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Nutrients, Chlorophyll - *a* and Primary Productivity in Maxwell Bay, King George Island, Antarctica

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킹죠지섬 맥스웰만의 영양염, 클로로필- *a* 및 일차생산력

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Abstract : Nutrients (phosphate, nitrate and nitrite) , chlorophyll - *a*, and primary productivity were measured in Maxwell Bay, King George Island, Antarctica during austral summer in 1988-89 . Nutrient concentrations were low in the surface layer and high in the bottom. Horizontaly nutrients and chlorophyll - *a* contents were high in the central part of the Bay , but low in the peripheral part . Primary productivity of 0.30 g/m²/d was found in the central Maxwell Bay while 0.14 g/m²/d in Marian Cove . Primary productivity due to nannofraction of phytoplankton occupied 74% and 24% of the total productivity for the central Maxwell Bay and Marian Cove , respectively . Some ecological differences between the central Maxwell Bay and Marian Cove were discussed intensively .
Key words : primary productivity , nutrients , chlorophll - *a*

요약 : 1988-89년 남극의 여름기간동안 남극반도의 킹죠지섬에 위치한 맥스웰만내에서 영양염(인산염, 질산염, 아질산염), 클로로필 *a* 와 기초생산력이 측정되었다. 수직적인 영양염의 분포는 저층에서 높고, 표층에서 낮게 나타났다. 수평적으로는 맥수웰만 중앙부위에서 영양염이 높고, 만의 안쪽과 브랜스필드 해협쪽은 낮게 나타났다. 클로로필 *a* 도 영양염과 같이 맥스웰만의 중앙부가 높고 내만과 브랜스필드 해협쪽이 낮게 나타났다. 만 중앙부에서 측정된 일차생산력은 0.30 g/m²/d 이었고, 마리안소만에서는 0.14 g/m²/d 이었다. 총 일차생산력 중 nannoplankton 이 차지하는 비율은 마리안소만에서는 74% 인 반면, 맥스웰만 중앙부에서는 24%였다. 맥스웰만 중앙부와 마리안소만은 생태학적으로 구분된다는 점에 대해 몇가지 의견이 제시되었다.
주요어 일차 생산력, 영양염, 클로로필

Introduction

The Antarctic Ocean is characterized with its abundant nutrient contents and low water temperature. As a result, the ocean is one of the most productive oceans in the world during austral summer (Thurman. 1985) . The coastal area around Antarctica is yet least affected by human impacts, consequently the area is one of the best regions in the world to study the natural background of chemical parameters in the environment. Nonetheless Bransfield Strait, the offshore side of the study area, is one of the most frequently studied region in Antarctica: Many works have been done on the hydrological properties (Martin et al., 1980) and several active researches are going on in this area. Polish scientists (Rakusa - Suszczewski, 1980) studied Admiralty Bay, the adjacent bay to the study area, for many years. Yet no work has been done for the basic parameters in oceanography such as nutrients, chlorophyll - *a* and primary productivity in Maxwell Bay until the 1 st year study of Korea Antarctic Research Program (KARP) (KORDI, 1988). As a part of the 2 nd year studies of KARP, nutrients (phosphate, nitrite and nitrate) , chlorophyll - *a*, and primary productivity were measured in Maxwell Bay.

Methodology and Material

1. 24- hour sampling station

Rossette sampler (5 ℓ capacity) was used to collect water samples from 7 depths (0, 10, 20, 30, 50, 75, 100 m) every 4 hours from a station in the central Marian Cove, from January 26 to 27 , 1989 (Fig. 1). Nitrite, nitrate and phosphate concentrations were determined by Parsons et al. (1984) in the laboratory in the King Sejong Station within 48 hours after collection. Relative chlorophyll - *a* contents were measured with Turner Design Field Flouorometer *in vivo* and the contents were not corrected with spectrophotometric method.

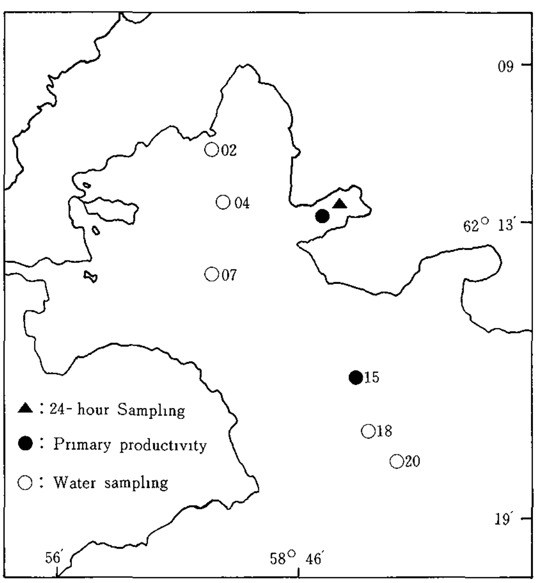

Fig. 1 Sampling stations in Maxwell Bay during 1988/89 austral summer.

2. Maxwell Bay

Water samples were collected from Stations 2, 4, 7, 15, 18, and 20 (Fig. 1) . From the above stations, 5 to 11 samples (from 0, 10, 20, 30, 75, 100, 200, 300, 400 m) of the volume of 5 ℓ were obtained with Rossette Sampler. Only surface water samples for chlorophyll - *a* analysis were collected from all of the 20 stations .

Primary production was measured as 14- C uptake in simulated in situ incubations from the central Marian Cove and the central Maxwell Bay during 13 : 00~17 : 00 o'clock for two consecutive days. The weather condition was very similar and the daily solar radiations was not more than 10% between two days. Samples were collected in Rossette samples from 5 estimated "optical" depths (100, 50, 25, 10 and 5% of surface radiation) and were treated with carbon -14 bicarbonate (10 μ Ci / ml) . BOD bottles (300 ml) were used as the incubation vessels. All the glasswares were washed with diluted acid (0. 1 NHCl) and rinsed thoroughly with distilled deionized water. Later they were rinsed with ambient filtered seawater before incubation in the field. Incubations were performed for 4 hours on deck under natual illumination and proper light attenuation was obtained by screening with nickel screen. Dark bottles were wrapped with black electrician's tape. Surface water temperature was maintained in the chamber by a continuous pumping with surface seawater.

Incubations were terminated by filteration of samples on HA Millipore filter (pore size : 0.45μm). Before the filteration with Millipore filter, samples were filtered through a plankton net (mesh No. 20, approximate mesh size of 20μm) to figure out the relative importance of nannofraction in primary productivity. Samples were filtered again with 10 ml prefiltered ambient seawater to wash inorganic carbon-14 retained in wet filters. Filtered samples were then kept frozen until counting their fixed carbon-14 activities by liquid scintillation desiccator with HCl for 2 minutes to strip off the inorganic carbon-14 absorbed in the filter. Instagel (Packard Co.) was used as scintillation cocktail. Counting was carried out on a Liquid Scintillation Counter (Rackbeta Ⅱ). For the calculation of depth intergrated primary production, the observed extinction coefficient was used for simulated *in situ* incubations. The extinction coefficient was calculated in accordance with Beer's law. Each sample was excuted as duplicate.

Result

1. 24-hour Sampling Station

가. Nutrients

Phosphate; Vertical variations of phosphate for 24 hours are shown in Fig. 2. Vertically, phosphate concentrations increased with depth. The concentrations were 1.8μM and 2.1μM for the surface and bottom, respectively. The profile looked like a tidal movement. Generally, the concentrations of phosphate were similar to those of the last year (KORDI, 1989).

Nitrate; Vertical variations of nitrate for 24 hours are shown in Fig. 3. Vertically, nitrate concentration increased with depth except minimum at 20 m depth at 16 : 00 hour. The

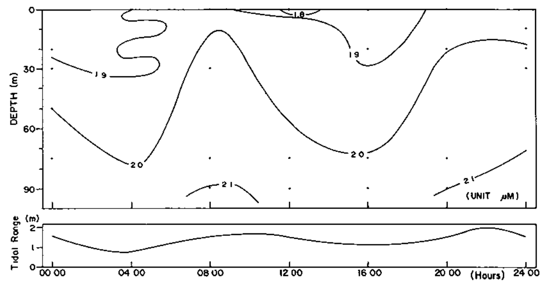

Fig. 2 Vartiation of phosphate concentrations with tidal range.

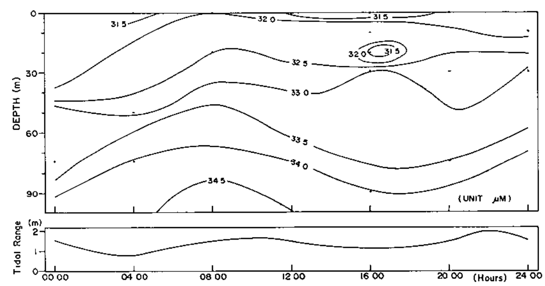

Fig. 3. Variation of nitrate concentration with tidal range.

concentration of nitrate was 31μM and 34μM for the surface and bottom, respectively. This values are about 10μM higher in concentration comparing to those of last year(KORDI, 1989). The profile looked like a tidal movement.

Nitrite; Vertical variations of nitrite are shown in Fig. 4. No vertical difference was found for 24 hours. The concentration was 0.2μM.

나. Chlorophyll-*a in vivo* Fluorescence)

The variations of relative chlorophyll-*a* contents are shown in Fig. 5. Generally, the maximum was found at 10 m depth and the concentration decreased with depth. An interesting fact was found that the chlorophyll-*a* maximum (16 : 00 hour) appeared at the consistant time with the nitrate minimum at 10 m depth. Eventhough diurnal variation is not distinct, the concentrations of chlorophyll-*a* was relatively high during the day time (10 : 00-20 : 00 hour) and decreased gradually

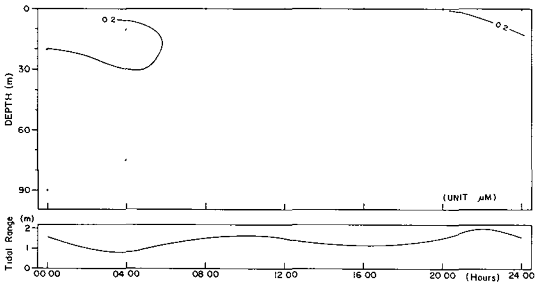

Fig . 4 Variation of nitrite concentrations with tidal range .

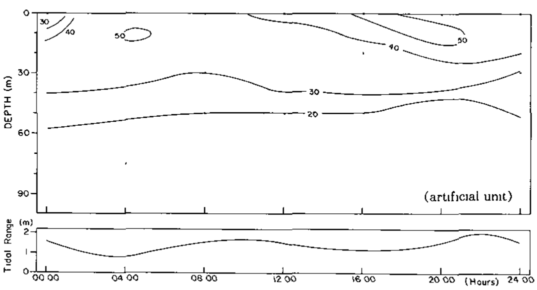

Fig . 5 Variation of chlorophyll - *a* concentrations with tidal range .

during the night showing minimum at 24 : 00 hour (Fig. 5).

2 . Maxwell Bay

가. Nutrients

Phosphate ; The vertical profile of phosphate in Maxwell Bay is shown in Fig 6. Vertically, the concentration of phosphate increased with depth. Horizontally, the maximum of 2.1 μ M was found at the central deep basin of Maxwell Bay, while 1.9 μ M at the surface.

Nitrate ; The vertical profile of nitrate in Maxwell Bay is shown in Fig. 7. Generally the concentrations increased with depth with the maximum of 36 μ M at deep central basin of Maxwell Bay. A distinct difference was found in samples collected from depth (>300 m) between station 20 and other stations. High concentrations of nitrate in the deep central Maxwell Bay were found, but such trend was not found at station 20.

Nitrite ; No vertical or horizontal variations of concentrations were found from the profile of nitrite (Fig . 8)

나. Chlorophyll - *a* (*in vivo* Fluorescence)

The vertical profile of relative chlorophyll - *a* contents is shown in Fig 9. Generally high concentrations were found at the surface and sharply decreased with depths greater than 100 m. Horizontally, high contents of chlorophyll - *a* were found in Stations 11 and 15 . An interesting point is that low nitrate and phosphate contents were found at the sampling stations.

다. Primary Productivity

Primary productivity of the central Maxwell Bay and the central Marian Cove was 0. 30 g c / m²/ d and 0. 14 g c / m²/ d, respectively Nannofraction occupied 74% and 24% of total productivity in the central Marian Cove and the central Maxwell Bay, respectively.

Discussion

1) Environmental Factors Affecting Primary Production in Maxwell Bay and Marian Cove

The environmental factors which influence the production of organic matter in antarctic waters are nutrient concentration, light intensity and stabilization of surface waters

First, major nutrients such as nitrate, phosphate and silicate are unlikely serious limiting factors for primary production in antarctic waters, while there are evidences that trace elements, indeed, affect organic production in these regions (El - Sayed , 1966) .

Volkovinsky (1966) showed the direct relationship between manganese and molybdenium concentrations and primary production in Sco-

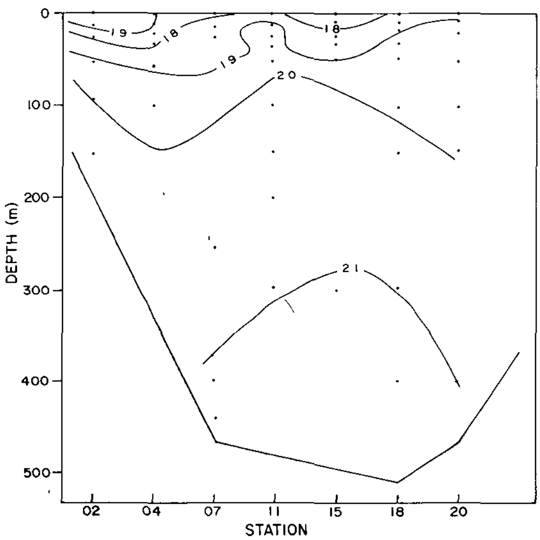

Fig. 6 North - South intersection of phosphate concentrations (μ M).

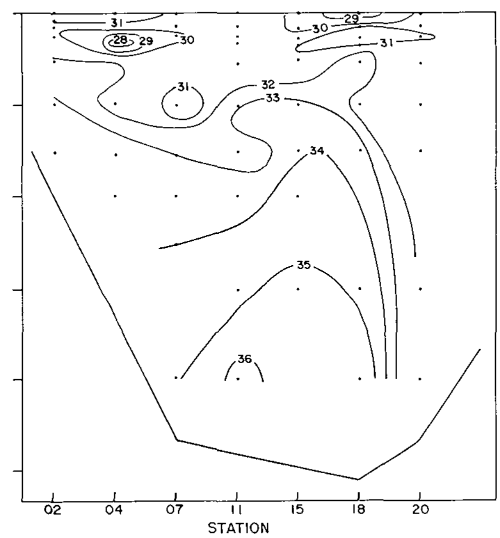

Fig. 7 North - South intersection of nitrate concentrations (μ M).

tia Sea. Moreover some organic compounds, the so - called growth stimulating consitituents are receiving increasing attention to explain the fluctuations of primary production in antarctic waters. Major nutrients (nitrate and phosphate) which were found high concentrations during the period of this study were not seemed to be limiting factors for primary productions in the study area. Furthermore, no distinct difference in nitrate and phosphate concentrations was found between the central Maxwell Bay and Marian Cove. As a consequence, the trace elements and the growth stimulating organic compounds could be candidates to explain the higher primary productivity in Maxwell Bay than Marian Cove. Unfortunately the analyses of trace elements and growth stimulating organic compounds have not been carried out during austral summer in 1988-89.

We can not give too much emphasis on the effect of light for primary production especially in antarctic waters.

Continuous daylight for the half of a year and perpetual darkness for another half of a year is typical light conditions of polar regions. Moreover incident light is affected by surface condition of the water, suspended solids contents and presence of ice covers on sea surface. In addition, the importance of euphotic depth was frequently raised to explain the outbursts of phytoplanktons in marine environment. If most of phytoplankton populations exist in a water mass below euphotic zone by vigorous turbulence, the productivity of the watermass can not be high due to the lack of incident light.

Another important factor which has great influence on primary production is the stability of surface water. High stability favors the maintenance of phytoplankton population in a zone of favorable light intensity Strong surface wind causes turbulence of surface water which destroys the stability of the water mass in a relatively short time

The study area is a semi-enclosed waterbody with 15km long 4km wide and has characteristics of a fjord with a narrow and steep coastling. The difference in local wind speeds

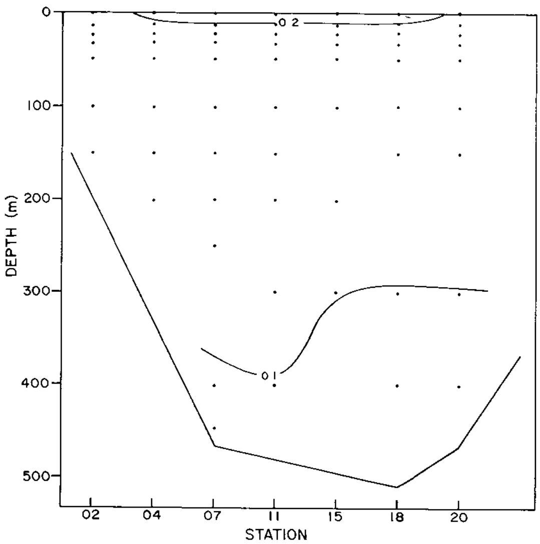

Fig. 8 North - South nitersection of intrite concentrations (μ M).

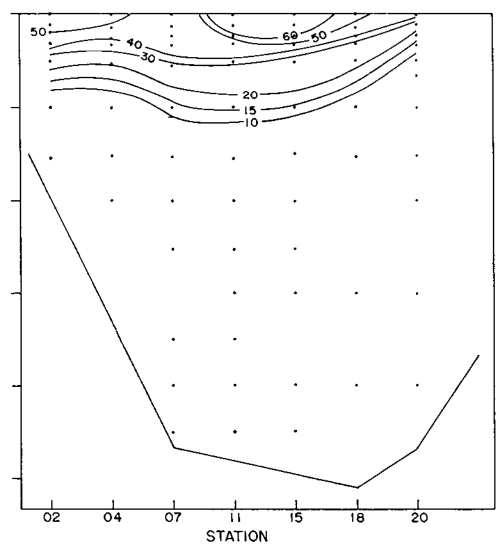

Fig. 9 North - South intersection of chlorophyll - *a* concentrations.

between Maxwell Bay and Marian Cove is not likely to be great due to the relatively short distance(10km) between two areas. Consequently wind-driven turbulence itself is not a major cause of the difference in primary productivity between the central Maxwell Bay and Marian Cove. Rather, since the strong wind with the average velocity of 20-30 knots is very common in the study area, the perpetual turbulence of surface water prevents settling of suspended solids. Sometimes, extremly strong wind can cause even the resuspension of bottom sediment.

This phenomenon is frequently observed by the scientists in the King Sejong Station. This is also evidenced by abundant appearance of benthic diatom (34.4% of total phytoplankton) from the water samples in Marian Cove than the central Maxwell Bay (< 9.5% of total phytoplankton) (KORDI, 1989). Surface wind works effectively for the resuspension of suspended solids and bottom sediment in Marian Cove due to its shallow depth (30-100 m) and narrow width (1 km) comparing to the central Maxwell Bay (500 m deep and 4 km wide). As a result, the euphotic depth of the central Maxwell Bay is much deeper than Marian Cove. The secchi disk depth in the study area was 2.5 m and 1.2 m for the central Maxwell Bay and Marian Cove, respectively. This difference between two area is probably not only due to shallow depth of Marian Cove but also much more frequent input of ice carried suspended solids in Marian Cove from adjacent glaciers.

Besides the abiotic factors such as light and stability of water mass, grazing by herbivore is one of the most important biotic factor to limit the size of the phytoplankton standing crop. In Marian Cove, cyclopoid copepods occupies more than 80% of total zooplankton and very few other zooplankton were found. In contrast, the central Maxwell Bay showed much more diverse composition of zooplankton (KORDI, 1989). Furthermore, the biomass of the herbivores in the central Maxwell Bay (47,000-67,000 ind./m^3) was more than double than that of Marian Cove (24,360 ind./m^3)(KORDI, 1989). Fecal pellets are the most common materials collected in sediment traps and sediment flux can be thought as a good index for the grazing pressure by herbivores in a water column. During the austral summer, sediment flux of Maxwell Bay(47-72 g/m²/d) is greater than that of Marian Cove(33-58 g/m²/d) (KORDI, 1989).

As described perviously, the depth of euphotic zone is suggested one of the most important factors to explain the difference in primary productivity between the central Maxwell Bay and Marian Cove. Marian Cove has low primary productivity due to shallow euphotic depth, caused by suspended solids by strong winds and ice carried debris, which probably brings low biomass of phytoplankton and consequently low occurrence of zooplankton. In contrast, the central Maxwell Bay has higher primary productivity than Marian Cove due to the deeper euphotic zone, which provides greater biomass of phytoplankton and zooplankton.

2) Importance of Nannoplankton as a primary producer in Marian Cove

The importance nannoplankton fraction in the total production tells us meaningful information to draw a basic scheme of a food chain or foodweb. In this study, the central Marian Cove and the central Maxwell Bay showed 74% and 34% of nannofraction from total primary productivity, respectively.

On the basis of the above fact, following hypothesis is established: the central Maxwell Bay has high chlorophyll-*a* content and high primary productivity, which was mostly produced by net plankton. In contrast, the central Marian Cove showed low chlorophyll-*a* content and low primary productivity indebted mostly to mannoplankton. In addition, the central Maxwell Bay have high assimilation number (defined as primary productivity per unit chlorophyll-*a* content), while the central Marian Cove showed low assimilation number (Table 1).

These two water masses, even though they separate only 10 km away, might have structural difference in their food chains or foodwebs. Maxwell Bay, with high chlorophyll-*a* content and high turnover rate (assimilation number), probably have abundant net plankton which are consumed by larger zooplankton. The large zooplankton are seemed to be foraged by thousands of penguins inhabit in their adjacent rookery. The micronutrient such as vitamins or some growth stimulating substances for algae could be supplied from the abundant excretes in the rookery.

In contrast, Marian Cove, with its low

Table 1. Comparison of the Central Maxwell Bay and Marian Cove

	Primary Productivity (g/m²/d)	Chlorophyll Content (artificial unit)	Relative Assimilation Number *	Nannofraction in Total Primary Productivity(%)	Zooplankton Biomass ** (Ind./m³)
Central Maxwell Bay	0.30	60	1.5	74	47,000 ~ 67,000
Marian Cove	0.14	40	1.0	24	24,360

*Assimilation number is defined as primary productivity per unit chlorophyll Content.
Herein, relative assimilation number of the Central Maxwell Bay to Marian Cove is presented.

**Data from KORDI (1989)

chlorophyll-*a* content, low assimilation number and low primary production, are characterized by importance of nannoplankton as a basis of food chain. This finding could be explained as that nannoplankton was grazed by microzooplankton and followed to macrozooplankton.

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