Korean J. Limnol. 34 (4): 267~276 (2001)

Primary Productivity of Phytoplankton at the Eutrophic down Reach of a Regulated River (the Han River, Korea)

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The downstream reach of the Han River adjoining Seoul in Korea was the upper boundary of an estuary where tidal effect on the flow rate could be exerted. According to the comprehensive river regulation project, the river was channelized and impounded by two overflow dams, which provided favorable condition for algal growth in this sewage polluted eutrophic reach. In this study primary productivity of phytoplankton was measured in the down reach and the autochthonous and allochthonous organic carbon loadings were estimated. Primary production of phytoplankton measured by C-14 uptake and P-I model method ranged from 140 to 4,890 mgC m^{-2} d^{-1} (median value 1,865 mgC m^{-2} d^{-1}) showing the level of eutrophic lakes. Phytoplankton density that varied according to water flow rate was highest in spring. Allochthonous organic carbon loading was dominated by sewage input through tributaries in most of days except flood flow period. The average proportion of autochthonous carbon generation by phytoplankton was 40.9%, which is very high proportion for a lotic habitat.

Key words : Primary production, Phytoplankton, Autochthonous organic carbon, Eutrophic river, Han River

INTRODUCTION

In general, phytoplankton growth is limited by water velocity and light availability in streams (Wetzel, 1983; Harris, 1986; Lambert and Sommer, 1997). But as the order of streams increase, the reduction of water velocity and the increase of nutrients enhance the growth and the primary production of phytoplankton (Wetzel, 1983; Harris, 1986; Lambert and Sommer, 1997). Impoundments and channelization further provide favorable condition for excessive algal growth.

Recently, many lotic ecosystems have been transformed into lentic ecosystem by the construction of dams to exploit freshwater resources in Korea. The Han River system is the most regulated river with a number of dams constructed in the upstream area, by which the ecosystem of the Han River was changed from lotic to a series of lentic habitats. The downstream reach of the Han River adjoining Seoul was the upper boundary of an estuary where tidal effect on the flow rate could be exerted. However, according to the comprehensive river regulation project, the river was deepened and impounded by two overflow dikes in order to keep stable water level facilitating water intake and sightseeing cruise, which provided favorable condition for algal growth in this sewage-polluted eutrophic reach.

Dynamics of the phytoplankton community and primary productivity in rivers have been investigated by many researchers and the general patterns could be deduced (Wetzel, 1983; Harris,

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1986; Descy, 1993; Sorokin and Sorokin, 1996; Wolfstein *et al*., 2000). Also, in Korea some studies on plankton reported high standing crop of phytoplankton in the Han River (Kim and Lee, 1999) and the Nakdong River (Ha *et al*., 1998; Kim and Joo, 2000), though primary productivity has been less examined. It is a general rule that the energy source in river ecosystems is terrestrial input. However, phytoplankton flourishes in eutrophic down reach of the Han River. Hence we examined primary production of phytoplankton as a possible major source of organic energy in the Han River, Korea.

MATERIALS AND METHODS

Study sites and period

The study area was the lower reach of the Han River from Paldang Dam to Haengju Bridge (Sta. S11) with length of 47.9 km and water surface area of 36.9 km^2 (Fig. 1). In this area two overflow water dikes were constructed near the Jamsil Bridge (Sta. S3) and near the Haengju Bridge (Sta. S11). Water quality and primary productivity of phytoplankton were measured at eleven stations (Sta. S1–Sta. S11 at Fig. 1). Allochthonous organic carbon loading from the watershed was surveyed at one mainstream site (Sta. S1) and seven tributary sites. Eight surveys were conducted from June 1993 to May 1994 to cover all seasons.

Water analysis

Water samples were collected at the 50 cm below surface at each station and transported to laboratory within a few hours. Underwater light intensity was determined using a submersible photometer (Li – Cor Li – 188B). The vertical light attenuation coefficient was determined from the logarithmic plot of light intensity. Water samples for nutrients analysis were preserved by the addition of sulfuric acid to pH 2. Total phosphorus was determined by ascorbic acid method after decomposing sample by persulfate digestion method (APHA, 1992). Total nitrogen was determined by autoanalyzer (SKALAR 5100) employing cadmium reduction column after decomposing sample by persulfate digestion method (APHA, 1992). Adequate aliquots of sample were filtered through Whatman GF/C filters and the filter papers were kept frozen for chlorophyll analysis. Filters for chlorophyll *a* analysis were ground in a tissue homogenizer with 6 mL of 90% acetone and centrifuged to remove turbidity. Concentrations of chlorophyll *a* were determined by spectrophotometric method (Lorenzen, 1967).

Photosynthesis – irradiance parameters

The photosynthesis–irradiance (P–I) relationship has been used to understand the physiological and ecological characteristics of phytoplankton in lakes. The parameters of initial slope (α), photoinhibition coefficient (β) and assimilation

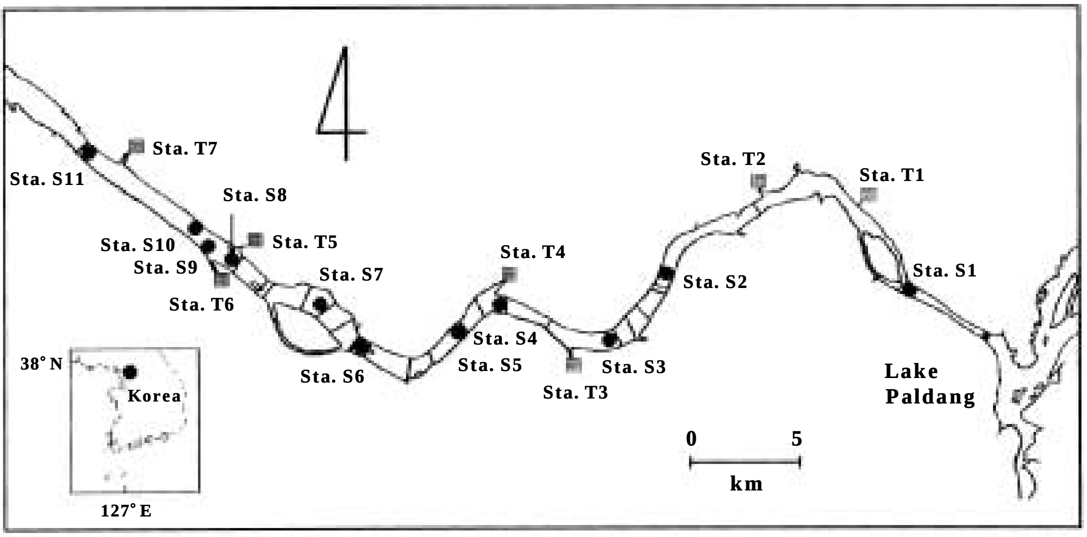

Fig. 1. Map showing sampling sites in the Han River, Korea.

number (AN) were calculated according to P−I curve model by Platt *et al.* (1980):

$$P = Ps \cdot (1 - e^{-\alpha I/Ps}) \cdot e^{-\beta I/Ps}$$

where P (mgC m^{-3} hr^{-1}) is photosynthetic rate, Ps (mgC m^{-3} hr^{-1}) is maximum potential photosynthetic rate, if there were no photoinhibition, α (gC m^2 $gChl^{-1}$ E^{-1}) is initial slope, β (gC m^2 $gChl^{-1}$ E^{-1}) is photoinhibition coefficient, and I (μE m^{-2} sec^{-1}) is light intensity.

Primary productivity and autochthonous organic carbon

Primary productivity of phytoplankton was calculated from the measurement of P−I curves and simulation of underwater light environment (Platt *et al.*, 1980; Kim and Kim, 1989). Photosynthetic rates were measured by C−14 method. Incubation of samples of Sta. S3 and Sta. S7 was performed at eight light gradients, including a dark condition, to obtain the P−I parameters. Samples of the other sites were incubated at three light intensities around optimum light intensity of 300 μE m^{-2} s^{-1} to measure the maximum photosynthetic rate. Primary productivity at the sites where P−I curves were not measured was calculated by using the P−I parameters of Sta. S3 or Sta. S7. Sodium bicarbonate solution of 1.25 microcurie C−14 was added to each 50 mL incubation bottle filled with sample water. At the end of incubation, bottles were transferred to a dark box and filtered immediately. Filters were acid−fumed for an hour to remove remaining inorganic carbonates, and immersed in 10 mL of scintillation cocktail. Activities of fixed C−14 were measured by Packard Scintillation Counter. Total CO_2 concentration was calculated from the alkalinity measured by Gran titration method (Gran, 1952) and dissociation factors that depend on water temperature and pH (Wetzel and Likens, 1991). Average autochthonous carbon loading of a season was obtained from the season average primary productivity (mgC m^{-2} day^{-1}) at each segment multiplied by the surface area of each segment.

Allochthonous organic carbon

Inflow rate of the mainstream were obtained from the monthly average of discharge from Lake Paldang. Inflow rate and chemical oxygen demand (COD) of major tributaries referred to the data of the report, 'A study on the Han River' (Seoul City, 1994). COD in oxygen unit (mgO_2 L^{-1}) was converted into carbon unit (mgC L^{-1}). COD concentrations were divided by the decomposition efficiency of organic matter in COD analysis, 0.9 (Shin and Kim, 1986), and multiplied by molecular weight ratio of C/O_2 (12/32). Allochthonous carbon loading was calculated from the inflow rates multiplied by the concentrations of organic carbon.

RESULTS AND DISCUSSION

Physical parameters

The sum of inflow rate of seven tributary streams varied from 28 to 80 m^3 sec^{-1}. The discharge from Lake Paldang ranged from 100 to 200 m^3 sec^{-1} during dry season, while it was elevated to 1,622 m^3 sec^{-1} during rainy season (Fig. 2). The ratio of inflow rate from tributary streams to mainstream showed to be 1 : 3 during dry season, but the ratio greatly increased to 1 : 25 in rainy season. Annual discharge from Lake Paldang contributed 89% of total water flow in this study period.

Water temperature at the downstream sampling sites was higher than the upstream sampling stations, but the difference between the stations was usually less than 0.6°C (Table 1). Light extinction coefficient was higher in summer (1.8 m^{-1}) than other seasons (1.4 or 1.5 m^{-1}) because of larger amount of turbid matter discharge in rainy season.

Nutrients and chlorophyll *a*

Total phosphorus (TP) concentrations varied

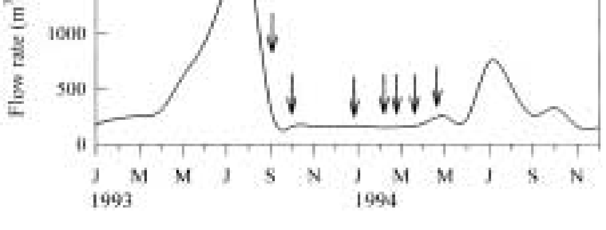

Fig. 2. Variation of inflow rate from Lake Paldang in the Han River, Korea. The arrows indicate sampling dates.

Table 1. Means and standard deviations of water temperature, light extinction coefficient, chlorophyll *a*, TP and TN concentrations in the Han River, Korea.

	Summer 1993 (n = 22)	Autumn 1993 (n = 11)	Winter 1994 (n = 33)	Spring 1994 (n = 22)
Temp. (°C)	21.5 ± 0.6	8.2 ± 0.2	2.9 ± 0.4	17.1 ± 0.5
Light (m^{-1})	1.8 ± 0.2	1.5 ± 0.3	1.5 ± 0.1	1.4 ± 0.2
Chl.*a* ($\mu g\ L^{-1}$)	3.5 ± 0.8	9.1 ± 6.7	36.4 ± 5.2	17.3 ± 5.7
TP ($mg\ m^{-3}$)	75.7 ± 56.9	70.3 ± 36.9	14.5 ± 10.9	735.0 ± 302.0
TN ($mg\ L^{-1}$)	3.3 ± 0.7	3.1 ± 1.0	3.9 ± 1.7	3.5 ± 1.4

greatly seasonally (Table 1). The mean concentration was high in spring (735.0 mg m^{-3}), while it was low in winter (14.5 mg m^{-3}). Sta. S1 showed the lowest TP concentration among the stations, and TP increased at Sta. S4 and Sta. S5. TP at the downstream site S6 was near 60 mg m^{-3} with less variation. This indicates that water quality of tributary streams (Sta. T3–Sta. T7) caused large increase of TP at the stations below Sta. S4.

Total nitrogen (TN) concentrations were near 3.5 mg L^{-1} with less seasonal variation than TP (Table 1). As river flow from Sta. S1 toward Sta. S11, TN became higher. TP and TN showed lower concentration in summer when the flow rate is high. Generally, in Korea the concentrations of river phosphorus in upstream area are higher in summer because of storm runoff from non-point sources laden with high phosphorus (Heo *et al.*, 1992; Lee *et al.*, 1993; Heo *et al.*, 1998). However, in highly populated downstream area nutrients concentration is lower in rainy season due to the dilution of sewage by storm runoff, as is the case of the Han River in this study.

Chlorophyll *a* concentrations varied between 2.6 and 50.2 μg L^{-1} with higher concentration in winter and lower in summer (Table 1). Reducing of chlorophyll *a* concentrations was consistent with higher flow rate and higher elevated light extinction coefficient (Table 1). Lower phytoplankton density can be expected in summer due to higher flow rate in Korean streams. However, in the Nakdong River, algal blooms occur in some dry summer (Kim *et al.*, 1996). In 1994 we had drought in summer, and the chlorophyll *a* concentration at the downstream of the Nakdong River increased from 7.0 ~ 27.6 μg L^{-1} in May to 33.0 ~ 223.0 μg L^{-1} in August, when cyanobacterial blooms were stimulated by warmer and stagnant water.

Chlorophyll *a* concentration in this study was greatly dependent on the water flow rate that varied between 150 $m^3\ sec^{-1}$ and 1,622 $m^3\ sec^{-1}$ (Fig. 3). Chlorophyll *a* decreased down to <10 μg L^{-1} at high water flow. Spearman Rank Correlation showed negative correlation between chlorophyll *a* and flow rate ($n = 82$, $r^2 = -0.78$, $P < 0.0001$). Therefore it can be concluded that discharge of Lake Paldang was an important controlling factor determining chlorophyll *a* in rainy season. Similar relationship with flow rate had been reported in Kainji Lake of Nigeria where during the flood, light transparency was low and phytoplankton production was low correspondingly (Karlman, 1982). Smith and Demaster (1996) reported that phytoplankton photosynthesis influenced by river flow appeared to be limited by low levels of available irradiance in Amazon River. High oscillation of discharge may bring also variations of phytoplankton structure. Also it had been reported that the biomass and community composition of phytoplankton were controlled by river discharge in the estuary of San Francisco Bay (Cloern *et al.*, 1983) and in the Aliakmon River of Greece (Montesanto and Tryfon, 1999). During this study periods, cyanobacterial blooms were not observed, although

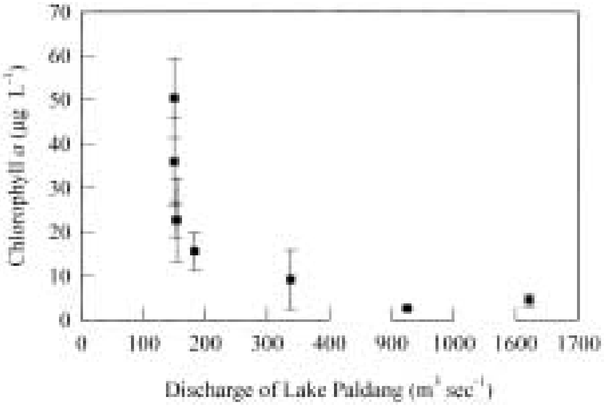

Fig. 3. Average chlorophyll *a* concentration of the Han River, Korea, as a function of discharge (n = 82).

Table 2. Initial slope (α), photoinhibition coefficient (β), assimilation number (AN) and light saturation value (I_k) of P–I curves at Sta. S3 and Sta. S7 (mean ± SD) from 1993 to 1994 in the Han River, Korea.

	α (gC m^2 $gChl^{-1}$ E^{-1})		β (gC m^2 $gChl^{-1}$ E^{-1})		AN (gC $gChl^{-1}$ hr^{-1})		I_k (μE m^{-2} sec^{-1})	
	Sta. S3	Sta. S7	Sta. S3	Sta. S7	Sta. S3	Sta. S7	Sta. S3	Sta. S7
Summer (n = 2)	23.5 ± 1.8	17.1 ± 5.3	0.569 ± 0.268	0.558 ± 0.372	15.0 ± 3.1	11.7 ± 5.6	176 ± 24	180 ± 36
Autumn (n = 1)	19.0	15.7	0.340	0.411	13.9	10.5	203	186
Winter (n = 3)	20.7 ± 6.2	17.1 ± 7.4	0.571 ± 0.271	0.634 ± 0.348	8.6 ± 1.9	9.7 ± 4.4	118 ± 13	156 ± 4
Spring (n = 2)	19.0 ± 6.1	22.0 ± 6.7	0.474 ± 0.143	0.499 ± 0.159	12.5 ± 2.9	18.7 ± 7.8	218 ± 112	227 ± 29

phytoplankton standing crop was high. Six phytoplankton groups −Bacillariophyceae, Chlorophyceae, Cyanobacteria, Dinophyceae, Cryptophyceae and Euglenophyceae− were represented (Seoul city, 1994). *Aulacoseira granulata* was dominant in summer (49.9% of the total cell density). In autumn, *Aulacoseira granulata* and *Cryptomonas ovata* co−occurred (35.0 and 41.6%, respectively). *Stephanodiscus hantzschii* and *Cyclotella* sp. dominated during winter (95.1%) and spring (69.1%), respectively.

Parameters of P−I curve model

Table 2 shows means and standard deviations of the P−I parameters at Sta. S3 and S7. Maximum photosynthetic rate (Pmax) was highest in winter and spring and was lowest in summer (Fig. 4). Pmax had its maximum in the end of February (521 and 703 mgC m^{-3} hr^{-1} at Sta. S3 and Sta. S7, respectively). Correlations between chlorophyll *a* and Pmax were highly positive ($n = 71$, $r^2 = 0.65$, $P < 0.001$), implying productivity is primarily determined by biomass as reported in Lake Soyang (Hwang, 1996).

Initial slope (α) of P−I curves at Sta. S3 and Sta. S7 showed similar range (Fig. 4). Initial slope was much higher than other reports from lakes, which implies phytoplankton in the Han River is suffering limitation of light because the variation of initial slope is thought to be the result of adaptation of algae to light availability. Harrison *et al*. (1985) reported initial slopes ranging 0.039 to 0.056 gC m^2 $gChl^{-1}$ hr^{-1} w^{-1} in two arctic and one temperate marine surveys, corresponding to 2.4 and 3.4 gC m^2 $gChl^{-1}$ E^{-1}. The variation of α in this study did not show significant seasonal variation pattern that was observed in a temperate lake (Kim and Kim, 1989).

Photoinhibition coefficient (β) ranged 0.340 ∼ 0.571 gC m^2 $gChl^{-1}$ E^{-1} and 0.411 ∼ 0.634 gC m^2 $gChl^{-1}$ E^{-1} at Sta. S3 and Sta. S7, respectively (Fig. 4). β can vary with species composition of phytoplankton and underwater light availability associated with light penetration and surface mixing depth. In this study β showed the seasonal trend that it was higher in winter than in autumn ($P < 0.05$). Hwang (1996) reported in Lake Soyang that β was measured 0.001 ∼ 0.10 gC m^2 $gChl^{-1}$ E^{-1} from April to September, then was elevated 0.05 ∼ 2.0 gC m^2 $gChl^{-1}$ E^{-1} from October to March, coinciding with the increase of mixing depth. In Lake Paldang, β had been reported to show a maximum of 0.69 gC m^2 $gChl^{-1}$ E^{-1} in August and minimum of 0.08 in May (Han *et al*., 1999). Transparency of 1.0 m in August and 1.5 m in May was attributed to the seasonal difference of β. Kim and Kim (1989) reported that β was much higher in autumn, which is thought to be caused by the adaptation of phytoplankton to low light intensity due to high turbidity.

Assimilation number (AN) is the photosynthetic rate per unit amount of chlorophyll *a* at the optimum light intensity that reflects overall efficiency of photosynthesis determined by temperature and nutrients concentration. In this study it varied between 8.6 and 15.0 gC $gChl^{-1}$ hr^{-1} at Sta. S3, and between 9.7 and 18.7 gC $gChl^{-1}$ hr^{-1} at Sta. S7 (Fig. 4). But AN did not show significant seasonal pattern. Hwang (1996) reported in Lake Soyang that AN was high in summer and low in cold seasons, which coincided with variations of temperature and phosphorus concentrations in lake water. In Lake Paldang, AN reached a maximum of 20.5 gC $gChl^{-1}$ hr^{-1} in August, then decreased to 11.3 gC $gChl^{-1}$ hr^{-1} in October (Han *et al*., 1999).

I_k, the light intensity at the intersection of an extension from the initial slope of P−I curves and Pmax, is often cited as a measure of light−adaptation. I_k showed significant variation between seasons, which was the highest in spring and the lowest in winter ($P < 0.05$). Hwang (1996) reported in Lake Soyang that I_k varied from 79 to 128 μE

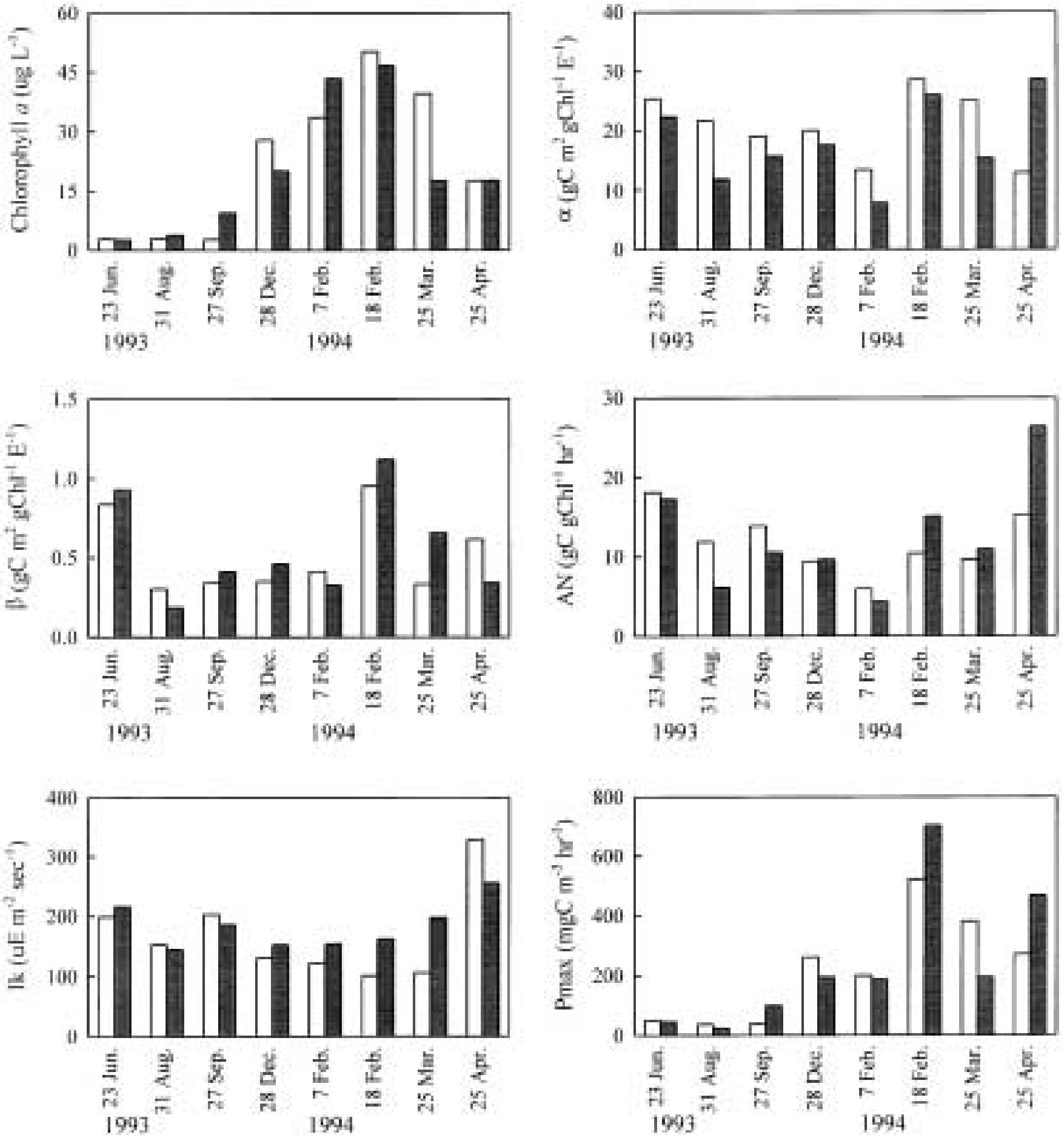

Fig. 4. Chlorophyll *a* concentraions, maximum phytosynthetic rate and P–I parameters (α, β, AN and Ik) at Sta. S3 (open bars) and Sta. S7 (shaded bars) in the Han River, Korea.

m^{-2} sec^{-1}, and it was higher in summer than in winter. Wolfstein *et al.* (2000) reported in the bay of Meldorf of the German Wadden Sea that I_k was low in spring (40 μE m^{-2} sec^{-1}) and increased towards summer (140 μE m^{-2} sec^{-1}).

Primary production of phytoplankton

Primary productivity of phytoplankton varied between 140 and 4,890 mgC m^{-2} day^{-1} (Fig. 5). Productivity was maximum at Sta. S3 and Sta. S4 with mean of 3,366 and 3,079 mgC m^{-2} day^{-1}, respectively, and it was lower at Sta. S1 and Sta. S11. The seasonal variations of productivity were very high. While productivity was low consistently, about 500 mgC m^{-2} day^{-1} in summer, it was elevated up to 1,000 mgC m^{-2} day^{-1} in autumn at the downstream sites of Sta. S6. In winter, productivity increased substantially to about 3,000 mgC m^{-2} day^{-1} at all sites except for Sta. S1. And productivity was maintained high up to 2,000 mgC m^{-2} day^{-1} at the upstream sites of Sta. S6 in spring.

Primary productivity of phytoplankton gene-

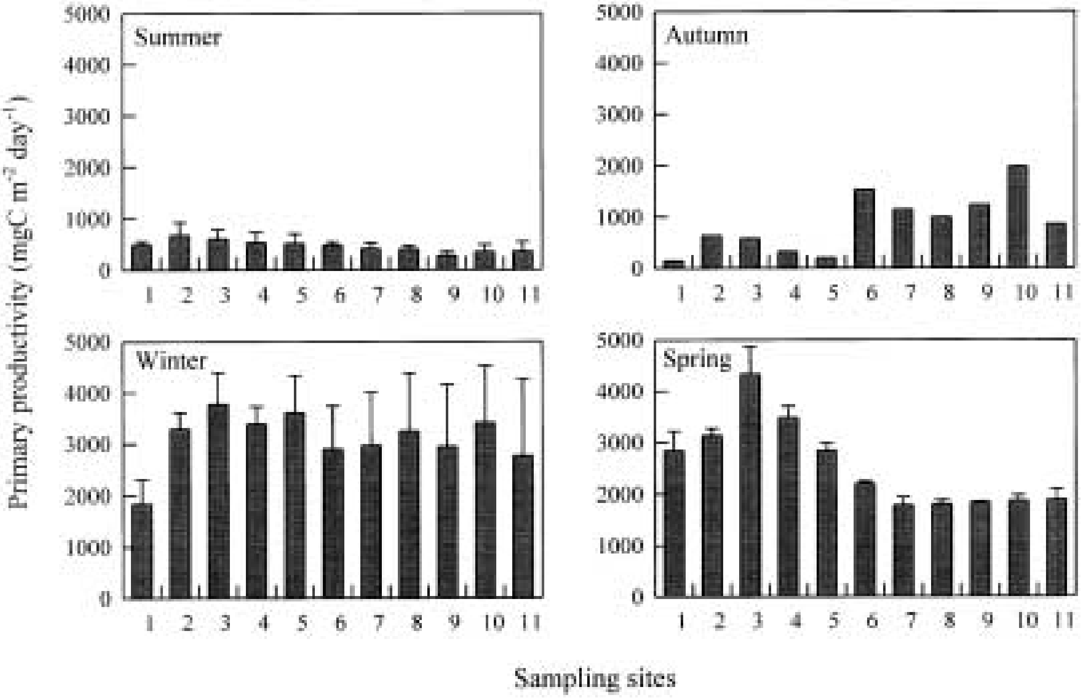

Fig. 5. Primary productivity of phytoplankton (mean ± SD) in the Han River.

rally increases with eutrophication (Likens, 1975; Wetzel, 1983). Typical productivity in oligotrophic, mesotrophic and eutrophic lakes range between 50 ~ 300, 250 ~ 1,000 and more than 600 mgC m^{-2} day^{-1}, respectively (Likens, 1975). In the Han River, high productivity in the seasons except for summer is typical of eutrophy to according to the classification scheme of Likens (1975). This indicates that high nutrients concentrations and low water velocity lead to eutrophication in the Han River (Table 1; Fig. 3; Fig. 5). Similar results have been recorded in the lower part of the Nakdong River. Estuarine dam was constructed at the Nakdong River mouth resulting in the increase of nutrients concentrations and stagnation of water body, and then it caused cyanobacterial blooms in a source of drinking water (Kwon, 1991; Ha *et al.*, 1998). High primary productivity of 1,000 mgC m^{-2} day^{-1} was reported in estuarine reservoir of the Youngsan River and the Kum River, too (Kim *et al.*, 1997b).

Even though the Han River is a lotic habitat, trophic state was similar to that of domestic large reservoirs, such as Lake Daechung, Lake Okjong and Lake Hapchon, from the point of high productivity all the year round (Hwang *et al.*, 1994; Kim *et al.*, 1997a; Kim *et al.*, 1998). Primary productivity was reported in the reservoirs located on the Han River as follows. In Lake Soyang, it was 141 ~ 1,156 mgC m^{-2} day^{-1} in 1995 ~ 1997 (Kim *et al.*, 2000b) and 255 ~ 828 mgC m^{-2} day^{-1} in 1998 ~ 1999 (Kim *et al.*, 2000a). In Lake Euiam, it was 1,293 mgC m^{-2} day^{-1} in 1993 ~ 1994 (Kim *et al.*, 1997b). In Lake Paldang, it was measured 1,000 ~ 2,000 mgC m^{-2} day^{-1} in 1993 ~ 1994 (Kim *et al.*, 1995) and 8,195 ~ 9,341 mgC m^{-2} day^{-1} in August 1992 (Han *et al.*, 1999). As rivers flow toward the lower part of the river from reservoirs located in upstream, productivity increased gradually. Growth of phytoplankton was likely to controlled by wash out and light transparency during stormy season in the Han River (Fig. 3).

Contribution of phytoplankton to organic carbon loading

Organic carbon loading by phytoplankton was from 18 to 112 tC day^{-1} (Table 3). It was higher in winter and spring when phytoplankton standing crop was higher (Fig. 5). Carbon loading from main stream varied from 15 to 195 tC day^{-1}, while organic matter discharge from tributaries show-

Table 3. The organic carbon loading from each source from 1993 to 1994 in the Han River, Korea. Within the parentheses are a percentage of each source.

	Autochthonous	Allochthonous		Total loading tC day^{-1}
	Phytoplankton tC day^{-1} (%)	Mainstream tC day^{-1} (%)	Tributary tC day^{-1} (%)	
Summer	18 (6.9)	195 (74.4)	49 (18.7)	26
Autumn	29 (22.0)	15 (11.3)	88 (66.7)	132
Winter	112 (56.6)	20 (10.1)	66 (33.3)	198
Spring	101 (44.1)	52 (22.7)	76 (33.2)	229
Mean	(32.4) (40.9)*	(29.6) (14.7)*	(38.0) (44.4)*	

*indicates calculation excluding data of summer season.

ed less variation ranging from 49 to 88 tC day^{-1}.

Phytoplankton production contributed average 32.4% of total carbon loading (Table 3). Contribution of allochthonous loading to total carbon loading was 67.6% with the contribution of main streams and tributaries of 29.6% and 38.0%, respectively. Kim *et al*. (1996) reported that contribution of primary production to total carbon loading was 49% in the Nakdong River that is high level, considering it was a lotic ecosystem. Discharge during flood period must be exclude in the calculation of relative organic carbon contribution because hydraulic residence time is very short during flash flood period and discharged material is just washed away to the sea without affecting ecosystem of the river itself. Even in large reservoirs such as Lake Soyang storm runoff laden with high concentrations of organic carbon and phosphorus just pass through the intermediate layer of stratified ecosystem (Kim *et al*. 2000b). If flood flow period is exclude from the loading calculation in the Han River, contribution of phytoplankton to total carbon loading become higher to 40.9%, while contribution of allochthonous loading become lower to 59.1% (main stream and major tributaries were 14.7% and 44.4%, respectively).

In conclusion, it can be concluded that primary productivity of phytoplankton in the downstream reach of the Han River is as high as eutrophic lentic habitats. Average 40.9% of organic carbon loading was contributed by phytoplankton production, which implies the necessity of additional processes for algal control in order to reduce organic matter pollution in the Han River. In addition to organic carbon removal from sewage as the primary target of water quality management nutrients control or flow rate control would be needed to further improve water quality in the downstream of Han river.

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(Received 1 Nov. 2001, Manuscript accepted 5 Dec. 2001)

＜**국문적요**＞

부영양한 한강하류수역에서 식물플랑크톤의 1차생산

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수도권의 중심부를 가로지르는 한강의 하류수역은 조수의 영향을 받을 수 있는 하구의 상단부에 위치해 있다. 한강 하류수역은 한강종합개발사업의 일환으로 이루어진 준설과 수중보 건설에 의해서 강물이 정체되었으며, 또한 지천으로부터 유입되는 많은 오염물질에 의해서 식물플랑크톤의 대량 발생을 촉진할 수 있는 환경으로 변화되었다. 본 연구에서는 부영양한 한강 하류수역에서 식물플랑크톤의 1차생산을 측정하였으며, 더불어 내부생성유기물과 외부기원유기물을 산정하였다. 1차생산력은 C-14 uptake법과 P-I 모델법으로 측정하였다. 1차생산력의 범위는 140～4,890 mgC m^{-2} day^{-1} (중앙값 1,865 mgC m^{-2} day^{-1})이었으며, 국내의 부영양한 호수와 유사한 수준이었다. 식물플랑크톤의 생물량 변동은 봄철에 최대치를 보였으며, 유량의 변화와 관련이 있는 것으로 나타났다. 외부기원유기물은 여름철 홍수기를 제외한 연중 내내 지천을 통하여 유입되는 오염물질에 의해서 좌우되었다. 총 유기물 부하량에 대하여 식물플랑크톤의 1차생산이 차지하는 기여도는 40.9%로서, 유수 생태계로서는 높은 수준이었다.