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Initial Preliminary Studies in National Long-Term Ecological Research (LTER) Stations of Daechung Reservoir

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Major objective of our study was to introduce initial researches of national long-term ecological monitoring studies on Daechung Reservoir, as one of the representative lentic reservoir ecosystems in Korea. For the long-term ecological research (LTER), we conducted preliminary field monitoring during 2008～2009 and analyzed biological parameters such as phytoplankton, zooplankton, and freshwater fish along with chemical water quality and empirical model analysis. According to phytoplankton surveys, major taxa have varied largely depending on seasons and sites sampled. Overall phytoplankton data showed that cyanophyta dominated in the summer period and diatoms dominated in the winter. In zooplankton analysis, 25 species including 20 rotifers, 3 cladocerans and 2 copepods were collected during the survey. The relative abundance of rotifers (86.5%) was always greater than that of cladocerans (6.3%) or copepods (5.1%). There were distinct spatial and inter-annual changes in the abundance of zooplankton in the reservoir, displaying similar patterns in three sites with the exception of S3 during the study. According to fish surveys, 8 families and 39 species were observed during 2008～2009. The most dominant fish was an exotic species of *Lepomis macrochirus* (23%), indicating an severe influence of exotic species to the ecosystem. TP averaged 17.9 μg L^{-1} (6～80 μg L^{-1}), which was judged as a mesotrophy, and showed a distinct longitudinal gradients. TN averaged 1.585 mg L^{-1} during the study and judged as hypereutrophic condition. Unlike TP, TN didn't show any large seasonal and spatial variations. Under the circumstances, nitrogen limitation may not happen in this system, indicating that nitrogen control is not effective in the watershed managements. These data generated in the LTER station will provide key information on long-term biological and water quality changes in relation to global warming and some clues for efficient reservoir ecosystem managements.

Key words : ecological study, LTER, national long-term ecological monitoring station, Daechung Reservoir

INTRODUCTION

The importance of long-term ecological monitoring researches in lentic ecosystems, based on global and national (regional) scale, have been emphasized due to approaching global warming (temperature changes) as well as rapid regional eutr-

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ophication and flow modification. World-wide and regional ecolological monitoring studies of natural lake and reservoir ecosystems (Zilov, 2001; straškrábová *et al*., 2005; White *et al*., 2008) showed that water resources are rapidly eutrophied over the time by nitrogen and / or phosphorus inputs from the watershed due to intense agricultural activities, rapid urbanization, and increased human population. Such nutrient enrichments in the waterbodies were often influenced by regional modifications of flow regime (flow reduction or increases), land-use patterns, and use of the water resource and overall these factors influenced up to human health throughout the drinking water-use as well as physical habitat and aquatic organisms.

Also, global influence (not regional) by climate changes and global warming (Vitousek, 1994; Burn and Simonovic, 1996; Rosa *et al*., 2002) was considered as important factor regulating or modifying the functions of lake and reservoir ecosystems. Global warming influencing the weather condition such as air temperature and light quantity is caused by CO_2 increases in the atmosphere, and this altered seasonal and temporal dynamics of chemical conditions of nitrogen and phosphorus (Wang *et al*., 2009), phytoplankton (Yoshimura *et al*., 2009), zooplankton (Helland *et al*., 2007), macroinvertebrate (Durance and Ormerod, 2007), and fish (Dudgeon *et al*., 2006) in lake and reservoir ecosystems. Under such circumstances, accelerated eutrophication and reduced biodiveristy in lentic ecosystems were diagnostic evidence over the world (Ferrari *et al*., 2007; Komatsu *et al*., 2007). For these reasons, long-term ecological monitoring researches are widely conducted as global and national (regional) scales in United States (US LTER Network, 1998; Jensen *et al*., 2007), Canada (White *et al*., 2008) and England (Johnes, 1999) and now national-level long-term ecological monitoring in Korean government is in stating point.

Generally, long-term ecological research is defined as a study on time-serial monitorings of various ecological parameters at the same region or ecoregion using a same methodology. Last several decades, few studies related to the long-term ecological monitoring were conducted in Korea, and only several researches over the period of less than 5～6 years have conducted in Korea. Long-term researches on freshwater ecosystem in Korea were usually confined to chemical water quality and water amount, some parameters associated with ecological structure and functions. In early 2000, some interests for long-term ecological research increased in relation with climate changes and global warming in Korea. As consequences, long-term ecological monitoring researches on forest, freshwater, estuary, and ocean were in progress all over the country. To coexist with human being and nature, it is necessary to understand structures and functions of aquatic ecosystems. Thus, the priority in long-term ecological researches was to analyze patterns and changes of various ecological parameters over the period. Most previous studies in North American and European lakes and reservoirs have wide ranges from microtaxa such as phytoplankton and zooplankton to higher consumer such as macroinvertebrates and fishes (Dudgeon *et al*., 2006; Durance and Ormerod, 2007; Helland *et al*., 2007; Yoshimura *et al*., 2009).

Korean government designated some long-term ecological monitoring stations such as terrestrial ecosystems (forests), aquatic ecosystems (wetlands, reservoirs), and estuary ecosystems in cope with global warming in the future. Daechung Reservoir, which is a study station in this paper, is one of the national long-term ecological monitoring stations designated in 2008 by the Ministry of Environment, Korea. Over 95% of all Korean lakes including Daechung Reservoir is man-made lake (reservoir) and were built since 1950s. So, the station represents lentic ecosystems in Korea and is most important source of drinking water. The reservoir were formed to be different fundamentally, compared to natural lakes. Thus, the reservoir system has morphological (structural) and functional differences, compared with natural lakes (Thornton, 1990; Wetzel, 1990), so long term national monitorings were required for lake conservation and protection in Korea.

Major objectives of our study was to introduce the initial researches of national long-term ecological monitoring station, which is Daechung Reservoir as one of the most representative reservoirs in Korean freshwater ecosystem. For the accumulation of long-term ecological information, we conducted preliminary field monitorings during 2008～2009 and analyzed biological parameters such as phytoplankton, zooplankton, and freshwater fish along with chemical water quality and empirical model analysis. These data generated in this station may provide some key information on long-term water quality and ecological changes in relation to global warming and some clues for efficient reservoir ecosystem managements.

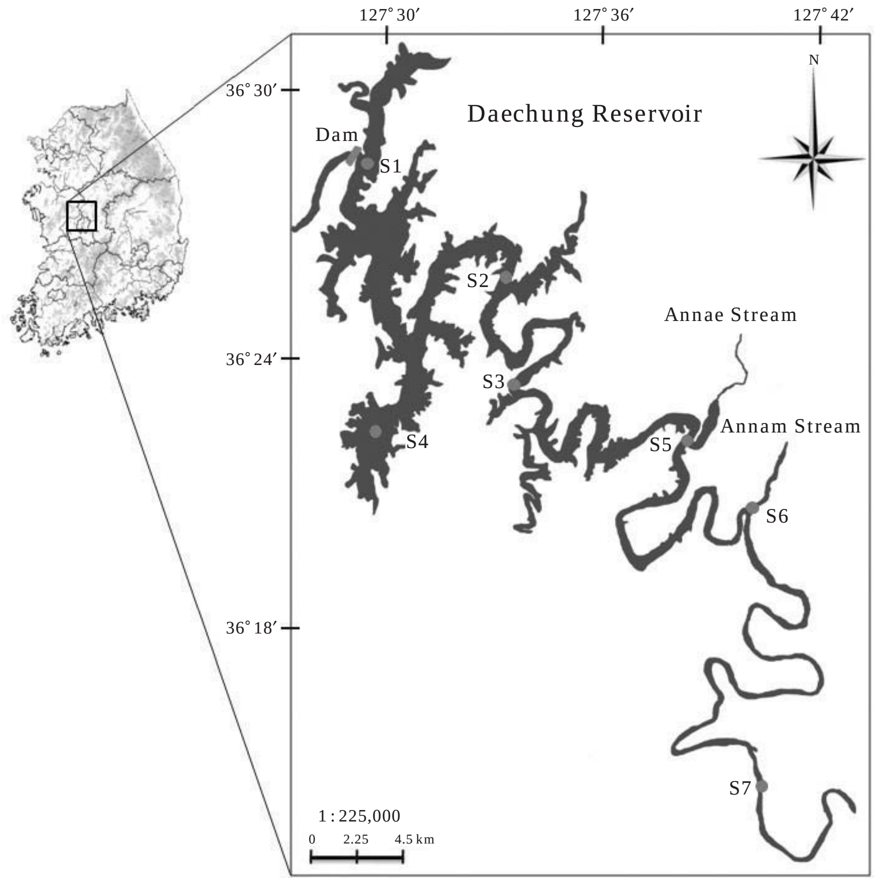

Fig. 1. Map showing the sampling sites (S1 ~ S4) of phytoplankton, zooplankton, and water quality in Daechung Reservoir. For the fish survey, we added more sites (S5 ~ S7), which is described in the section of "sampling sites".

MATERIALS AND METHODS

1. Descriptions of sampling sites and periods

Daechung Reservoir is a large dam reservoir, which was built in 1980 and supplies mainly drinking-water to Daejeon and Cheongju cities as well as mid-downstream region of the Geum River. The reservoir has surface area of 72.8 km^2, total length of 80 km, and watershed area of 4,134 km^2. For the long-term ecological monitoring purposes, we choose 4 regular sites (Fig. 1) of Daechung Reservoir Station, which were considered longitudinal gradients from the up-reservoir to down-reservoir (dam) within the reservoir and in these sites we monitored spatial and temporal dynamics of phytoplankton and zooplankton and water quality parameters. In addition to the regular sites, we added 3 more sites including two inflowing tributaries of Annae Stream and Annam Stream, and one mainstem inflowing site of Geum River. The sites of S5, S6, and S7 added are as follows; S5: Janggye bridge, Janggye-ri, Annae-myeon, Okcheon-gun, Chungcheongbuk-do (N36° 22′16.7″ E127° 38′12.8″), S6: Yeonju-ri, Annam-myeon, Okcheon-gun, Chungcheongbuk-do (N36° 20′48.7″ E127° 39′ 51.2″) and S7: Ewon-ri, Ewon-myeon, Okcheon-gun, Chungcheongbuk-do (N36° 14′25.3″ E127° 40′ 14.5″). The sampling sites for long term ecological research (LTER) are as follows;

S1: Dam site, Micheon-ri, Moonweui-myeon, Cheonwon-gun, Chuncheongbuk-do (N36° 30′ 39.6″ E127° 29′57.6″).
S2: Wheonam large bridge, Saeum-ri, Boeun-gun, Chungcheongbuk-do (N36° 25′57.6″ E127° 33′1.5″).
S3: Banga-sil, Daejeong-ri, Gunbuk-myeon, Okcheon-gun, Chungcheongbuk-do (N36° 23′ 16.8″ E127° 32′54.5″).
S4: Chudong intake tower, Dong-gu, Daejeon

city (N36° 22′15.0″ E127° 28′44.3″). Inflow streams

The samplings were conducted during 2008～2009 as an initial part of long-term ecological research (LTER). During the study period, phytoplankton surveys and water quality analysis were conducted once per month, while zooplankton and fish surveys were 4～5 times a year.

2. Analytical methods

1) Phytoplankton analysis

We collected 1 L water from the surface layer in the four LTER sampling sites and the samples were fixed using Lugol's solution for standing crop analysis of the phytoplankton. Initial 1 L water were concentrated by 50 mL according to natural precipitation method.

The quantitative sampling of phytoplankton were conducted by phytoplankton net of 20 μm mesh-size and the cell counting of phytoplankton were measured by optical plastic plankton counter (MATSUNAMI Class ind. LTD, Japan). We also measured cell numbers of cyanophyta, chlorophyta, distoms, dinoflagellate and cryptophyta using photo microscope (Nikon ECLIPS 80*i*, Japan) under the 200 magnification. Also, we analyzed community structures of phytoplankton using species dominance index (Simpson, 1949) and species diversity index (Shannon and Weaver, 1949) and compared them in the sampling sites. The equations for two indices are as follows:

(I) Simpson's dominance index

$$\lambda = \sum \frac{N_i^2 - N}{N(N-1)}$$

(N=the total number of *i*-th species; N_i=the total number of *i*-th species)

(II) Shannon-Weaver diversity index

$$H' = -\sum P_i \operatorname{Log}_{10} P_i$$
$$(P_i = N_i / N)$$

2) Zooplannkton analysis

We collected 20 L surface water near 0.5 m depth using a 3.21 Van Dorn water sampler for zooplankton analysis. This water was filtered through a 35 μm mesh net, and the zooplanktons retained were preserved with 10% formalin (final concentration 4%). Large-size (0.2 mm and exclusively copepods and cladocerans) and small-size zooplanktons (0.2 mm and mostly nauplii and rotifers) were counted separately because they differed substantially in their numerical densities. Large zooplankton was counted using an inverted microscope at 2550 magnification. Small zooplankton was counted at 100400 magnification. Zooplankton taxa were identified to genus or species (except for juvenile copepods) after taxa indentification approaches of Koste (1978), Smirnov and Timms (1983), Koste and Shiel (1987) and Bayly (1992).

3) Fish collections

For the fish sampling, kick-net (4×4 mm) and casting-net (5×5 mm) were used. All fishes were identified at the sampling locations and then immediately released, except for same ambiguous fishes for the identification. Ambiguous specimens to identify were preserved in 10% formalin solution and bring it to the laboratory to further taxa and species identification. Fish classification were followed by approaches of Kim and Park (2002) and Nelson (1994). For the community structure analysis, we calculated for species dominance index (Magurran, 1988), species diversity index (Pielou, 1969), species evenness index (Pielou, 1969), and species richness index (Margalef, 1958).

4) Empirical models

For the analysis of physicochemical water quality data, we applied the monthly data from water quality monitoring sites conducted by the ministry of environment, Korea (MEK). According to Korean monsoon characteristics usually the rainfall centralizing in the summer, we also analyzed the precipitation effect on water quality using rainfall data obtained from Daejeon Meteorological Station, Korea. Also, we developed empirical models using major trophic variables such as total phosphorus (TP), total nitrogen (TN), TN : TP ratios, and chlorophyll-*a* (CHL). To predict and assess the nutrient status we analyzed empirical relations of Log_{10}-transformed TP-TN, TP-N : P ratios, TN-N : P ratios, TP-SD, and TN-SD. We also conducted correlation and regression analysis using water quality variables among the sampling sites and seasons using SPSS statistical package (Window version 12.0). Through the statistical analysis, we analyzed the relations and primary factors regulating trophic sate and key nutrients regulating the phytoplankton productions in the long-term sites.

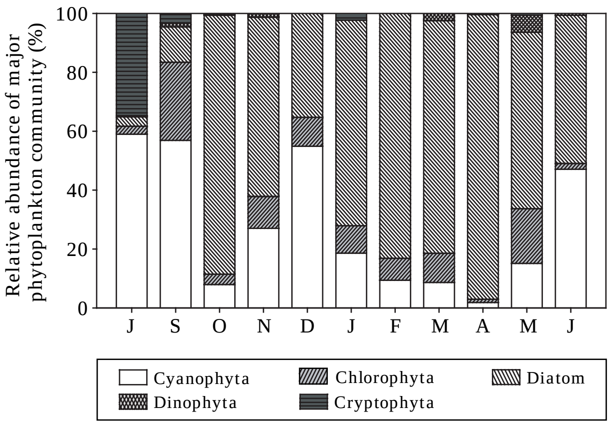

Fig. 2. Relative abundance of dominant phytoplankton taxa sampled during 2008～2009.

RESULTS AND DISCUSSION

1. Species fauna and community structures of phytoplankton

During the study, seasonal and spatial variations were showed in dominant species. In 2008, minimum number of species were observed on July in the Site 4 (S4), whereas maximum were observed at all sites in September (Table 1). Relative abundance analysis of phytoplankton community showed that cyanophyta dominated the phytoplankton community by 59% and 57%, respectively in July and September and that cyanophyta and diatom dominated the phytoplankton community by 47% and 50%, respectively during the June. In other seasons of January～May and October～November, diatoms dominated the community by 77% (Fig. 2). In 2009, relative abundance of cyanophyta was minimum (1.8%), increased by 47% in June, and then peaked by 59% in July. The diatom peak rapidly decreased by 7.9% in October 2009. When the standing crop of diatoms peaked on October 2008, total cell number was 2.1×10^3 cells $\cdot$ mL^{-1} and the diatom was made of 88% of the total phytoplankton compositions

The season when the abundance of diatoms was highest (96.7%) was April 2009 and the standing crop was 1.3×10^3 cells $\cdot$ mL^{-1}. chlorophyta showed consistant appearance during the study period, but the relative abundance of chlorophyta was relatively low (9.2), Compared to other taxa. flagellate algae such as dinophyta and cryptophyta had minor abundance (>5% of the total) except for short period of July 2008 (35.1%). According to analysis of dominant taxa in each sampling site,

Table 1. Total number of phytoplankton species (S, cell $\cdot$ mL^{-1}), cell number (N, cell $\cdot$ mL^{-1}), and community indices of species dominance index (H', cell $\cdot$ mL^{-1}) and species diversity index (λ, cell $\cdot$ mL^{-1}) during 2008～2009.

Sampling	Site	S	N	H'	λ
Jul. 2008.	S1	9	111	0.4106	1.169
	S2	5	8	0.3038	1.139
	S3	3	100	0.5079	1.892
	S4	1	3	1	0
Sep. 2008.	S1	17	345	0.2197	2.022
	S2	16	205	0.2849	1.935
	S3	23	415	0.3264	1.892
	S4	25	450	0.2229	2.243
Oct. 2008.	S1	8	710	0.8008	0.518
	S2	5	520	0.7980	0.441
	S3	8	855	0.7076	0.658
	S4	8	310	0.6791	0.767
Nov. 2008.	S1	6	50	0.2857	1.498
	S2	4	95	0.4401	1.056
	S3	4	50	0.3469	1.168
	S4	9	80	0.3544	1.449
Dec. 2008.	S1	3	30	0.3678	1.011
	S2	6	100	0.3232	1.373
	S3	5	85	0.2997	1.365
	S4	3	40	0.5833	0.736
Jan. 2009.	S1	5	30	0.1954	1.561
	S2	4	80	0.5807	0.822
	S3	5	55	0.2424	1.468
	S4	5	40	0.2308	1.494
Feb. 2009.	S1	7	200	0.1734	1.821
	S2	6	135	0.1791	1.738
	S3	7	385	0.6760	0.771
	S4	4	290	0.6701	0.674
Mar. 2009.	S1	6	30	0.1379	1.792
	S2	11	170	0.2079	1.929
	S3	6	55	0.3266	1.421
	S4	9	150	0.1812	1.887
Apr. 2009.	S1	7	70	0.2340	1.673
	S2	5	1030	0.9428	0.168
	S3	9	145	0.2098	1.784
	S4	6	115	0.2334	1.560
May 2009.	S1	15	490	0.1636	2.140
	S2	7	115	0.2143	1.678
	S3	5	30	0.1954	1.561
	S4	10	225	0.1905	1.889
Jun. 2009.	S1	11	170	0.1107	2.262
	S2	9	125	0.1871	1.881
	S3	7	125	0.1452	1.981
	S4	9	355	0.1880	1.833

the frequency of diatom dominance was >83.0% during January～March and >66.0% during April ～June along with 75.0% during October～December. In the period of June and September, cyanophyta of *Anabaena flos-aquae* and *Microcystis aeruginosa* dominated by 75.0% the phytoplankton community. In the analysis of class-level taxa, diatoms were most dominant taxa, and *Aulacoseria* of the datum taxa was 32% in the analysis. And the second dominant taxa were *Asterionella* which is a diatom, and followed by *Oscillatoria* (13.6%) along with *Microcystis aeruginosa*, *Anabaena flos-aquae*, *Cyclotella* and *Staurastrum* in the order of abundance. We found that *Aulacoserea* dominated the community in all four sites during October～November and *Asterionella* dominated the community during January～April. These results indicate that the texa dominated appeared during the cold season, so the dominance may be regulated by low temperature. According to analysis of Simpson's dominance index, site 4 (S4) showed highest (1.0) in July, while site 2 (S2) also showed value (0.9428) in June. In the meantime, species diversity index had inverse correlation with the dominance index; species diversity index was 0.0 in the site 4 during July, while it was highest (2.262) in the site 1 during June (Table 1).

2. Monitoring of zooplankton fauna and abundance

A total of 25 species of zooplankton were identified (20 rotifers, 3 cladocerans and 2 copepods) during the survey. The relative abundance of rotifers (86.5%) was always greater than that of cladocerans (6.3%) or copepods (5.1%) (Fig. 3). Among the rotifers, *Brachionus calyciflorus*, *Keratella cochlearis*, and *Polyarthra* spp. were the most common species. *Bosmina longirostris* accounted for more than 63% of the total cladoceransabundance. Copepods were dominated by cyclopoids. Adult cyclopoid abundances were low and the relative abundances of nauplii was more than 47% during study.

There were distinct spatial and inter-annual changes in abundance of zooplankton in the lake (Fig. 4), displaying similar patterns in three sites with the exception of S3 during study. Annual mean of total zooplankton abundance in three sites (S1, S3, and S4) was much higher than in S2 for both years. High inter-annual variation of total zooplankton abundance was observed in three sites

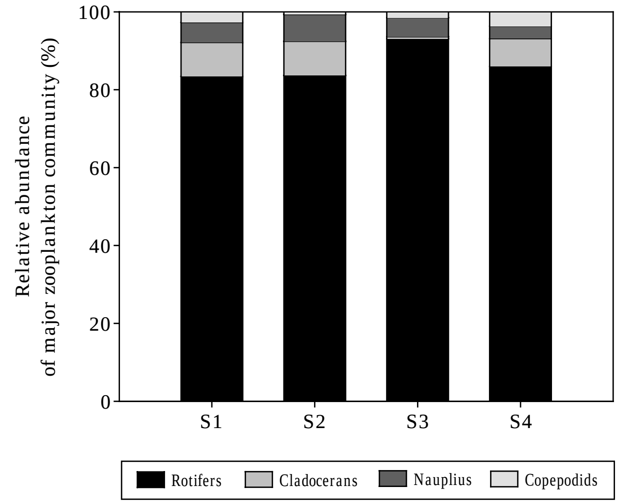

Fig. 3. Relative abundance of major zooplankton community sampled during 2008～2009.

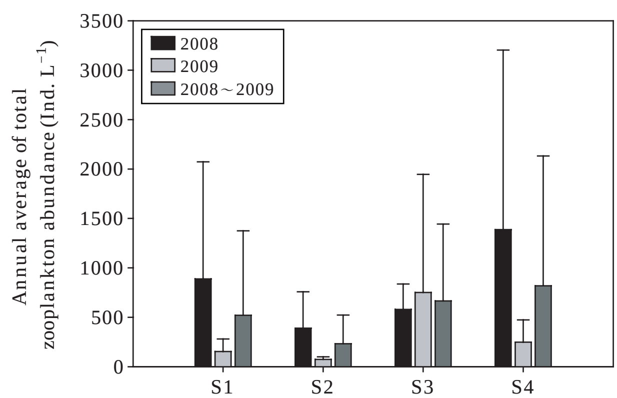

Fig. 4. The spatial variation of total zooplankton abundance, based on annual averages.

of S1, S2, and S4, while low variation was observed in S3 during the study.

3. Fish fauna and compositions

According to fish surveys, based on 7 times collections, during 2008～2009, 8 families and 39 species (3,908 individuals) were observed in Daechung Reservoir. Cyprinidae was the most dominant with 67.3%, showing the highest appearance ratio and exotic Centrarchidae also showed a high appearance with 27.9%. Among the Cyprinidae, it was dominant for *Squalidus chankaensis tsuchigae*, *Zacco platypus*, *Opsariichthys uncirostris amurensis*, and *Hemiculter eigenmanni* which species usually prefer lentic region and inhabit

Table 2. Fish fauna and compositions collected at Daechung Reservoir (RA, Relative abundance; ※, Endemic species; ★, Endangered species; ▲, Exotic species).

Scientific name	2008									2009								
	S1	S2	S3	S4	S5	S6	S7	Total	RA (%)	S1	S2	S3	S4	S5	S6	S7	Total	RA (%)
Cyprinidae																		
Cyprinus carpio				7		3		10	0.60	1							1	0.04
Carassius auratus			1	2	5	54	24	86	5.16						6		6	0.27
Carassius cuvieri			1					1	0.06									
Acheilognathus lanceolatus			47		24		9	80	4.80			43		7	35	15	100	4.46
※*Acheilognathus yamatsutae*						59	20	79	4.74						9	4	13	0.58
Acheilognathus rhombeus			1				4	5	0.30					7		16	23	1.03
Pseudorasbora parva						1		1	0.06									
Pungtungia herzi						1	20	21	1.26						1	26	27	1.20
※★*Pseudopungtungia nigra*							4	4	0.24							13	13	0.58
※*Coreoleuciscus splendidus*							6	6	0.36							43	43	1.92
※*Sarcocheilichthys variegatus*						1	1	2	0.12						3	8	11	0.49
※*Sarcocheilichthys nigripinnis morii*							2	2	0.12									
※*Squalidus chankaensis tsuchigae*	9	5	13	7	15	44	9	102	6.12	45		37	26	78	45	2	233	10.39
Hemibarbus labeo		1	3					4	0.24	2		3	1		8	5	19	0.85
Hemibarbus longirostris							3	3	0.18						9	20	29	1.29
Pseudogobio esocinus	4	1	1	8	20	25	5	64	3.84	11		3	5	8	44	9	80	3.57
※★*Gobiobotia macrocephala*																15	15	0.67
※★*Gobiobotia brevibarba*																1	1	0.04
Rhynchocypris oxycephalus							1	1	0.06									
Zacco temmincki							14	14	0.84							22	22	0.98
※*Zacco koreanus*																1	1	0.04
Zacco platypus	40	6	8	4	33	37	42	170	10.20	45	50	72	23	29	101	177	497	22.17
Opsariichthys uncirostris amurensis	19	4	2	11	74	134	5	249	14.95	41	24	38	11	32	11	3	160	7.14
※*Hemiculter eigenmanni*	25		18	14	15	26		98	5.88	42	23	249	3	2	17		336	15.0
Cobitidae																		
Misgurnus anguillicaudatus							1	1	0.06									
Iksookimia koreensis							2	2	0.12									
Cobitis lutheri						8		8	0.48					4			4	0.18
Bagridae																		
Pseudobagrus fulvidraco						9		9	0.54					6			6	0.27
Osmeridae																		
Hypomesus nipponensis												2					2	0.09
Plecoglossus altivelis										11							11	0.49
Centropomidae																		
Siniperca scherzeri							6	6	0.36		1			2		1	4	0.18
※*Coreoperca herzi*							14	14	0.84							5	5	0.22
Centrarchidae																		
▲*Lepomis macrochirus*	235	13	197	71	1			517	31.03	97	65	155	53				370	16.5
▲*Micropterus salmoides*	1	30	29	19	7			86	5.16	19	33	16	42	9			119	5.31
Odontobutidae																		
※*Odontobutis platycephala*							5	5	0.30						1	1	2	0.09
※*Odontobutis interrupta*														1	1	2	4	0.18
Gobiidae																		
Rhinogobius giurinus														1			1	0.04
Rhinogobius brunneus							4	4	0.24			1			7		8	0.36
Tridentiger brevispinis	1	6	2		2	1		12	0.72	22	29	2	6	7	10		76	3.39
Number of individuals	334	66	323	143	196	403	201	1666		336	225	621	170	193	308	389	2242	
Number of species	8	8	13	9	10	14	22	32		11	7	12	9	14	16	21	33	
Dominance	0.52	0.26	0.40	0.28	0.21	0.18	0.09	0.15		0.16	0.19	0.25	0.20	0.22	0.17	0.23	0.12	
Diversity	1.04	1.61	1.36	1.66	1.84	1.99	2.64	2.37		2.03	1.73	1.68	1.77	1.92	2.13	2.07	2.46	
Eveness	0.50	0.77	0.53	0.75	0.80	0.75	0.85	0.68		0.85	0.89	0.68	0.80	0.73	0.77	0.68	0.70	
Richness	1.20	1.67	2.08	1.61	1.71	2.17	3.96	4.18		1.72	1.11	1.71	1.56	2.47	2.62	3.35	4.15	

withour any preference for lotic or lentic region. In addition, some species, such as *Gobiobotia macrocephala*, *Gobiobotia brevibarba*, and *Zacco temminckii* were only appeared in a inflow stream site (S7) remained lotic status over year. The most dominant species in the study was *Lepomis macrochirus* with 22.7%, relative abundance (RA) and subdominant species were *Zacco platypus* (17.1% RA), *Hemiculter eigenmanni* (11.1% RA) and *Opsariichthys uncirostris amurensis* (10.5% RA), respectively. In addition, bluegill sunfish (*Lepomis macrochirus*) was appeared all survey sites except S6 and S7 where maintain the lotic condition.

According to fish survey result of 2008, 32 fish species and 1,666 individuals were sampled and dominant familes were Cyprinidae (60.1%) and Centrarchidae (36.2%) as similar as the entire survey results. It was dominated in the order of RA as *Lepomis macrochirus* (31.0% RA) *Opsariichthys uncirostris amurensis* (14.9% RA), and *Zacco platypus* (10.2% RA). In 2009, 33 speceis and 2,242 individuals were sampled and Cyprinidae (72.7%) and Centrarchidae (21.8%) were dominant as same as other year with slight difference of percentage. *Zacco platypus* was the most dominant species with 22.2% RA and *Lepomis macrochirus* (16.5% RA) and *Hemiculter eigenmanni* (15.0% RA) were subdominant, respectively. From the annual analysis, Comparison of RA with top 10 species in the appearance showed the similar pattern with just slight ratio differences. It was almost same order in appearance but showed a little placing changes in annual analysis. This order change was occurred only in species showing relatively lower RA. Endemic and endangered species were increased in 2009 than in 2008. In case of endemic speceis, it was appeared. total 13 species for endemic fish. According to the annual variation of endemic species, 9 species was presented in 2008 and 12 species was in 2009. It was added 4 more new species in 2009 but disappeared 1 species previously sampled. In case of endangered species, 1 species, *Pseudopungtungia nigra* was sampled in 2008 and 2 more species, *Gobiobotia macrocephala* and *Gobiobotia brevibarba* were added in 2009. Though species diversity and richness was not showing an wide annual variation, these two indices were slightly increased in 2009. In dominance index, It was appeared higher in inside of the dam in 2008 but decreased in 2009. Also, diversity and richness were presented higher in inflow stream than inside of the dam but dominance index was showing low (Table 2).

Now, most of survey were limited in short-term research on specific sites from necessity in Korea. These short term study could respond the condition on some specific sites on certain period. However, it could hardly speak for a long-term response in aquatic ecosystem. According to environmental variations, ecosystem change was appeared with long term response instead of short term except some specific case (e.g. direct inflow of toxicants and pollutants). Also, cause and effect in this change were occurred in a time lag (Magnuson, 1990). Therefore, it should cause some serious problems to manage and conserve environment if we didn't care for the long-term respose in research (Magnuson, 1990). Variation analysis of fish fauna in Daechung Reservoir should require this long term study to understand its ecosystem. It have study background for fish fauna in Daechung Resercoir previously conducted (Choi *et al*., 1977; Choi *et al*., 1997) However, most of them was res-

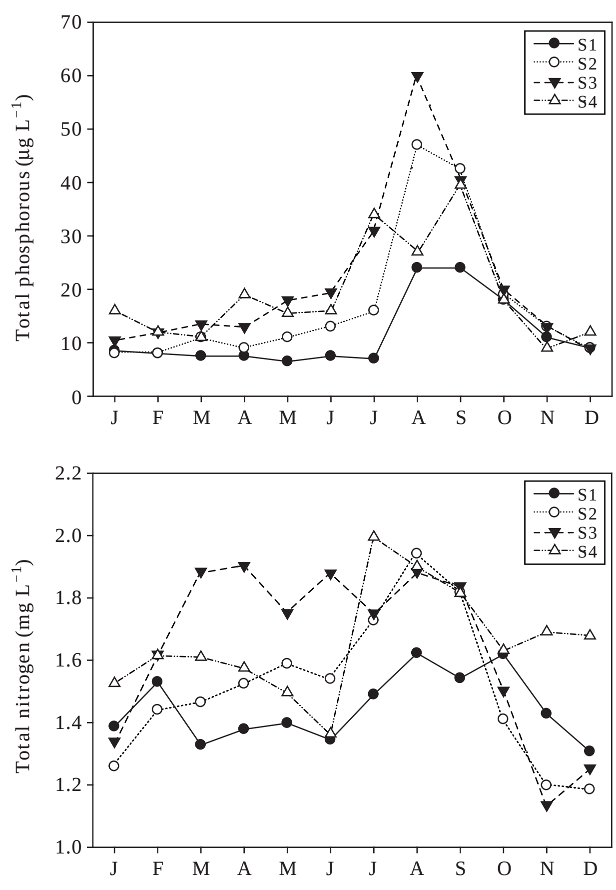

Fig. 5. Temporal distirbutions of Total Phosphorus (TP) and Total Nitrogen (TN) in the Daechung Reservoir.

tricted to short term study so that it was difficult to analyze ichthyological variations by the comparison of present and past result. Moreover, research result usually could under or over-estimate by the seasonal variation of species appearance. Also, it could misjudge the result as human affected condition, even occurred in a natural condition under the analysis of short term dataset (Penczak *et al*., 1998).

4. Ambient nutrient concentrations and empirical models

Monthly average concentration of TP was 17.9 $\mu g\ L^{-1}$ in Daechung Reservoir and varied largely from 6 to 80 $\mu g\ L^{-1}$, depending on the season and location. Trophic sate, based on the mean annual TP, was mesotrophy by the trophic criteria of Forsberg and Ryding (1980). Monthly variation trends of TP in study period showed a distinct longitudinal gradients (variations) along the main axis of the upreservoir to the dam site (Fig. 5). Our data showed that S3 was characterized as riverine zone, which peaked by 61 $\mu g\ L^{-1}$ in August (Fig. 5), showing almost maximum 9 times difference between the highest concentration and the lowest. In contrast, S1 showed a typical lacustrine zone with low mean TP of 11.3 $\mu g\ L^{-1}$ (range: 6～39 $\mu g\ L^{-1}$), which showed 5 times differences between upreservoir and the dam site (Fig. 5). Concentrations of TP showed a typical decreasing trend along the longitudinal gradients from the upreservoir to downstream reach of Daechung Reservoir, especially during the monsoon period of July～August (Fig. 5). Such gradients was evidently caused by largely sedimentation of particulate phosphorus and suspended solids and also partly up-take of phosphorus by primary producers (phytoplanktons; Kennedy *et al*., 1981). Our result is supported by previous researches (An, 2000) in Daechung Reservoir where inflow of TP was rapidly decreased toward the downreservoir (dam site) and the spatial difference is most pronounced during monsoon season with highest TP. This effect was cor-

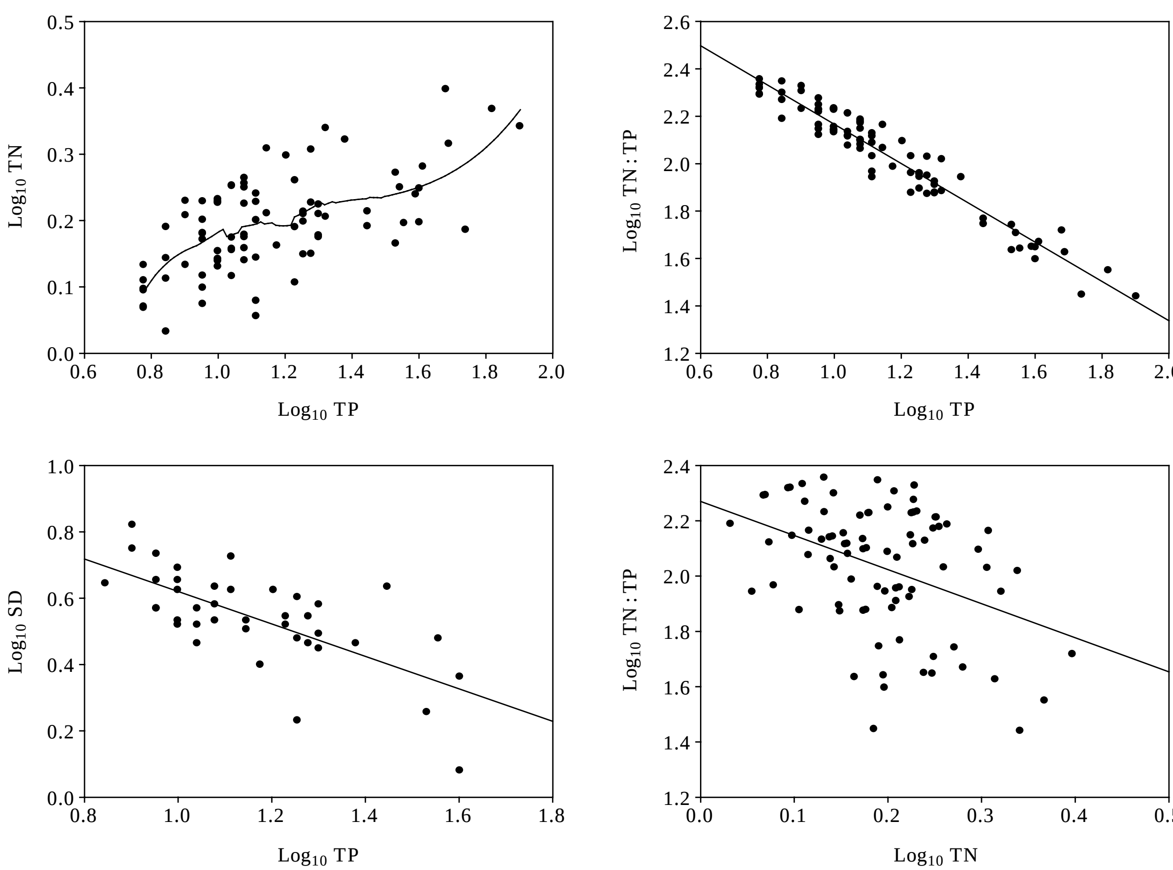

Fig. 6. Empirical models on TN-TP, TP-TN : TP, TN-TN : TP and SD-TP relations. All data were log-10 transformed for the analysis.

respond with result of this research which increased in approximately 1.5 fold during July ~ August when about 54% of annual rainfall occurred in the watershed. Phosphorus of monsoon inflowing water was mostly composed of particulate phosphorus, which came from soil erosion by river run-off, and this condition made phosphorus more sedimented out from the water column. For this reason, input of TP to the down-reservoir may directly contribute to algal growth and blooms under the severe P-limitation by the sedimentation processes and algal uptake, so that it was necessary to manage the phosphorus inputs near the lacustrine sites.

Concentration of TN averaged 1.585 mg L^{-1} during the study (Fig. 5) and judged as hypereutrophic condition by the criteria of Forsberg and Ryding (1980). Unlike TP, TN didn't show large seasonal and spatial variations in Daechung Reservoir (Fig. 5). Such pool of TN was mainly composed of dissolved form of nitrate-nitogen (NO_3-N) and the nitrogen contents in Daechung Reservoir were evidently higher than general nitrogen contents from North American and European lakes and reservoirs. Under the circumstances, nitrogen limitation may not happen in this system, indicating that nitrogen control is not effective in the watershed managements. According to the correlation analysis between log-transformed TP and TN using locally weighted sequential smoothing (LOWESS), TN showed slight positive relations with TP and little relations between the range of log-transformed TP of 1.0 ~ 1.4 as shown in Fig. 6.

Forsberg and Ryding (1980) suggested that N-limitation on phytoplankton growth occurs under the condition of TN : TP ratio less than 10 and at over 17 TN : TP ratios P-limitation is frequently occured in lake studies. In our study of long-term ambient nutrient analysis, monthly average TN : TP ratio was 121, indicating a severe P limitation on the phytoplankton growth. Previous nutrient studies in other Korean reservoirs also showed potential P-limitation, which is prevalent in Korean reservoirs (Forsberg and Ryding 1980; Smith 1982).

According to empirical analysis of trophic variables (Fig. 6), log-transformed TN : TP ratio had a weak positive correlation ($p < 0.001$, $R^2 = 0.159$, n=84) with TN but had strong positive correlation ($p < 0.001$, $R^2 = 0.935$, n=84) with TP. This result indicates that N : P ratio was mainly regulated by variations of TP rather than TN (Fig. 6). Regression model of transparency, based on Secchi depth (SD), showed a negative correlation ($p < 0.001$, $R^2 = 0.471$, n=40) with TP, but the relation was weak between SD and TN (Fig. 6). This data suggest that water clarity was mainly determined by phosphorus level rather than nitrogen. For this reason, phosphorus may be a primary key nutrients regulating lake trophic state and eutrophication in Daechung Reservoir.

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