Research in Marine Sciences
Volume 9-Issue 2- 2024
Pages 474-495

Hydrogeographic investigation of the east coast lagoon: Hwajinpo Lake

Woo-Myung Heo[1, *], Sang-Yong Kwon [1], Jaeil Lee[1], Dong-Jin Kim[2], and Bom-Chul Kim[3]

[1]Department of Environmental Engineering, Samchok National University, Samcheok, 245-711, South Korea

[2]Wonju Regional Environmental Management Office, Wonju, 220-041, South Korea

[3]Department of Environmental Science, Kangwon National University, Chuncheon, 200-701, South Korea

Received: 2024-05-10 *Accepted: 2024-06-23*

Abstract

Physicochemical factors, plankton biomass, and sediment were measured from 1998 to 2000 at two months' interim in a eutrophic shoreline Lake, Hwajinpo, in Korea. The lake is isolated from the sea by a narrow sand hill. Coastal zone is well vegetated with floating leaved marine plants. The lake basin is divided into two sub-basins by a shallow ridge. It has disturbance of seawater by stormy waves. Stable chemoclines are made by salinity variations at depth of 1 m around the year. Dissolved Oxygen was often very low (<1 mgO_2/L) at hypolimnion. Temperature reverse were detected in November. Nitrate and Ammonium concentrations were also very low (< 0.1 mgN/L), while TN was usually 2.0~3.5 mgN/L. In general, TN/TP was lower than the Redfield ratio. Transparency was 0.2~1.7m, and COD, TP, and TN of sediment were 3.1~40.3 mg O_2/g, 0.91~1.39 mgP/g, and 0.34~3.07 mgN/g, respectively. Phytoplankton chlorophyll-a concentrations were mostly over 40 mg/m^3. Two basins showed different phytoplankton groups with *Oscillatoria* sp., *Trachelomonas* sp., *Schizochlamys gelatinosa*, and *Anabaena spiroides* dominant in South basin, and with *Trachelomonas* sp., *Schroederia* sp., *Schizochlamys gelatinosa*, and *Trachelomonas* sp. dominant in the North basin. The seasonal progression of phytoplankton was quick, probably because of unexpected variations in physical environments, such as salinity, turbidity, wind, and light.

Keywords: Hydrogeographic factors; Hwajinpo; Lake; Stormy wave; Wind.

---

* Corresponding Author's Email: woomyheo@samcheok.ac.kr

1. Introduction

Hwajinpo Lake is a natural lake created by a hill due to the action of ocean currents. The water depth is shallow and it is always influenced by sea water. The water surface has a gentle slope and the water level is stable throughout the year, so wetland vegetation is well developed. Unlike freshwater lakes, Hwajinpo Lake is a mixture of seawater and freshwater and has the characteristics of a brackish lake. Hwajinpo Lake is a natural pond created by a ridge due to the action of ocean currents. The water is shallow and is always influenced by seawater. The slope is gentle and the water level is stable throughout the year, so wetland vegetation is well developed. Unlike freshwater lakes, Hwajinpo Lake has the characteristics of a brackish lake because seawater and freshwater are mixed. Although the water depth is relatively shallow, vertical mixing between the surface and deep layers is extremely limited, and deep oxygen depletion phenomenon frequently occurs. Brackish water lakes on the east coast have frequent exchanges between freshwater and the sea, and have unique ecological characteristics compared to artificial or natural lakes in the inland (Hong *et al*., 1969). Because of these characteristics, freshwater species with strong tolerance to high salinity and marine species with strong tolerance to low salinity inhabit brackish lakes. Ki Suho is the mass propagation of certain species due to the periodic influx of nutrients.

There are about 10 lagoons on the east coast, from Hwajinpoho Lake, located in the northernmost part, to Pungho Lake. Among them, Hwajinpo Lake has the largest lake area, and is composed of South Lake, which has a relatively large basin area and has many pollution sources, and North Lake, which has relatively few pollution sources. South Lake and North Lake are connected by a narrow waterway, so horizontal mixing is extremely limited, and in the case of South Lake, water body congestion is extremely severe. Due to the coexistence of freshwater and seawater, a chemical layer is always formed within the lake (Huzzey *et al*., 1994). Large amounts of nutrients flow in from cotton pollutants scattered throughout the watershed, often resulting in massive proliferation of phytoplankton. In general, eutrophication of lakes is caused by the influx of phosphorus, which increases the existing amount and productivity of phytoplankton and reduces transparency. When excessive amounts of nutrients such as nitrogen (N) and phosphorus (P) are introduced, water quality deteriorates, with algae initially increasing and low-quality sediments accumulating, leading to active nutrient recirculation. Phosphorus exists in soil or organic matter particles decomposed by living organisms, so the amount of soluble phosphorus is small, and biologically useful phosphorus is less than nitrogen (Horne and Goldman, 1994).

In general, when the N/P ratio is 10 to 17 or more, P is evaluated as being relatively deficient compared to N, and is known to primarily limit the growth of algae (Smith, 1982). In evaluating the eutrophication of the East Coast Lagoon, Heo *et al*. (1999) stated that the TN/TP ratio of the East Coast Lagoon was 6 to 14, which was lower than that of the estuarine lake (20 to 30). Research on relatively large lakes and reservoirs in Korea has been conducted continuously for a long time and there is a lot of research data, but research results on lagoons on the east coast such as Hwajinpo Lake are insufficient despite the scarcity of natural lakes. As for Hwajinpo

Lake, Hong *et al*. (1969) conducted two studies that revealed the physicochemical water quality and plankton phase, and Eom (1971) studied the production structure of phytoplankton communities in brackish water lakes such as Hwajinpo and Yeongnang Lake and studied the vertical distribution of chlorophyll., and an attempt was made to categorize each appeal. Hong and Na (1975) investigated water quality and plankton four times at Hyangho, Maeho, Yeongnangho, Songjiho, Gwangpoho, and Hwajinpo to investigate hydrological characteristics. And Cho *et al*. (1975) investigated the distribution of plankton in six brackish water lakes on the east coast, including Hyangho, Maeho, Yeongyeokho, Gwangpoho, Songjiho, and Hwajinpoho, and classified the brackish water lakes according to their relationship with water quality. The characteristics have been revealed. Kim *et al*. (1981) investigated physicochemical water quality characteristics, production potential, floating organisms, benthic organisms, and swimming organisms. Osamu *et al*. (1984) reported urea, dissolved organic carbon, nitrogen, and phosphorus.

Regarding urea, dissolved organic carbon, nitrogen, and phosphorus, Pyeon (1984) reported on the environment and biota of brackish lakes. Regarding the water quality investigation of natural lakes on the East Coast, Jeon *et al*. (1996) pointed out that most natural lakes on the East Coast were at the hypereutrophic level based on chlorophyll-a and total phosphorus. Heo *et al*. (1999) also attempted to evaluate the eutrophication of the East Coast lagoon based on data such as water quality and phytoplankton. The lagoon on the east coast is one of the few natural lakes in Korea and has long been famous for its spectacular scenery. Not only is the natural scenery very beautiful, but it is also of great conservation value considering its rare value as a brackish water lake ecosystem and the ecological characteristics of the wetlands of the natural lake. high. Therefore, in this study, we investigated the distribution of basic water quality items, nutrients, bottom quality, and plankton, which serve as basic data for inland water ecological research on Hwajinpo Lake.

2. Materials and Methods

The water surface area and basin area of Hwajinpo Lake are 2.3 and 19.9 km^2, respectively (Table 1). The water surface area of South Lake is about four times larger than that of North Lake, and the basin area is about three times larger. Fluctuations in water level are relatively small except during rainfall due to low inflow water. The average annual precipitation over the past 30 years in the Hwajinpo area was approximately 1,422 mm, and approximately 60% of the total annual precipitation was concentrated between June and September, the summer season (Figure 1). In 2000, about 1,345 mm fell, with about 80% falling between June and September, which appears to have had a significant impact on the aquatic ecosystem due to soil runoff in the basin. In particular, in recent years, the distribution of rainfall has been shown to be inconsistent compared to previous years due to abnormal temperature phenomena such as El Niño.

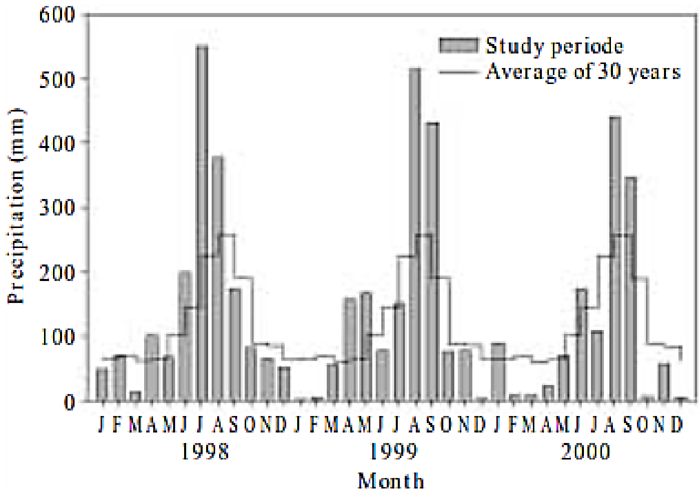

Figure 1. Monthly Precipitation of the Sokcho city

The hydraulic characteristics, watershed usage status, and pollution load of Hwajinpo Lake are shown in Table 1, and the basic unit for each source was based on data from the National Environmental Research Institute (1990). The amount of pollution generated was 270 and 48 kg/day for nitrogen and phosphorus, respectively.

Table 1. Hydrological characteristics and utilization of drainage basin and generation loadings (N, P) of Lake Hwajinpo.

Surface area (km^2)	2.3 ($0.46^1/1.84^2$)
Drainage area (km^2)	19.9 ($4.86^1/15.08^2$)
Maximum depth (m)	4.6 (3.5^2)
Drainage area : Surface area ratio (N)	8.7 ($11^1/8^2$)
Field area in drainage basin (km^2)	4.19
Forest area in draniage basin (km^2)	10.97
Livestock in drainage basin	
cattle	753
pig	936
poultry	227
Population in drainage basin (persons)	1,739
Generation N loading (kg/day)	270
Generation P loading (kg/day)	48

[1]North area, [2]South area

Water quality and bottom quality were surveyed at 4 to 7 peaks from 1998 to 2000 at two-month intervals, excluding the winter harvest season (Figure 2). Samples were collected using a PVC Van Dorn water sampler, and the collected samples were filtered through a GF/C 0.45 μm glass filter. Filter paper was cryopreserved and used to measure chlorophyll a, and the concentration was calculated using the method of Lorenzen (1967). The filtered water was used for nutrient analysis. Nitrate nitrogen and ammonia nitrogen were analyzed using an automatic water quality analyzer (AutoAnalyzer3, BRAN±LUEBBE), and dissolved inorganic phosphorus (PO4P) was analyzed using the ascorbic acid method of Standard methods (APHA, 1992). did. Samples for total phosphorus and total nitrogen analysis were unfiltered samples, and after persulfate digestion, total phosphorus was analyzed using the ascorbic acid method and total nitrogen was analyzed using an automatic water quality analyzer (AutoAnalyzer3, BRAN±LUEBBE) using the cadmium reduction method. COD was measured using the potassium permanganate method (water pollution process test method), and transparency was measured using a 30 cm transparent plate. Water temperature, dissolved oxygen, salinity, conductivity, and pH were measured. was measured on site using Multiprobe (YSI6000). Phosphorus (P) analysis by form in the reservoir followed the method of Hieltjes and Lijklema (1980).

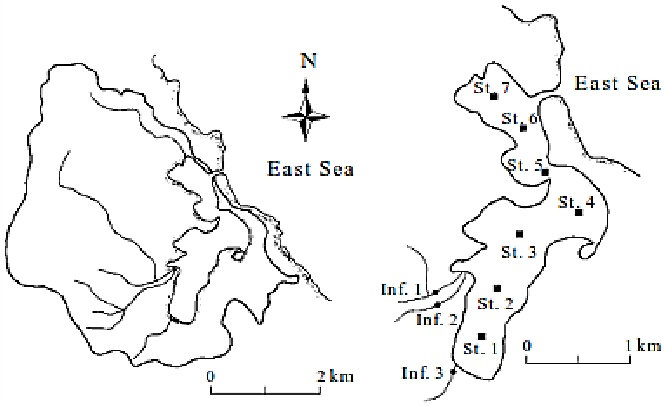

Figure 2. Map showing the watershed (left) and sampling sites (right) of Lake Hwajinpo

Phytoplankton was collected with a PVC Van Dorn water sampler, fixed with Lugol's solution, transported to the laboratory, left on a stable laboratory table for one week, then concentrated with Siphon for 48 hours in order from the top, and analyzed under an optical microscope by Mizuno (1964) and Hirose and Yamagishi (1977). Zooplankton was collected by a vertical seine from one selected point using a plankton net (diameter: 25 cm, net size: 75 µm), fixed in the field with neutral formalin to a final concentration of 5%, and transported to the laboratory. transported. For qualitative analysis of zooplankton, the samples were placed in a hole-slide glass, softened with Latic acid, and then dissected under a dissecting microscope for the external form that was characteristic of classification for each animal group. Afterwards, a temporary preparation was made in the specimen preservation solution and identified and classified under an optical microscope. Meanwhile, quantitative analysis took a certain amount (10 mL) of the concentrated sample, placed it in a Bogorov Counting Chamber, counted it, converted it into the number of individuals per unit volume (indiv/m^3), and expressed it as biomass. The Trophic State Index (TSI) was calculated from transparency, chlorophyll-a concentration, total phosphorus, and total nitrogen suggested by Carlson (1977) and Havens (2000).

3. Results and Discussion

3.1.Water temperature, salinity, dissolved oxygen and transparency

The water temperature ranged from 7.9 to 28.6 °C during the survey period, similar to seasonal changes in air temperature, and became lower the deeper you went. However, in November, a water temperature inversion phenomenon occurred at peak 7, where the deep water temperature was higher (Figure 3). This appears to be because, despite the shallow water depth, the surface water temperature was lowered by the atmospheric temperature, and vertical mixing between the surface and deep layers was extremely limited due to the strong chemical stratification (chemocline) formed in the middle layer. Heo *et al*. (1999) also revealed in an evaluation of the eutrophication of the East Coast lagoon that a water temperature inversion phenomenon occurs in the deep water during the winter. The vertical distribution of salinity appears to have a significant impact on the distribution of dissolved oxygen (DO) and water temperature. A chemical layer was formed at the water depth where salinity increased rapidly, and mixing up and down between water layers was found to be limited. As a result of these results, it is judged that the decomposition of organic matter progresses very slowly while maintaining an anaerobic state in the deeper water bodies, where stagnation of the water body intensifies. In addition, salinity was high due to the influence of seawater near the drainage area and in the depths of the North Lake (Figure 4). Hwajinpo Lake is always affected by seawater, and a chemical layer due to salt is formed in the middle layer, so mixing of surface and deep water bodies is extremely limited despite the shallow water depth. In estuaries or lagoons, chemical layers are formed due to freshwater inflow or groundwater infiltration (Huzzey *et al*., 1994). Chemical stratification can also be destroyed by wind, tides, and freshwater inflow (Schroeder *et al*., 1990; Uncles *et al*., 1990). Among these factors, freshwater inflow is the most important in the stratification and stratification process (Schroeder *et al*., 1990). In general, it is known that even though mixing occurs well in coastal lagoons, horizontal salinity distribution occurs due to the inflow of freshwater (Wolanski *et al*., 1990).

Dissolved oxygen in the surface layer showed a high concentration of over 15.6 mgO_2/L at all peaks in May 1999, which appears to be due to a significant increase in photosynthesis due to excessive reproduction of phytoplankton. At water depths below the chemical stratification layer, the dissolved oxygen concentration appears to have decreased rapidly due to a decrease in solubility due to salinity and the decomposition process of large amounts of organic matter. The low concentration of around 1 mgO_2/L in most water depths except for Peak 4 of South Lake in July 2000 is believed to be due to the movement of deep water with low dissolved oxygen to the surface due to mixing of water bodies by wind. In addition, there is a possibility that dissolved oxygen was consumed during the decomposition of organic matter due to the floating of the bottom layer containing organic matter. In shallow coastal lagoons, wind is an important factor causing mixing (Smith, 1990). Mizuno and Cho (1980) investigated Hwajinpo Lake and found that the dissolved oxygen in the deep layer was depleted, and that the anoxic layer rose to around -1 in the middle layer, especially in summer. In this survey, it was observed that an anoxic layer was formed in the depths seasonally from May, and it appears to repeat every year.

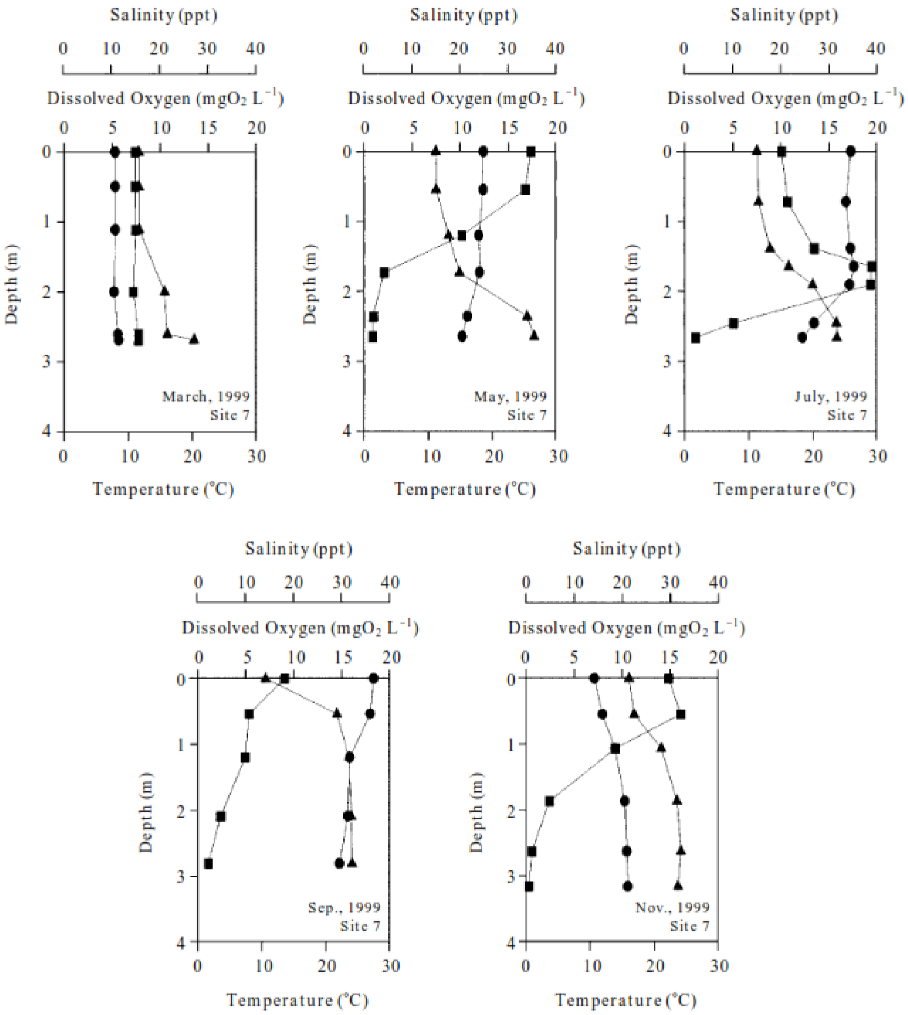

Figure 3. Vertical profiles of temperature, dissolved oxygen and salinity at the Site 3 (●: Temp.,■: DO, ▲: Sal).

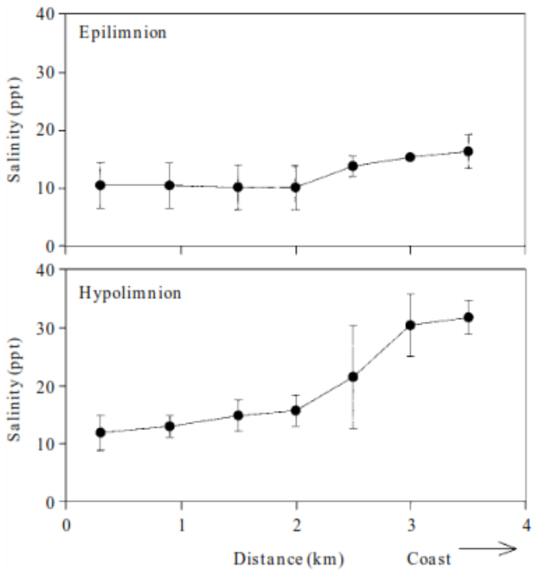

Figure 4. Horizontal variations of salinity (‰) in the epilimnion and the hypolimnion.

Major factors that affect transparency in the water environment include color caused by soluble substances, inorganic suspended solids such as silt, and organic suspended solids. Generally, in lakes, there is a high correlation between total phosphorus concentration and chlorophyll concentration, and transparency It is a generally known fact that the degree has an inverse correlation with the chlorophyll concentration (Oh, 1998). During the survey period, transparency ranged from 0.2 to 1.7 m, with the lowest value of 0.2 m at peak 3 in July 2000 (Figure 5). This was due to the massive breeding of phytoplankton and sediment runoff due to rainfall. In July 2000, the concentrations of chlorophyll-a and suspended solids (SS) in South Lake were as high as 145.8 mg m -3 and -1, respectively. Suspended matter in the lake is mainly caused by phytoplankton, inorganic suspensions introduced during rainfall, and floating lagoons within the lake. In Hwajinpo Lake, the South Lake shows lower transparency compared to the North Lake, and the COD and SS concentrations of 35.0 mg L are high. This is due to ①massive proliferation of phytoplankton due to eutrophication of the lake, ②inflow of inorganic suspensions due to rainfall, ③waves, etc. It is believed that the main cause is the increase in suspended solids due to disturbance and injury of the bottom layer due to weather changes. Heo *et al*. (1999) stated that the low transparency of Gyeongpo Lake and Yeongnang Lake, around 0.5 m, was due to an increase in suspended solids due to disturbance of the sedimentary layer due to dredging. According to the Organization for Economic Cooperation and Development (OECD, 1982) standards, an annual average transparency of 1.5 m or less is considered a hypertrophic unit. However, in the case of Hwajinpo Lake, it can be seen that it is a very eutrophic lake, even considering the inflow of soil and sand due to rainfall and disturbance of low quality due to wind during the survey period.

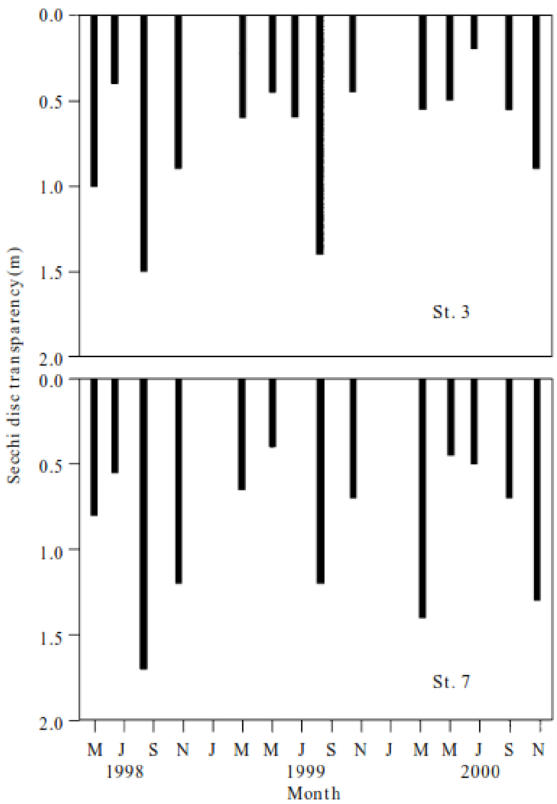

Figure 5. Monthly variations of Secchi disc transparency (m) in the Site 3 and Site 7

3.2.Nutrients, chlorophyll a concentration and eutrophication index (TSI)

The total phosphorus concentration in the surface layer was relatively higher in South Lake than in North Lake with a distribution of 0.024~0.275 mgP/L (Figure 6), and was 0.255 and 0.255 at peak 2 in September-January 1998 and peak 1 in July 1999, respectively. It was the highest at 0.275 mgP/L. Total phosphorus (TP) and dissolved inorganic phosphorus (DIP) showed high concentrations in the spring when seasonal cultivation begins and in the period after the rainy season. In addition, the higher concentration in South Lake compared to North Lake appears to be due to the fact that rivers flowing in from non-point pollution sources scattered around are biased towards South Lake. In particular, the concentration of ammonia nitrogen in South Lake also increased during this period, which appears to be due to agricultural drainage in the fertilized area. Heo *et al*. (1992) reported that the phosphorus concentration flowing into lakes generally increases during the rainy season. In addition, Heo *et al*. (1999) reported that phosphorus concentration decreases in lakes close to seawater in an evaluation of eutrophication in the East Coast lagoon, and a similar trend was found in Hwajinpo Lake. The introduced dissolved inorganic phosphorus is in a form that algae can use immediately, and large outbreaks of harmful algae occur when the inorganic phosphorus concentration is above 0.010 mgP/L (Sawyer, 1947). Therefore, the inorganic phosphorus concentration in Hwajinpo Lake averaged 0.015 mgP/L from 1998 to 2000, and the occurrence of harmful algae is expected. In particular, the high phosphorus concentration in Hwajinpo Lake is due to, first, the long residence time in the water body, and second, most of the sediment flowing in from the basin settles within the lake.

Second, this appears to be because the sediments discharged into the water body are actively extracted from low-quality soil due to the formation of a deep anoxic layer as the flourishing aquatic weeds around the lake repeatedly grow and die (Kwon, 2000).

Theis and McCabe (1978) reported that extraction from low-quality soil occurs faster under anaerobic conditions than under aerobic conditions. Total nitrogen was higher in the South Lake than in the North Lake, ranging from 0.24 to 3.15 mgN/L in the surface layer (Figure 7). In the case of total nitrogen (TN), it increased during the spring and rainy seasons, and as with total nitrogen, the concentration of ammonia nitrogen was also high, which appears to be largely related to the fertilization of surrounding farmland in spring. Nitrogen loss greatly increases with the level of land-use and increased fertilization, which is believed to be due to the ease of movement of soluble nitrogen complexes.

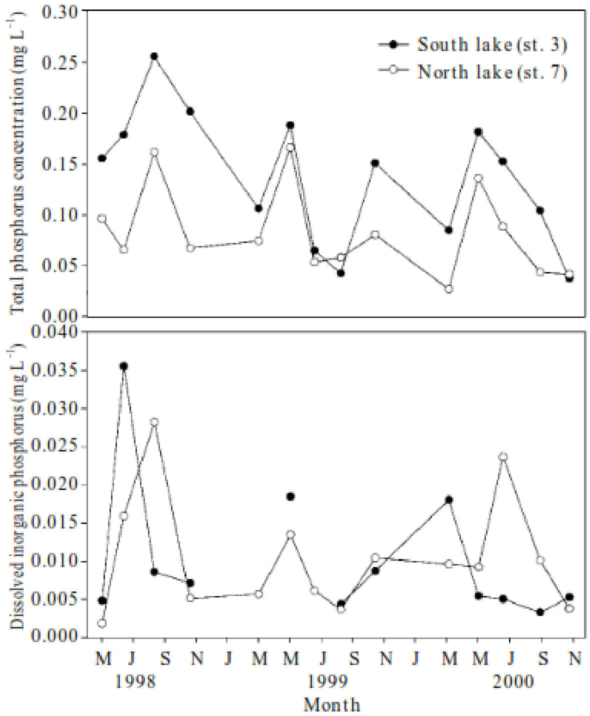

Figure 6. Monthly variations of TP and DIP concentration (mgP/L) in the Site 3 and Site 7

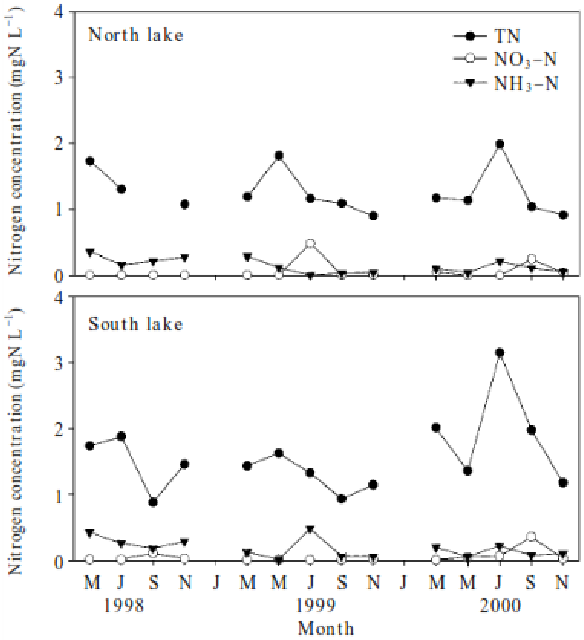

Figure 7. Monthly variations of nitrogen concentration (mgN/L)

Nitrate nitrogen in the surface layer was depleted in most places, but nitrate nitrogen was observed at low concentrations near the inflow water of South Lake or near the coast. Low nitrate nitrogen concentration acts as a limiting nutrient for phytoplankton growth. It is judged that there is a high possibility that there is (Table 2). Ammonia nitrogen was relatively high in the South Lake, ranging from 0.00 to 0.78 mgN/L, and the average value in the North Lake during the survey period was relatively low, ranging from 0.00 to 0.32 mgN/L. In particular, in July 1999, North Lake showed depletion. The composition ratio of nitrogen by type in the surface and deep layers was organic nitrogen, ammonia nitrogen, and nitrate, with organic nitrogen taking up the majority, and ammonia nitrogen was more than twice as high in the deep layer compared to the surface layer (Figure 8). This appears to be more than twice as high in the deep layer compared to the surface layer due to anaerobic decomposition due to the formation of anoxic layer in the deep layer.

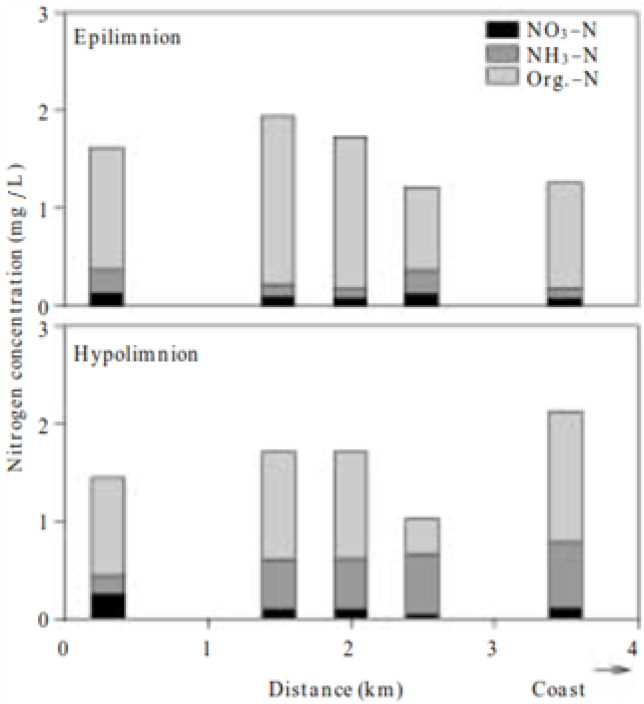

Figure 8. Distributions of the monthly average nitrogen concentration (NO3-N, NH3-N, Org-N) in the epilimnion and the hypolimnion according to distance.

The TN/TP weight ratio ranged from 3 to 44 and was lowest at Peak 2 in September 1998, and the average values for the South and North Lakes were 14 and 17, respectively, which was lowest in the South Lake. In addition, the TN/TP ratio was mostly lower than 16, and since the low TN/TP ratio was seen during the period when the amount of chlorophyll-a increased, it was determined that nitrogen rather than phosphorus was acting as a limiting nutrient. The TN/TP weight ratio at each vertex was found to increase slightly from the South Lake to the North Lake. Considering that South Lake is more eutrophic than North Lake, the TN/TP ratio is believed to be significantly related to eutrophication. Additionally, the TN/TP ratio showed a small value overall, which is believed to be because nitrogen is relatively small compared to phosphorus. Therefore, in order to prevent eutrophication of the lake, it is judged that it is absolutely necessary to reduce the human load flowing from the basin. In general, nitrogen is known to act as a limiting nutrient in seawater, and Hwajinpo Lake appears to exhibit characteristics of seawater. U.S. EPA (1976) stated that the Chl-a concentration was over 10 mg/L, and Likens (1975) estimates it to be more than 30 mgP/m^3 for total phosphorus and total nitrogen, and Vollenweider (1968) reported 10 mgP/m^3 for total phosphorus and inorganic nitrogen, respectively, and 300 mgN/L was classified as eutrophication level. Based on these standards, Hwajinpo Lake appears to be exceeding the level of eutrophication.

The concentration of chlorophyll-a in the surface layer showed a relatively wide range of 3.5 to 145.8 mg/m^3 during the survey period. Seasonally, it tended to be higher in spring than in summer, but in the case of Nam Lake, the value was high at around 50 mg/m^3 in November, the winter season. During the survey period, the average concentration in Nam Lake in November was 60.3, 68.9, and 54.7 mg/m^3 in ’98, ’99, and ’00, respectively. This seems to be the result of the massive proliferation of diatoms, as the concentration of silicate in the spring appears to be depleted and the silicon introduced in the summer decreases sharply in November. Therefore, it is considered highly expected that silicon acted as a limiting nutrient for the growth of diatoms. The concentration appears to be higher in South Lake compared to the North Lake, because it is less affected by seawater. Furthermore, a higher concentration of nutrients in North Lake providing favorable conditions for the growth of phytoplankton. In addition, since there is a positive correlation between nitrogen concentration and chlorophyll a concentration (Figure 9), it appears that nitrogen is likely to act as a limiting nutrient in Hwajinpo Lake.

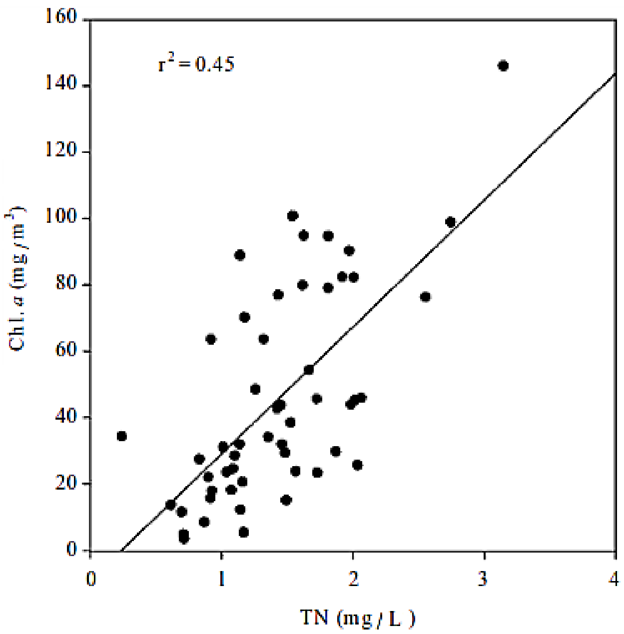

Figure 9. Scatterplot of Chl. a vs. TN

Table 2. Monthly variations of nutrients and chlorophyll a concentration. Values are average of south and north lake of Hwajinpo.

Year	Month	Site	SiO_2 (mg L^{-1})	TP (mg L^{-1})	DIP (mg L^{-1})	TN (mg L^{-1})	NO_3-N (mg L^{-1})	NH_3-N (mg L^{-1})	Chl. *a* (mg m^{-3})	TN/TP
'98	May	South	–	0.159	0.004	1.88	0.00	0.43	45.5	12
		North	–	0.121	0.002	1.90	0.00	0.32	34.7	16
	Jul.	South	–	0.126	0.033	1.77	0.00	0.21	42.1	17
		North	–	0.128	0.011	1.00	0.00	0.14	11.6	12
	Sep.	South	–	0.199	0.012	1.01	0.55	0.19	10.4	6
		North	–	0.163	0.021		0.01	0.21	7.2	–
	Nov.	South	–	0.131	0.008	1.44	0.01	0.28	60.3	15
		North	–	0.091	0.033	1.17	0.00	0.28	33.4	13
'99	Mar.	South	–	0.143	0.013	1.48	0.00	0.12	40.6	11
		North	–	0.073	0.005	1.15	0.00	0.20	28.6	16
	May	South	–	0.220	0.020	1.77	0.00	0.02	81.1	8
		North	–	0.177	0.014	1.81	0.00	0.07	86.9	10
	Jul.	South	–	0.169	0.018	1.94	0.00	0.25	69.9	15
		North	–	0.071	0.007	1.36	0.24	0	22.2	20
	Sep.	South	–	0.058	0.016	0.97	0.01	0.12	24.5	18
		North	–	0.051	0.029	0.96	0.00	0.05	26.1	19
	Nov.	South	–	0.124	0.009	1.03	0.00	0.05	76.2	8
		North	–	0.071	0.010	0.76	0.01	0.05	17.9	11
'00	Mar.	South	0.0	0.081	0.019	1.75	0.00	0.18	48.7	22
		North	0.1	0.049	0.016	1.36	0.06	0.17	53.1	33
	May	South	0.0	0.195	0.007	1.41	0.07	0.07	33.1	7
		North	0.1	0.079	0.009	0.69	0.00	0.04	33.2	9
	Jul.	South	21.1	0.134	0.023	2.95	0.04	0.50	122.4	22
		North	6.9	0.094	0.022	2.01	0.04	0.26	34.8	22
	Sep.	South	8.4	0.118	0.003	1.80	0.38	0.08	92.6	16
		North	6.8	0.056	0.008	1.26	0.30	0.10	26.5	23
	Nov.	South	4.9	0.047	0.005	0.95	0.09	0.09	36.8	22
		North	4.9	0.045	0.004	0.81	0.08	0.31	10.3	18

Table 3. TSI (trophic state index), during warm season average (July-September)

		TSI				Average
		SD	Chl	TP	TN	
1998	South	67	69	76	59	68
	North	62	60	75	57	63
1999	South	63	76	68	59	67
	North	60	71	63	58	63
2000	South	74	85	74	63	74
	North	69	73	66	61	67
Avg.	South	68	77	73	61	70
	North	64	68	68	59	64
Total average		66	72	70	60	67

In light of this evidence, it is believed that nitrogen acts as a limiting nutrient for the growth of phytoplankton in Hwajinpo Lake. In addition, it can be assumed that the size of the particles that scatter light in the water is large, and in this case, the growth of algae appears to be highly likely to be limited by feeding on zooplankton (Figure 10). The results of this analysis are highly reliable and consistent, and generally agree well with results obtained by other direct methods (Havens, 2000).

The data used to calculate TSI were from July and September, considering the growth season of phytoplankton. The average values of South Lake and North Lake are 67-74 and 63-67, respectively, showing that South Lake is more eutrophic (Table 3). This appears to be similar when compared to the TSI (56~79) of the east coast lagoon calculated by Heo *et al.* (1999). Havens (2000) suggested the following regarding TSI.

TSI (TP)<TSI (CHL), P is limiting

TSI (TN)<TSI (CHL), N is limiting

TSI (TP) and TSI (TN)<TSI (CHL), neither P nor N are limiting

TSI (CHL)<TSI (SD), light is limiting

TSI (CHL)>TSI (SD), zooplankton grazing is limiting

3.3.Moisture, solids, COD, TN and TP in the sediment

Looking at the moisture and solid content of five peaks, peaks 1, 3, 4, 5, and 7, the solid content was found to be around 40% at all points except peak 5 (Figure 11). In the case of peak 5, unlike other peaks, it showed a solid content of about 70% or more. This is due to the fact that, unlike other peaks, due to surrounding construction, the low-quality components were more sand particles than organic matter, microorganisms, and plant corpses. It appears that there is. This seems to be due to the fact that, unlike other peaks, the low-quality components were more sand particles than organic matter, microorganisms, and plant corpses due to nearby construction. was investigated. The COD concentration of the surface bottom was 12.2 mg/gdw in North Lake. The surface sediment COD of South Lake was approximately twice as high as that of North Lake, with 32.1 mg/gdw in South Lake.

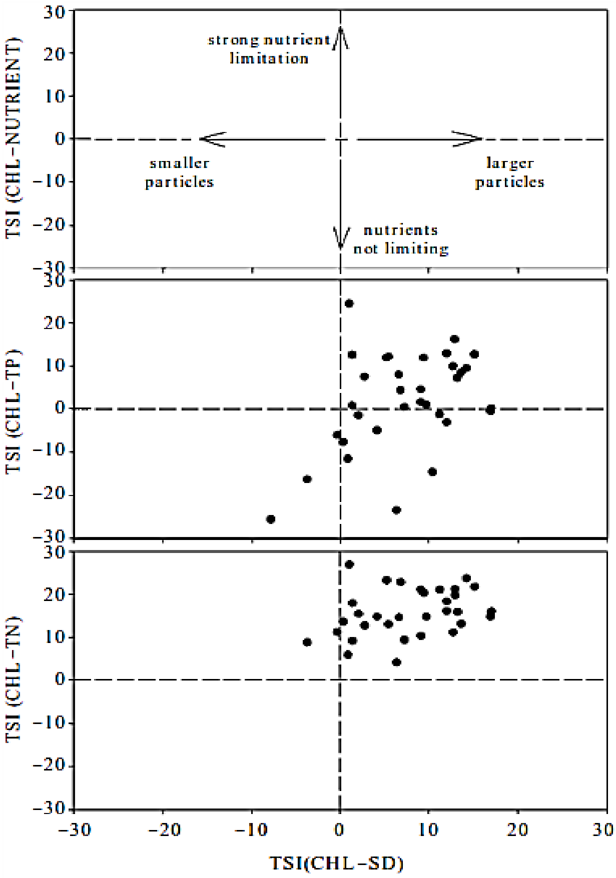

Figure 10. Differences among trophic state index (TSI) indicating the extent of nutrient limitation and the composition of seston

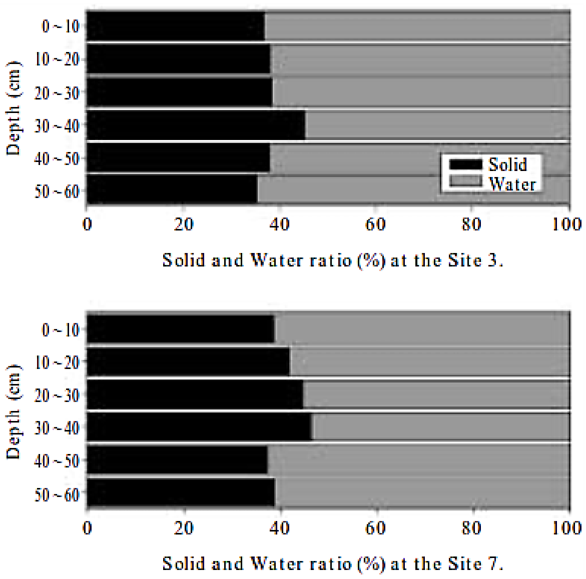

Figure 11. Vertical distributions of solid and water ratio in lake sediment

This appears to be due to ① the inflow of organic matter due to influent water, ② the deposition of plankton corpses that proliferate excessively compared to the North Lake, and ③ the outflow of organic matter is restricted due to the narrow drainage area (Figure 12). The average concentration of total phosphorus in the low-quality surface layer was 1.05 mgP/gdw and 1.11 mgP/gdw in South Lake and North Lake, respectively. Additionally, the average concentration of total nitrogen was 2.81 mgN/g and 2.88 mgN/g in South Lake and North Lake, respectively. Peak 5 showed particularly low concentrations, and total phosphorus and total nitrogen were lower than other peaks, at less than 0.15 mgP/gdw and 0.7 mgN/gdw, respectively. However, in both items, there was no significant difference between the southern and northern lakes (Figure 13). It is estimated that Hwajinpo Lake has accumulated a lot of organic matter, aquatic plants, and dead organisms over the long period of time since its creation, forming a bottom layer of about 1 to 3 meters deep throughout the lake. The total phosphorus content of low quality was found to be highest at peak 1, approximately 1.38 mgP/gdw, and lowest at peak 4, at 0.03 mgP/gdw.

The amounts of Adsorbed-P(H2O±NH4Cl), NAI-P, Apatite-P, and Residual-P by existence form at two points were 0.08, 0.17, 0.01, and 1.12 mgP/gdw at peak 1, respectively, and at peak 5. showed very low values compared to peak 1, at 0.001, 0.019, 0.000, and 0.006 mgP/gdw, respectively. This is believed to be due to differences in low-quality components. When looking at phosphorus (P) by existence type as a percentage, approximately 82% was Residual-P at all vertices except vertex 5, and NAI-P was found to be approximately 73% at vertex 5 (Table 4).

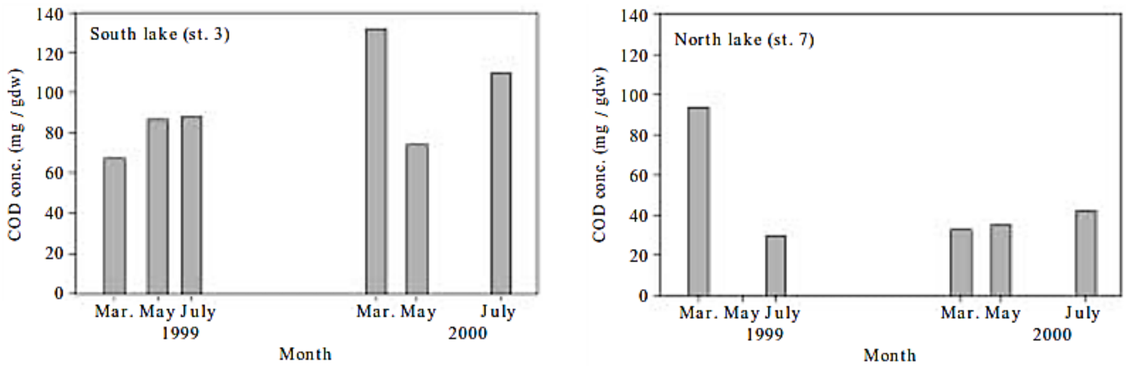

Figure 12. Monthly variation of COD in surface sediment at the Site 3 and Site 7

Table 4. Fractional composition of phosphorus in the sediment (mgP/gdw)

Ext. sol.	Adsorbed-P		NAI-P	Apatite-P	Residual-P	T-P
	H_2O	NH_4Cl	NaOH	HCl		
Site 1	0.0699 (5.1%)	0.0100 (0.7%)	0.1697 (12.3%)	0.0058 (0.4%)	1.1227 (81.5%)	1.3781
Site 3	0.0248 (2.7%)	0.0048 (0.5%)	0.1267 (14.0%)	0.0091 (1.0%)	0.7415 (81.8%)	0.9069
Site 4	0.0611 (5.4%)	0.0122 (1.1%)	0.1589 (14.1%)	0.0040 (0.4%)	0.8923 (79.1%)	1.1285
Site 5	0.0004 (1.6%)	0.0010 (4.0%)	0.0186 (72.8%)	0.00004 (0.1%)	0.0055 (21.4%)	0.0255
Site 7	0.0561 (4.9%)	0.0132 (1.2%)	0.1684 (14.7%)	0.0093 (0.8%)	0.9004 (78.5%)	1.1475

( ): fractional percentage of total phosphorus

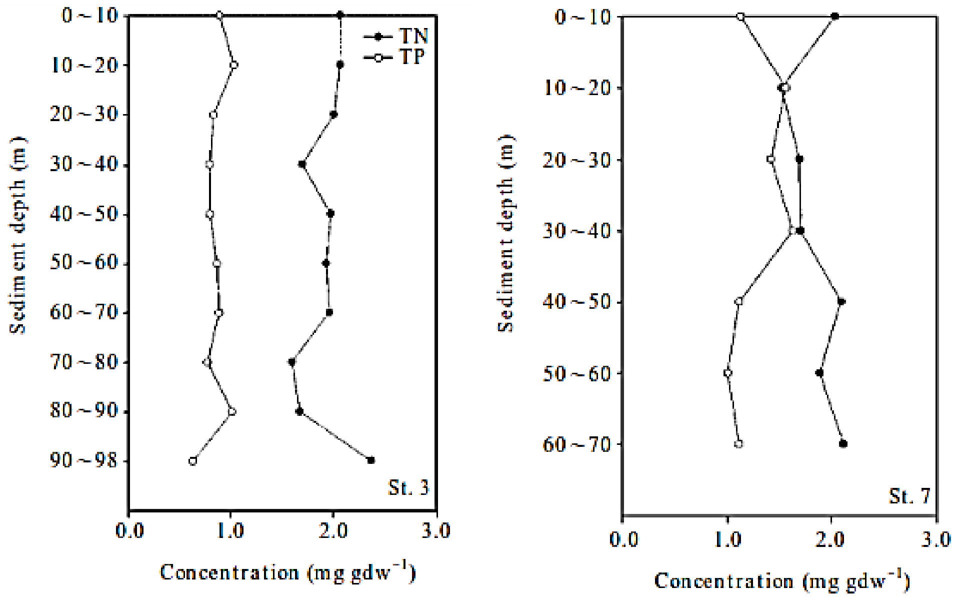

Figure 13. Vertical distributions of TP and TN concentration in lake sediment

It is known that Adsorbed-P and NAI-P have a very high possibility of dissolution even with small physical and chemical changes within the lake. At all peaks, 3.2 to 6.5% of the total phosphorus in the entire bottom was found to be Adsorbed-P, and NAI-P was found to be Adsorbed-P. At peak 5, it was the highest at 72.8%, and at other peaks it was 12 to 14%. In general, the direction of phosphorus (P) movement between the bottom and the water body depends on the difference in phosphorus concentration between the pore water of the bottom and the water layer, and when the balance of phosphorus (P) is disturbed by the abundance of phosphorus (P) in the upper water layer, the direction of phosphorus (P) movement between the bottom and the water body varies. It is known that phosphorus (P) movement to the soil occurs, and conversely, if the amount consumed as phytoplankton grows in the water body reduces the phosphorus (P) concentration to a level below the equilibrium concentration, it can induce phosphorus (P) leaching from the bottom. (Imboden and Lerman, 1980). In particular, NAI-P is very sensitive to environmental changes and can move depending on the pH or redox potential of the water, so the amount of phosphorus (P) in this form is very important. In addition, this study found that most of the phosphorus in the reservoir was composed of Residual-P and NAI-P, which can be seen as being at a similar level to the results of the study in Soyang Lake (Jeon and Park, 1989; Park, 1992).

3.4. Animal/phytoplankton

A total of 61 species of phytoplankton appeared in Hwajinpo Lake, including 22 species of green algae, 19 species of diatoms, 13 species of cyanobacteria, 2 species of Euglena, 2 species of dinoflagellates, and the classes of yellow flagellates, brown flagellates, and yellow-green algae. There was one paper each. In 1998, the dominant species of major flora was found to be Oscillatoria sp., a blue-green alga, from May to November. In 1999, the overall dominant species was euglenoids, and in 2000, green algae were found to be dominant in March and May, and blue-green algae were dominant in July and September.

This phenomenon of blue-green algae dominance seems to be a similar result to the seasonal change in which blue-green algae increases in summer in eutrophic lakes in temperate regions and the phenomenon of blue-green algae dominating most lagoons in the summer in other lagoons in the East Sea.

In addition, in the case of Hwajinpo Lake, it is believed that due to the shallow water depth, the bottom layer is easily disturbed by wind or waves, which may have contributed to the increase in the amount of phytoplankton present by increasing the supply of nutrients to the surface layer. Typically, blue-green algae blooms occur in eutrophic and nitrogen-depleted lakes (Tezuka, 1988). In the case of Hwajinpo Lake, biodiversity is low, but the amount of living organisms appears to be very large (Figure 14). In other words, the number of species was limited, but the number of individuals per species was high. This appears to be because it has no natural enemies or competitors and is rich in nutrients (Kim *et al.*, 2001). In the investigation of Cho *et al.* (1975), it was revealed that the netplankton facies is very simple due to the unstable brackish lake state. A survey by Hong *et al.* (1969) showed that biomass and diversity were higher in South Lake compared to North Lake because it was not directly affected by inflow from rivers and fields and seawater. Cho *et al.* (1975) and Pyeon (1984) also reported that South Lake had high diversity, and that freshwater species were mostly dominant.

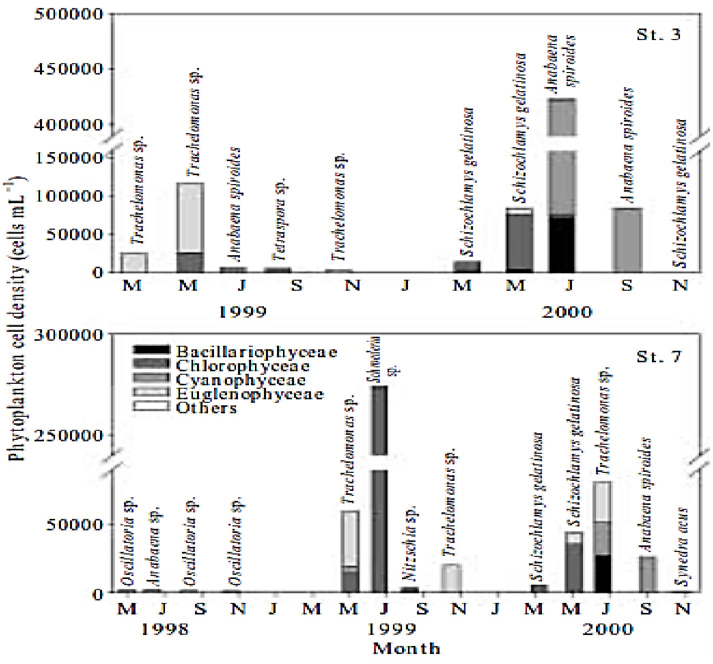

Figure 14. Seasonal variations of phytoplankton cell density (cells m/L) and dominant species.

A total of 28 species of zooplankton in 3 phyla and 4 classes were identified in 1998, reaching to the highest biomass at 712,137 indiv/m^3 in November. In 1999, there were 28 species in 3 phyla and 4 classes, with a larger population in South Lake than in North Lake. There were a total of 19 species of zooplankton in 3 phyla, 4 classes, and 3 orders in Hwajinpo Lake in 2000, of which 5 species in 3 classes were protozoa, 5 species in 1 class were arthropods, 6 species in 1 class were cyclozoans, and 2 species were larvae. It was a bell. In Hwajinpo Lake, unlike inland freshwater lakes, zooplankton with characteristics of freshwater species, saltwater species, and saltwater and brackish water species all appeared.

Seasonally, the most species appeared in November. The proportion of whorls of the total zooplankton was found to be very high at peaks 3 and 7 in March, at 99.5% and 94.5%, respectively. In July, the arthropod phylum was dominant in the South Lake, and the angiosperm phylum was dominant in the North Lake. Larvae appeared frequently, accounting for more than 70% of the total biomass at all peaks except peak 1 in July. During this survey period, a dominance phenomenon by a single species was generally observed due to physical and chemical influences within the lake ecosystem, and there was no clear trend in overall biomass (Figure 15).

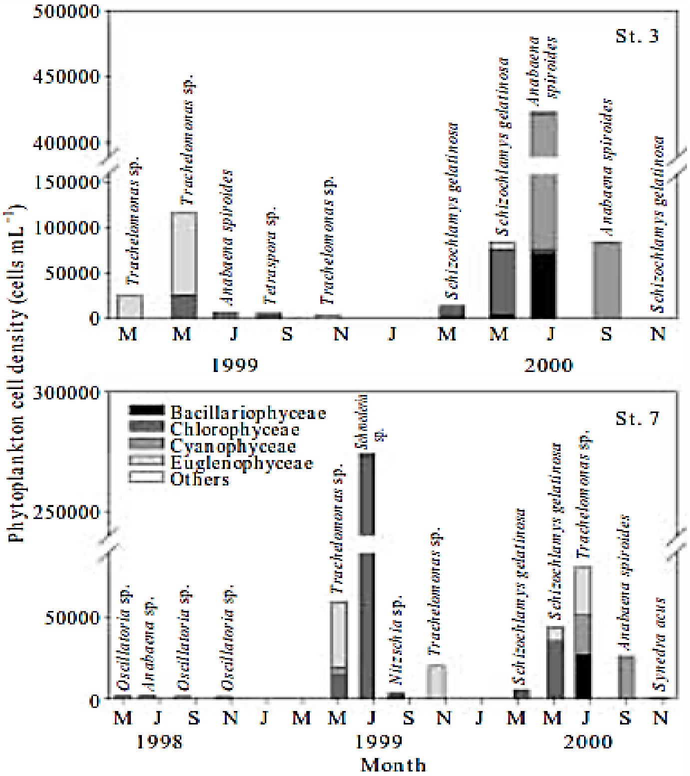

Figure 15. Seasonal variations of zooplankton density (indiv/m^3) and dominant species

The predominance of rotifer species at most locations during the survey period was due to the mass reproduction of species tolerant to water temperature and the removal of macrozooplankton due to selective predation by fish, thereby reducing the predation pressure of macrozooplankton on rotifers. However, it is believed that there is a cause. In addition, crustaceans and copepods belonging to the crustacean class of the arthropod phylum, and rotifers belonging to the protozoa phylum are microherbivores that directly feed on phytoplankton, which is the primary producer at the lower trophic level of the aquatic ecosystem, and are involved in the process of biological production and water circulation. It plays an important role, and species composition and biological quantity vary depending on physical, chemical, and biological changes. This will also affect benthic biota and fish fauna. Zooplankton, which appeared as a dominant species during the survey period, is a small number of species, and biomass changes are occurring due to the dominant species. The species diversity index and dominance index ranged from 0.31 to 1.72 and 0.2 to 0.99, respectively. According to Cho (1985), species diversity is directly related to the stability of the ecosystem and is low in physicochemically dominated ecosystems (which are easily influenced by physical and chemical limiting factors) and high in biologically dominated ecosystems. As shown in this survey, it is believed that the high biomass and diversity index in the fall is because the lake ecosystem is stable.

Total nitrogen in the surface layer ranged from 0.24 to 3.15 mgN/L, and changes by peak and period showed a similar trend to total phosphorus. Nitric acid nitrogen in the surface layer was mostly depleted at the peak, and its concentration increased as it moved to the North Lake adjacent to the coast. The composition ratio of each type of nitrogen in the surface and deep layers was in the order of organic nitrogen, ammonia nitrogen, and nitrate nitrogen. In the case of ammonia, the value was more than twice that in the deep layer compared to the surface layer. TN/TP was high in the North Lake, ranging from 3 to 44. The eutrophication index (TSI) according to the Carlson (1977) equation showed transparency and chlorophyll a to be 65, 62, 72 and 65, 73, and 79, respectively, in '98, '99, and '00, and total phosphorus and total nitrogen. were 76, 66, 70 and 59, 59, 62, respectively. A total of 61 species of phytoplankton appeared, of which there were 22 species of green algae, 19 species of diatoms, 13 species of cyanobacteria, 2 species of Euglena, 2 species of dinoflagellates, and 1 species each of yellow flagella, brown flagella, and yellow-green phytoplankton. There were a total of 19 species of zooplankton in 3 phyla, 4 classes, and 3 orders in 2000, of which 5 species were in 3 classes in the phylum Protozoa, 5 species in 1 class in Arthropoda, 6 species in 1 class in Cyanozoa, and 2 species were larvae.

Conclusions

To study the inland water ecological characteristics of Hwajinpo Lake, physicochemical water quality items, total phosphorus (TP), Total nitrogen (TN), transparency (SD), and chlorophyll-a concentrations were investigated. The water temperature showed seasonal differences, ranging from 10 to 30 °C, and in November, the deep water temperature was slightly higher than the surface water temperature. Looking at the vertical distribution of salinity, although there are differences by peak and season, a chemical stratification (chemocline) was formed at a depth of about 1m, and it was higher in North Lake, which is adjacent to the sea, than in South Lake. DO was frequently observed at low concentrations of around 1 mgO_2/L when mixing water bodies and water depths below the chemical stratum. Furthermore, transparency ranged from 0.2 to 1.7 m, and COD concentration ranged from 0.2 to 20.5 mgO_2/L. The total phosphorus concentration in the surface layer was distributed between 0.024 and 0.275 mgP/L, showing a relatively higher concentration in the South Lake compared to the North Lake. Seasonally, high values were observed in spring and after the rainy season. The concentration of chlorophyll-a in the surface layer ranged from 3.5 to 145.8 mg/m^3. Seasonally, higher concentrations appeared more frequently in spring than in summer, and in the case of Nam Lake, high values of around 50 mg/m^3 were seen even in November, the winter season.

References

APHA (American Public Health Association). 1992. Standard Methods for the examination of water and wastewater 18thed, Washington D.C.

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography, 22: 361-369.

Cho, G.-S., Hong, S. W., and Na, G. H. 1975. Comparative study of landwater conditions and plankton phase of brackish lakes on the east coast. Korean Journal of Meat Science and Technology, 8: 25-37.

Eom, G.-b. 1971. A study on the production structure in appeal. Journal of Botany, 14: 15-23.

Havens, K.E. 2000. Using Trophic State Index (TSI) Values to Draw Inferences Regrding Phytoplankton Limiting Factors and Seston Composition from Routine Water Quality Monitoring Data. Korean Journal of Limnology, 33(3): 187-196.

Heo, W.M., Kim, J.O. and Kim, B. 1999. A study of water quality variations on the artificial aeration in water supply system (Lake Dalbang). Journal of Korean Society and Water Quality, 15(3): 335-343.

Hieltjes, A.H.M. and L. Lijklema, 1980. fractionation of inorganic phosphates in calcareous sediment. Journal of Environmental Quality,9(3): 405-407.

Hirose, H. and T. Yamagishi. 1977. Illustration of the Japanese fresh-water algae. Uchidaroka-kuno Publishing Co. Japan.

Hong, S.-W., Na, G.-H. 1975. Hydrogeometric study of East Coast brackish water lakes. Seongdaenon Collection, 20: 87-95.

Hong, S.-W., Cho, G.-S., and Na, G.-H. 1969. Study on water quality and plankton in Hwajinpo. Korean Journal of Meat Science and Technology, 2: 35-42.

Horne, A.J. and C.R. Goldman. 1994. Limnology, 2nd ed. MaGraw-Hill, New York, etc., 576p.

Hu, W. M., Kim, B. Ch., Ahn,T. S., and Lee, J. 1992. Phosphorus Budget and Phosphorus Budget from the Soyang Lake basin and dam. Korean Journal of Physical Education and Mathematics, 25: 207-214.

Hu, W.-m., Kim, B.-ch., Jeon, M. S. 1999. Eutrophication assessment of east coast lagoons. Journal of the Korean Meat Science Society, 32(2): 141-151.

Huzzey, L.M., M.A. Noble and G.F.m. Ryan. 1994. Temporal changes in stratification in Mobile Bay. Eos 75(3), 81.

Imboden, D.M. and A. Lerman. 1980. Chemical models of lakes. pp.341-356. In A. Lerman [ed.] Lakes: chemistry, geology, physics, Springer-Verlag, New York, NY.

Jeon, S., Park, Y. 1989. On the existence form and leaching potential of phosphorus contained in Soyang Lake sediments. Korean Journal of Meat Science and Technology, 22: 262-272.

Jeon, S.-H., Jeon, W., and Yoo, S.H. 1996. Water quality survey of natural lakes on the East Coast, (Gangneung City Council) East Coast Lake Conservation Symposium, Gangneung, 83-118p.

Jo, G. S. 1985. Overview of freshwater plankton in Korea and its geographical distribution 2) About copepods. Horim Fisheries Aquaculture Development Research Institute, 62-103p.

Kim, I.-h. 2001. Contribution of aquatic animals to the purification of water quality in brackish lakes on the East Coast. Symposium on East Coast Lagoon Water Quality Conservation Measures. Wonju Regional Environmental Officer Lee Cheong, Samcheok University Environmental Technology Research Institute, 73-81p.

Kim, H., Ilki Hwang, and Yangbae Kim. 1997. Seasonal changes in aquatic plant distribution and phytoplankton communities in brackish water lakes along the Gangwon coast. Gangneung National University, 48-76p.

Kim, J.-m., Lee, S.-g., Heo, S.-b., Kim, D.-y., Lee, J.-h., and *et al.* 1981. Marine ecological study of brackish lakes (Hyangho, Songjiho, and Yeongnangho) on the East Coast. Bulletin of KORDI, 3: 29-38.

Kwon, S.-y. 2002. Inland water ecology study of Hwajinpo Lake. Samcheok University Engineering Master's Thesis.

Likens, G.E. 1975. Primary production of inland aquatic ecosystem. In H. Lieth and R.H. Whittaker (eds). Primary productivity of the biosphere. springer Verlag. New York. 185-202p.

Lorenzen, C.J. 1967. Determination of chrolophyll and pheo-pigments: Spectrophotomentric equation. Limnology and Oceanography, 12: 343-346.

Mizuno, T. 1964. Illustrations of the freshwater plankton of Japanl Hoikusa publishing co., LTD.

Mizuno, T., and K.S. Cho. 1980. Paleolimnological study from the present status of the lake hwajin-po and yeong-rang. Korean Journal of Limnology, 13: 17-22.

National Environmental Research Institute. 1990. Study on Paldang Waterway Protection Comprehensive Plan, pp. 251-268.

OECD. 1982. Eutrophication of Waters: Monitoring, Assessment and Control. OECD, Paris. 154p.

Oh, I. 1998. Ecological study of Daecheong Lake. Journal of the Korean Meat Science Society, 31(2): 79-87.

Osamu, M., and Cho, K.S. 1984. Urea, DOC, DON, and DOP in two brackish lagoons on the eastern coast of Korea. Korean Journal of Limnology, 17: 73-80.

Park, J. 1992. Study on phosphorus dynamics in Soyang Lake, Master of Science thesis, Kangwon National University.

Pyeon, Ch.G. 1984. Report on the environment and biota of Gisu Lake (Hyangho, Maeho, Yeongrangho, Songjiho, Hwajinpo). Journal of Jeju National University, 18: 93-105.

Sawyer, C.N. 1947. Fertilisation of lakes by agricultural and industrial drainage. New England Water Works Association. 61: 109-27.

Schroeder, W.W., Dinnel, S.P., and Wiseman, W.J.W. 1990. Salinity stratification in a river-dominated estuary. Estuaries, 13(2): 145-154.

Smith, N.P. 1990. Wind domination of residual tidal transport in a coastal lagoon. In: Cheng, R.T. (ed.), Residual currents and longterm transport, New Yori: SpringerVerlag, 123-133p.

Smith, V.H. 1982. The nitrogen and phosphorus dependence of al gal biomass in lakes: An empirical and theoretical analysis. Limnology and Oceanography, 27: 1101-1112.

Tezuka, Y. 1988. Phosphorus as a possible factor stimulating in the appearance of Anabaena bloom in the south basin of Lake Biwa. Japanese Journal of Limnology, 49: 201-214.

Theis, T.L., and P.J. McCabe. 1978. Phosphrus dynamics in hypereutrophic lake sediments. Water Resources, 12: 667685.

Uncles, R.J., J.e. Ong and W.K. Gong. 1990. Observations and analysis of a stratification-destratification event in a tropical estuary. Estuarine, Coastal and Shelf Science, 31: 651-665.

U.S. EPA. 1976. Water Quality Criteria Research of the U.S. Environmental Protection Agency, proceeding of an EPA Sponsored Symposium, EPA-600 (3-76-079): 185.

Vollenweider, R.A. 1976. Advance in defining critical loading levels for phosphorus in lake eutrophication. Mem. Inst. Idrobiol. 33: 53-83.

Wolanski, E., Y. Mazda, B. King and S. Gay. 1990. Dyanmics, flushin and trapping in Hinchinbrook Channel, a giant mangrove swamp, Australia. Estuarine, Coastal And Shelf Science, 31: 555-579.