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The Limnological Survey of a Coastal Lagoon in Korea (4); Lake Songji

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Physicochemical parameters, plankton community structure, and sediment were surveyed from 1988 to 2002, at two months interval, in a eutrophic coastal lagoon (Lake Songji, Korea). The lake basin is separated from the sea by a narrow sand dune, and a shallow sill divides the lake basin into two sub-basins. The stable stratifications and chemoclines are maintained all through the year at 1-2 m depth. DO was often very low (<1 $mgO_2 \cdot L^{-1}$) in the monimolimnion. Secchi disc transparency was in the range of 0.5-2.7 m. TP, TN, and Chl. *a* concentration in the mixolimnion were 0.015-0.396 $mgP \cdot L^{-1}$, 0.223-3.521 $mgN \cdot L^{-1}$, and 0.5-129.8 $mg \cdot m^{-3}$, respectively. TSI was in the eutrophic range of 54 to 62. Sediment was composed of silt and coarse silt. COD, TP, and TN content of the sediment were 51.4-116.9 $mgO_2 \cdot gdw^{-1}$, 0.04-1.46 $mgP \cdot gdw^{-1}$ and 0.12-1.03 $mgN \cdot gdw^{-1}$, respectively. The 49 phytoplankton species were identified. The maximum phytoplankton abundance obscured the lake in September 2001 (max. density: 23,350 $cells \cdot mL^{-1}$). The Chlorophyte *Schroederia judayi* was dominant species in summer (max. density: 20,417 $cells \cdot mL^{-1}$). The lake showed unique limnological features of a brackish lagoon in respect to biological community, chemical characteristics, and physical phenomena.

Key words : Lake Songji, brackish lagoon, trophic state, chemocline

INTRODUCTION

The brackish lagoon in the eastern coastal part of S. Korea was generated by sand dunes. Salinity was generally higher due to the slow velocity of inflowing fresh water and frequent intrusion of seawater thus, greatly affecting the macrofauna (Cho *et al*., 1975). Due to the poor flushing conditions, the salinity was over 0.5‰, and thus enabled to categorize the water body as brackish water (Horne, 1994). Well-developed aquatic plants were found in the littoral zone due to the demoted water exchange. The lagoon's brackish water has distinct functional properties and is characteristically different from the freshwater and seawater (Heo *et al*., 1999; Kwon, 2002; Hung, 2003). Serious dystrophic condition resulted in the stagnant anaerobic hypolimnion was uninterrupted due to the formation of stratification (Pretus, 1989). Due to the shallow depths, wind is an important mixing factor in the brackish lagoons despite the formation of stratification (Smith, 1990; Arfi *et al*., 1993).

Estuaries and coastal lagoons (estuarine environments) are typical transitional ecosystems

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between land and sea, where seawater is mixed with fresh water. It is well known that estuarine environments are very valuable ecosystems because of their unique ecological functions and geographical features, as well as socioeconomic values. In lagoons, a unique ecological interaction is found as organisms of brackish water, seawater and freshwater coexists (Wonju Regional Environmental Office, 1997).

A narrow sill divides Lake Songji into southern and northern part. Lake Songji has the surface area of 0.563 km^2 and the shoreline length of 5,560 m (Ministry of Environment, 2002). In comparison with other lagoons in the eastern coastal areas of Korea, Lake Songji has fairly preserved aquatic flora and water quality. However, the mountain fire has destroyed the terrestrial ecosystem of the drainage area. In the study of "Evaluation of eutrophication of lagoons in the eastern coast of Korea" Heo *et al.* (1999) showed that most of lagoons of Korea are hyper−eutrophic.

Earlier researches on Lake Songji were mostly done for short period and were primarily motivated towards collecting basic data of fisheries (Cho *et al.*, 1975, Kim *et al.*, 1981 and Pyen, 1984). The southern part of Lake Songji yielded an average of about 100 tons per year of Corbiculidae (general name: Asian Clam) (Ministry of Environment, 2002). The fish catch composed of both salt−water fishes such as mullet, dace, as well as fresh water fishes such as carp and crucian.

Lake Songji serves as an important stopover for migratory birds and is a habitat for endangered birds such as Whooper Swan (*Cygnus*) and Steller's Sa−eagle (*Haliaeetus pelagicus*). (IUCN, 2005). A total of 1,675 birds were cited consisting of 7 different species in the year of 1999 (Birds International, 2001). Thus, Lake Songji has been officially designated as the sanctuary for birds and beasts since 1985.

This study was conducted to evaluate the limno−ecological characteristics from May 1998 to November 2002 on bi−monthly basis. Various physico−chemical parameters including temperature salinity, secchi disc transparency, TN, TP, organic matter in sediment and Chl. *a* were measured. Changes of dominant species and cell density of phytoplankton were also measured.

MATERIALS AND METHODS

Lake Songji, located in the region of Gosung−gun, has an average yearly precipitation of 1,342 mm and the yearly average air temperature of 12.1°C. From June to September, about 60−80% of yearly precipitation are recorded (Fig. 1). N and P generation in the drainage area was 55 kgN · day^{-1} and 9 kgP · day^{-1} respectively (Heo *et al.*, 1999). Water samples collected from 1998 to 2002 for 5 sites (Fig. 2), were filtered with GF/C filter. The filter papers were kept frozen, and homogenized at the time of chlorophyll−*a*

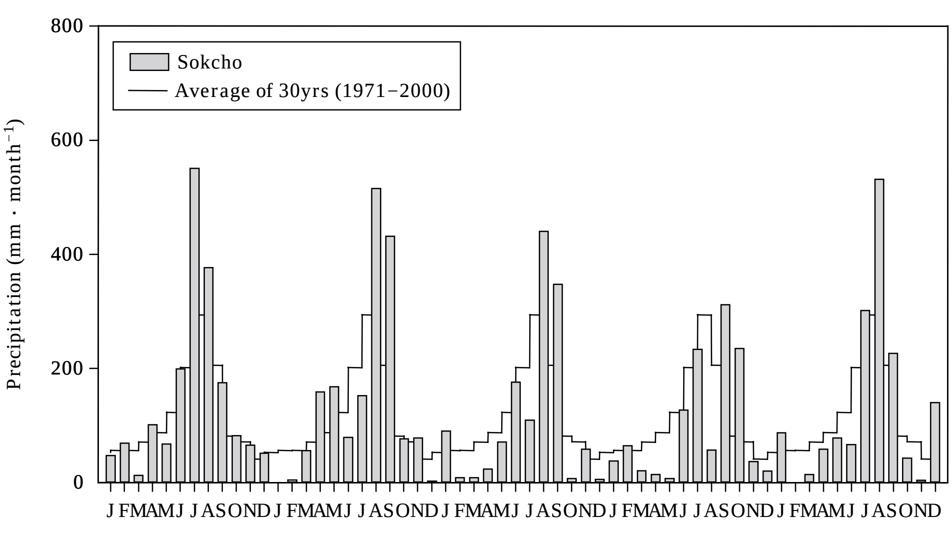

Fig. 1. Monthly variations of precipitation of Sokcho city.

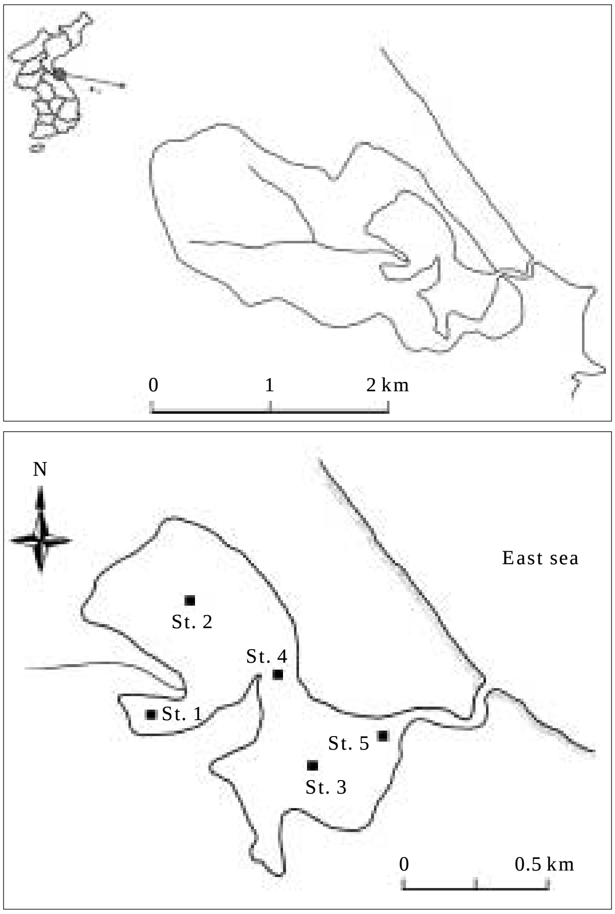

Fig. 2. Map showing the watershed and sampling sites.

analysis. Lorenzen's (1967) method was used to calculate chlorophyll−*a* concentration. Filtrate was then used to calculate dissolved nitrogen and phosphorus. TP was determined according to Standard Methods (APHA, 1992), employing persulfate digestion and ascorbic acid method. TN was determined by the cadmium reduction method after persulfate digestion, using a flow injection autoanalyzer (BRAN+LUEBBE, Auto Analyzer3). Temperature and salinity were measured with a multiprobe meter (YSI, 6000). Trophic State Index (TSI) was calculated according to Carlson (1977). The phytoplankton samples were fixed by adding Lugol's solution. The samples were transported to the laboratory, and stored for one week. The samples were concentrated by siphon and were counted under the optical microscope with the resolution of 400−600x. Pictorial handbooks of Mizuno (1964) and Algae of Japanese Freshwater (Hirose and Yamagishi, 1977) were used as reference for the identification of phytoplankton. The sediment samples were used to measure the moisture content and total solid. COD of sediment was measured by using the wet samples, while TP and TN of sediment were measured using dry samples after Kjeldal digestion method on the basis of the Standard Method (APHA, 1992).

RESULTS AND DISCUSSION

1. Temperature, Salinity, DO and Secchi Disc transparency

During the study period, the average temperatures were in the range of 7.4−28.2°C (Table 1). Although the minimum winter temperature couldn't be recorded as the lake freezes during the winter seasons, the maximum temperature was 28.7°C in September 1999. Seasonal variations of temperature of all the years were similar with comparable trends. Average salinity of mixolimnion at sites 2 and 3 were 7.7 and 7.7‰ respectively (Fig. 3). But the monimolimnion of the same sites showed higher average concentrations of 9.8, 11.6 and 13.3‰, respectively. Due to the frequent tidal interference, site 3 had higher salinity than other sites. The seasonal variation of salinity was in the lower ranges of 2.2−9.9‰ in the late rainy seasons (July to September).

Table 1. A statistical summary of nutrients and the relevant hydrographical parameters.

	Mean±SD	Range	N
Temp. (°C)	18.5±7.3	7.3−28.7	97
Cond. (μS cm^{-1})	13578±5185.	101−22088	97
Salinity (ppt)	7.9±3.2	0.1−13.3	97
DO ($mgO_2 \cdot L^{-1}$)	10.4±3.4	3.7−26.5	97
pH	7.98±0.83	5.92−10.23	97
Tur. (NTU)	5.4±5.5	0.1−20.2	34
SD (m)	1.2±0.5	0.4−2.8	96
COD ($mgO_2 \cdot L^{-1}$)	3.7±1.8	0.6−11.6	89
TP ($mgP \cdot L^{-1}$)	0.050±0.052	0.005−0.396	96
DIP ($mgP \cdot L^{-1}$)	0.012±0.034	0.000−0.319	94
TN ($mgN \cdot L^{-1}$)	0.847±0.457	0.223−3.521	95
NO_3−N ($mgN \cdot L^{-1}$)	0.091±0.142	0.000−1.000	96
NH_3−N ($mgN \cdot L^{-1}$)	0.127±0.127	0.000−0.804	96
NO_2−N ($mgN \cdot L^{-1}$)	0.005±0.005	0.000−0.015	35
SiO_2 ($mg \cdot L^{-1}$)	1.9±1.5	0.0−6.2	69
Chl. *a* ($mg \cdot m^{-3}$)	13.5±21.1	0.5−129.8	94
SS ($mg \cdot L^{-1}$)	17.6±26.0	0.5−222.0	86

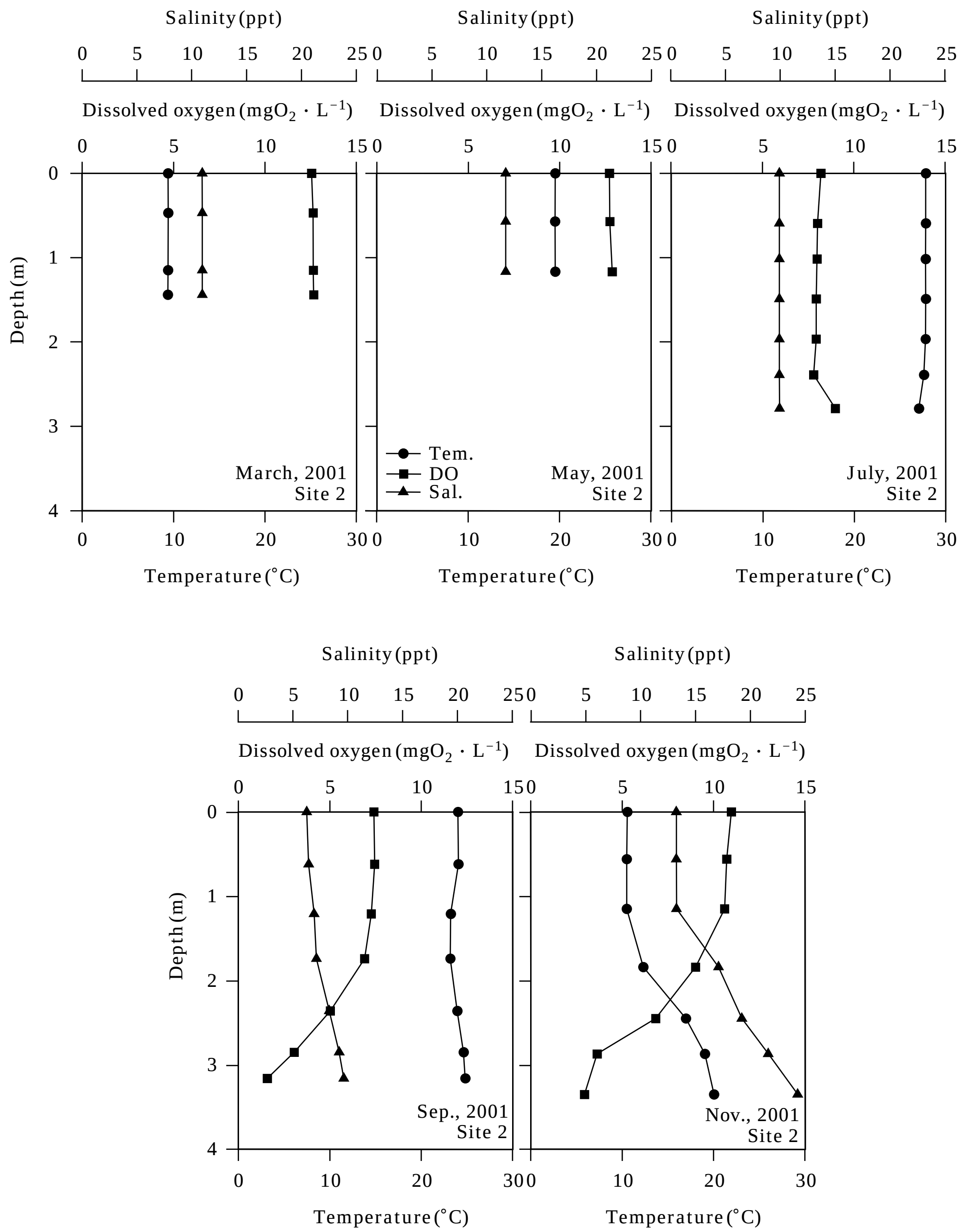

Fig. 3. Seasonal variations and vertical distribution on temperature, dissolved oxygen, and salinity at the site 2 and 3, March-November, 2001.

Previous study done in Lake Songji (Kim *et al.*, 1981) reported that the salinity in the mixolimnion and monimolimnion were in the range of 5.2-9.4‰ and 6.6-16.9‰, respectively (July to November). Pyen (1984) reported that salinity of Lake Songji was about 10‰ from February till June, then decreased to about 3‰ in August and increased to above 12‰ in December. Due to the seawater intrusion, the southern part of the lake showed higher salinity concentration than the central and northern part. Higher variations in salinity were seen after the periods of high rainfall and high tides. Seasonal variations of salinity showed lower concentrations in the summer season but higher in the spring season. Seasonal vertical variation of temperature, salinity and DO are show in Fig. 4. From March to September 2001, all the sites showed very low temperature

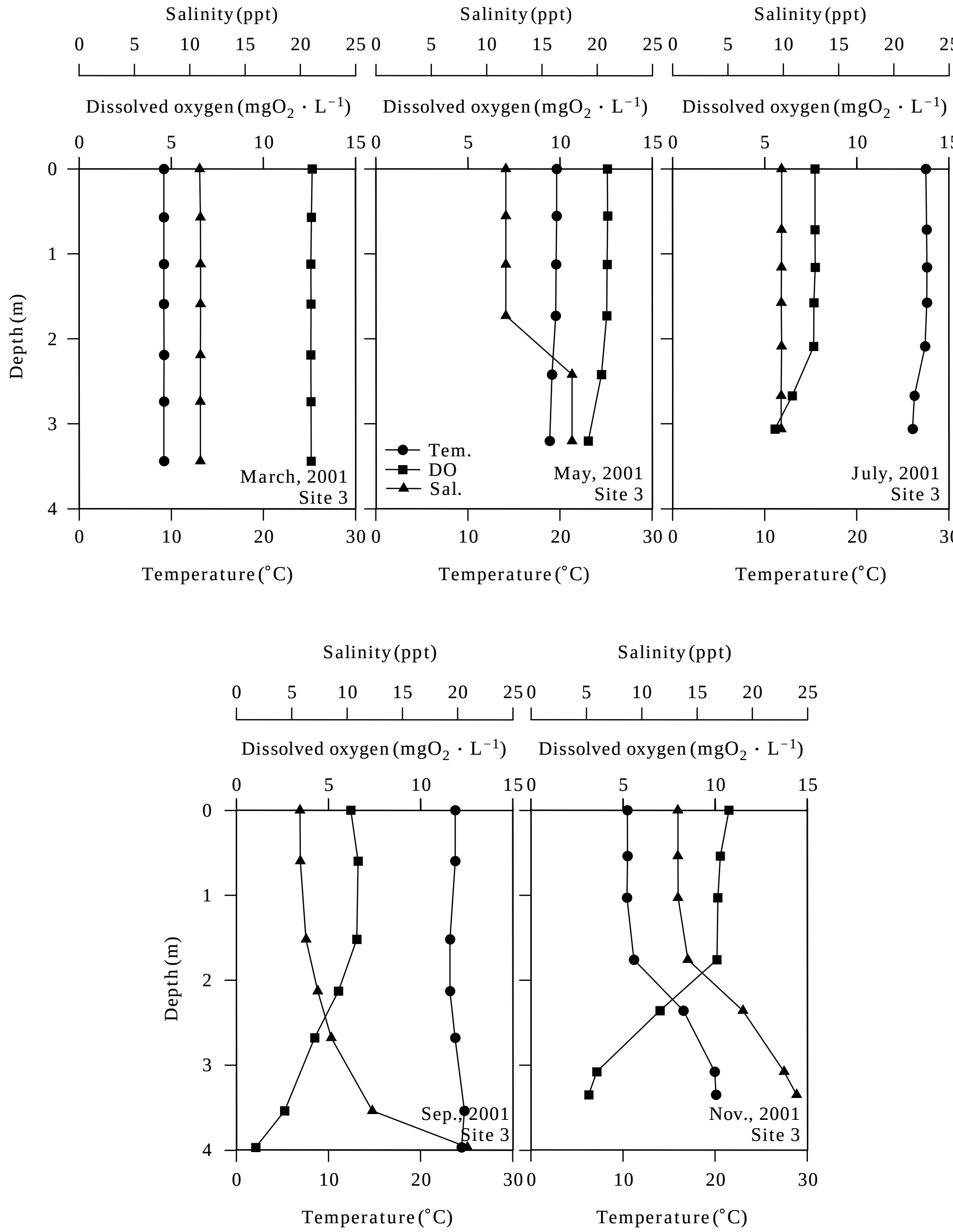

Fig. 3. To be continued.

differences of about 1 and 2°C. In November, temperature of mixolimnion and monimolimnion in site 1 were 10.9°C and 15.7°C respectively. Temperature of mixolimnion of sites 2 and 3 were about 10°C and 20°C respectively. Thus, temperatures below the metalimnion were higher than mixolimnion. The formation of chemocline in the metalimnion prevented vertical mixing (Heo *et al.*, 1999; Heo *et al.*, 2001; Kwon, 2002). The seasonal variations of chemocline from September to November were higher. External forces such as wind, tides and inflowing water sometimes destroys the chemocline (Uncles *et al.*, 1990). Rainfall and tidal intrusion were of great significance as they highly affected the variations of salinity (Hung, 2003). The distribution of salinity effects DO concentration. In November 1999, DO concentrations of mixolimnion were in the higher range of 11.8−12.3 $mgO_2 \cdot L^{-1}$ but DO concentration in the monimolimnion were in the

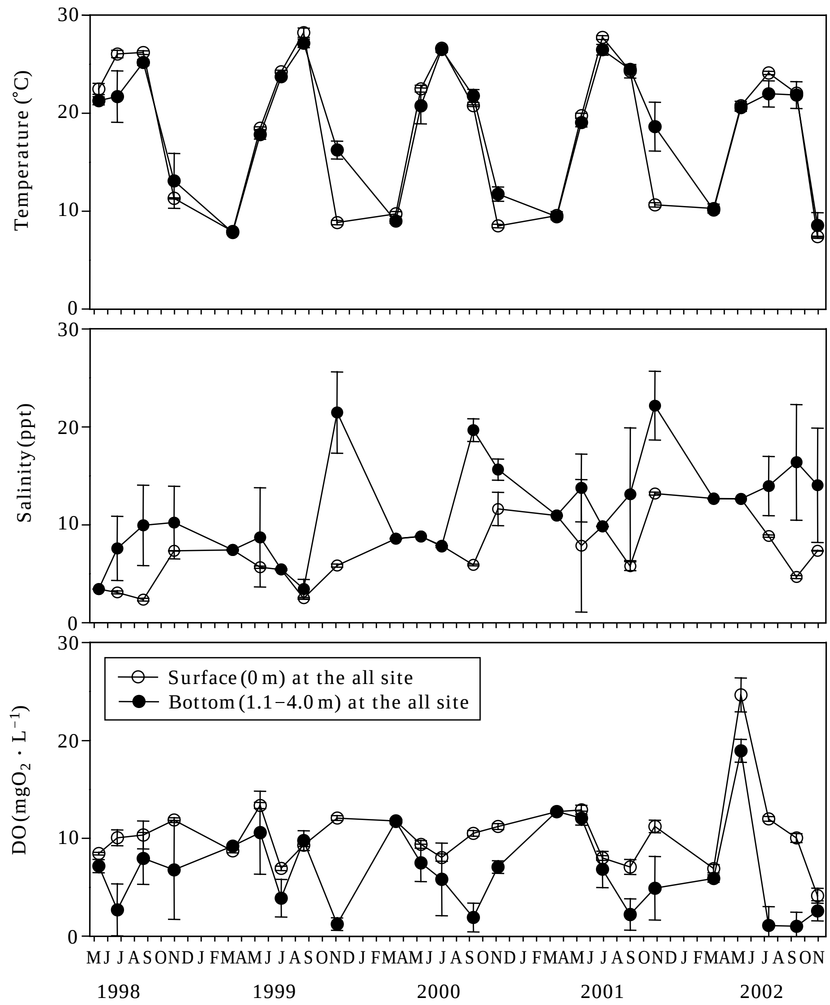

Fig. 4. Seasonal variations of temperature, salinity and dissolved oxygen concentration.

range of 0.7–1.9 $mgO_2 \cdot L^{-1}$ (Fig. 4). Similarly, DO concentration below chemocline was at the lowest because of low oxygen solubility in saline water and high decomposition rate in monimolimnion. Kim *et al.* (1981) pointed out that below the 3 m depth almost anoxic condition existed limiting the benthic organisms. Heo *et al.* (1999) reported that in most of the lagoons, in the eastern coast of Korea, chemocline is formed in the metalimnion and below the chemocline DO concentration decreased while that of salinity increased.

During the study period secchi disc transparencies were in the relatively lower range of $0.5 \pm 0.0 – 2.7 \pm 0.1$ m (Fig. 5). A trend of increase in the Secchi disc transparency over the Lake Songji can be observed from north to south, as the distance to the southern part was long enough for the suspended matters to settle on the way. The variations of secchi depth in each site showed similar trends at that of Lake Chongcho (Heo *et al.*, 2001). In the study of Lake Hwajinpo, Kwon (2002) exhibited that secchi disc transparency decreased with the increases in the biomass of phytoplankton and suspended solid in the inflowing water during rainy seasons. Heo *et al.* (1999) showed that secchi disc transparency reduced to less than 1 m due to the higher suspended solid concentration and increase in biomass of phytoplankton.

The presence of higher salinity, low DO in the mixolimnion, formation of round the year chemocline make most of the lagoons a unique habitat that is very different from general fresh water

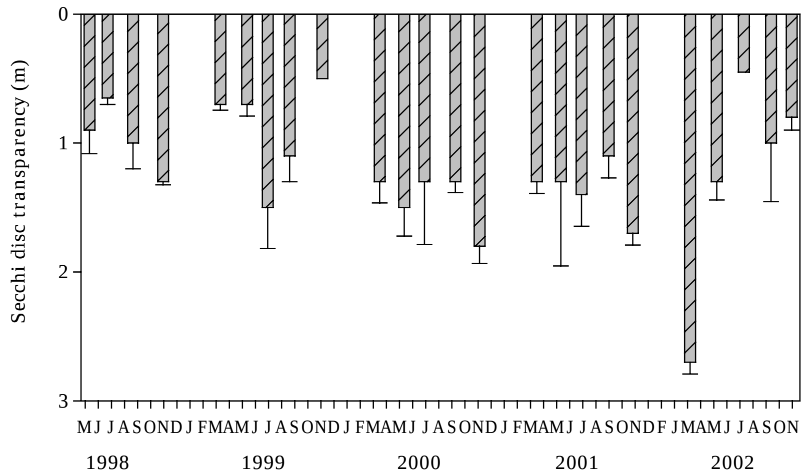

Fig. 5. Seasonal variations of secchi disc transparency.

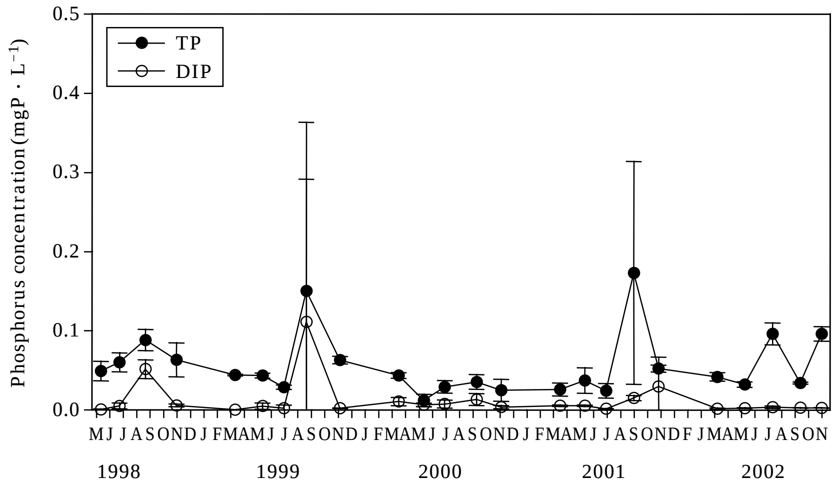

Fig. 6. Seasonal variations of TP and DIP concentration at study sites.

lakes (Hong *et al.*, 1962; Kim *et al.*, 1998; Heo *et al.*, 1999; Heo *et al.*, 2000; Heo *et al.*, 2001; Kwon, 2002; Heo *et al.*, 2004a, b, c; Heo and Kim, 2004).

2. Nutrients, chlorophyll *a* and trophic state

In September 1999, TP and DIP concentrations in the mixolimnion were high after rainy seasons (Fig. 6). During the study period, TP and DIP concentration in the mixolimnion were in the range of 0.015–0.396 mgP · L^{-1} and 0.000–0.319 mgP · L^{-1} respectively. The average TP concentrations in site 1 were the highest (0.064 mgP · L^{-1}) and the concentrations in site 2 and 3 were 0.016 and 0.045 mgP · L^{-1} respectively. Heo *et al.* (1999) and Kwon (2002) reported that phosphorus concentration in the sites near the outlet were lower which is similar to the result of this study. Heo *et al.* (1999) reported that among the seven studied lagoons in eastern coast of Korea, Lake Songji has the lowest TP concentration. Similarly, DIP concentrations in Lake Songji were also lower than other lakes because watershed was rarely inhibited (Wonju Regional Environmental Office, 1997). This study showed that the average TP concentration were 0.050 mgP · L^{-1} which is higher than the US EPA eutrophication classification (1976) on the basis of TP concentration (0.020 mgP · L^{-1}). Lake Songji is eutrophic as per

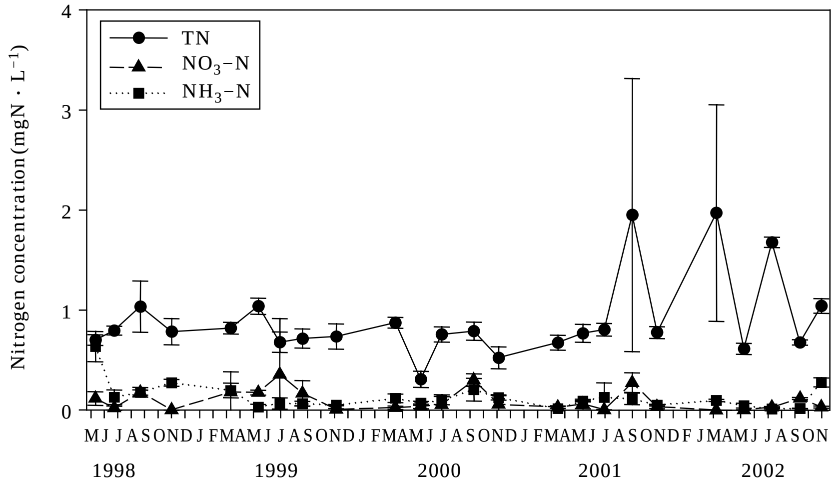

Fig. 7. Seasonal variations of TN, NO_3-N and NH_3-N concentration at study sites.

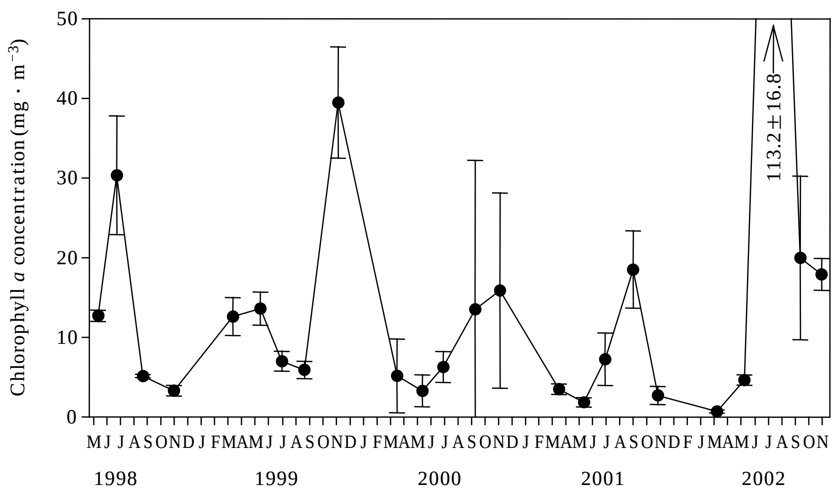

Fig. 8. Seasonal variations of chlorophyll *a* concentration at study sites.

the guidelines set by the OECD (1980) has classified lakes into eutrophic (0.035–0.100 mgP · L^{-1}) on the basis of phosphorus concentration. DIP concentration of Lake Songji is 0.012 mgP · L^{-1}, which is over the Sawyer (1947) limit of 0.010 mgP · L^{-1}, when the harmful algae bloom begins. Most of the lagoons in the eastern coast of Korea, including Lake Songji, have relatively longer hydraulic residence time, higher inflow of suspended particles and settlement rate, and comparatively rapid annual life cycle of macrophytes around the littoral zone.

TN concentrations of the mixolimnion were in the range of 0.223–0.794 mgN · L^{-1} with the highest concentration in September 2001 (Fig. 7). The average TN concentrations of the northern and the southern part were 0.883 and 0.794 mgN · L^{-1} respectively. Higher concentrations of TP and TN were found in the northern part. The concentrations of NO_3-N and NH_3-N were in the range of 0.000–1.000 mgN · L^{-1} and 0.000–0.804 mgN · L^{-1} respectively. TN and NH_3-N concentrations didn't showed much seasonal variations but the seasonal variations of NO_3-N concentration showed increasing trend after the rainy season but might be due to utilization of NO_3^- by the bacteria in the absence of DO.

Very low concentrations of silicate (0.02–6.2 mgSi · L^{-1}) were found from March to May. Silicate concentrations showed higher seasonal vari-

Table 2. TSI (trophic state index) in Lake Songji. TSI was calculated from warm season (May−Sept.) average by surface water (SD: Secchi disc depth in m, CHL: chlorophyll *a* concentration in mg · m^{-3}, TP: total phosphorus in mgP · L^{-1}, TN: total nitrogen in mgN · L^{-1}).

	TSI				Average
	SD	CHL	TP	TN	
1998	62	65	64	56	62
1999	59	60	59	56	58
2000	57	55	49	54	54
2001	57	56	57	57	57
2002	62	70	60	56	62

Table 3. Water content and nutrient concentration of the sediment in Lake Songji.

Site	Water content (%)	Org. Matter content (%)	COD (mgO_2 · gdw^{-1})	TN (mgN · gdw^{-1})	TP (mgP · gdw^{-1})
1	64.7	21.4	116.9	0.88	1.46
2	56.9	19.4	85.9	0.42	0.65
3	72.1	16.9	98.8	0.83	0.96
4	66.9	40.4	112.1	1.03	0.86
5	21.8	24.6	51.4	0.12	0.04

ations. In the spring seasons, lower silicate concentrations were found because of the utilization by the growing diatoms. So, silicate was the limiting nutrient for the phytoplankton growth (Ministry of Environment, 2002).

Chl. *a* concentration of mixolimnion was in the range of 0.7 ± 0.2−113.2 ± 16.8 mg · m^{-3}, with the highest concentration in July 2002 (Fig. 8). The average Chl. *a* concentration in each sites 1, 2, and 3 were 15.3, 15.2 and 16.0 mg · m^{-3} respectively. US EPA (1976) classified lakes as eutrophic if the Chl. *a* concentration is over 10 mg · m^{-3}. Forsberg and Ryding (1980) classified lakes as hyper−eutrophic if the Chl. *a* is over 40 mg · m^{-3}. As per these classifications, Lake Songji is classified as an eutrophic lake. TP, Chl. *a*, Secchi disc transparency and TN were used to calculate the Trophic State Index (TSI). Data of the growing seasons (May to September) were used to calculate the TSI. The average TSI of Lake Songji were in the range of 54−62, with the highest value in 2000 (Table 2). Heo *et al.* (1999) showed that the average TSI value of lagoons in eastern coastal area were in the range of 59−77.

3. Sediment

The average water content of sediment were in the range of 21.8−72.1%. Relatively lower sediment depths and sediment water content were found near the areas of inflowing stream and tidal inlet point (Table 3). Particle size distribution of the sediment of each site, excluding outlet and inlet areas, was in the range of 0−125 μm. The sediments of the inlet and outlet area contained more of coarse particles that the central part of the lake. Inlet area contained allochthonous sediments but the central part had much of autochthonous sediments such as organic matter, debris of plants etc. COD concentration was in the range of 51.4−116.9 mgO_2 · gdw^{-1} (mean 93.0 mgO_2 · gdw^{-1}). This value is higher than Lake Hyangho, Lake Ssangho and Lake Maeho (Ministry of Environment 2002). Higher COD concentration was due to the narrow outlet, causing much of degradable matter to reside in lake for longer time. In the outlet and inlet areas of the lagoon, relatively greater grain size distribution of particles were found, which is due to erosion, deposition of organic matter and debris of dead littoral plants, aquatic plants and microorganisms. The average organic content was about 24.5%, which is higher than Lake Hyangho, Lake Maeho and Lake Ssangho (Ministry of Environment, 2002). TP and TN of the sediments were in the range of 0.04−1.46 mgP gdw^{-1} and 0.12−1.03 mgN · gdw^{-1}, respectively. The TN and TP concentration in site 5 were the lowest because this site is near the outlet area containing lower organic sediments.

4. Phytoplankton

During the survey period, a total of 49 phytoplankton species were recorded (Fig. 9). The total density were in the range of 50−23,350 cells · mL^{-1} and with the highest cell density in September 2001, when Chlorophyceae *Schroederia judayi* dominated the cell density of 20,417 cells · mL^{-1}. In 2002 July, total density was 19,514 cells · mL^{-1} and the dominant species were Cyanophyceae *Anabaena spiroides* with the cell density of 12,218 cells · mL^{-1}. Also during the same period, Chlorophyceae *Schizochlamys gelatinosa* were the subdominant species with cell density of 5,578 cells · mL^{-1}. Heo *et al.* (1999) showed that most of lagoons in the eastern coastal areas of Korea were dominated by the Cyanophyceae.

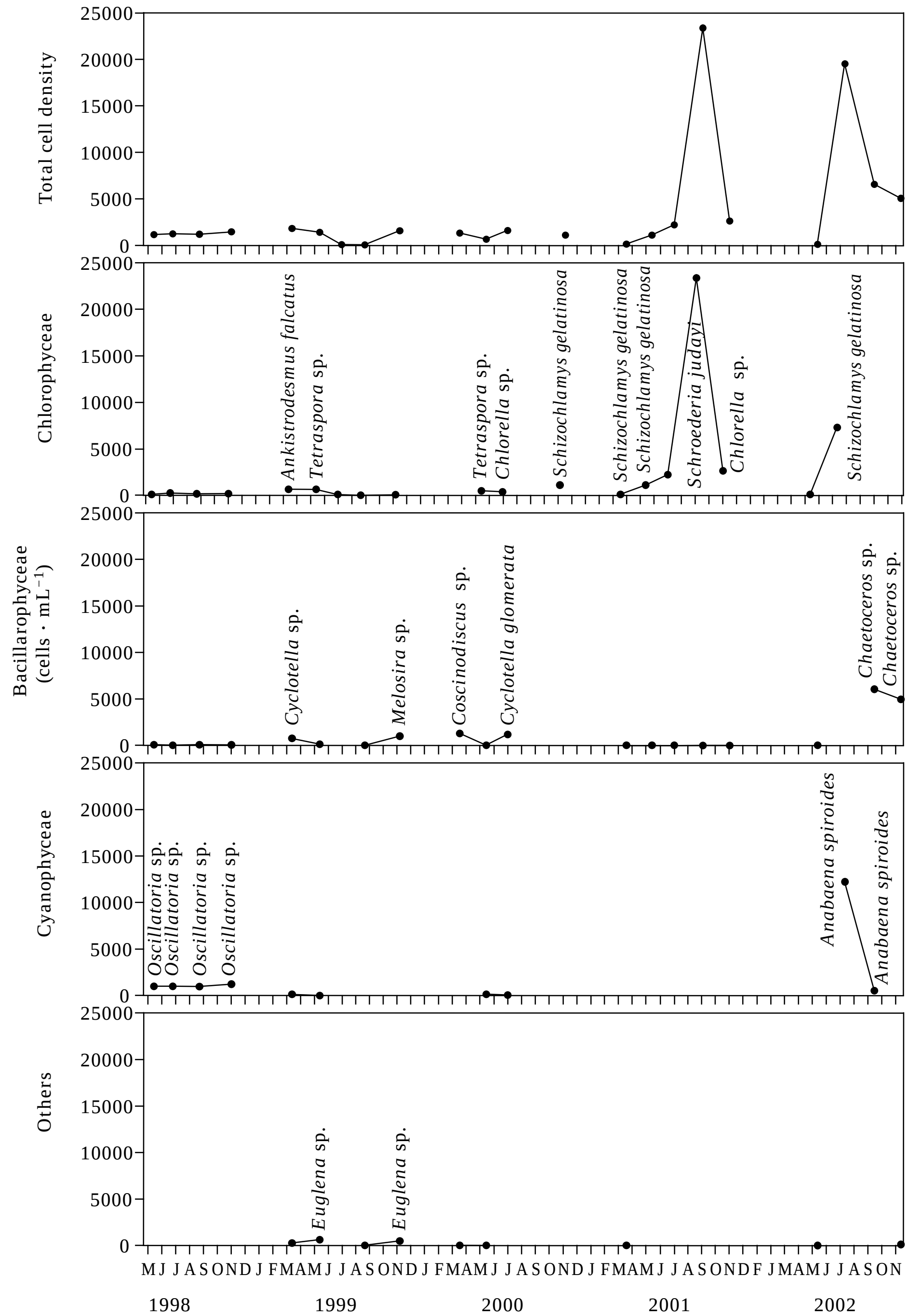

Fig. 9. Seasonal variations of phytoplankton cell density (cells · mL^{-1}) and dominant species.

Kwon (2002) showed that in Lake Hwajinpo, Cyanophyceae were dominant in the summer. These studies of phytoplankton communities were different that this lake excluding 1998, because in this study of Lake Songji Chlorophyceae and Bacillariophyceae dominated totally. Kim *et al.* (1981) showed in the study of marine ecology of eastern coastal brackish lakes, phytoplankton *Coccone scutellum*, *Thalassiothrix frauenfeldii*, *Cyclotella striata*, *Chaetoceros costatus* and *Amphora hyaline* were dominant, and the marine species had the higher ratio of 53.3%.

Table 4. Pearson correlation coefficients between nutrient species and limnological parameters (using st. 2 data). Refer to Table 1 for units of each parameter

	Phyto	Chl. *a*	SD	Temp.	Cond.	Sal.	DO	pH	Tur.	COD	SS	TP	DIP	TN	NO_3−N	NH_3−N	NO_2−N	SiO_2	TN/TP
Phyto	(22)	0.659**	−0.300	0.207	−0.064	−0.073	−0.153	0.571**	0.792**	0.069	0.359	0.052	0.016	0.268	−0.017	−0.123	0.303	0.525	−0.206
Chl. *a*		(23)	−0.456*	0.096	−0.034	−0.039	0.038	0.556**	0.877**	0.288	0.670*	0.068	−0.086	0.259	−0.099	−0.161	0.095	0.162	−0.173
SD			(23)	−0.204	0.590*	0.595*	−0.127	−0.371	−0.591	−0.034	−0.270	−0.175	−0.080	0.341	0.055	−0.130	−0.092	−0.185	0.651*
Temp.				(23)	−0.484	−0.480*	−0.022	0.101	0.141	0.199	0.031	0.248	0.365	−0.146	0.281	−0.063	0.252	0.334	−0.101
Cond.					(23)	0.999*	0.289	0.073	−0.095	0.052	0.223	−0.409*	−0.412	0.199	−0.312	−0.354	−0.105	−0.197	0.509*
Sal.						(23)	0.296	0.064	−0.104	0.065	0.213	−0.408*	−0.414*	0.197	−0.320	−0.321	−0.095	−0.197	0.503*
DO							(23)	0.281	−0.180	0.085	0.090	−0.125	−0.121	−0.232	−0.221	−0.258	0.503	−0.092	−0.135
pH								(23)	0.419	0.463	0.394	−0.115	−0.188	0.202	−0.360	−0.382	0.540	0.305	−0.125
Tur.									(11)	0.411	0.901*	−0.001	−0.122	0.095	0.089	−0.145	−0.357	0.836	−0.218
COD										(23)	0.298	−0.222	−0.389	0.174	−0.243	−0.056	−0.118	0.070	0.005
SS											(22)	−0.097	−0.202	0.183	−0.191	−0.205	−0.285	0.066	0.040
TP												(23)	0.943*	0.087	−0.042	−0.006	0.101	0.161	−0.483*
DIP													(22)	−0.020	0.034	−0.057	0.193	0.650*	−0.348
TN														(23)	−0.167	−0.091	−0.182	−0.115	0.241
NO_3−N															(23)	0.040	0.378	0.436	−0.119
NH_3−N																(23)	−0.339	0.252	−0.241
NO_2−N																	(10)	0.205	−0.407
SIO_2																		(14)	−0.351
TN/TP																			(23)

1. Sample number is given in small bracket 2. *Significant correlation coefficients is 0.05, **Significant correlation coefficients is 0.01

Eastern coastal lagoons have shallow depths and sometimes exchange occur with seawater and freshwater. So, for the living organism it's difficult to survive (Pyen, 1984). Also, net-planktons were found to be simple because of unstable brackish water condition (Cho *et al.*, 1975). In the lagoon, fresh water species should adapt in high salinity and marine species should adopt in lower salinity. So, species diversity is generally low but due to the high nutrient content, bloom of some species occurs resulting in higher primary productivity (Kim, 1997). In this study, the correlation coefficients were calculated between the biomass of phytoplankton and environmental factors. Chl. *a*, pH, and turbidity was proven to be the better indicators of environmental changes as they showed stronger correlation coefficient values of 0.659, 0.571, and 0.792 respectively (Table 4). Phytoplankton communities showed no significant correlation coefficient with other environmental gradients except a positive value of 0.525 with silicate. So, silicate is thought to be the limiting factor in the growth of diatom.

CONCLUSION

To manage the water quality of Lake Songji and to increase its limnological value, the chemocline should be destroyed so that the turnovers can occur more frequently which will supply the benthic reason with higher DO concentrations. The decomposition of the organic carbon in the sediment will help in enhancing the water quality of the Lake Sonji.

The response of plankton biomass and structure to changing water chemistry, which might be either due to the changes in meteorological and inflow conditions or human induced changes such as reduction in the lake level, will continue. To slow down the eutrophication rate of Lake Songji and to maintain a well-oxygenated monimolimnion, the seawater intrusion should be controlled by artificially constructing a more effective dike which facilitates the constant exchange of sea water and fresh water. The experiences from other lagoons in Korea teach us that the watershed area should be properly managed to reduce the ever-increasing concentrations of the allochthonous materials, especially anthropogenic inflows. Also, the storm-water should be controlled by constructing either a settling pond with fully developed macrophytes on the littoral regions or a diversion for storm-water in the upstream area. But, any future advances must be conditioned by an awareness of current deficiencies.

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<국문적요>

동해안 석호의 육수학적 조사(4); 송지호

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송지호 표층의 평균 수온은 겨울 결빙기를 제외하고는 7.4–28.2°C로 최저 7.3°C 및 최고 28.7°C 이였다. 표층의 염분은 0.1–13.3‰의 범위로 분포하였으며, 중층 부근에서 화학성층이 형성되었다. 화학성층이 강하게 나타났던 1999년 11월 표층의 용존산소는 11.8–12.3 $mgO_2 \cdot L^{-1}$이었으나, 심층에서는 0.7–1.9 $mgO_2 \cdot L^{-1}$으로 매우 낮았다. 표층의 총인과 용존무기인의 농도는 각각 0.005–0.396 $mgP \cdot L^{-1}$ 및 0.000–0.319 $mgP \cdot L^{-1}$의 범위이였으며, 북호와 남호의 대표 정점으로 볼 수 있는 정점 2와 3에서의 평균농도는 각각 0.061 및 0.045 $mgP \cdot L^{-1}$로 북호쪽의 농도가 더 높았다. 표층의 총질소(TN)는 0.223–3.521 $mgN \cdot L^{-1}$로 분포하였으며, 북호와 남호의 평균농도는 각각 0.883 및 0.794 $mgN \cdot L^{-1}$로 총인과 마찬가지로 북호쪽에서 높았다. 질산성질소(NO_3–N) 및 암모니아성질소(NH_3–N)의 농도는 각각 0.000–1.000 $mgN \cdot L^{-1}$ 및 0.000–0.804 $mgN \cdot L^{-1}$이였다. 규소농도는 0.0–6.2 $mgSi \cdot L^{-1}$의 범위로 3–5월에 매우 낮았으며, 계절적인 변화가 뚜렷히 나타났다. 저질의 입자는 0–125인 silt 및 coarse silt로 이루어져 있으며, COD는 51.4–116.9 $mgO_2 \cdot gdw^{-1}$ 로 평균 93.0 $mgO_2 \cdot gdw^{-1}$이였다. 저질내의 TP 및 TN의 농도는 각각 0.04–1.46 $mgP \cdot gdw^{-1}$ 및 0.12–1.03 $mgN \cdot gdw^{-1}$이었다. 표층의 엽록소 *a*의 정점별 평균값은 정점 1, 2 및 3에서 각각 15.6, 15.2 및 16.0 $mg \cdot m^{-3}$으로 유사하였다. 식물플랑크톤은 총 49종이 출현하였으며, 생물량은 50–23,350 $cells \cdot mL^{-1}$로 2001년 9월에 가장 많았다. 이 시기의 우점종은 녹조류인 *Schroederia judayi* 이였으며, 생물량은 20,417 $cells \cdot mL^{-1}$이였다.

송지호의 수질을 개선하기 위해서는 인위적으로 화학성층을 파괴시켜 심층에 용존산소를 공급시켜야 할 것으로 판단되며, 모래톱으로 인해 막혀져 있는 해수교환을 항상 원할 하게 유지될 수 있도록 하는 것이 필요할 것으로 판단된다.