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A Study on Sea Water and Ocean Current in the Sea Adjacent to Korea Peninsula

1. Physical Processes Influencing the Surface Distributions of Chlorophyll and Nutrient in the Southern Sea of Korea in Summer

Han-Soeb YANG and Seung-Soo KIM
Department of Oceanography, National Fisheries University of Pusan, Pusan 608-737, Korea

한반도 근해의 해류와 해수특성

1. 여름철 韓國 南海 表層水중 클로로필과 營養鹽의 濃度分布에 影響을 주는 物理的 過程

梁漢燮·金聲秀
釜山水産大學校 海洋學科

Effect of physical processes on the surface distributions of chlorophyll-a and nutrients was investigated in the southern sea of Korea during summer season. The northwestern area of Cheju Island had higher concentrations of the chlorophyll-a and nutrients than its southeastern area. A nutrient-rich patch was observed in the western area of Cheju Island and the northern area of 34° N respectively. It seems that the patch in the western area of Cheju Island is formed by horizontal extension of the low-saline Coastal Water of China Contiental(CWCC), while the patch in the northern area of 34° N by vertical mixing. Also, the high chlorophyll-a in the vicinity of Cheju Island appears to be ascribed to sufficient supply of nutrient from bottom water by coastal upwelling.

Introduction

Several waters with different property occur in the southern sea of Korea, such as the Tsushima Warm Water, the Coastal Water of China Continental and the Yellow Sea Bottom Water. The distribution of these waters shows also temporal and spatial variation. Therefore, oceanographic conditions in this sea are very complicate. Since the classic works of Uda(1934; 1936), physical characteristics and the distribution of the water masses in the southern sea of Korea have been well known by previous investigators(Gong, 1971; Kang, 1974; Lim, 1976; Nakao, 1977; Kim and Lee, 1982; Rho and Kim, 1983; Na et al., 1990). Biological surveys were also performed in relation to oceanographic conditions(Shim and Park, 1984; Park and Lee, 1990; Park et al., 1990). They reported that species composition of plankton and their distributions were closely related to water masses. Also, some studies were made concerning on the distributions of chlorophyll-a and dissolved nutrients in the extremely restricted region or in the vicinity of Cheju Island(Park, 1982; Cheon and Go, 1983; KORDI, 1986).

In spite of so many studies, the regional distribution pattern of surface nutrients and chlorophyll-a related to primary production is not yet clear in the southern sea of Korea. The main purpose of the present work is to investigate geographical profiles of nutrients and chlorophyll-a and physical processes influencing their distributions at the surface in the southern sea of Korea in summer season.

Materials and Methods

Samples were collected during 6~15 of August in 1986 at 56 stations that were located in the area less than approximately 100 *km* from the coast of Cheju Island except for the northeastern region (Fig. 1). We sampled seawater at depths with a Van-Dorn sampler and a PVC Niskin sampler. Water temperature was measured on deck with reversing thermometers attached to the Van-Dorn sampler, and salinity was determined by the argentimetric titration.

After collection, chlorophyll-a sample was immediately filterd with a 0.45 *μm* Membrane filter, frozen and stored for subsequent laboratory analysis. Contents of chlorophyll-a were determined colorimetrically after 24-hour extraction in 90% acetone (Strickland and Parsons, 1971).

Unfilterd seawater for nutrient analysis was frozen in polyethylene bottles with a small volume of 1% $CuSO_4$ solution and stored in the dark until analyzed ashore. Prior to analysis, the samples were brought to room temperature. Colorimetric determinations were made according to the procedures described by Strickland and Parsons (1971) for phosphate and reactive silicate, and by Nishi-

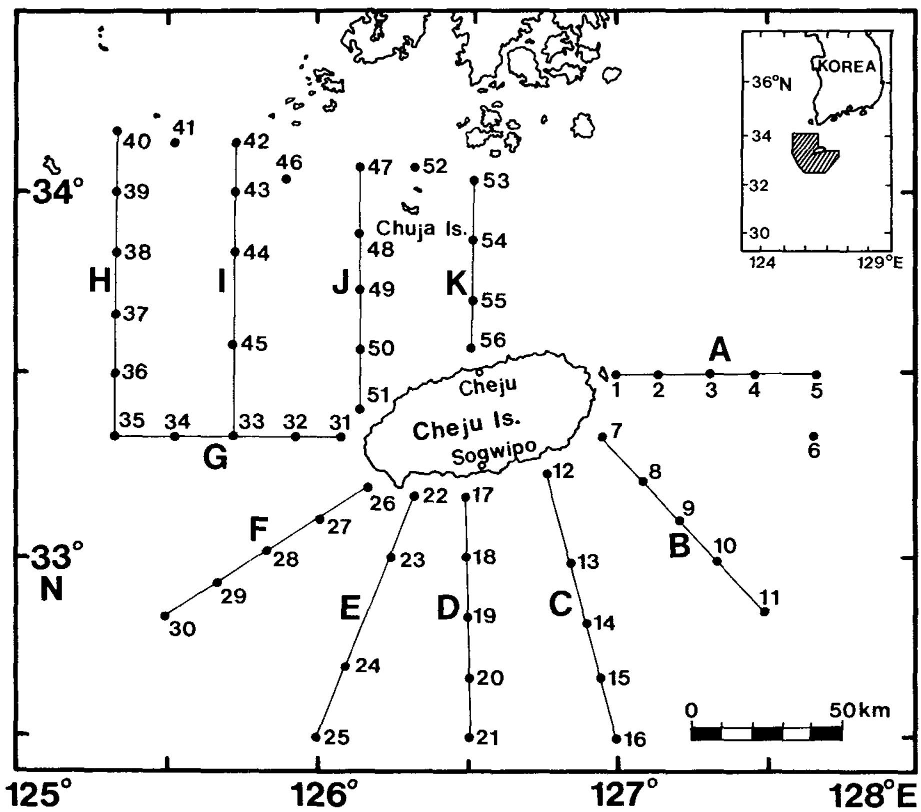

Fig. 1. Locations of the sampling stations on 11 transects in the southern sea of Korea.

mura and Matsunaga(1969) for nitrate.

Results and Discussion

Geographical Distributions of Chemical Components

Horizontal contours of nutrients and chlorophyll-a at the surface are depicted in Fig. 2, together

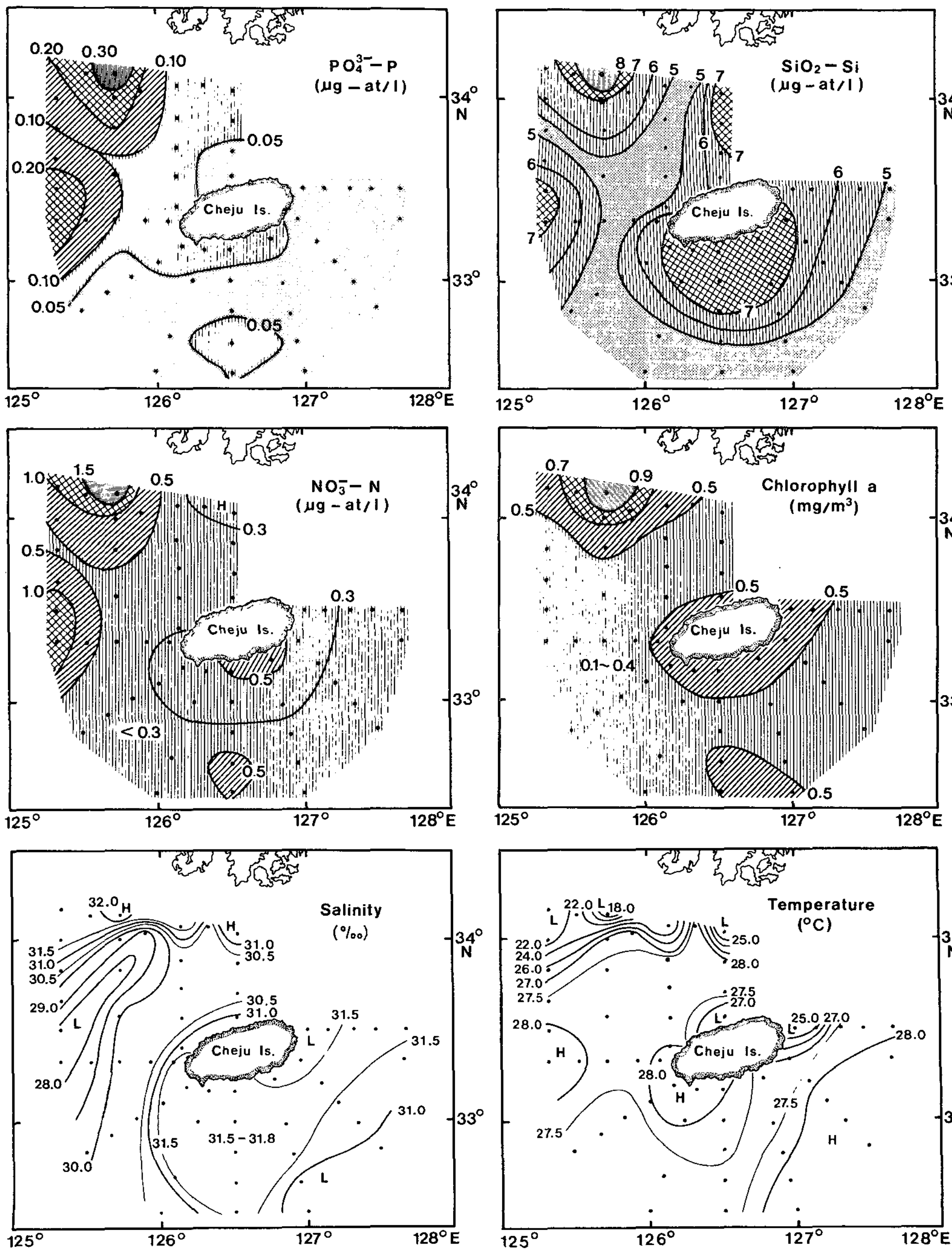

Fig. 2. Horizontal distributions of nutrients, chlorophyll-a, water temperaure and salinity in surface water during summer season of 1986.

with the distributions of salinity and water temperature. Based on their profiles and topography, the study area can be widely divided into two regions: the southeastern region over six transects from A-line to F-line and the northwestern region located above F-line. In general, the latter is shallower in depth and higher in nutrients and chlorophyll-a than the former.

In the northwestern region, concentration of surface nutrient was high in the area far from Cheju Island and low at the intermediate part or the coast. The maxima in nutrients were found at the northernmost station(Stn. 42) of Transect I. This station showed the lowest temperature of 17.5 ℃ and the highest salinity of 32.59‰. Also, significantly high level of the nutrients was observed at the westernmost site(Stn. 35) of G-line, where represented the minimum of salinity (27.29‰) and relatively high temperature(28.2 ℃). In the narrow area around the two stations, a nutrient-rich and fan-shaped patch exists separately. As shown from the lateral profiles of temperature and salinity, water of these two patches is obviously distinguished by physical property. For instance, the patch in the northern area of 34° N is higher in salinity and lower in temperature compared with the patch in the western area of Cheju Island. It seems that the northern patch is probably formed by the South Korean Coastal Water(SKCW) with low temperature and the western patch by the Coastal Water of China Continental(CWCC) with low salinity. Such an interpretation would be more reasonable from the relationships between surface nutrient and conservative parameters(See the next section). Unlike phosphate and nitrate, another silicate-rich patch is present at the northern part of Cheju city and the concentration is comparable with that in the western patch.

On the other hand, the distribution of nutrients in the southeastern region showed a pattern that the concentration was high at the coastal zone and decreased gradually toward a great distance of the coast. This trend is opposite to that in the northwestern region and is noticable in silicate. Particulary, the high silicate concentrations more than 7 μg-at/*l* were observed in the southern area to about 30 *km* from the coast.

The regional distribution of chlorophyll-a is more monotonous than nutrient. However, the highest value of chlorophyll-a was found at Stn. 42 such as nutrients, and the relatively high and patchy distribution was present in the region around the station too. The concentration in this region ranged from 0.5 to 1.6 mg/m^3 and was similar to those in surface water of the East China Continental Shelf (Saijo et al., 1969). Strong thermal front was also formed in the northern region of 34° N. Therefore, high concentrations of chlorophyll-a in the northern area of 34° N seem to be attributed to high primary production. It was thus reported that abundance of phytoplankton or zooplankton was very high at the frontal zones in the northeastern sea of Cheju Island(Park and Lee, 1990; Park et al., 1990) and in the East Sea of Korea(Chung et al., 1989). While, at some southern stations(Stn. 16, 20, 21) and inshore less than about 20 *km* the concentrations of chlorophyll-a were slightly low(0.5~0.7 mg/m^3), but they were higher than the values in the Kuroshio surface water(Aruga and Monsi, 1962). Kim and Lee(1982) observed presence of vertically homogeneous water in the northwestern vicinity of Cheju Island, and they explained the formation of the homogeneous water in terms of strong tidal mixing and upwelling. Shim and Park (1984) also reported high abundance of phytoplankton in the same area. Accordingly, the relatively high chlorophyll-a in the inshore region surrounding Cheju Island may be resulted from enrichment of nutrient in surface seawater by intense upwelling or intermixing of bottom water.

Physical Processes Contributing to the Distributions of Chlorophyll-a and Nutrients.

As previously described, the northwestern region above F-line showed relatively high concentrations in chlorophyll-a and nutrients. In this region, the interrelationships between nutrients and chlorophyll-a in surface water are preferentially discussed. Results of the statistical analysis are given in Table 1, along with the correlations of surface nitrate against conservative parameters. At all stations in the northwestern area, there is a high coefficient (r=0.95) of linear between the concentrations of

Table 1. Results of the statistical analysis for surface water in the northwestern region. Units are μg-at/l in nutrient and mg/m^3 in chlorophyll-a

Relationship	Regression equation	Correlation coefficient (r)	Ratio of the slope	No. of data (n)	Remarks
N=fP	N=4.58P−0.05	0.95	$\Delta N/\Delta P=4.58$	26	For all the stations
Si=fP	Si=10.9P+4.1	0.93	$\Delta Si/\Delta P=10.9$	21	Excepted Stn. 31 and all 4 stations on K-line
Chl.a =fN	Chl.a=0.59N+0.18	0.90	$\Delta Chl.a/\Delta N=0.59$	23	Excepted Stn. 35, 36, and 37 on H-line
$N=f\sigma_t$	$N=0.58\sigma_t-11.81$	0.94	$\Delta N/\Delta\sigma_t=0.58$	7	For Stn. 39, 40, 41, 42, 47, 53 and 56($\sigma_t>20$)
	$N=-0.51\sigma_t+9.73$	0.95	$\Delta N/\Delta\sigma_t=-0.51$	16	For stations with $\sigma_t<19.5$ Excepted Stn. 31, 38 and 52

nitrate and phosphate. The slope($\Delta N/\Delta P=4.6$) is much less than the normal value($\simeq 16$) in the open sea observed by the earlier studies(Redfield et al., 1963; Ryther and Dunstan, 1971; Goldman et al., 1979). This suggests that nitrate rather than phosphate acts as the main limiting nutrient for plant growth. Shim et al.(1989) also reported the similar results in the southern waters of the Korean East Sea in early spring. It is generally assumed that nitrate, not phosphate, is the major limiting factor for production in coastal environment(Strickland, 1963; Riley and Chester, 1971). The relationship between silicate and phosphate also is nearly linear, if excluding some stations(Stn. 31, 53, 54, 55, 56) which have almost the same slope but high silicate concentrations by~2 μg-at/l. The reason for the anomalous concentrations at these stations could be not yet understood. However, the slope, $\Delta Si/\Delta P=11$, remains slightly small when compared to the ratio ($\simeq 16$) in the surface water of the Korean East Sea (Kido and Nishimura, 1973). The significantly high ratio(>50) in deep waters of the Korean East Sea as well as the Pacific Ocean was found by Kido and Nishimura(1973) and Tsunogai(1972). They ascribed the high ratio to the delayed regeneration of silicate from the siliceous tests of marine organisms. As a result, the surface water in the northwestern region of Cheju Island appears to be younger than the intermediate water or deep water of the Korean East Sea. Chlorophyll-a also exhibits a good and linear correlation with nitrate, even if Stn. 35, 36 and 37 depart from a regression line. At the three stations on H-line, the concentration of chlorophyll-a is not high despite of relatively high nutrient. It probably seems to be consequent on insufficient assimilation of nitrate which was supplied instantaneously (only during summer season) from the Coastal Water of China Continental(CWCC).

To discuss contribution of physical processes to surface nutrient concentrations in the northwestern region of Cheju Island, nitrate versus sigma-t at the surface is plotted in Fig. 3a. Except of the values at a few stations(Stn. 31, 38 and 52), the other data are separated into two groups. For instance, one group with high density($\sigma_t>20$) and another group with low density($\sigma_t<19.5$). The nitrate represents a good correlation with the sigma-t, a conservative parameter, for each group. Because of a positive relation between nitrate and chlorophyll-a as well, it is undoubted that distribution of nitrate in the surface water depends largely on any physical processes. However, the relationship between nitrate and sigma-t is proportional for one group of stations with sigma-t more than 20, while reciprocal for another group of stations with sigma-t less than 19.5. The opposite relationship at two groups suggests that their nitrate concentrations are controlled by different processes. It could be clear from the relation of nitrate against $\delta\sigma_t$(Fig. 3b). The $\delta\sigma_t$ of the difference in sigma-t between the surface and 50 *m* layer implies vertical stability of water. In fact, stations with $\sigma_t>20$ have smaller values of $\delta\sigma_t$($\delta\sigma_t<5$) than those at stations with $\sigma_t<19.5$. Also, concentration of nitrate at the surface is inversely to vertical stability at earlier stations, but increases as increment of the stability at later stations. Rho and Kim(1983) observed relatively cold and saline surface water in the southwestern coastal area of Korea during summer season with high stratification. By Kang(1974) and Lim(1976), it was also known that the Coastal Water of China Continental(CWCC) was extended toward the western area of Cheju Island in summer and consequently dropped surface salinity of its adjacent sea below ca. 31‰. Conclusively, it seems that in summer the surface concentration of nutrient is greatly controlled in the restricted northern area of 34° N by intense vertical and tidal mixing, whereas in the mostly northwestern area of Cheju Island by lateral extension of the Coatal Water of China Continental (CWCC).

In the southeastern region from A-line to F-line, the concentration of silicate is generally lower at a distance from the coast of Cheju Island, even if both C-line and D-line maintain about the same concentrations to ca. 50 *km* from the coast(Fig. 4a). The inshore stations(Stn. 1 and 2) on A-line show the lower value than those at equal distance on the other lines. But, the concentration of surface silicate represents roughly a inverse relation with the anomaly of salinity, δS, which is the difference in salinity between the surface and 50 *m* layer(Fig. 4 b). Indeed, the silicate concentrations are high at

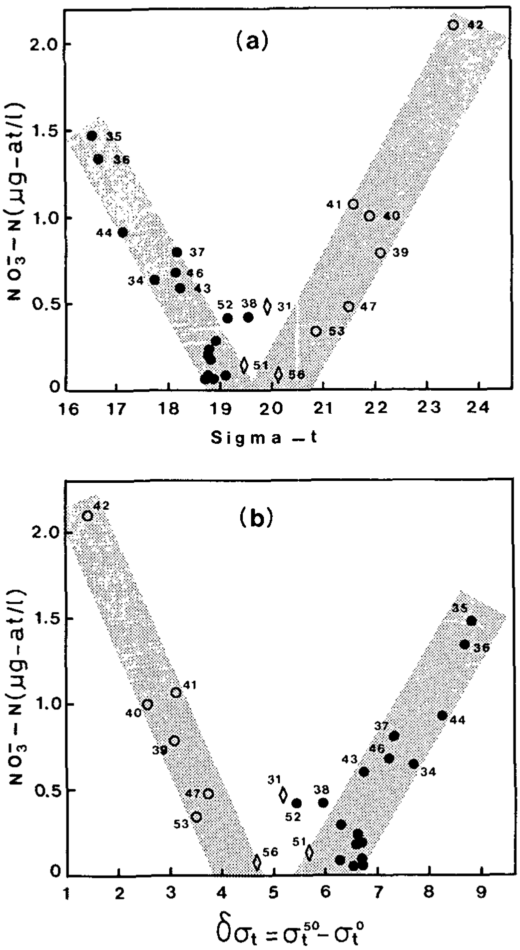

Fig. 3. Plotts of surface nitrate versus surface sigma-t (a) and the difference in sigma-t between the surface and 50 *m* (b) in the northwestern area of Cheju Island. The numerals represent the station numbers.

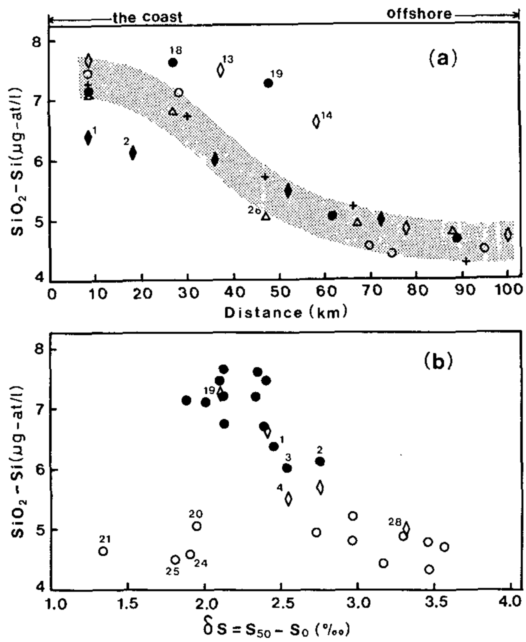

Fig. 4. Concentrations of surface silicate with a distance from the coast(a) and surface silicate vs δS(b) in the southeastern area. δS indicates the difference in salinity between the surface and 50 *m*.

the coastal stations with the smaller anomaly and low at the outward stations with the greater anomaly. The high silicate at the coastal stations may be influenced by coastal upwelling as suggested by Kim and Lee(1982) and Shim and Park (1984). The unexpectedly small anomaly of salinity at the southwestern outward stations(Stn. 20, 21, 24 and 25) is caused by occurrence of water with relatively low salinity at 50 *m* layer. This water is probably regarded as the Yellow Bottom Cold Water.

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要　　約

여름철 韓國南海 表層水중 營養鹽類 및 클로로필의 水平分布와 그 분포에 영향을 주는 物理的過程에 대하여 연구했다. 그 결과, 濟州島를 중심으로 북서쪽해역이 남동쪽해역보다 영양염류 및 클로로필의 농도가 높았다. 영양염류 농도로 볼때 북서쪽해역은 다시 2~3개의 小區域으로 나눌 수 있다. 그 중 34° N 以北海域에서는 강한 水溫前線이 형성되어 있고, 영양염류 및 클로로필의 농도가 상당히 높았으며, 이는 강한 垂直混合에 의한 것으로 판단된다. 또한 제주도 서쪽해역은 中國大陸沿岸水의 확장에 의해 표층수중 영양염류가 비교적 풍부하나 클로로필의 농도는 그다지 높지 않았다. 그러나 제주도 주변 연안해역에서는 클로로필의 농도가 상당히 높은데, 이는 沿岸湧昇作用에 의해 基礎生産力이 높아지기 때문이라 생각된다. 여름철 본 조사해역의 표층수중 溶存營養鹽類 및 클로로필의 水平濃度分布는 生物化學的 過程보다는 주로 地理的 차이에 따른 垂直混合 혹은 성질의 다른 水塊의 水平擴散에 의해 좌우된다.

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