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On the primary productivity in the southern sea of Korea

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韓國南海域의 一次生産力

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Southern sea of Korea was investigated for primary productivity during four scientific cruises of Korea Ocean Research and Development Institute. Frontal structure appeared to be an important physical characteristic in enhancing the phytoplankton production in the study area. Relatively high productivity was occured near the front between Tsushima Warm Current Water and Coastal Waters of China Continent in March 1990 and in November 1989, and near the front between Tsushima Warm Current Water and Korean Coastal Water in April 1989. In August 1988 high productive zone was limited to the tidal front off the southwestern coast of Korea. Nutrient supply related to the frontal structure might play a dominant role in increasing the primary productivity but mechanisms of nutrient enrichment are not clear. Average column productivity showed its maximum in April 1989 (1727 $mgC/m^2/day$) while relatively low values were measured in March 1990 and in November 1989 (314 and 517 $mgC/m^2/day$). In the Coastal Waters of the China Continent, incident light may be an important factor in regulating the phytoplankton production because of low light penetration rate resulting from high turbidity.

한국남해역의 일차생산력을 한국해양연구소의 3, 4, 8, 11월 4회에 걸친 현장조사에서 측정하였다. 조사해역에서 일차생산력이 높게 나타나는 곳은 전선구조와 밀접한 관계가 있는 듯하다. 1990년 3월과 1989년 11월에는 대마-난류수와 중국대륙연안수 사이에 비교적 높은 일차생산력이 나타났다. 1988년 8월에는 한국남서해안의 조석전선에서 비교적 일차생산력이 높았다. 전선구조에 따른 영양염의 공급이 일차생산력을 증가시키는 요인이라 생각되나 물리적 환경과 영양염의 공급구조등에 대한 과정은 명확하지 않다. 수층의 평균 일차생산력은 1989년 4월에 1,727 $mgC/m^2/day$로 가장 높았고 1990년 3월과 1989년 11월에는 각각 314, 517 $mgC/m^2/day$였다. 중국대륙연안수의 영향을 받는 곳에서는 높은 탁도에 의한 투과광량의 감소가 낮은 일차생산력의 원인인 것같다.

INTRODUCTION

Photosynthetic production by phytoplankters is the basis of marine life. Thus the measurement of primary productivity is essential in understanding the foodweb structure of ecosystem and fisheries yields. Primary productivity may have an important effect upon the distribution and fluxes of properties in the ocean (Deuser, 1986) and its rate is a fundamental aspect of phytoplanktonic community structure and biogeographical patterns (Steele, 1974).

In many earlier oceanographic studies on Korean Waters, comparatively little emphasis was paid to the area off the south coast of Korea. Various water masses including the Tsushima Warm Current Water, the Korean Coastal Water, the Coastal Waters of the China Continent and the Yellow Sea Bottom Cold Water are expected to be under the complicated lateral interaction in the

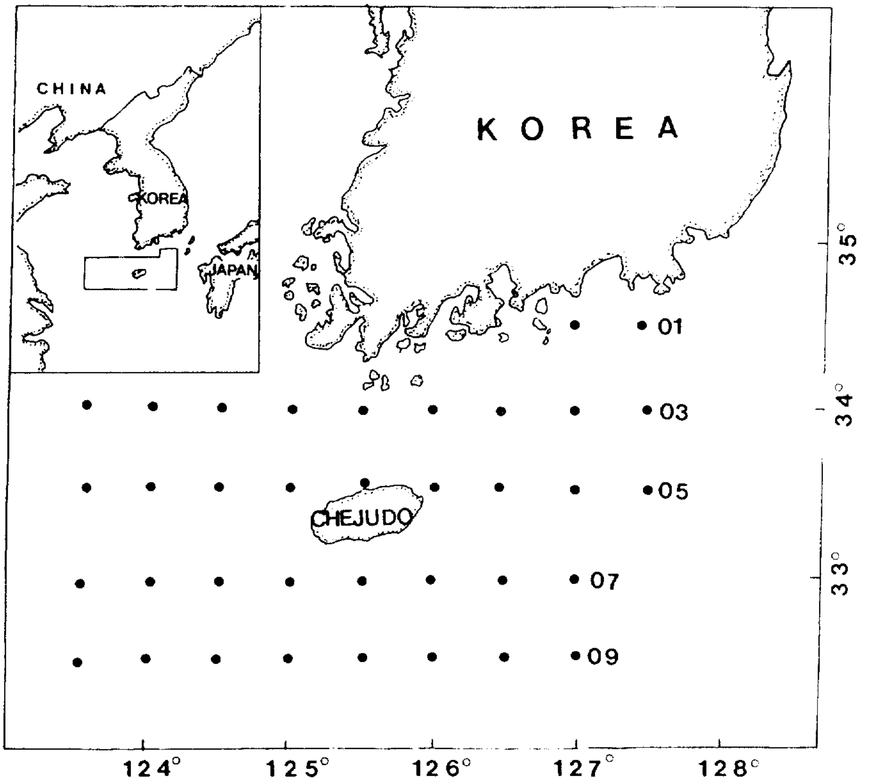

Fig. 1. Sampling stations in the outhern sea of Korea.

southern sea of Korea. The Tsushima Warm Current branches from the warm and haline Kuroshio and approaches the southern coast of Korea during all seasons. One branch of the Tsushima Warm Current flows northwest carrying waters of high salinity and temperature. In summer this water has its characteristics largely modified compared to those in winter since the Tsushima Warm Current is originated from mixed water between the Kuroshio and freshwaters on the continental shelf in the East China Sea. Gong (1971) reported that a coastal water mass is located in the southern sea of Korea throughout the year, extending a considerable distance from the shore: and there exists conspicuous fronts between this Korean Coastal Water and the Tsushima Warm Current Water. These fronts are located farther offshore in summer than in winter. Cyclonic eddies related to these fronts are particularly dominant in the southeast of Sorido Island (Lim, 1976). In the west of Jeju Island thermohaline front is formed between Thushima Warm Current Water and Coastal Waters of the China Continent and this front is likely to appear as an eddy (Lee, 1983).

Frontal structure is important in enhancing the phytoplankton growth in the ocean since consequent lateral mixing and upwelling processes induce high nutrient pools to the adjacent waters (Pingree, 1978). Thus high biological activities not only in the primary producers but also in the higher trophic level could be observed in the frontal zone (Pingree and Mardell, 1981; Atkinson and Targett, 1983). Gong (1971) reported that frontal structure in the southern sea of Korea are important for mackerel fishery.

Little is known about the characteristics of primary productivity in the southern sea of Korea. Most of the previous observations dealt with the productivity of the coastal waters (Choi and Chung, 1966; Kang, 1967).

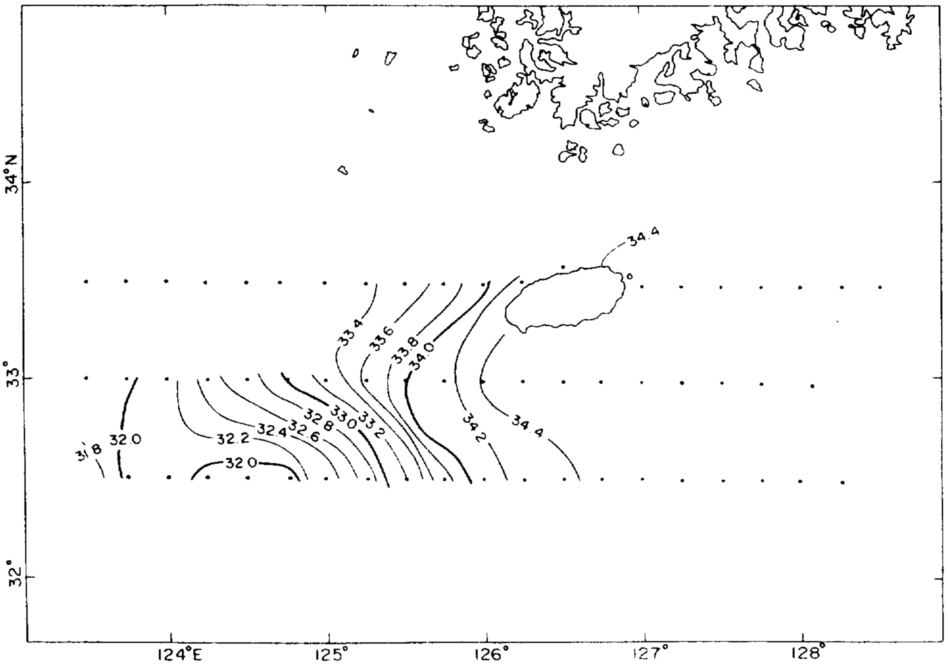

Fig. 2. Distribution of salinity in the surface waters in March, 1990 (‰).

The purpose of this study is to report a preliminary result of primary productivity measurements obtained from the cruises of Korea Ocean Research and Development Institute in the southern sea of Korea and to relate these results to the hydrographic regime.

MATERIALS AND METHODS

Data were obtained from four scientific cruises made in March 16-27, 1990, April 17-26, 1989, August 16-27, 1988 and November 16-26, 1989. Sampling stations are shown in Fig. 1. Temperature and salinity data were obtained from CTD casts obtained by phisical oceanography team of KORDI (KORDI, 1989, 1990). Nitrate concentraions were determined by using the Technicon Autoanalyzer II following the method described by strickland and parsons (1972). Chlorophyll a was measured on the acetone extracts spectrophometrically using the method described in Parsons *et al.* (1984). Light penetration and sample dephths for primary production measurements were usually estimated from the secchi depth. A 1% light level at 3 times the secchi depth was assumed. For the measurements of primary productivity 220 m*l* of seawater samples taken at four depths were incubated on deck. 5μCi of C-14 labled $NaHCO_3$ were innoculated at each bottle. Bottles were kept in polyethylene cylinder covered with nickel screen which provides the incident light corresponding to each sampling depth. Incubation periods were 2 to hours. At the end of the incubation samples were immediately filtered onto the 0.45 μm Millipore filter paper. After inorganic carbon was driven off by acidification C-14 uptake rates were measured on LKB 1215 Liquid Scintillation Counter using Instagel (Packard. Co.) as a scintillation cocktail. Light uptakes were corrected by subtraction of the dark uptake, which was usually a small fraction of the light uptake. Daily primary productivity was calculated from PI (Photosynthesis/Irrandiance) curve and incident light data. Optimal light intensity was measured by incubating samples at four different light conditions (100, 50, 25, 12.5%). Nickel screen and Licor-185B quantummeter were used for the control of light condition.

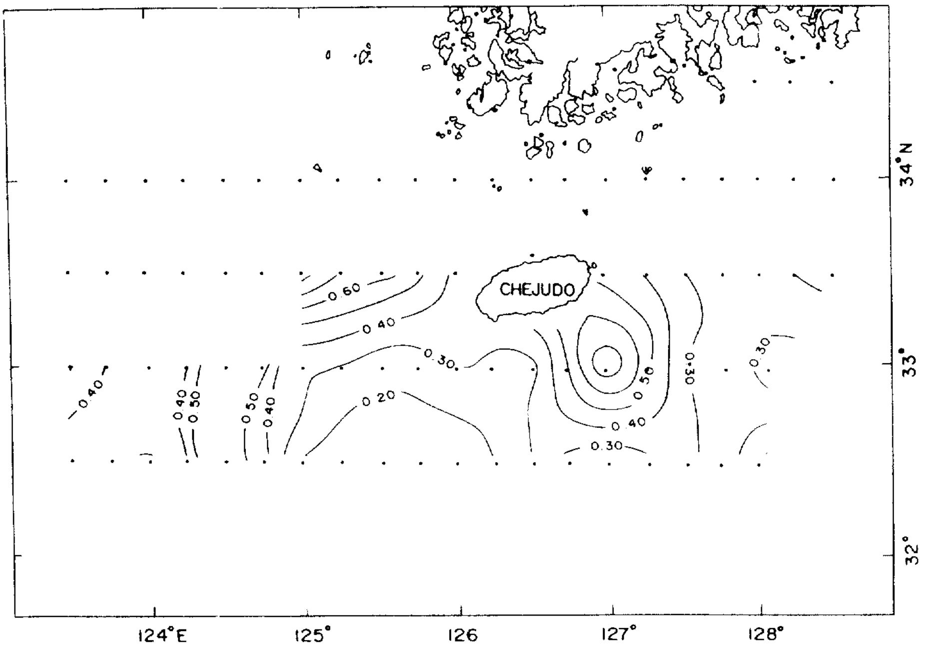

Fig. 3. Distribution of chlorophyll a in the surface waters in March. 1990 (µg/l).

RESULTS

March, 1990

In March, warm saline waters of Tsushima Warm Current (T>14℃, S>34‰) widely distributed in the east and south of Jeju Island (Fig. 2). Colder and less saline waters of Coastal Waters of the China Continent (T<10℃, S<32.2‰) could be observed in the southwestern extremities of study area.

Surface nitrate contents ranged from 1.40 to 8.76 µM and water column was vertically homogeneous in nitrate concentrations (KORDI, 1990). Less than 4 µM was measured in the Tsushima Warm Current Water while higher values were found in the western part of the study area where influence of Coastal Waters of the China Continent, Yellow Sea Bottom Cold Water and Korean Coastal Water was dominant (KORDI, 1990).

Surface cholrophyll a concentrations ranged from 0.09 µg/l(Fig. 3) with higher values located near the edge of coastal water (KORDI, 1990). In March 1990, the depth of the euphotic zone averaged to be only 4m in the area influenced by Coastal Waters of the China continent, but it reached up to 50m in the Tsushima Warm Current Water (KORDI, 1990).

Surface productivity in March 1990 varied from 3 to 140 $mgC/m^3/day$ (Fig. 4). High surface productivity was confined to the edge of Tsushima Warm Current area bordering the haline front with Coastal Waters of the China Continent. In the west of 124°E, it seems that the relatively low productivity in nutrient rich waters might be resulted from the weak light condition in the turbid water (KORDI, 1990) and from low temperature (less than 10° C). Optimal light intensity for the primary production estimated from PI curve in the west of 124° E was about 160 $\mu E/m^2/sec$ whereas this value for the whole area averaged to be 234 µE/m2/s. Assimilation number ranged from 1.7 to 19.5 mgC/mg Chl a/h. In March 1990, water column productivity varied from 80 to 610 $gC/m^2/day$ ($M=0.31\ gC/m^2/day$).

April 1989

In April 1989 steep thermal gradients in the surface waters extended northeast separating Tsu-

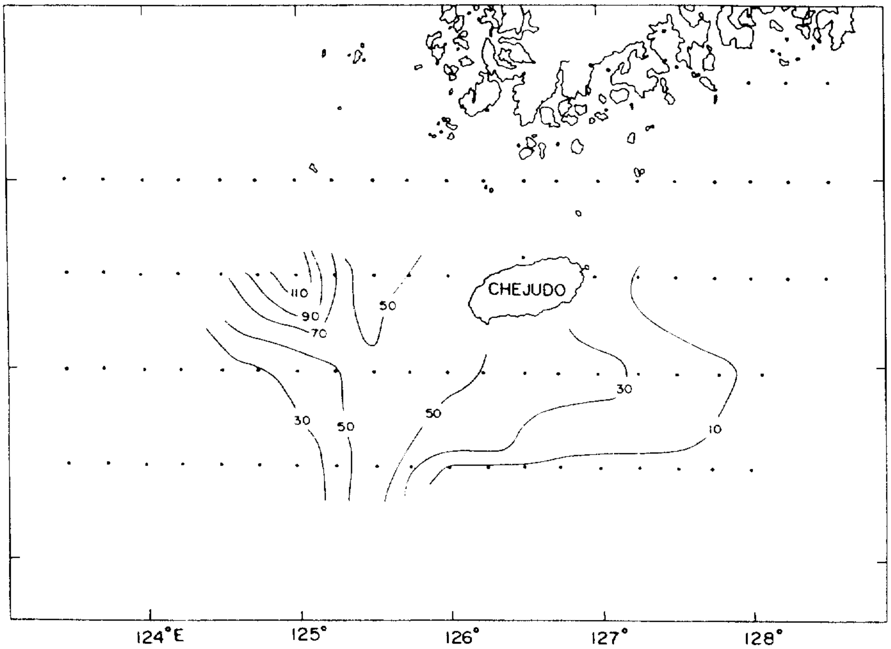

Fig. 4. Distribution of surface primary productivity in March, 1990 (mgC/m^3/day).

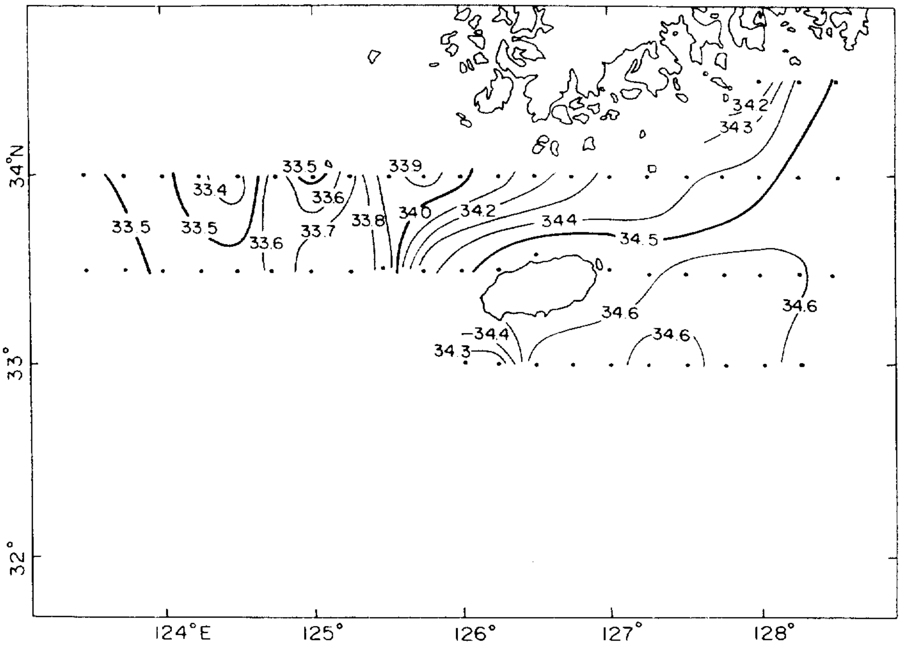

Fig. 5. Distribution of salinity in the surface waters in April, 1989 (‰).

shima Warm Current Water from coastal waters (Fig. 5). This front was located in the west and north of Jeju Island.

Surface nitrate contents showed less than 1 μM at most of the stations. From 20-30 m layer nitrate contents incresed with increasing depth due to the

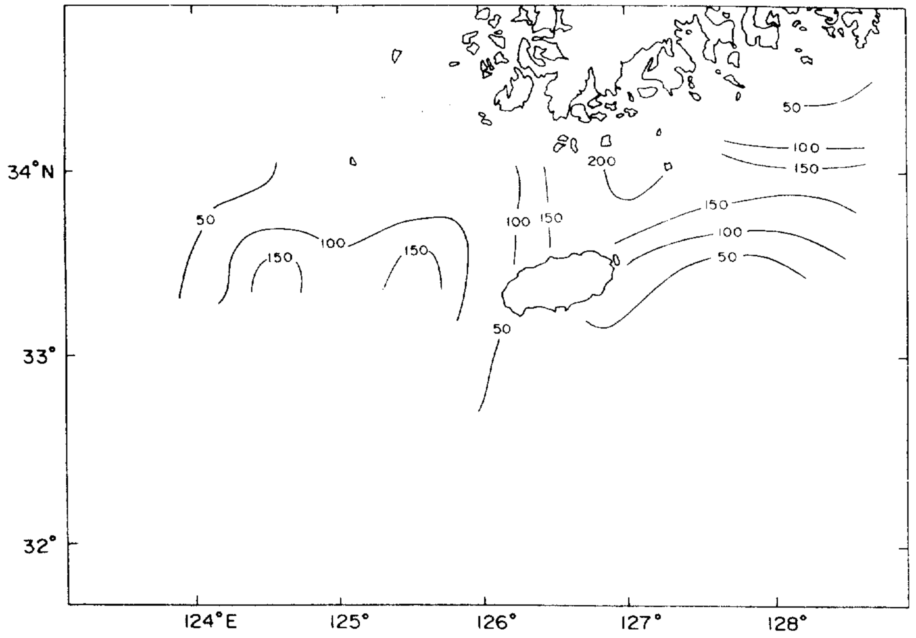

Fig. 6. Distribution of surface primary productivity in April, 1989 (mgC/m³/day).

onset of thermocline (KORDI, 1989). Less than 0.2 μg/l of surface chlorophyll a was measured in the Tsushima Warm Current Water (KORDI, 1989). Vertical distribution of chlorophyll a showed higher values at 10-30m depth which implies vertical flux of nutrients is important in supporting the phytoplankton biomass. The depth of the euphotic zone estimated from secchi disc depth was 19-43m averaging 31m. Surface productivity in Aril 1989 ranged from 22.8 to 222 mgC/m³/day (M=99. 8 mgC/m³/day) which are four times higher than summer values (Fig. 6). Surface productivity of more than 150 mgC/m³/day was found at the front between Tsushima Warm Current Water and Korean Coastal Water from which it might be suggested that cross frontal mixing and/or physical structure related to this frontal structure is favorable for the phytoplankton growth. In the western part of the study area mainly influenced by Coastal Waters of the China Continent (KORDI, 1989) surface productivity exceeded also 150 mgC/m³/day. In this area more than 1.5 μg/l of subsurface chlorophyll maximum was observed at 10-20 m layer (KORDI, 1989). Though surface productivity was also high in this region in March 1990 available hydrographic data are not sufficient to explain relatively high biological activity in this zone. Water colmn productivity in April averaged to be 1727 mgC/m²/day which is the highest value during the sampling period. Assimilation number in the surface water ranged from 4.3 to 25.8 mgC/mg Chl a/h.

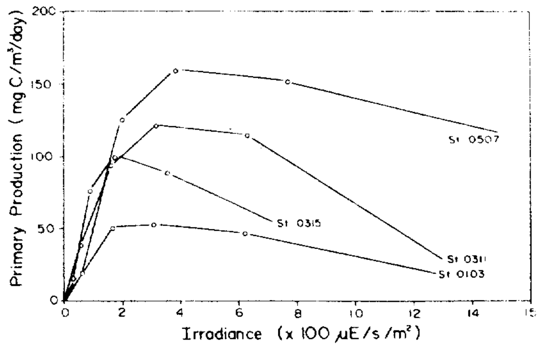

Fig. 7. Photosynthesis/Irradiance curve in April, 1989.

Photosynthetic ability of phytoplankton increased with increasing light intensities at low light level. However it showed maximum at 25-50% surface illumination corresponding 141-386 μE/m2/s and decreased at high light intensities (Fig. 7).

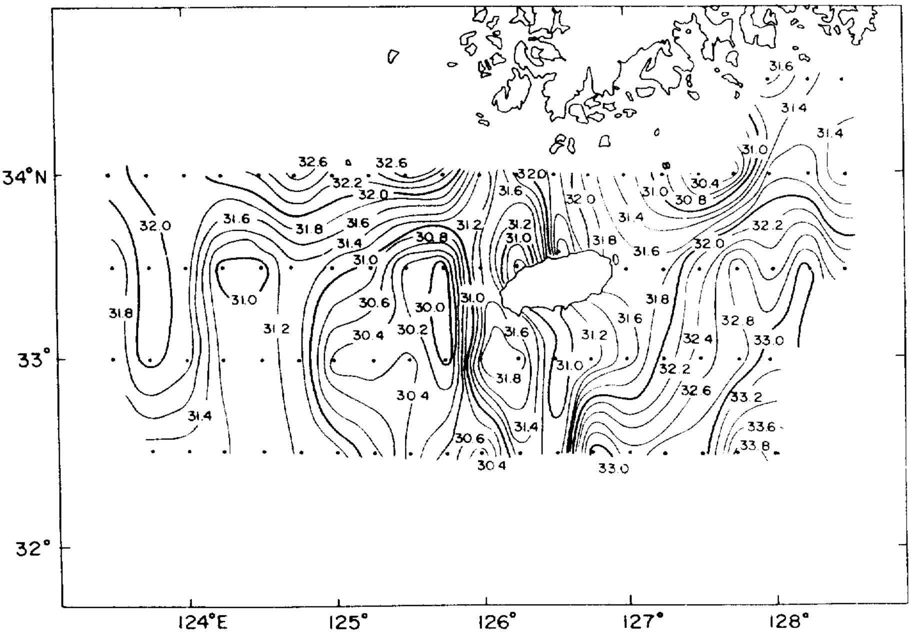

Fig. 8. Distribution of salinity in the surface waters in August, 1988 (‰).

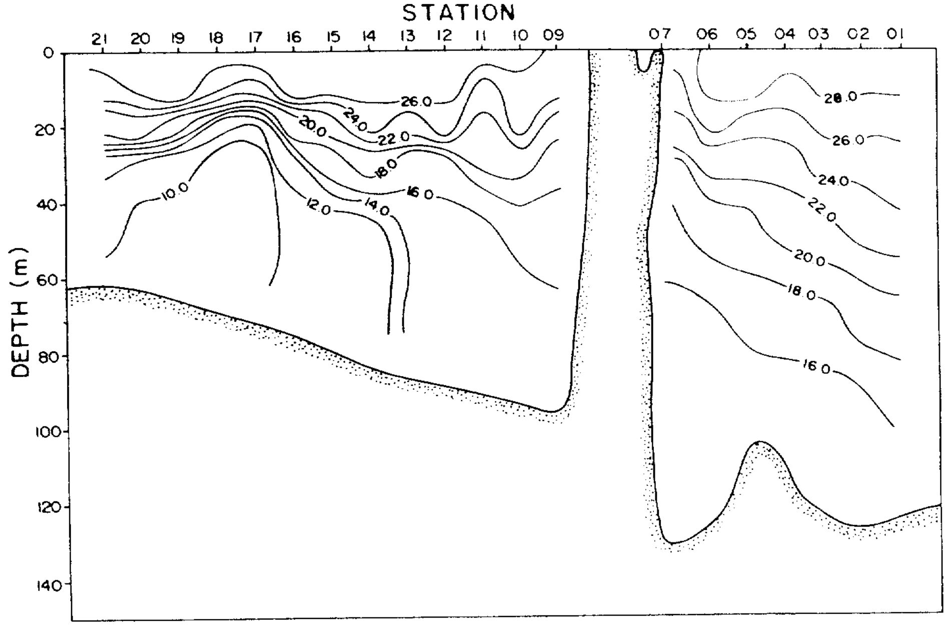

Fig. 9. Vertical distribution of temperature along 33° 30′ N in August, 1988 (° C).

August 1988

In August surface salinity decreased by to 4‰ compared to that of winter, 1987 (KORDI, 1988) due to the freshwater inflow (Fig. 8). No steep horizontal temperature gradient could be observed in the surface layer in August 1988 (KORDI, 1989). Distinct thermocline was observed at 20-40m de-

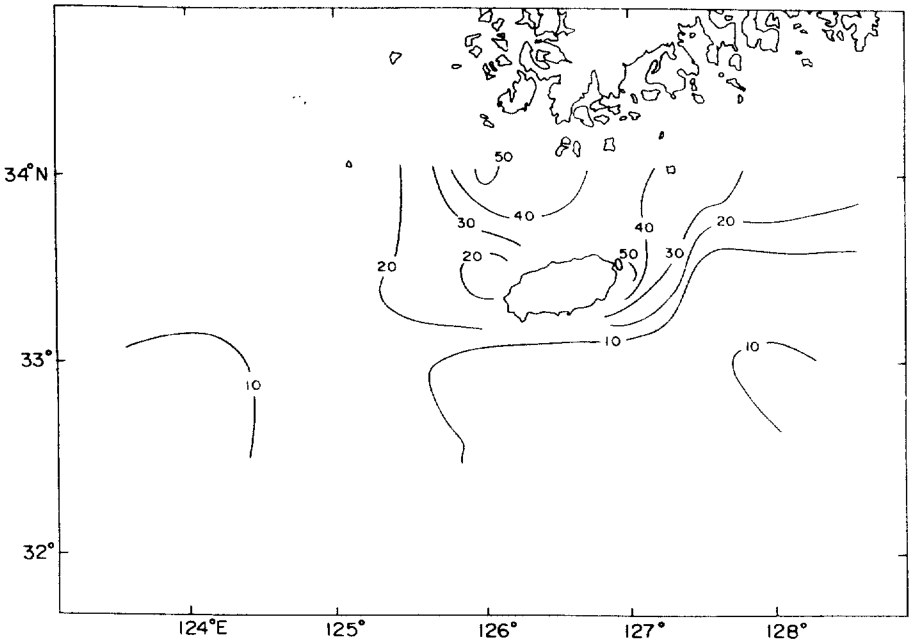

Fig. 10. Distribution of surface primary productivity in August, 1988 (mgC/m^3/day).

pth (Fig. 9). Nitrates (M=0.2 μM) were nearly depleted in the upper layer because upward flux of nitrogen from bottom layer is limited due to the strong seasonal thermocline. Mean Chlorophyll a content was 0.16 μg/*l* in the surface waters (KORDI, 1989). Subsurface cholrophyll maximum of over 0.5 μg/*l* could be found at some stations off the western tip of Jeju Island. Euphotic zone depth estimated from secchi disc depth varied from 22 to 54m (M=40m). In August 1988 euphotic zone depth in the western part of the study area reached 38m which is an order of magnitude higher than in March 1990. Maximum chlorophyll a values were observed at 5-10% of surface illumination depth which correspeonds to nutricline. It is well known that temperate coastal waters stratified during the summer months are generally characterized by well defined subsurface chlorophyll maxima associated with a relatively shallow pycnocline and nutricline (Cullen and Eppley, 1981).

Surface primary productivity ranged from 2.8 to 56.4 mgC/m^3/day (M=18.4 mgC/m^3/day). High productivity was located in the coastal waters off the southern coast (Fig. 10).

November 1989

As shown in Fig. 11, distinct haline front could be observed between 125° E and 126° E in the southeast of Jeju Island in November 1989. According to Lee (1983), off the southwest coast of Korea, changes in hydrographic fields from stratified state of summer to a vertically homogeneous one of winter appeared to occur most actively in November. He stated that during this transitional period coincident thermal and salinity fronts are formed along the boundary between water masses.

Surface chlorophyll a ranged from 0.05 to 1.57 μg/*l* averaging 0.50 μg/*l* (KORDI, 1990). Near the front more than 1 μg/*l* of chlorophyll was found in the surface waters (Fig. 12). In the Tsushima current Water and the Coastal Waters of the China Continent surface chlorophyll a concentrations were generally low. On the vertical profile relatively high chlorophyll a concentrations were observed at 12-25% depth of surface illumination. Euphotic zone depth in the southwestern part of study area was only 5m showing the influence of turbid water from the coast of China.

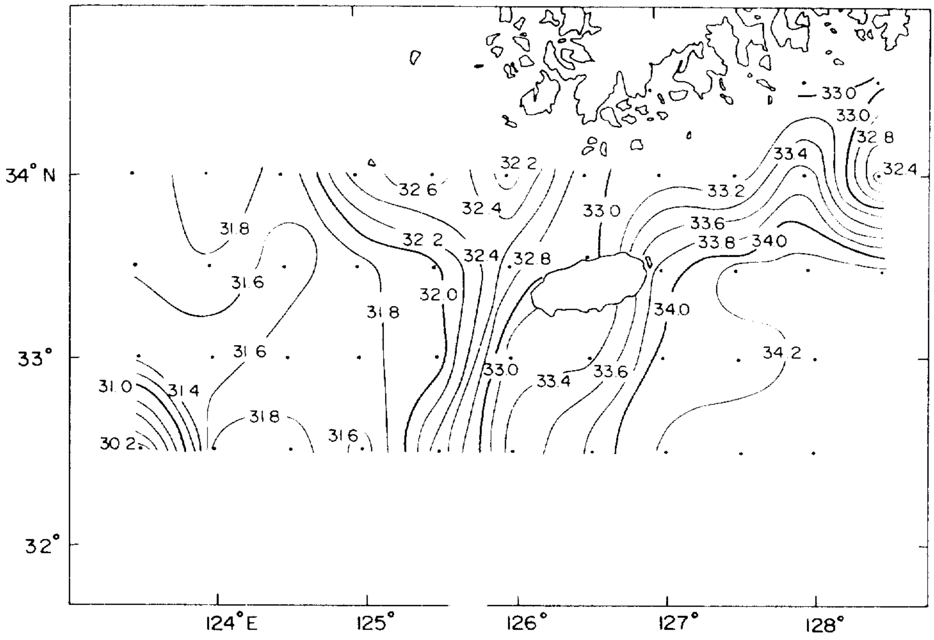

Fig. 11.Distribution of salinity in the surface waters in November. 1989 (‰).

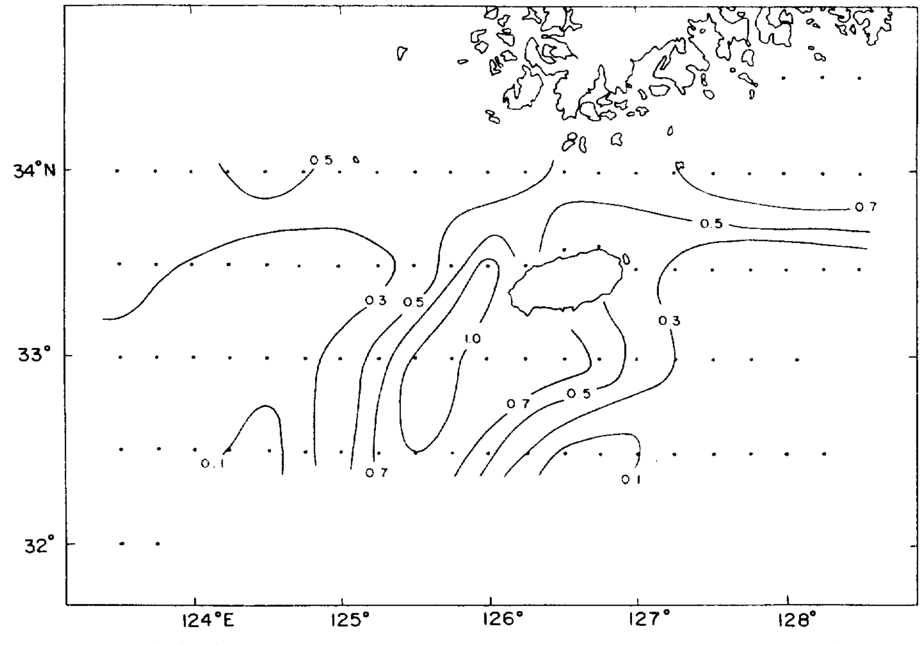

Fig. 12.Distribution chlorophyll a in the surface waters in November. 1989 (μg/l).

Surface primary productivity ranged from 2 to 114 mgC/m^3/day (M=41mgC/m^3/day). High surface productivity was located in the frontal zone as was the case of chlorophyll a (Fig. 13). It is interesting to note that one can not observe the high surface productivity in the frontal zone between

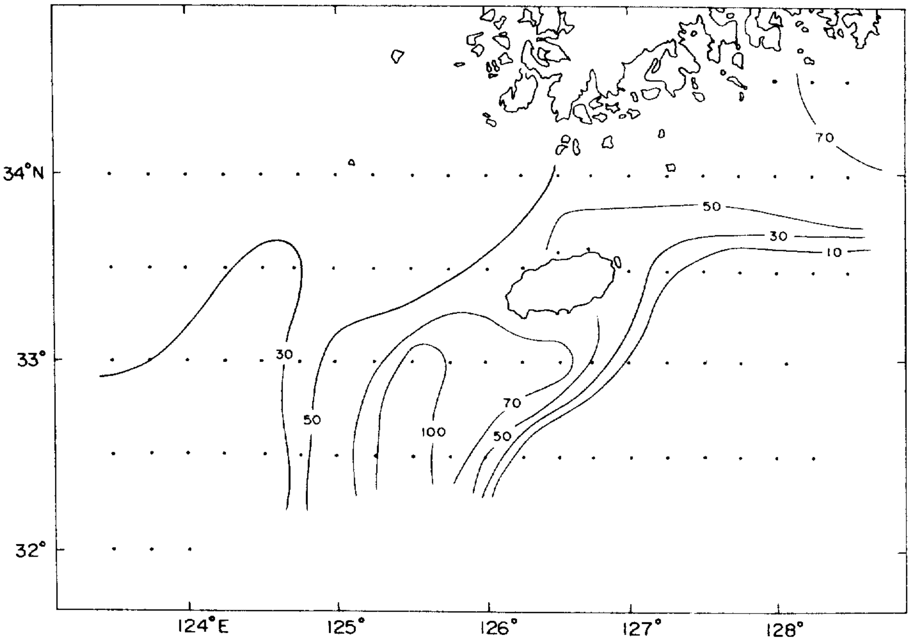

Fig. 13.Distributiuon of surface primary productivity in November, 1989 (mgC/m^3/day).

Korean Coastal water and Tsushima Warm Current Water. Mean water column productivity was 517 mgC/m2/day with higher values in the frontal zone. Photosynthetic ability increased with increasing light intensity but optimal light intensity occured at 12-25% depth of surface illumination (104-218 μE/m^2/s, M = 116 μE/m^2/s). Assimilation number ranged from 2 to 22 mgC/mg Chl a/h showing higher values in the frontal zone.

DISCUSSION

As shown above frontal structure seems to be an important physical characteristics enhancing the high phytoplankton production in some portion of the southern waters of Korea. High productivity was found at the front between Tsushima Warm Current Water and Coastal Waters of the China Continent in March and in November, and at the front between Tsushima Warm Current Water and Korean Coastal Water in April. Surface productivity was high near the tidal front off the southwestern coast in August. Thus nutrients supply near the frontal structure might play a dominant role in supporting the higher rate of primary production in the frontal zone than adjacent waters.

During warm period tidal fronts are known to be formed off the western and southwestern coast of Korea (Lie, 1985, 1989). The modulation of the intensity of tidal mixing by variable bottom depth in shallow seas results in areas of well-mixed and stratified waters separated by frontal discontinuties (Simpson and Hunter, 1974). In the English Channel and Celtic Sea the highest levels of chlorophyll a during the summer months are associated with temperature gradients, both in surface fronts between well-mixed and well-stratified waters and in the seasonal thermocline (Pingree *et al.*, 1978). Favourable conditions for phytoplankton production could be met by nutients brought up to the mixed layer in the frontal zone. It is not clear, however, whether the cross-frontal mixing or other physical progresses related to the frontal structure is an important process for the nutrient enrichment in the frontal zone. Cyclonic eddies frequently result in the upwelling of nutrient rich bottom water as in the Gulf Stream (Yoder *et al.*, 1981) and off the eastern coast of New Zealand (Bradford *et al.* 1982). At present it is difficult to explain the mechanisms of nutrient enrichment in the frontal zone hence physical processes occurring in this zone are poorly understood. More extensive studies are needed in order to relate physical properties to the chemical and biololgical consequences in the sothern waters of Korea.

Another important physical properties regulating the phytoplankton production might be an incident light intensity. Optimal light intensity is important in that the phytoplankton shows photoadaptation under low light intensity and photoinhibition under high light intensity. Thus PI(Photosynthesis/Irradiance) curve is important in understanding the interaction between organisms and environment. Above the compensation intensity, if other factors remain optimal, production increases more or less linearly with increase in light intensity. With further rise in light intensity, the rate of increase in production tends to fall until a level is achieved at which the response is maximal.

Optimal light intensities for the primary production in the study area were 234 μE/m^2/sec in March, 300 μE/m^2/sec in November as was shown in previous chapter. It seems that phytoplankton community is adapted to seasonal variation of light intensity. The depths at which optimal light intensity occurred were 25-50% of surface illumination in April and 12-25% in November. In August chlorohpyll maximum layer was located at 5-10% surface illumination. In the Coastal Waters of the China Continent euphotic zone depth was less than 5m in March and in November suggesting the diminution of photosynthetic ability due to the light attenuation by suspended solids originated from Chinese coast.

Productivity is often limited to the availablility of nitrogenous nutrients in sea water. Using C/N value of 6, nitrogen requirement in this area in March 1990 is calculated to be 1.1-8.5 mg at N/m^2/day (m = 4.3 mg at N/m^2/day) from the productivity values. Considering the turnover time of nitrogenous obtained by dividing in situ nitrate concentrations with nitrogen requirement rates which is mostly less than 1 day (KORDI, 1990) other sources of nutrients e.g. river discharges, upward flux or eddy diffusion might be important in supporting the primary productivity. Nitrogen requirement in April 1989 was 1.2 mg at N/m^2/day which is higher than in summer. This means that nitrogenous nutrients are rapidly recycled and external supply of nutrients is essential in maintaining the high phytoplankton productivity.

During the study period average water column productivity showed its maximum in April (1727 mgC/m^2/day) and relatively low values in March and November (314, 517 mgC/m^2/day). It is difficult to estimate the annual primary productivity because water column productivity was measured in summer. If we assume summer productivity value as a mean of those in March and November, annual productivity in the southern waters of Korea is estimated to be about 270 gC/m^2/yr. But this value is only an estimation and further detailed study would provide more relialbe water column productivity data. Our suggested value might be an overestimation if one compares thi; value to the productivity data of other regions. Ryther (1969) reported average primary productivity values of world ocean as 50, 100 and 300 gC/m^2/yr for open ocean, continental shelf and upwelling area repectively. Estimation of Finenko (1978) is not very different from that of Ryther. He reported 28, 91, 237 gC/m^2/yr for oligotropic area, tropical upwelling area and neritic zone of the Pacific Ocean respectively. Our estimate of primary productivity in the southern sea of Kerea is close to the values for the neritic zone reported by Finenko (1978).

Around Korean peninsula annual primary productivity was reported to be 141 gC/m^2/yr for the mid-eastern Yellow Sea (Choi et al., 1988), 150-200 gC/m^2/yr for East China Sea including Yellow Sea (Nishimura, 1983) and over 180 gC/m^2/yr cold waters of Japan Sea (Koblentz-Mishke *et al.* 1970).

CONCLUSION

Present study showed distribution of primary productivity in the southern sea of Korea with maximum value occurrng in spring. Productive areas were localized near the front between watermasses in some portion of the study area. Although large areas of southern sea of Korea were investigated for primary productivity during this study, much has to be done to evaluate the primary productivity in this area. Detailed descriptions of the phytoplankton production in terms of the physical processes of mixing and stabilization and the interaction of these processes with light and nutrient requirements for phytoplankton growth should be made in the future.

For a better evaluation of primary productivity classical sampling methods in that stations and sample depths are chosen with long interval should be reconsidered. The subsurface phytoplankton populations in shelf environments probably make an important contibution to total annual primary production. Difficulties of sampling these subsurface layers and of measuring net production under conditions equivalent to those experienced by plant cells within the water column restricts atempts to quantify photosynthetic rates. Furthermore fronts in the southern sea exhibit great seasonal and interannual variability (Gong, 1971). More sophisticated time/space sampling of physical, chemical and biological parameters is needed in the future in order to provide better insight into the paradigm of increased biotic activity at fronts.

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