Korean Journal of Polar Research 11(1): 19-26

Photosynthetic Parameters of Phytoplankton Assemblages in the Surface Water of Maxwell Bay and the Weddell Sea during the 1996/97 Austral Summer

Kyung Ho Chung*, Sung-Ho Kang, Jae-Shin Kang, SangHoon Lee, and Dong-Yup Kim

Polar Sciences Laboratory, Korea Ocean Research and Development Institute, Ansan P.O. Box 29, Seoul 425-600, Korea

ABSTRACT. Photosynthetic parameters (P_m, α, β and I_m) were estimated from the relationship between photosynthesis (P) and irradiance (I) for natural phytoplankton assemblages in the surface water of Maxwell Bay and the Weddell Sea in order to understand regional photosynthetic characteristics between Antarctic coastal waters and deep pelagic waters during the 1996/97 austral summer. P_m values of the Weddell Sea were generally lower than Maxwell Bay, and it is likely to be associated with low temperature in the Weddell Sea. On the other hand, relatively high α and β values and low I_m values were observed at Maxwell Bay. These results indicate that phytoplankton assemblages in the surface waters of Maxwell Bay were more efficiently adapted to lower light intensity and have higher susceptibility to inhibition than that of the Weddell Sea. However, the variations of photosynthetic parameters in relation to environmental factors at each region were negligible.

Key Words: Photosynthetic parameters, phytopankton assemblages, inorganic nutrients.

Introduction

The Antarctic Ocean is characterized by the strong variations in light conditions, consistently low water temperatures, high ambient inorganic nutrient concentrations, and formation and melting of sea ice throughout the year. The combination of these factors has led to control both the seasonal and the regional distribution of Antarctic phytoplankton. Therefore, the pattern of photosynthesis by phytoplankton in Antarctic Ocean could differ from phytoplankton in temperate and tropical regions. Antarctic phytoplankton have been subjected to diel and seasonal variations in incident radiation, with nearly continuous darkness in winter alternating with continuous light in summer (Holm-Hansen, 1985; Rivkin & Putt, 1987; Tilzer & Dubinsky, 1987). In addition, ice cover reduces the amount and quality of light entering the water column, which serves as one of the major factors controlling primary production (Eicken, 1992; Smetacek *et al.*, 1992). Temperature in Antarctic waters is low but constant, and biological responses to low temperature have been investigated for several Antarctic marine phytoplankton. The primary production in Antactic surface water is limited by temperature effect on metabolic reactions (Neori & Holm-Hansen, 1982; Tilzer *et al.*, 1986; Tilzer & Dubinsky, 1987). Inorganic nutrient concentrations are relatively high and do not represent a limiting factor (Jacques, 1983; Sakshaug & Holm-Hansen, 1984). Despite high concentration of nutrients, phytoplankton biomass and primary production are known to be low (Priddle *et al.*, 1986; Holm-Hansen & Mitchell, 1991).

During summer time, on the other hand, Antarctic coastal waters are influenced by tide, local wind, meltwater from glaciers, icebergs and snow,

*corresponding author (khchung@kordi.re.kr)

enriched by essential nutrients from land. Thus the variability of these environmental factors may play a role in growth of coastal phytoplankton assemblages (Klöser *et al.*, 1993; Brandini & Rebello, 1994; Kang *et al.*, 1997b). In the deep pelagic water near Antarctic Peninsula, the growth of phytoplankton assemblages was closely related to the water column stability induced by input of meltwater from the retreating sea-ice and glaciers (Park *et al.*, 1999). For these reasons, it was expected that the structure and function of coastal phytoplankton assemblages in habitable environment could differ from those of deep pelagic water.

In this study, we focus primarily on regional photosynthetic characteristics between Antarctic coastal and deep pelagic water ecosystem. For this purpose, environmental factors, such as physical properties (temperature, salinity), inorganic nutrients, chlorophyll-a and photosynthetic parameters (P_m, α, β and I_m) for phytoplankton assemblages in the surface water of Maxwell Bay and Weddell Sea were measured simultaneously during the 1996/1997 austral summer. It is expected that photosynthetic parameters derived from photosynthesis-irradiance curves can be used as an important biological parameter to detect the photosynthetic characteristics relating to environmental factor (Perry *et al.*, 1981; Marra & Heinemann, 1982).

Materials and Methods

This study was conducted at 4 stations located from head to mouth in Maxwell Bay (Fig. 1), and 4 stations located in the northern part of marginal ice zone (MIZ) in the Weddell Sea (Fig. 2) during the 1996/97 austral summer, as part of the 10th Korea

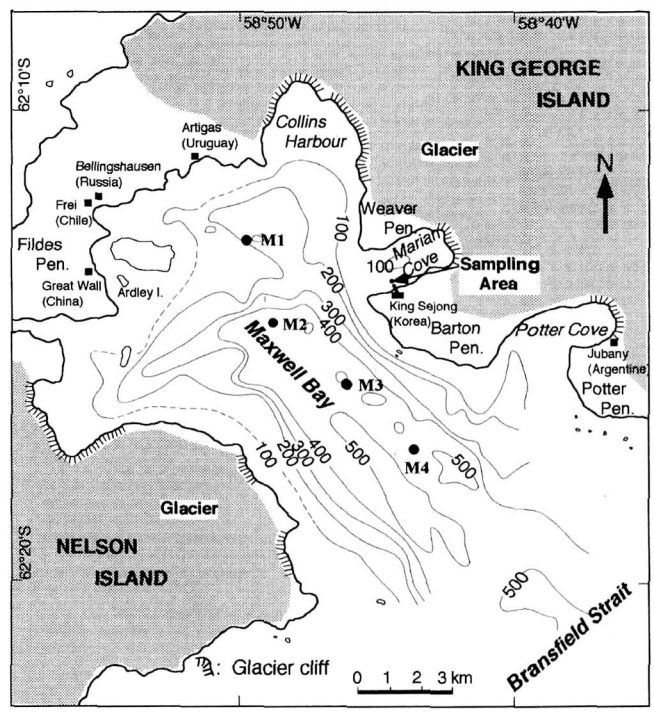

Fig. 1. Location of the surface water sampling in Maxwell Bay

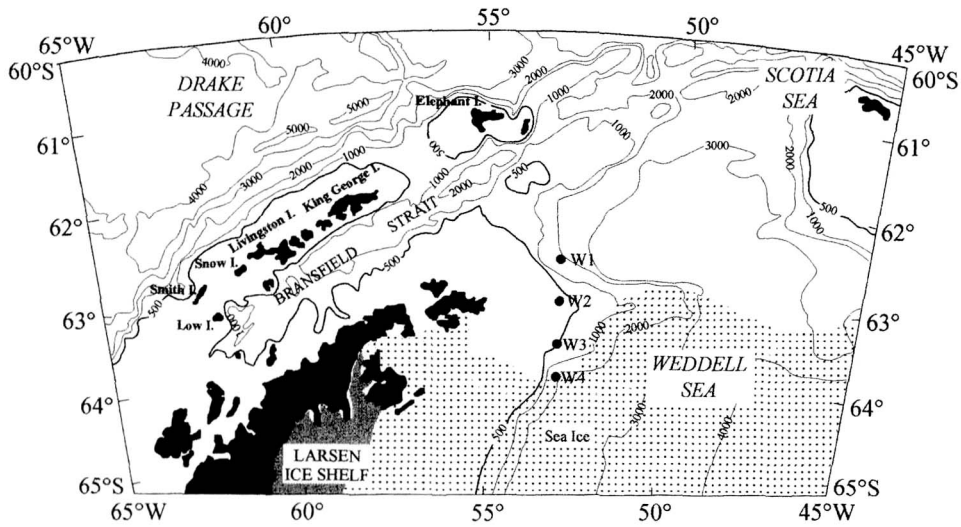

Fig. 2. Location of the surface water sampling in the Weddell Sea

Antarctic Research Program (KARP).

Physical properties (temperature and salinity) of the surface water were measured with the Sea-Bird conductivity-temperature-depth (CTD) profiler.

For inorganic nutrients (nitrate, phosphate and silicate), 200 ml of seawater sample were filtered through Whatmann GF/F glass fiber filter, and the filtrates were stored frozen in acid cleaned polyethylene bottles at −45°C. The samples were kept frozen with dry ice during transport to KORDI. Later in the lab, inorganic nutrients determinations were carried out by means of a Lachat QuickChem AE autoanalyzer according to Parsons *et al.* (1984).

Chlorophyll-a was determined by filtration of 500 ml of seawater sample through Whatmann GF/F glass fiber filters. Filters were extracted in 90% acetone and storaged a refrigerator for 24 hrs. Their extracts were determined by the spectrophotometric method according to Parsons *et al.* (1984).

Primary production was measured using the ^{14}C method. Surface water samples were collected with 5 liter PVC Niskin bottle, screened through a 200 μm net, and immediately filled into 250 ml acid-washed polycarbonate bottles. Each bottle was inoculated with 5μCi $NaH^{14}CO_3$ (Du Pont Inc.). Samples were incubated on the deck for 2-4 hours under perforated nickel screen simulating 100, 50, 32, 15, 3, 1% and 0% of surface PAR (photosynthetically available radiation). Incubation system consists of 20 liter transparent acrylic bath. Bath was held at ambient temperature by circulating surface seawater and adding crushed ice when necessary. Incident PAR was continuously recorded by LiCOR photometer and measurements were made in the same positions as the incubation system. After incubation, each sample was filtered onto a Whatmann GF/F glass fiber filter under low vacuum, and rinsed with filtered ambient seawater. Filters were fumed with concentration HCl for 10 minutes in a desiccator and placed scintillation vials with 20 ml Lumac LSC cocktail. Incorporated radioactive carbon activity was measured later in the laboratory with a liquid scintillation counter (Packard-Tricarb Co.). Quenching was determined by the external standard method.

The P versus I curves were generated by mathematical adjustment of data relative to the ^{14}C-bicarbonate assimilation by phytoplankton cell as a function of irradiance, using the equations of Platt et al. (1980).

$$P_m = Ps \cdot (1 - \exp(-\alpha \cdot I/Ps)) \cdot \exp(-\beta \cdot I/Ps)$$

In this equation, P_m is the maximum specific production rate at light saturation (mgC·mg Chl-a^{-1}·h^{-1}), i.e., assimilation number, α is the initial slope of P-I curve (mgC·mg Chl-a^{-1}·h^{-1}[100μE·m^{-2}·sec^{-1}]$^{-1}$), β is the negative slope of P-I curve (mgC·mg Chl-a^{-1}·h^{-1}[100 μE·m^{-2}·sec^{-1}]$^{-1}$), i.e., photoinhibition parameter and I_m is the irradiance optimal for photosynthesis (x100 μE·m^{-2}·sec^{-1}).

Results and Discussion

Hydrography, inorganic nutrients, chlorophyll-a

Temperature of surface water in Maxwell Bay ranged from 1.1°C at central part of bay to 1.4°C at the mouth of bay. Salinity was recorded 33.7 PSU in all stations (Table 1) in spite of increased local flow of freshwater from melting snow and ice. In the Weddell Sea, temperature ranged from −1.1 to −0.6°C and salinity ranged from 34.1 to 34.4 PSU (Table 1). Temperature and salinity gradually decreased from the northern part toward marginal sea-ice zone (MIZ). This indicated that the MIZ was strongly affected by influence of ice melting water from glacier, resulting in the lowest salinity and temperature at St. W4. Based on the distributions of temperature and salinity, consequently, surface waters in Maxwell Bay were characterized by high temperature (>1.0°C) and low salinity (<34.0 PSU). On the contrary, surface waters of the Weddell Sea were characterized by low temperature (<−0.6°C) and high salinity (>34.0 PSU).

The concentrations of chlorophyll-*a* showed marked contrast between two study areas (Table 1). Chlorophyll-*a* in Maxwell Bay generally exceeded 2.0 mg·m^{-3} and higher values were obtained at the mouth of bay. In the Weddell Sea, chlorophyll-*a* con-

Table 1. Spatial variations in environmental factors in the surface water of Maxwell Bay and the Weddell Sea.

Study area	Station	Temp. (°C)	Sal. (PSU)	Chl-*a* ($mg \cdot m^{-3}$)	Nitrate (μM)	Phosphate (μM)	Silicate (μM)
Maxwell Bay	M1	1.3	33.7	2.1	27.02	1.92	65.59
	M2	1.1	33.7	2.0	25.49	1.93	66.61
	M3	1.2	33.7	2.6	27.05	1.56	57.21
	M4	1.4	33.7	2.4	24.62	1.73	63.12
	Avg.	1.3	33.7	2.3	26.05	1.79	63.13
	S.D.	0.1	0.0	0.3	1.20	0.18	4.21
Weddell Sea	W1	− 0.6	34.3	0.7	25.33	2.40	72.25
	W2	− 0.8	34.4	0.7	26.91	2.54	78.15
	W3	− 1.0	34.4	0.7	25.63	2.51	75.40
	W4	− 1.1	34.1	15.3	16.86	1.69	64.00
	Avg.	− 0.9	34.3	4.3	23.68	2.29	72.45
	S.D.	0.2	0.1	7.3	4.60	0.40	6.13

Avg. = Average value
S.D. = Standard deviation

centrations showed less than 1.0 $mg \cdot m^{-3}$ except in St.W4. The highest chlorophyll-*a* concentration (15.28 $mg \cdot m^{-3}$) was observed in St.W4. It indicated that phytoplankton bloom developed at surface water of MIZ due to the stabilization of water mass, increased light intensity through water column and high nutrients supply during the austral summer.

Surface concentrations of nitrate, phosphate and silicate in Maxwell Bay ranged from 24.62 to 27.05 μM, 1.56 to 1.93 μM, and 57.21 to 66.61 μM, respectively. In the Weddell Sea, ranged from 16.86 to 26.91 μM, 1.69 to 2.54 μM, and 64.00 to 78.15 μM, respectively (Table 1). The lowest nutrient concentrations were found in St. W4 in the Weddell Sea and it was attributed to active uptake by phytoplankton assemblages during blooming. However, concentrations of inorganic nutrients in both regions, except in St.W4, were high and believed to be sufficient for phytoplankton to sustain the maximum growth rate in Antarctic water.

Photosynthetic parameters

The photosynthesis-irradiance curves and photosynthetic parameters are given in Figs. 3 and 4 and listed in Table 2.

P_m values, the maximum specific production rate at light saturation, ranged from 0.79 to 1.01 mgC·mg chl-$a^{-1} \cdot hr^{-1}$ with an average of 0.88 ± 0.10mgC·mg chl-$a^{-1} \cdot hr^{-1}$ in Maxwell Bay and ranged from 0.46 to 0.99 mgC·mg chl-$a^{-1} \cdot hr^{-1}$ with an average of 0.69 ± 0.22 mgC·mg chl-$a^{-1} \cdot hr^{-1}$ in the Wedell Sea. On average, the P_m values of both regions we obtained revealed relatively less difference but generally lower in the Weddell Sea. It is considered that phytoplankton assemblages in surface water of the Weddell Sea have comparatively lower metabolic processes, which were attributed to lower temperature level than Maxwell Bay.

α values, the initial slope of P-I curve, ranged from 1.81 to 2.14 mgC·mgchl-$a^{-1} \cdot hr^{-1}$ (100 $\mu E \cdot m^{-2} \cdot sec^{-1})^{-1}$ with an average of 1.97 ± 0.18 mgC·mgchl-$a^{-1} \cdot hr^{-1}$(100 $\mu E \cdot m^{-2} \cdot sec^{-1})^{-1}$ in Maxwell Bay, ranged from 1.19 to 2.57 mgC·mgchl-$a^{-1} \cdot hr^{-1}$(100 $\mu E \cdot m^{-2} \cdot sec^{-1})^{-1}$ with an average of 1.62 ± 0.65 mgC·mgchl-$a^{-1} \cdot hr^{-1}$(100 $\mu E \cdot m^{-2} \cdot sec^{-1})^{-1}$ in the Weddell Sea. Average α values of Maxwell Bay were also higher than those of the Weddell Sea, and it means that phytoplankton assemblages in Maxwell Bay have higher photo-

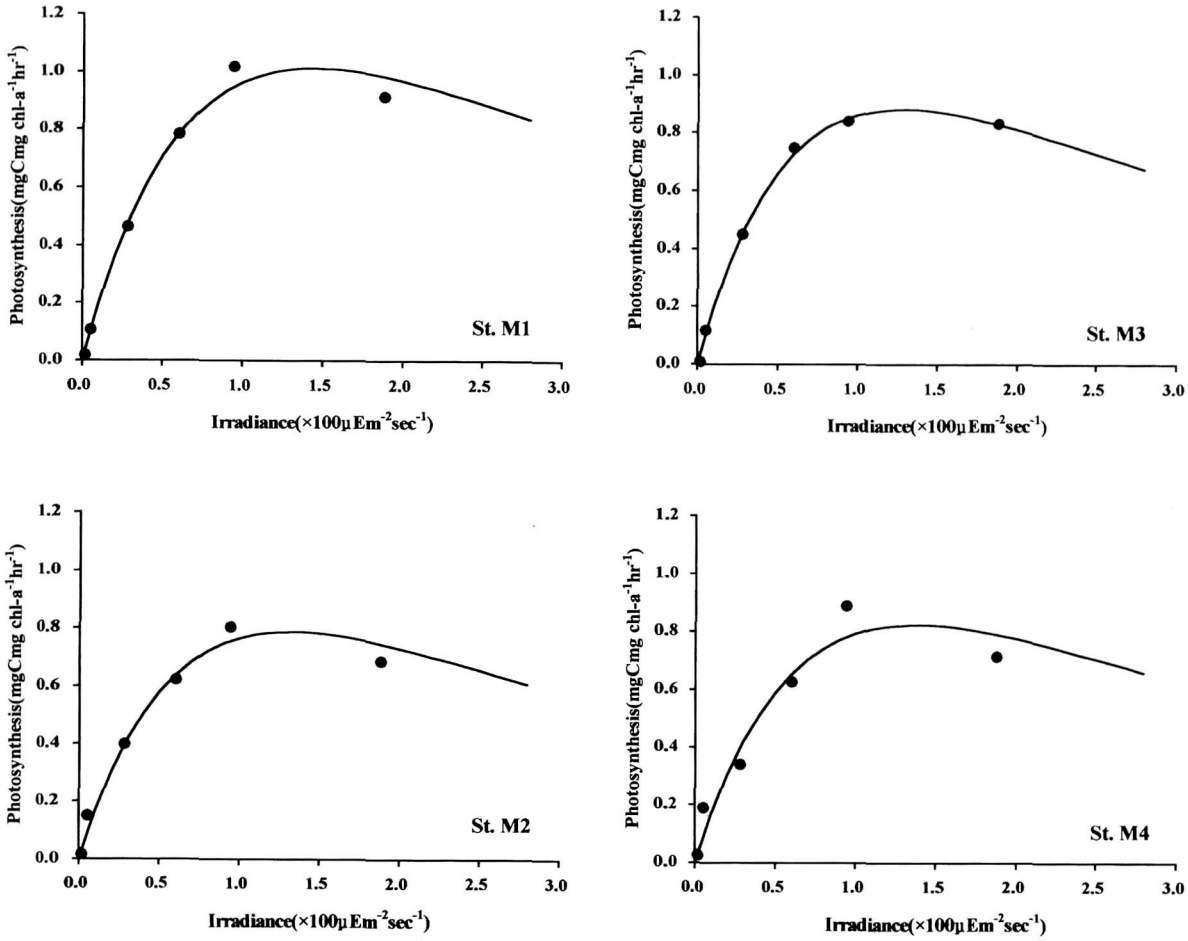

Fig. 3. Photosynthesis-irradiance curves obtained with phytoplankton assemblages in the surface waters of Maxwell Bay

chemical reaction rate, i.e., higher efficient in capturing light and fixing carbon in low light intensity than in the Weddell Sea. During the austral summer, surface water of Maxwell Bay showed high turbidity due to high concentration of suspended particulate matter (SPM), which originated from terrigenous input and reworking of SPM in bottom sediment by tide and local wind (Yoon & Park, 1996, Kang *et al.*, 1997a). We also observed high concentration of SPM above 30 mg·l^{-1} in all stations during study period. For this reason, phytoplankton assemblages in surface water of Maxwell Bay should have been experienced low light conditions, and thus more efficiently responsible for the low light intensity for saturated photosynthesis. Cabrera and Montecino (1990) reported that higher α values might be attributed to phytoplankton from less illuminated zone. On the contrary, phytoplankton assemblages in the Weddell Sea were exposed to relatively higher light intensity because downwelling irradiance increased through water column while water mass was stabilized. Therefore, they should have lower photochemical reaction rate to low light intensity than in Maxwell Bay. These results were also explained by differences of I_m values between both regions.

I_m values, the irradiance optimal for photosynthesis, ranged from 1.28 to 1.44 × 100 μE·m^{-2}·sec^{-1} with an average of 1.36 ± 0.07 × 100 μE·m^{-2}·sec^{-1} in Maxwell Bay, and ranged from 1.70 to 2.35 × 100 μE·m^{-2}·sec^{-1} with an average of 1.97 ± 0.30 × 100 μE·m^{-2}·sec^{-1} in the Weddell Sea. I_m values, on average, in the Weddell Sea were generally higher than in Maxwell Bay. It means that maximum specific production for phytoplankton assemblages in the Weddell Sea was occurred in higher light intensity than that of Maxwell Bay. Despite of regional difference of α and I_m values between both regions, how-

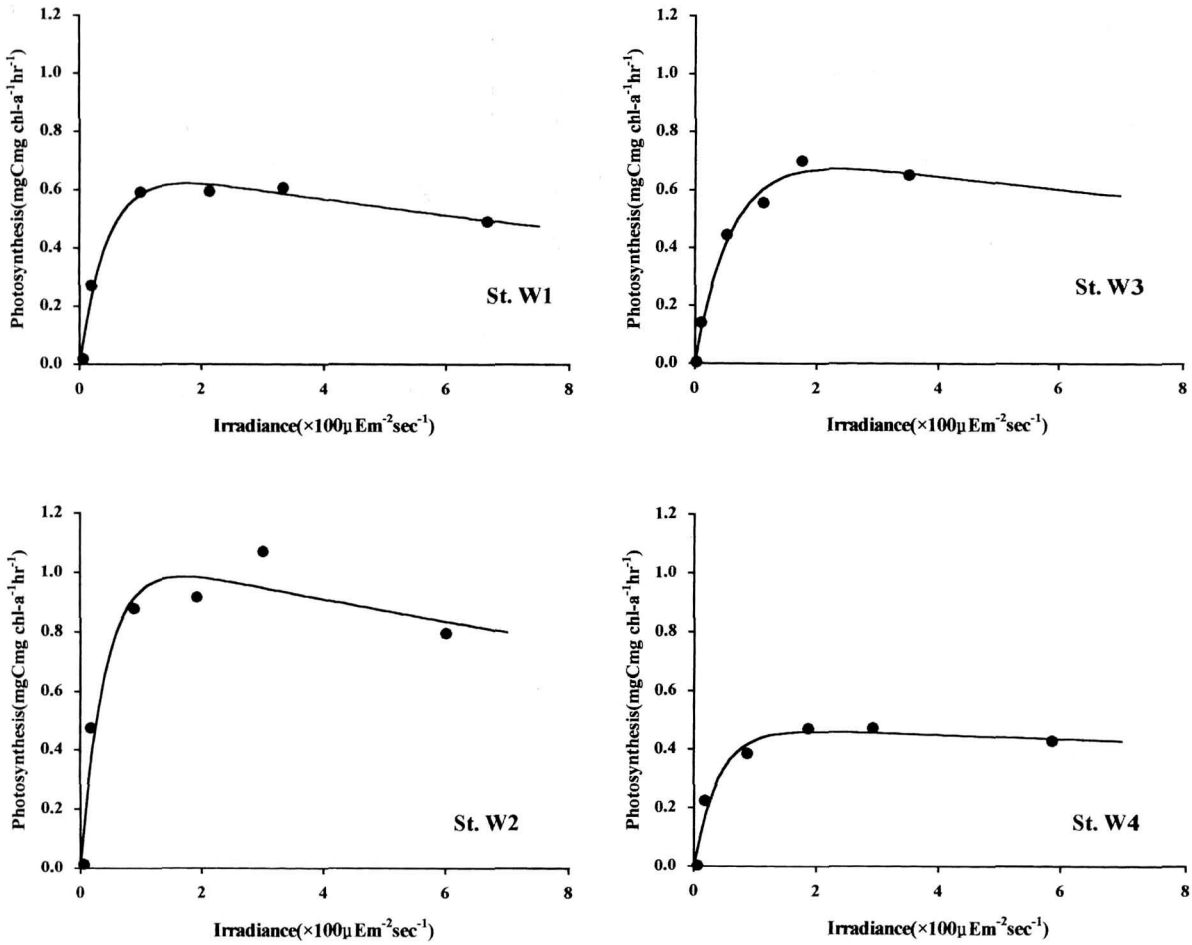

Fig. 4. Photosynthesis-irradiance curves obtained with phytoplankton assemblages in the surface waters of the Weddell Sea

ever, most Antarctic phytoplankton were adapted to low light conditions and considered to be shade-adapted generally.

On the other hand, β values, the negative slope of P-I curve, ranged from 0.17 to 0.43 mgC·mgchl-*a* $^{-1}$·hr^{-1}(100 μE·m^{-2}·sec^{-1})$^{-1}$ with an average of 0.36 ± 0.03 mgC·mgchl-*a*$^{-1}$·hr^{-1}(100 μE·m^{-2}·sec^{-1})$^{-1}$ in Maxwell Bay, ranged from 0.01 to 0.05 mgC·mgchl-*a* $^{-1}$·hr^{-1}(100 μE·m^{-2}·sec^{-1})$^{-1}$ with an average of 0.03 ± 0.02 mgC·mgchl-*a*$^{-1}$·hr^{-1}(100 μE·m^{-2}·sec^{-1})$^{-1}$ in the Weddell Sea. The average β value in Maxwell Bay was higher than in the Weddell Sea. The average β value is higher in low light adapted phytoplankton assemblages with the expectation of increased susceptibility to inhibition but photoinhibition in the Weddell Sea was negligible.

In addition, we found that benthic diatoms such as *Fragilaria striatula*, *Licmophora belgicae*, and *Pseudogomphonema kamchaticum* dominated in nearshore, and planktonic diatoms such as *Thalassiosira antarctica*, and *Corethron criophilum* were dominated in central part of Maxwell Bay during the same study period. Unfortunately, compositions of phytoplankton species in the Weddell Sea could not identified. However, it is well reported that open water species and Prymnesiophyte *Phaeocystis antarctica* in gelatinous colonial stage dominated the phytoplankton stock in the Weddell Sea (Hayes *et al.*, 1984, Fryxell and Kendrick, 1988, Kang *et al.*, 1995). Therefore, it is also considered that composition of phytoplankton species was one of variable factor which affected on the differences of photosynthetic parameters between both regions although we could not research the photosynthetic characteristics of these phytoplankon species at the species level.

On the other hand, in order to find relationship between photosynthetic parameters and environmental factors in each region we have used pearson

Table 2. Photosynthetic parameters calculated from photosynthesis-irradiance curves for phytoplankton in the surface water of Maxwell Bay and the Weddell Sea. P_m in uints of mgC·mg chl-a^{-1}·hr^{-1}; α in units of mgC·mgchl-a^{-1}·hr^{-1}(100 μE·m^{-2}·sec^{-1})$^{-1}$; β in units of mgC·mgchl-a^{-1}·hr^{-1}(100 μE·m^{-2}·sec^{-1})$^{-1}$; I_m in units of × 100 μE·m^{-2}·sec^{-1}

Study area	Station	Temp. (°C)	P-I parameters								Chl-*a* (mg·m^{-3})
			P_m	α	β	P_s	I_m	I_s	I_k	I_b	
Maxwell Bay	M1	1.3	1.01	2.14	0.17	1.79	1.44	0.84	0.47	3.85	2.1
	M2	1.1	0.79	1.81	0.42	1.43	1.32	0.79	0.44	3.39	2.0
	M3	1.2	0.88	2.12	0.43	1.53	1.28	0.72	0.42	3.52	2.6
	M4	1.4	0.83	1.81	0.41	1.49	1.38	0.82	0.46	3.60	2.4
	Avg.	1.3	0.88	1.97	0.36	1.56	1.36	0.79	0.45	3.59	2.3
	S.D.	0.1	0.10	0.18	0.03	0.16	0.07	0.05	0.02	0.19	0.3
Weddell Sea	W1	− 0.6	0.62	1.48	0.04	0.70	1.77	0.47	0.42	19.62	0.7
	W2	− 0.8	0.99	2.57	0.05	1.08	1.70	0.42	0.38	23.41	0.7
	W3	− 1.0	0.67	1.22	0.03	0.75	2.35	0.61	0.55	27.93	0.7
	W4	− 1.1	0.46	1.19	0.01	0.48	2.05	0.40	0.39	66.26	15.3
	Avg.	− 0.9	0.69	1.62	0.03	0.75	1.97	0.48	0.44	34.31	4.4
	S.D.	0.2	0.22	0.65	0.02	0.25	0.30	0.09	0.08	21.57	7.3

Avg. = Average value
S.D. = Standard deviation

correlation matrix. Unfortunately we can not find any significant correlation between them. Simply, inorganic nutrients were negatively correlated with concentration of chlorophyll-a in each region. This result can be explained by the fact that spatial difference of environmental factors between stations in each region was too small to induce the distinct spatial difference of photosynthetic parameters in relation to environmental factors. In other words, temperature difference between stations was below 0.3°C in Maxwell Bay, and below 0.5°C in the Weddell Sea. Inorganic nutrient concentrations and other environmental factors also showed a little variation between stations. Thus, photosynthetic parameters of phytoplankton assemblages of surface waters in each region could not show the distinct patterns relating to their environmental factors, although the production process within any ecosystem is controlled by environmental factors affecting metabolic rates. Therefore, it is considered that the variations of photosynthetic parameters measured in each region during study period might to be closely related to changes in the structure of phytoplankton assemblages, not environmental factors, because of this study dealt with a day phenomenon, which was shortened time scale. Harrison and Platt (1986) also reported that the variation of photosynthetic parameters such as P_m, and α were related to changes in the community structure when the time scale were shortened to day-to-day values.

Consequently, although the variations of photosynthetic parameters in relation to environmental factors between stations in each region were not clear, differences of photosynthetic parameters between both regions were basically evident due to the differential adaptation of phytoplankton assemblages to the distinct temperature level, water stability, and light regimes within their habitat.

References

Brandini, F. P. and J. Rebello, 1994. Wind field effect on hydrography and chlorophyll dynamics in the coastal pelagial of Admiralty Bay, King George Island, Antactica. Antarct. Sci., 6:433-442.

Cabrera, S. and V. Montecino, 1990. Photosynthetic parame-

ters of the entire euphotic phytoplankton of the Bransfield Strait, summer 1985. Polar Biol., 10:507-513.

Eicken, H., 1992. The role of sea ice in structuring Antarctic ecosystems. Pol. Biol., 12:3-13.

Fryxell, G. A. and G. A. Kendrick, 1988. Austral spring microalgae across the Weddell Sea ice edge: spatial relationships found along a northward transect during AMERIEZ 83. Deep-Sea. Res., 35:1-20

Harrison. W. G. and T. Platt, 1986. Photosynthesis-irradiance relationship in polar and temperate phytoplankton population. Polar. Biol., 5:153-164.

Hayes, P.K., T.M. Whitaker, T. M. and G. E. Fogg, 1984. The distribution and nutrient status of phytoplankton in the Southern Ocean between 20° and 70° W. Pol. Biol., 3:153-165.

Holm-Hansen, O., 1985. Nutrient cycles in Antarctic marine ecosystem. In Siegfried, W. R., P. R. Condy and R. M. Laws(ed). Antarctic nutrient cycles and food webs. Springer-Verlag, New York, pp 6-11.

Holm-Hansen, O. and B. G. Mitchell, 1991. Spatial and temporal distribution of phytoplankton and primary production in the western Bransfield Strait region. Deep-Sea Res., 38: 961-980.

Jacques, G., 1983. Some ecophysiological aspects of the Antarctic phytoplankton. Polar. Biol., 2:27-33.

Kang, S. H., S. H. Lee, M. Y. Lee, K. H. Chung, 1995. Phaeocystis-dominated Antarctic phytoplankton assemblage at the marginal sea-ice zone of the northwestern Weddell Sea, January, 1994. The studies on natural environment and conservation of Antarctica. KORDI. 1st report. p. 435-499.

Kang, S. H., J. S. Kang, K. H. Chung, M.Y. Lee, B. Y. lee, H. S. Chung, Y. D. Kim and D. Y. Kim, 1997a. Seasonal variation of nearshore Antartic microalgae and environmental factors in Marian Cove, King George Island, 1996. Korean J. Polar Res., 8:9-27.

Kang, J. S., S. H. Kang, J. H. Lee, K. H. Chung and M. Y. Lee, 1997b. Antarctic micro- and nano-phytoplankton assemblages in the surface water of Maxwell Bay during an austral summer, 1997. Korean J. Polar Res., 8:35-45.

Klöser, H., G. Ferreyra, I. Schloss, G. Mercuri, F. Laturnus and A. Curtosi, 1993. Seasonal variation of algal growth conditions in sheltered Antarctic bays: The example of Potter Cove(King George Island, South Shetlands). J. Mar. Sys., 4:289-301.

Marra, J. and D. Heinemann, 1982. Photosynthesis response by phytolankton to sunlight variability. Limnol. Oceanogr., 27:1141-1153

Neori, A. and O. Holm-Hansen, 1982. Effect of temperature on rate of photosynthesis in Antarctic phytoplankton. Polar. Biol., 1:33-38.

Park, M. G., S. R. Yang, S.H. Kang, K. H. Chung and J. H. Shim, 1999. Phytoplankton biomass and primary production in the marginal ice zone of the northwestern Weddell Sea during austral summer. Polar. Biol., 21: 251-261

Parsons, T. R., Y. Maita and C. M. Lalli, 1984. A manual of chemical and biological methods for seawater analysis. Pergamon Press. p.177

Perry, M. J., M. C. Talbot and R. S. Albert, 1981. Photoadaptation in marine` phytoplankton: response of the photosynthetic unit. Mar. Biol., 62:91-101.

Platt, T., C. L. Gallegos and W. G. Harrison, 1980. Photoinhibition of photosynthesis in natural assemblages of marine phytoplankton. J. Mar. Res., 38:687-701.

Priddle, J., I. Hawes, J. C. Ellis-Evans and T. J. Smith, 1986. Antarctic aquatic ecosytems as habitats for phytoplankton. Biol., Rev(61): 199-238

Rivkin, R. B. and M. Putt, 1987. Photosynthesis and cell division by Antarctic microalgae: comparison of benthic, planktonic and ice algae. J. Phycol. 23:223-229.

Sakshaug, E. and O. Holm-Hansen, 1984. Factors governing pelagic production in polar oceans. In: Holm-Hansen O.(ed) Lecture notes on coastal and estuarine studies, Springer, Berlin Heidelberg, New York, pp 1-18.

Smetacek, V., R. Scharek, LI. Gordon, H. Eicken, E. Fahrbach, G, Rohardt and S. Moore, 1992. Early spring phytoplankton blooms in ice platelet layers of the southern Weddell Sea. Antarctica. Deep-Sea. Res., 39:153-168.

Tilzer, M. M., M. Elbrachter, W. W. Gieskes and B. Beese, 1986. Light-temperature interactions in the control of photosynthesis in Antarctic phytoplankton. Polar Biol., 5:105-111.

Tilzer, M. M. and Z. Dubinsky, 1987. Effects of temperature and daylength on the mass balance of Antarctic phytoplankton. Polar Biol., 7:35-42.

Yoon, H. I., and B. K. Park, 1996. Distribution and dispersal pattern of suspended particulate matter in Maxwell Bay and its tributary, Marian Cove, in the South Shetland Islands, Antarctica. The studies on natural environment and conservation of Antarctica. KORDI. 3rd report. p.133-160.

Received 6 April 2000

Accepted 10 May 2000