 0.200 | 0.929 | 1.629 | 0.713 |
| C6-20 | 23.4 | 8.29 | 28.60 | 6.70 | 3.79 | 6.56 | 6.643 | 0.257 | 10.714 | 17.614 | 5.167 |
| C6-30 | 22.7 | 8.27 | 29.11 | 5.60 | 3.62 | 119.84 | 0.643 | 0.228 | 3.000 | 3.871 | 0.267 |
| C7- 0 | 23.0 | 8.23 | 30.84 | 5.96 | 2.64 | 2.90 | 0.286 | 0.086 | 0.357 | 0.729 | 0.223 |
| C8- 0 | 22.8 | 8.29 | 30.60 | 6.30 | 3.79 | 2.96 | 0.500 | 0.057 | 2.429 | 2.986 | 0.312 |
| C9- 0 | 23.3 | 8.11 | 30.61 | 7.30 | 2.06 | 2.22 | 0.429 | 0.200 | 0.286 | 0.915 | 0.267 |
| C9-20 | 11.0 | 8.04 | 31.16 | 12.14 | 2.22 | 2.89 | 0.286 | 0.200 | 1.143 | 1.629 | 0.356 |
| C10- 0 | 24.6 | 8.19 | 31.32 | 5.70 | 2.31 | 4.22 | 0.429 | 0.171 | 0.286 | 0.886 | 0.445 |
| C10-20 | 23.8 | 8.19 | 30.62 | 7.53 | 2.14 | 5.17 | ND | 0.200 | 0.286 | 0.486 | 0.312 |
| C10-30 | 10.5 | 7.89 | 32.36 | 9.63 | 2.52 | 5.92 | 0.500 | 0.257 | ND | 0.757 | 0.579 |
| C11- 0 | 25.6 | 8.19 | 30.78 | 5.63 | 2.64 | 3.26 | 0.643 | 0.057 | 2.214 | 2.914 | 0.178 |

Mean temperatures of surface water on the side of Korea and the side of China were 18.6℃ and 24.7℃, respectively. The difference in mean temperature of surface water between both sides was 6.1 ℃. The temperature of surface water on the side of Korea was found to be lower than that on the side of China and the cold water ( < 10℃) was present in the bottom layer of central part in the Yellow Sea as shown in Fig. 4.

Mean salinity of surface water on the side of Korea and the side of China were 32.71 ‰ and 27.27 ‰, respectively. The difference in mean salinity of surface water between both sides was 5.44 ‰. The distribution of salinity was similar to that of water temperature as shown in Fig. 2, Fig. 3 and Fig. 4. The salinities of surface water on the side of Korea were 31.29~33.43 ‰, while those on the side of China were 20.72~31.32 ‰. The lower salinity was found to be 22.16 ‰ at the station C5 which is located southeast about 130*km* away from Changjiang estuary. The freshwaters from the Changjiang River were found to affect the station C4 adjacent to Cheju Island. The distributions of water temperature and salinity in the Yellow Sea were found to be similar to the results from Su *et al.* (1989) and Pang *et al.* (1992).

### 2. Dissolved oxygen (DO) and chemical oxygen demand (COD)

The distributions of DO and COD in surface warer over the Yellow Sea are illustrated in Fig. 5 and Fig. 6, respectively.

Mean concentrations and saturation percentages of DO in surface water were 8.44*mg/l* and 109.5%

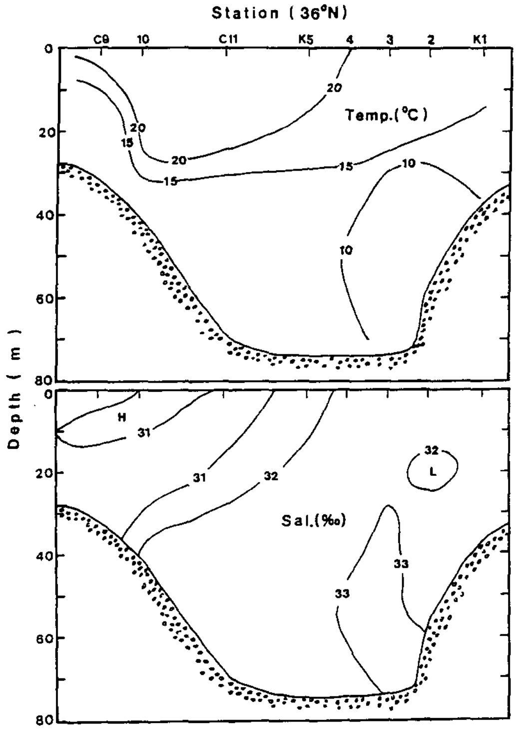

Fig. 4. Vertical profiles of water temperature (℃) and salinitiy (‰) on the cross-section along the latitude line of 36° N in the Yellow Sea.

on the side of Korea and 7.39*mg/l* and 102.5% on the side of China, respectively, and those were found to be 5.37*mg/l* and 75.4% at station K5 on the side of Korea and 5.49*mg/l* and 76.1% at station C5 on the side of China, respectively as minima. In particular, the concentration and saturation percentage of DO were 3.74*mg/l* and 50.1%, respectively, in the bottom layer of station C5. Su (1989) reported DO to be 3.0~3.5$mgO_2/l$ in the Changjiang estuary. Thus, it may be suggested that the lower level of DO appears in the bottom layer of the Changjiang estuary and its adjacent waters due to the pollution of organic matters. According to Yanagi (1989), Yellowtail is restricted in its physiological function under the condition below 4.3 $mgO_2/l$ in the water, and the DO concentration below 2.2*mg/l* do harm to benthonic shellfish.

In surface layer, mean COD values were 2.11 *mg/l* on the side of Korea and 2.59*mg/l* on the side of China, and higher COD values were 3.82*mg/l* at station K1 adjacent to Keum River of Korea and 4.00*mg/l* at station C5 adjacent to the Changjiang estuary. On the other hand, DO saturation percentages in surface water were 116.0% at station K1 and 76.1% at station C5. On the whole, however, COD values on the side of China were found to

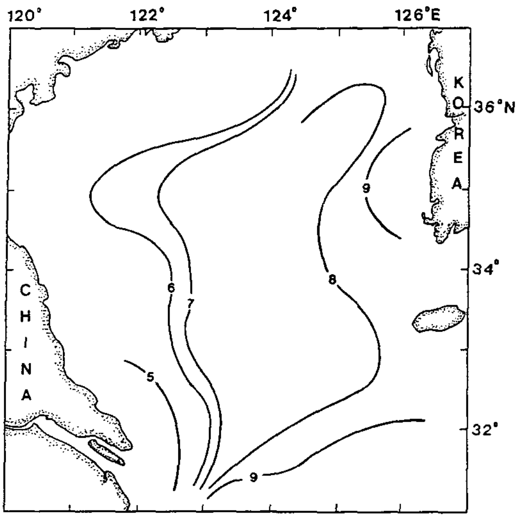

Fig. 5. Distribution of DO (*mg/l*) in surface water over the Yellow Sea.

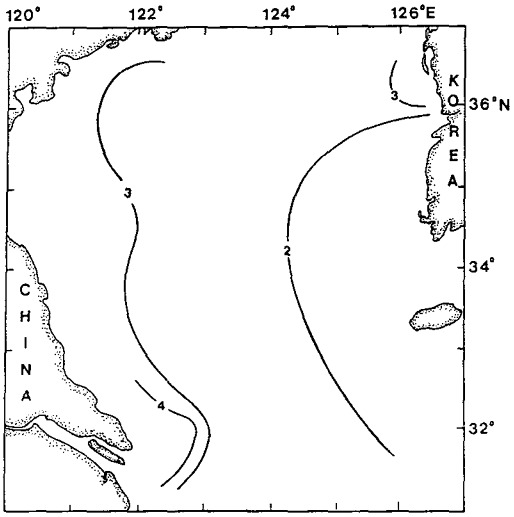

Fig. 6. Distribution of COD (*mg/l*) in surface water over the Yellow Sea.

exceed the concentration of 2*mg/l*, which is the value of Japanese criterion on water quality for fisheries(Japanese Association for Protection of Fisheries Resources, 1973). In particular, possibly, the pollution of organic matters becomes serious in the waters adjacent to the Changjiang estuary, in the light of high COD value and low DO saturation percentage at station C5 on the side of China. In general, COD is one of the parameters for evaluating the pollution of organic matters. The major pollutants flowing into the Yellow Sea from China have been reported to be the organic matters and the annual discharge of COD from China was reported to reach about 6.2 million tons which was about 15 times higher than that from Korea (Lee and Valencia, 1992; Ministry of Environment ROK, 1993b). For the conservation of ecosystem and marine resources in the Yellow Sea, therefore, it is necessary to survey systematically and research further into the sources of marine pollution and the alternative plans for the reduction of pollution loads from rivers.

### 3. Nutrients

The distributions of DIN and $PO_4^{3-}$-P in surface water over the Yellow Sea are shown in Fig. 7 and Fig. 8, respectively.

Mean concentrations of DIN in surface water were 1.31*ug*-at/*l* on the side of Korea and 3.85*ug*-at/*l* on the side of China. The difference in mean DIN concentration of surface water between both sides was 2.54*ug*-at/*l*, and mean DIN concentration on the side of China was about 3 times higher than that on the side of Korea. Higher DIN concentrations in surface water were found to be 4.15*ug*-at/*l* at station K1 adjacent to Keum river of Korea and to be above 5.00*ug*-at/*l* at stations C1, C2 and C5 on the side of China. In particular, DIN in surface water of station C2 was measured to be 16.94*ug*-at/*l*, exceeding by far the concentration of 7.14*ug*-at/*l*, which is the value of Japanese criterion on the potentiality of red tide occurrence(Japanese Association for Protection of Fisheries Resources, 1973).

Mean percentages for each form of nitrogen ($NH_4^+$-N, $NO_2^-$-N, $NO_3^-$-N) in DIN of surface water at all stations in the Yellow Sea are shown in Table 4.

Mean percentages of $NH_4^+$-N and $NO_3^-$-N in DIN were found to be 11.5% and 78.4% on the side of Korea and 32.6% and 59.0% on the side of China, respectively, and mean percentage of $NH_4^+$-N in DIN on the side of China was about 2.8 times as high as that on the side of Korea. On the other hand, mean percentage of $NO_3^-$-N in DIN

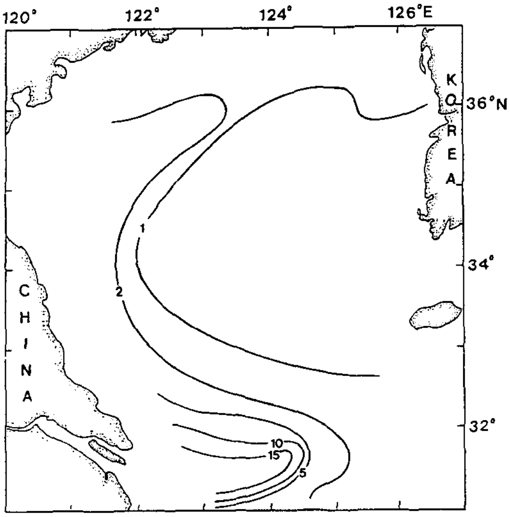

Fig. 7. Distribution of DIN (*ug*-at/*l*) in surface water over the Yellow Sea.

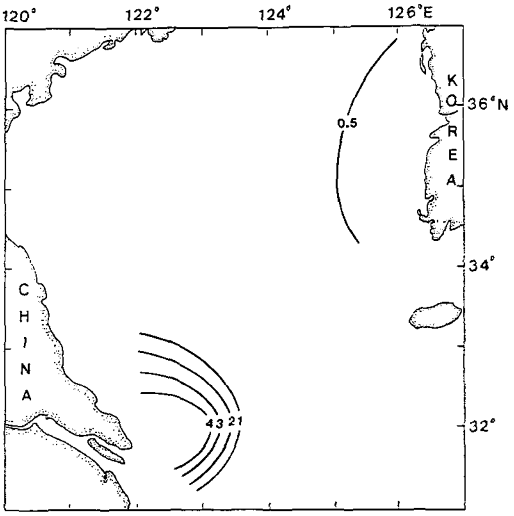

Fig. 8. Distribution of $PO_4^{3-}$-P (*ug*-at/*l*) in surface water over the Yellow Sea.

Table 4. Percentage for each form of nitrogen ($NH_4^+$-N, $NO_3^-$-N, $NO_2^-$-N) in DIN of surface water at all stations in the Yellow Sea

| Eastern Part | | | | | Western Part | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Stn No. | DIN (*ug*-at/*l*) | $NH_4^+$-N ( | $NO_3^-$-N % | $NO_2^-$-N ) | Stn No. | DIN (*ug*-at/*l*) | $NH_4^+$-N ( | $NO_3^-$-N % | $NO_2^-$-N ) |
| K1 | 4.15 | 12.0 | 86.1 | 1.9 | C1 | 5.01 | 0.0 | 89.8 | 10.2 |
| K2 | 1.43 | 40.0 | 60.0 | 0.0 | C2 | 16.94 | 4.2 | 92.8 | 3.0 |
| K3 | 0.86 | 0.0 | 100.0 | 0.0 | C3 | 2.50 | 17.2 | 82.8 | 0.0 |
| K4 | 2.07 | 17.2 | 82.8 | 0.0 | C4 | 1.74 | 73.7 | 24.6 | 1.7 |
| K5 | 0.70 | 0.0 | 28.6 | 71.4 | C5 | 6.13 | 59.5 | 32.6 | 7.9 |
| K6 | 0.71 | 9.9 | 90.1 | 0.0 | C6 | 1.63 | 30.7 | 57.0 | 12.3 |
| K7 | 0.64 | 0.0 | 100.0 | 0.0 | C7 | 0.73 | 39.2 | 49.0 | 11.8 |
| K8 | 0.56 | 31.7 | 44.2 | 24.1 | C8 | 2.99 | 16.7 | 81.4 | 1.9 |
| K9 | 0.21 | 0.0 | 100.0 | 0.0 | C9 | 0.92 | 46.9 | 31.3 | 21.9 |
| K10 | 1.77 | 4.0 | 92.8 | 3.2 | C10 | 0.89 | 48.4 | 32.3 | 19.3 |
| | | | | | C11 | 2.91 | 22.1 | 76.0 | 2.0 |
| Mean | 1.31 | 11.5 | 78.4 | 10.1 | Mean | 3.85 | 32.6 | 59.0 | 8.4 |

on the side of Korea was about 1.3 times as high as that on the side of China. Because the process of nitrification converting 1.0*mg*$NH_4^+$-N/*l* to 1.0 *mg*$NO_3^-$-N/*l* demands 4.57*mg*$O_2$/*l*, about 0.06*mg*$O_2$/*l* is required for the production of 1.0*ug*-at$NO_3^-$-N/*l*. Thus, it is expected that the high oxygen demand on the side of China might be due to the nitrification process.

Mean concentrations of $PO_4^{3-}$-P in surface water were 0.30*ug*-at/*l* (0.13~1.13ug-at/*l*) on the side of Korea and 0.70*ug*-at/*l* (0.18~4.28*ug*-at/*l*) on the side of China. The difference in mean $PO_4^{3-}$-P concentration of surface water between both sides was 0.40*ug*-at/*l* and $PO_4^{3-}$-P concentration on the side of China was about 2.3 times as high as that on the side of Korea. Comparing with the mean $PO_4^{3-}$-P concentration of 0.18*ug*-at/*l* (0.07~0.51*ug*-at/*l*) obtained on eastern part of the Yellow Sea in June and August by National Fisheries Research and Development Agency, ROK (1989), the $PO_4^{3-}$-P concentrations on the side of Korea and China were 1.7 times and 3.9 times higher, respectively. In particular, the maximum $PO_4^{3-}$-P concentration in surface water was found to be 4.28*ug*-at/*l* at C5 station on the side of China, exceeding by far the concentration of 0.48*ug*-at/*l* which is the value of Japanese criterion on the potentiality of red tide occurrence (Japanese Association for Protection of Fisheries Resources, 1973). Thus, possibly, considerable amount of $PO_4^{3-}$-P flows into the Yellow Sea through the Changjiang River.

In general, the atomic ratio of N/P in phytoplankton biomass, namely, Redfield ratio is known to be 16. If the atomic ratio of N/P in the seawater is greater than 16, $PO_4^{3-}$-P is the limiting factor in the growth of phytoplankton. On the contrary, if the ratio of N/P is lower than 16, DIN is the limiting factor(KORDI, 1983). In this study, the average atomic ratios of N/P were found to be 8.11 (range: 0.47~32.17) on the side of Korea and 11.3 (range: 1.43~54.29) on the side of China in the Yellow Sea. Therefore, on the whole, the limiting factor in the growth of phytoplankton was proved to be inorganic nitrogen in the Yellow Sea.

## 4. Evaluation of eutrophication level

The trophic level of sea area may be judged by an eutrophication index, which indicates the potentiality of red tide occurrence. Okaichi (1972) suggested the following expression in which the eutrophication level might be expressed by eutrophication index(EI):

$$EI=\frac{COD(mg/l)\times DIN(ug\text{-}at/l)\times PO_4^{3}\ \text{-}P(ug\text{-}at/l)}{3.43}$$

According to the above expression, for instance, EI will be 1 on the condition that 7.14*ug*-at N/*l* and 0.48*ug*-at P/*l* of nutrients in waters indicate the possibility of red tide occurrence (Japanese Association for Protection of Fisheries Resources, 1973) and 1*mg/l* of COD(=0.83*mgC/l*) in the waters of $10^3$ diatom cells/*ml* indicates the early stage of red tide.

EI on the side of Korea and the side of China in the Yellow Sea as shown in Table 5 were in the range 0.04 to 0.60 and in the range 0.12 to 30.60, respectively. In particular, EI of C1, C2 and C5 stations adjacent to the Changjiang estuary were 0.93, 3.35 and 30.60, respectively. Choi (1993) reported that EI in summer and winter were 1.9~23.8 and 0.5~33.8, repectively in Jinhae bay of Korea where red tide often occurred habitually. The EI range of three stations (C1, C2 and C5) in waters adjacent to the Changjiang estuary was found to be similar to that of Jinhae bay, and thereby, suggesting that the waters adjacent to the Changjiang estuary might have the high potentiality of red tide occurrence.

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We would like to thank the Masters and crews of T/S Haelim and T/S Haelim No. 3 for helping collect seawater samples.

Table 5. Eutrophication indices of surface water at all stations in the Yellow Sea

| | COD | DIN | $PO_4^{3}$ -P | INDEX |
|---|---|---|---|---|
| St. No. | (*mg/l*) | ( *ug*-at/*l* ) | | |
| K1 | 3.82 | 4.15 | 0.13 | 0.60 |
| K2 | 2.81 | 1.43 | 0.39 | 0.46 |
| K3 | 2.19 | 0.86 | 1.13 | 0.62 |
| K4 | 1.48 | 2.07 | 0.13 | 0.12 |
| K5 | 2.64 | 0.70 | 0.18 | 0.10 |
| K6 | 1.79 | 0.71 | 0.13 | 0.05 |
| K7 | 1.48 | 0.64 | 0.16 | 0.04 |
| K8 | 1.87 | 0.56 | 0.16 | 0.17 |
| K9 | 1.64 | 0.21 | 0.45 | 0.05 |
| K10 | 1.33 | 1.77 | 0.16 | 0.11 |
| C1 | 2.36 | 5.01 | 0.27 | 0.93 |
| C2 | 2.19 | 16.94 | 0.31 | 3.35 |
| C3 | 2.19 | 2.50 | 0.31 | 0.49 |
| C4 | 1.86 | 1.74 | 0.36 | 0.34 |
| C5 | 4.00 | 6.13 | 4.28 | 30.60 |
| C6 | 2.47 | 1.63 | 0.71 | 0.83 |
| C7 | 2.64 | 0.73 | 0.22 | 0.12 |
| C8 | 3.79 | 2.99 | 0.31 | 1.02 |
| C9 | 2.06 | 0.92 | 0.27 | 0.15 |
| C10 | 2.31 | 0.89 | 0.45 | 0.27 |
| C11 | 2.64 | 2.91 | 0.18 | 0.40 |

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## Water Quality of the Yellow Sea in Summer

# 하계 황해의 수질 환경 특성

유선재 · 김종구 · 김광수*
군산대학교 해양환경학과
*부산수산대학교 환경공학과

1994년 6월~7월에 황해의 수질 특성을 조사하였으며, 황해의 수온, 염분, 용존산소, 화학적 산소요구량, 용존무기질소 및 인산인에 관한 분포 특성을 기술하였다.

수온과 염분의 분포를 살펴본 결과, 양자강에서 유입하는 담수는 제주도 주변 해역에까지 영향을 미치는 것으로 나타났다.

용존산소 및 화학적 산소요구량의 분포에 의하면 중국측에 위치한 황해 서부 해역은 한국측에 위치한 황해 동부 해역보다 수질이 악화되어 있었으며, 또한 영양염 농도와 화학적 산소요구량을 이용하여 나타낸 부영양도는 황해 서부 해역에서 높게 나타났다.

따라서 중국으로부터 다량의 오염물질이 황해의 서부 해역으로 유입하는 것으로 보이며, 황해 서부 해역은 적조 발생 잠재력이 높은 것으로 평가되었다.