Korean J. Limnol. 42 (4): 441~451 (2009)

Water Quality in Artificial Reservoirs and Its Relations to Dominant Reservoir Fishes

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The major objectives of this study were to evaluate trophic state of reservoirs using major water quality variables and its relations in terms of trophic guilds and tolerance guilds with dominant lentic fishes. For this study, we selected 6 artificial reservoirs such as Namyang Reservoir (N_yR), Youngsan Reservoir (Y_sR), Daechung Reservoir (D_cR), Chungju Reservoir (C_jR), Chungpyung Reservoir (C_pR), and Paldang Reservoir (P_dR), and collected fish during 2000～2007 along with data analysis of water quality monitored by the ministry of environment, Korea. Biological oxygen demand (BOD) and chemical oxygen demand (COD), indicators of organic matter pollution, varied depending on types of the reservoirs and the spatial patterns in terms of trophic gradients were similar to patterns of nutrients, Secchi depth and chlorophyll-*a*. Analysis of trophic state index (TSI) showed that reservoirs of D_cR and C_jR were mesotrophy and other 4 reservoirs were eutrophic state. The relations of trophic relations showed that TSI (Chl-*a*) had a positive linear function [TSI (CHL)=0.407 TSI (TP)+28.2, n=138, $p<0.05$] with TSI (TP) but had a weak relation with TSI (TN). Also, TSI (TP) were negatively correlated (R^2=0.703, $p<0.05$) with TSI (SD), whereas TSI (TN) was not significant ($p>0.05$) relations with TSI (SD). Tolerance guilds of lentic fishes, based on three types of the reservoirs, reflected the exactly water quality in the TN, TP, BOD, and COD, and similar trends were shown in the fish feeding/trophic guilds.

Key words : nutrient, lentic ecosystem, reservoir, fish, trophic guilds, water quality

INTRODUCTION

Man-made reservoirs have dominated the lake in Korea, and have distinct structural and morphological differences in compared with natural lakes (Kent *et al*., 2002). Such differences resulted in modifications of hydrological regime by seasonal water uses (irrigation pattern), and ecological characteristics in artificial reservoirs (Kong *et al*., 2009). Such structural characteristics influence reservoir functions such as nutrients and physiochemical characteristics (Macan, 1974; Krenkel *et al*., 1979; Rada and Wright, 1979). Most studies were generally focused on physico-chemical dynamics in the reservoir ecosystems (Park, 2005; Lee *et al*., 2007; Park and An, 2007), but recently studies showed importance of linkage of water quality with food chain and compositions (Thornton, 1990; Eklöv *et al*., 1998; McQueen, 1998; Ion *et al*., 2002). Water quality variation have an positive and negative effects on biological population structures of reservoir ecosystems, so determine temporal and spatial dynamics of invertebrates such as zooplankton and macroinvertebrate (Thornton, 1990; Kim and Hwang, 2004) as well as phytoplankton biomass or algal communities in reservoirs (Wetzel, 1990; White *et al*., 2004).

Through such food-chain interactions, in the end, compositions and biomass of fish are directly

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or indirectly influenced by the physico-chemical water quality and low trophic levels (Ryder *et al.*, 1974; Ranta and Lindström, 1993; Drenner *et al.*, 1996). Thus, previous numerous studies (Oglesby, 1977; Matuszek, 1978; Kerr and Ryder, 1988, Ranta and Lindström, 1993) showed that water quality based on primary production, determined the total production of fish (Downing *et al.*, 1990) and total dissolved solids had a linear functional relations with fish productions in lake ecosystems (Ryder, 1965; Ryder *et al.*, 1974). Also, simple linear models of fish had positive linear functions with total phosphorus or total nitrogen in the reservoir waters (Quirós, 1995) and explained the variation in terms of simple morphometric measures such as mean depth and lake area (Rounsefell, 1946; Rawson, 1952; Rawson, 1955). In early studies of the reservoir, advanced models using the parameters (Ryder, 1965) showed some relations of reservoir production to alkalinity and total dissolved solids. For management of fish production in reservoirs, morphoedaphic index (MEI) was widely applied (Ryder, 1982; Leach *et al.*, 1987) and linear models of fish production-phytoplankton were developed for reservoirs (Melack, 1976; McConnell *et al.*, 1977; Oglesby, 1977). It is well known that parameters or variables such as alkalinity, algal biomass (chlorophyll-*a*), mean depth, phytoplankton productivity, total dissolved solids, total nitrogen, and total phosphorus concentrations were employed for estimation of fish productions in lake and reservoir environments. Recently, these models are widely applied in other countries and are more advanced (Downing *et al.*, 1990).

Little is known about the relations of water quality and fish production/biomass in Korean reservoirs (Keum and Yang, 2002), even though simple works such as surveys of fish fauna and distributions, diversity analysis based on community index, and seasonal variations of fish communities have been frequently conducted in Korean lentic ecosystems (Choi *et al.*, 2006). Particularly, although the studies about fish distribution is the core study to manage fish resource in reservoir ecosystems, ecological studies on fish fauna and community survey in relation to water quality's degradation and fish trophic/feeding guilds are deficient in reservoirs (Yang *et al.*, 1991; Choi, 2005). Also, in the past, management strategy in Korean reservoirs were focused on evaluations of chemical water quality and also biological evaluations, even if tried, were also simple. For this reason, it is not easy to get appropriate data for maintenance and management of lentic ecosystems. This is the reason why we had difficult mutual compatibility between acquired data for efficient managements (MEK, 2001). The absence of biological management technique caused more eutrophication in Korean reservoirs and decreased biodiversity.

Our purposes of the study were to analyze water quality and trophic state in various types of 6 reservoirs such as Namyang Reservoir (N_yR), Youngsan Reservoir (Y_sR), Daechung Reservoir (D_cR), Chungju Reservoir (C_jR), Chungpyung Reservoir (C_pR), and Paldang Reservoir (P_dR) along with some relations of dominant fish populations with physiochemical water quality. This study may provide some clues for efficient reservoir managements and conservations.

MATERIALS AND METHODS

1. Sampling sites and some parameters

For this study, we selected six reservoirs including Namyang reservoir (N_yR), Youngsan Reservoir (Y_sR), Daechung Reservoir (D_cR), Chungju Reservoir (C_jR), Chungpyung Reservoir (C_pR), and Paldang Reservoir (P_dR), and collected fish samples during 2004～2007. We conducted numerous fish surveys of N_yR during October 2005～August 2007 (3 sites, 4 times), Y_sR during July 2006～May 2007 (3 sites, 3 times), D_cR during September 2005～May 2006 (4 sites, 2 times), C_jR during July 2004～April 2005 (3 sites, 2 times), C_pR during September 2005～May 2006 (3 sites, 2 times), P_dR during July 2004～March 2005 (3 sites, 2 times) were sampled. Fishes collected by sampling gears such as casting net (mesh: 5×5 mm), kick net (mesh: 4×4 mm), and fyke net (mesh: 5×5 mm, high: 1 m, leader net: 15 m) and the catch per unit of effort (CPUE), based on the approach of An *et al.* (2006), were used for the biomass/individual calculations. For the samplings of casting and kick net, sampling time of 60 minutes and sampling distance of about 200 m along the reservoir shore were applied in the survey and overnight setting for the fyke net were applied in the survey. Some ambiguous specimens were preserved in 10% formalin to identify the taxa in the laboratory. Fish species collected were identified according to the methods of species identification (Nelson, 1994).

Also, we used the 8-year dataset during 2000~2007 for analysis of water quality, obtained from water quality monitoring stations of the Ministry of Environment, Korea and Agricultural Corporation. The parameters used are as follows; biological oxygen demand (BOD), chemical oxygen demand (COD), total phosphorus (TP), total nitrogen (TN), suspended solids (SS), chlorophyll-*a* (CHL), Secchi depth (SD), and electrical conductivity (EC).

2. Analysis of trophic and tolerance fish guilds

Trophic guilds and tolerance guilds were analyzed by the approach of U.S. EPA (1993) and Barbout *et al.* (1999), and the guild analysis of regionally different species, compared to the North America and Europe, were conducted by the approach of An *et al.* (1992) and the Ministry of Environment, Korea (2008). Ecological characteristics in terms of water quality were classified three categories of sensitive species (Ss), intermediate

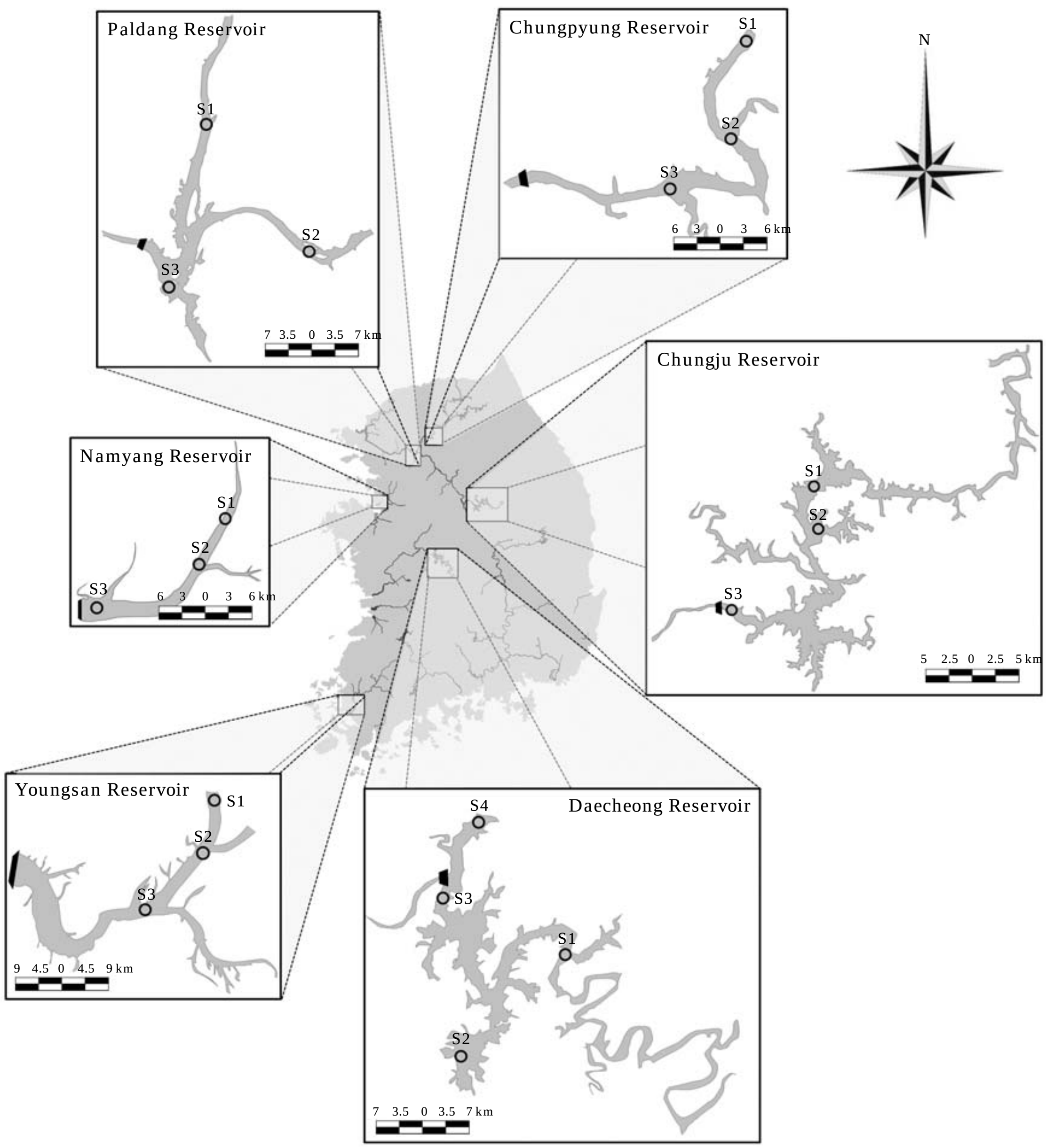

Fig. 1. The map showing 6 reservoirs and each sampling sites used in the study (Namyang Reservoir, Youngsan Reservoir, Daechung Reservoir, Chungju Reservoir, Chungpyung Reservoir and Paldang Reservoir).

species (Is), and tolerance species (Ts). Also, trophic characteristics or feeding guilds were classified 4 groups of carnivore species (C), insectivore species (I), omnivore species (O), herbivore species (H), according to the criteria of Ohio EPA (1989). Still, the trophic and tolerance guild analysis should be further studied because primary source of food or tolerance to the habitat vary depending on the food source limited and water quality within the location.

3. Trophic state index and data analysis

Trophic state index, based on 4 parameters of total phosphorus (TP), chlorophyll-*a* (CHL), and Secchi depth (SD), were calculated for the trophic relations in the reservoirs (Carlson, 1977). Trophic state index of total nitrogen (TN) was conversed according to the approach of Kratzer and Brezonik (1981). Statistical analysis using SPSS (2004, Version 12.0K for Windows) were performed to find significant difference at the level of 95% CI (Confidence interval) in the and linear regression was analysed using SPSS 14.0K Statistic Package program.

RESULTS AND DISCUSSION

Biological oxygen demand (BOD) and chemical oxygen demand (COD), indicators of organic matter pollution, varied depending on types of the reservoirs. Mean BOD in Namyang Reservoir (N_yR) and Youngsan Reservoir (Y_sR) averaged 6.7 ± 4.1 mg L^{-1} and 3.1 ± 1.9 mg L^{-1}, respectively, and showed large variations by 19 mg L^{-1} in the N_yR and 8.2 mg L^{-1} in the Y_sR (Fig. 2a). In contrast, BOD in Daechung Reservoir (D_cR) averaged 1.0 ± 0.3 mg L^{-1} and was similar to the mean (1.1 ± 0.3 mg L^{-1}) of Chungju Reservoir (C_jR). Also, BOD in Paldang Reservoir (P_dR) and Chungpyung Reservoir (C_pR) averaged 1.1 ± 0.5 mg L^{-1} and 1.7

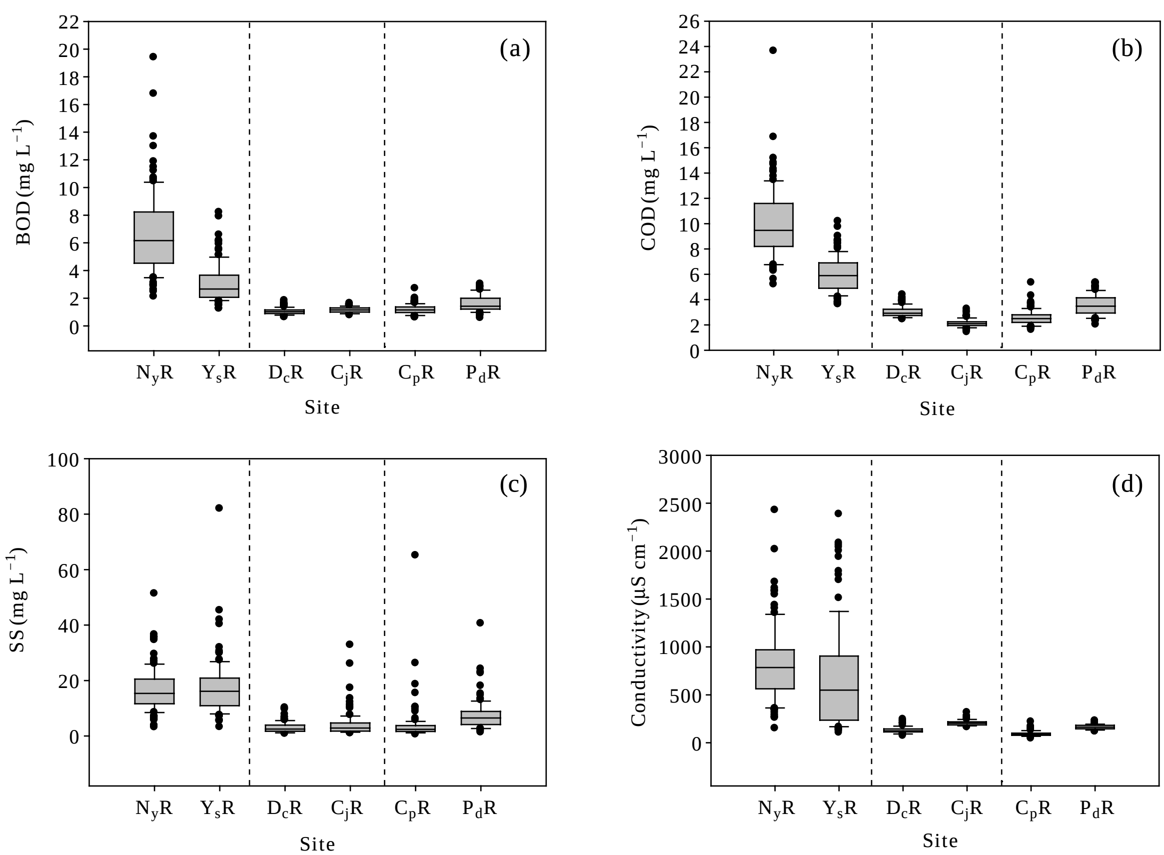

Fig. 2. Biological oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), and electrical conductivity in Namyang Reservoir (N_yR), Youngsan Reservoir (Y_sR), Daechung Reservoir (D_cR), Chungju Reservoir (C_jR), Chungpyung Reservoir (C_pR), and Paldang Reservoir (P_dR). The data indicate average mean by each reservoir sampled during 2000～2007.

$\pm$0.9 mg L^{-1} which was similar to the mean of D_cR and C_jR (Fig. 2a). Thus, The mean BOD (5.18 mg L^{-1}) of N_yR and Y_sR was greater than that (1.4 mg L^{-1}) of C_pR and P_dR, and the mean (1.1 mg L^{-1}) of D_cR and C_jR was less than the mean of C_pR and P_dR (1.41 mg L^{-1}; Fig. 2a).

Values of COD in the reservoirs followed the pattern of BOD (Fig. 2b). Similarly, total suspended solids (TSS) in the N_yR averaged 10.1$\pm$3.7 mg L^{-1}, which is similar to the mean of Y_sR. The mean was 2 times greater in the N_yR and Y_sR, compared to the means (range: 1.425$\sim$5.33 mg L^{-1}) of D_cR, C_jR, C_pR, and P_dR. Conductivity, values showed largest spatial variations during the study, and the mean (744.02 mg L^{-1}) and range (105$\sim$2427 mg L^{-1}) of N_yR and Y_sR was greater than the mean (168.92 mg L^{-1}) and the range (71.25$\sim$315.5 mg L^{-1}) of D_cR and C_jR, and the mean of C_pR and P_dR (129.06 mg L^{-1}). This results indicates that ionic contents, based on conductivity, were evidently, higher in the N_yR and Y_sR than any other total suspended solids (TSS) the high values are closely related with estuary downstreams (Kim *et al*., 2003) of lowland.

Typical variables of trophic state including total phosphorus (TP), total nitrogen (TN), Secchi depth (SD), and chlorophyll-*a* (Chl-*a*) showed a similar pattern with organic matter and ionic contents (conductivity). Mean TP in Namyang Reservoir (N_yR) was 100$\pm$120 μg L^{-1} and individual observations increased up to 451 μg L^{-1}, indicating a hypertrophic conditions, based on the criteria of Forsberg and Ryding (1980; Fig. 3a). In the Youngsan Reservoir (Y_sR), the mean TP was 200$\pm$160 μg L^{-1} which is even higher than the values in the N_yR (Fig. 3a). In contrast, the mean of D_cR and C_jR was 20 μg L^{-1}, indicating an eutrophic conditions. And the mean TP of C_pR and P_dR (48 μg L^{-1}; Fig. 3a) was slightly higher than the mean (20 μg L^{-1}) of D_cR and C_jR as shown in Fig. 3a.

Nitrogen content in all reservoirs were $>$1.5 mg L^{-1} indicating that nitrogen may not be a limiting nutrient (Kim and Hwang, 2004) controlling the phytoplankton growth. In fact, highest TN values were observed in the N_yR (9.22 mg L^{-1}) and Y_sR (6.58 mg L^{-1}), and the reservoir mean values

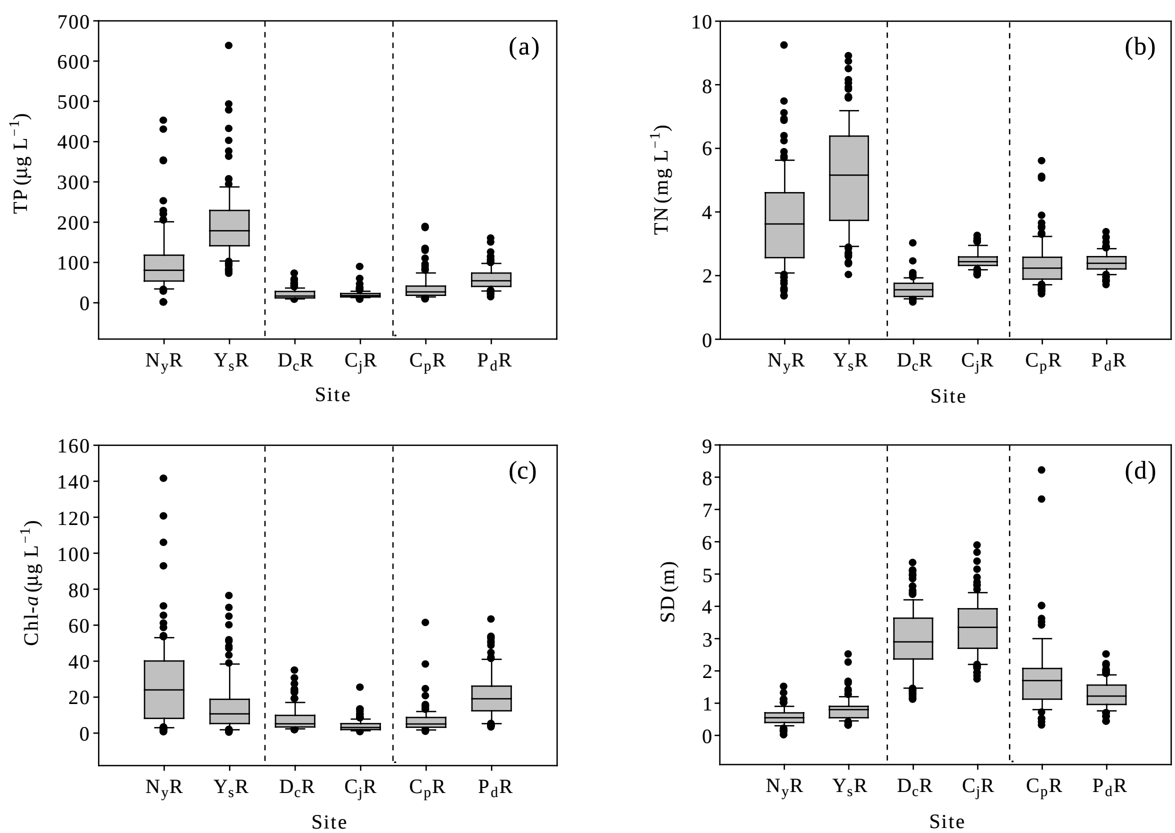

Fig. 3. Total phosphorus (TP), total nitrogen (TN), chlorophyll-*a* (Chl-*a*), and Secchi depth (SD) in the six reservoirs. Abbreviations of reservoir name are same as Fig. 1.

were > 3.5 mg L^{-1} (Fig. 2a). Largest variations in TN occurred in the N_yR and Y_sR and the high variation may be closely associated with seasonal monsoon rain (An, 2000). Previous reservoir studies (An and Shin, 2005) pointed out that nitrogen decreases by the dilution of lake water by the low ionic rainwater during Asian monsoon seasons during July ~ August in Korea. For this reason, low values of < 2 mg L^{-1} may be a ionic dilution of the reservoir water during the summer seasons.

Lake clarity, measured as Secchi depth (SD), reflected the contents of ambient nutrients (N, P) and organic matter (BOD, and COD). In Namyang Reservoir (N_yR) and Youngsan Reservoir (Y_sR), SD averaged 0.56 m and 0.80 m, respectively, and the values were lower than any other reservoirs (Fig. 3d). The conditions were judged as "eutrophic condition" by the criteria of Forsberg and Ryding (1980) and the Ministry of Environment, Korea (2001). Water transparency in the D_cR and C_jR were 2.94 m and 3.32 m, respectively, and the mean values (combined) were higher than any other reservoirs, indicating an mesotrophic (Fig. 3d). Thus, the reservoirs were categorized as three types of clear (D_cR, C_jR), intermediate (C_pR, P_dR), and turbid reservoirs (N_yR, Y_sR) as shown in the Fig. 3d. The reservoir clarity was largely influenced by phytoplankton biomass, estimated by the chlorophyll-*a* (Chl-*a*). Mean Chl-*a* value in the N_yR was 28.2 μg L^{-1}, classifying as eutrophic conditions, and the individual observations increased up to 142 μg L^{-1} depending on the seasons (Fig. 3c). In the mean time, mean Chl-*a* value (15.33 μg L^{-1}) in the Y_sR were lower than the values of the N_yR (Fig. 3c), even if the concentrations of TP and TN in the Y_sR were higher than the values of N_yR (Fig. 3a, 3b). This result indicates that phytoplankton production in the reservoirs is not directly influenced by only the

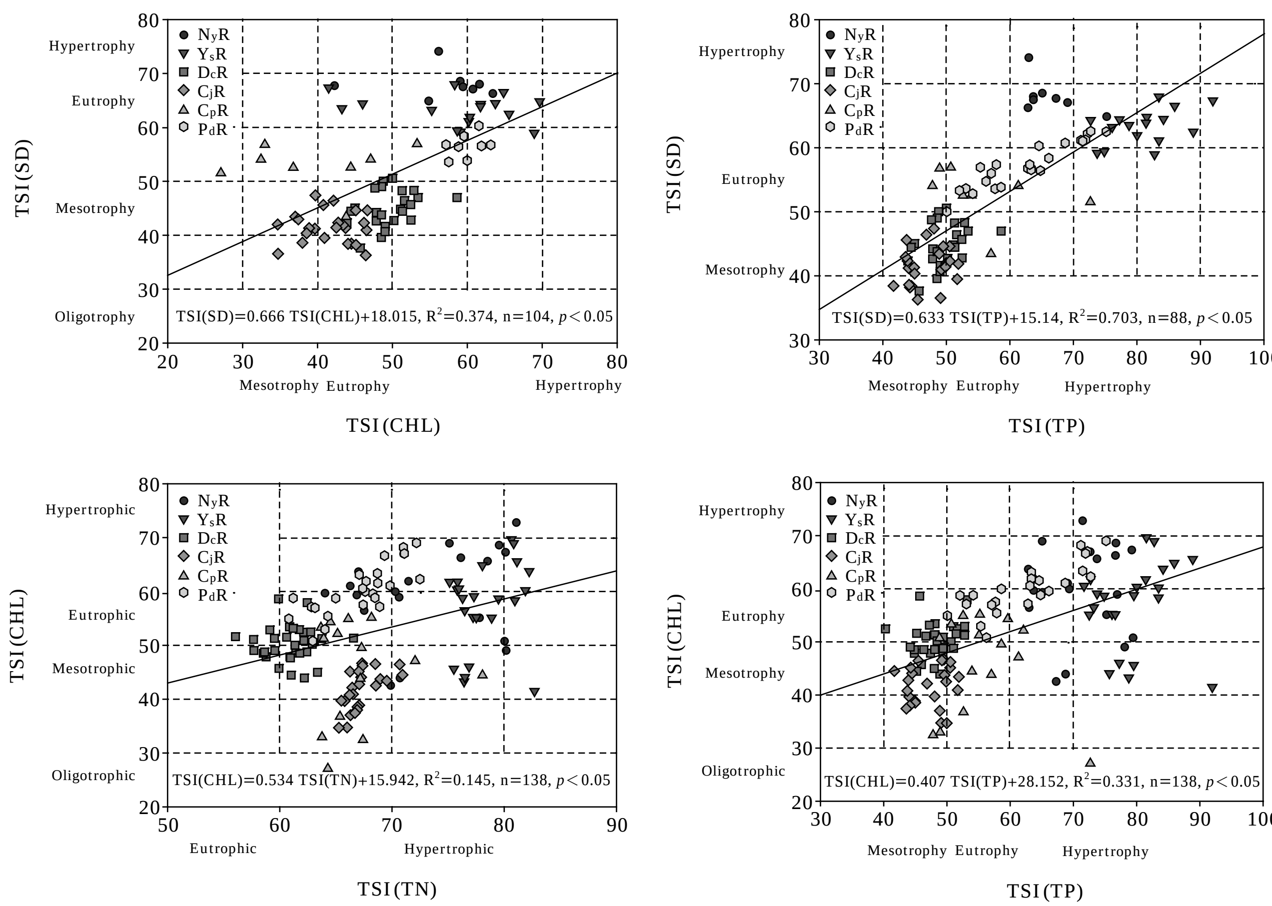

Fig. 4. The interrelations of Trophic State Index (TSI), based on chlorophyll-*a* (CHL), total nitrogen (TN), total phsophorus, and Secchi depth (SD) by Carlson (1977) and the regression lines along the trophic gradients.

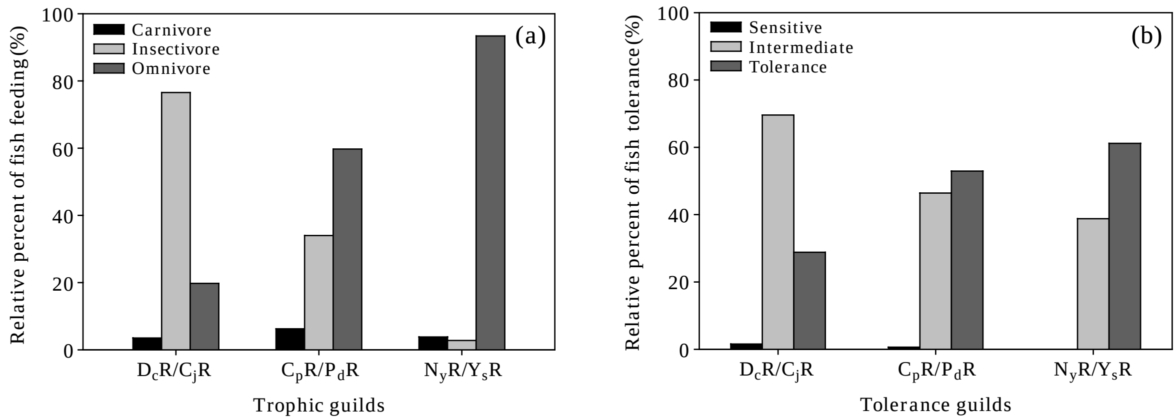

Fig. 5. Relative percentages of feeding/trophic guilds (a) as carnivore (C), insectivore (I), and omnivore species (O) and tolerance guilds (b) as sensitive species (S), intermediate species (I), and tolerant species (T) in Namyang Reservoir (N_yR), Youngsan Reservoir (Y_sR), Daechung Reservoir (D_cR), Chungju Reservoir (C_jR), Chungpyung Reservoir (C_pR), and Paldang Reservoir (P_dR).

nutrients and also that zooplankton grazing and nutrient ratios (N/P) may play important roles on the chlorophyll-*a* along with light regime (Choi *et al*., 2003; Kim *et al*., 2005).

Relations of Trophic State Index (TSI), based on trophic variables of TP, Chl-*a*, and SD, showed evident trophic categories depending on the types of the reservoirs. In the relations of TSI (TP) and TSI (Chl-*a*), reservoir data of >50% N_yR and 100% Y_sR fell into the hypertrophic conditions, based on the TP, and reservoirs of D_cR and C_jR fell into the mesotrophic data of >50 (Fig. 4). Also, TSI (Chl-*a*) had a positive linear function (TSI (CHL) =0.407 TSI (TP)+28.152, n=138) with TSI (TP) and significant ($p<0.05$) in the relations, while TSI (Chl-*a*) had weak relations with TSI (TN; Fig. 4). In the TSI analysis, the variation of water clarity, measured as TSI (SD), was explained 70.3% by TSI (TP; Fig. 4).

Tolerance guilds of fish were compared among three types of the reservoirs in terms of trophic state as shown in Fig. 5. Tolerant species in the reservoirs of N_yR/Y_sR, C_pR/P_dR, and D_cR/C_jR were 61.2%, 52.9%, and 28.8% of the total fishes, respectively and the intermediate species were 38.8%, 46.4%, and 69.6% of the total fishes (Fig. 5a). Also, the sensitive species were highest in the D_cR/C_jR and followed by C_pP/P_dD and then N_yR/Y_sR (Fig. 5a). This result suggests that the tolerance guilds in the three types of the reservoirs reflected the exactly water quality in the TN, TP, BOD, and COD.

Omnivore species in the reservoirs of N_yR/Y_sR, C_pR/P_dR, and D_cR/C_jR were 93.4%, 59.7%, and 19.8% of the total fishes, respectively, whereas carnivore species in the same reservoirs were 2.8%, 34%, and 76.6% of the total fishes (Fig. 5b). U.S. EPA (1993) and Barbour *et al.* (1999) pointed out that as the water quality degradates in stream environments, omnivore species increases and in contrast insectivore species decreases. These references suggest that the reservoirs of N_yR/Y_sR are degradated in terms of fish trophic guilds and tolerance guilds, and the reservoirs of D_cR/C_jR are good conditions, even though the reservoirs are all eutrophic lakes in the nitrogen and phosphorus criteria (Drenner *et al*., 1996). Formerly study showed that in reservoir processing eutrophication such as Namyang Reservoir, more simple species composition and higher appearance of omnivore species and tolerant species (Han and An, 2008).

In the relations of fish to the water quality (BOD, COD, TP and TN), water quality specificity of fish varied depending on the species and the parameters used. The mean range of BOD in all fish species sampled in the reservoirs varied from 0.2 mg L^{-1} in *Acanthorhodeus macropterus* (*A.m*) to 0.85 mg L^{-1} in *Oryzias sinensis* (*O.s*) and averaged 2.17 mg L^{-1} (Fig. 6).

In the reservoir survey, mean BOD of most species, except for two species (*Rhodeus uyekii*, *R.u*, *O. sinensis*, *O.s*), were less than 3 mg L^{-1} (Fig. 6), indicating a low variation in each species. The maximum of BOD, however, showed large differences between the two groups; one group had

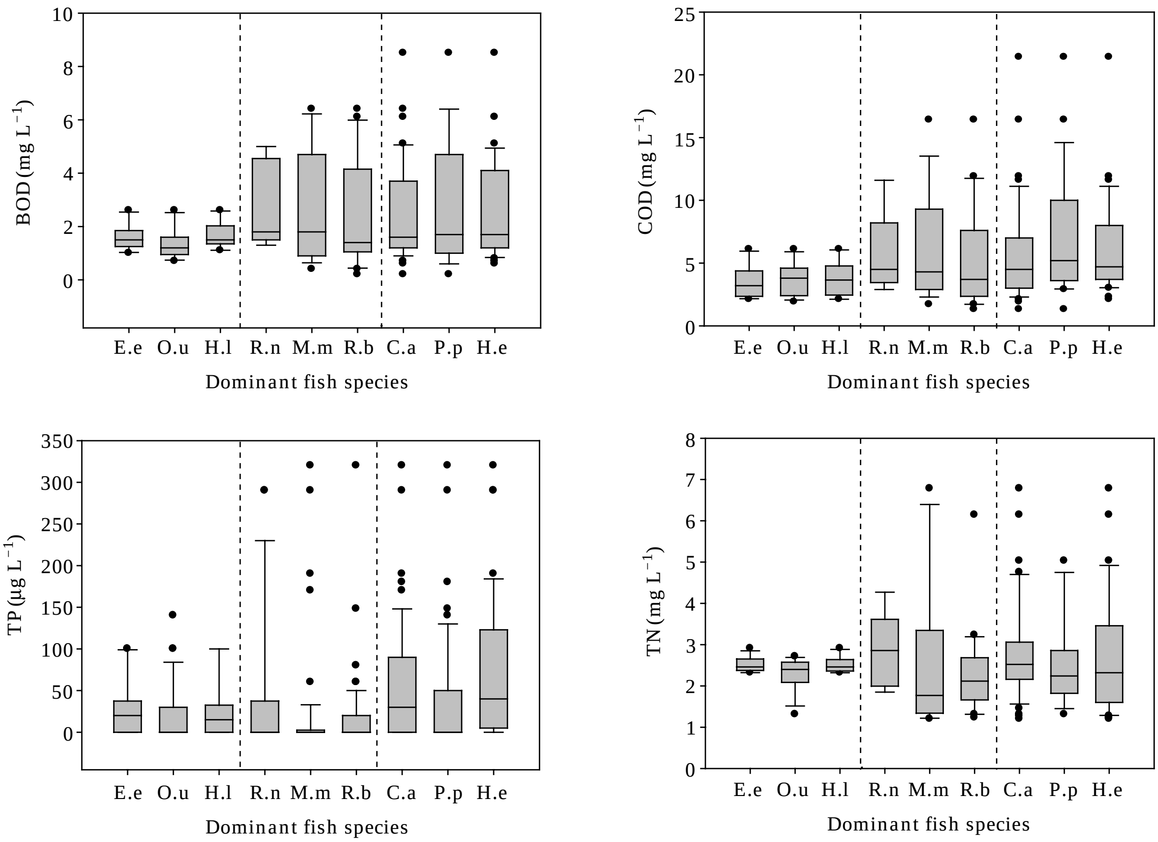

Fig. 6. Mean, maximum, and minimum of water quality as BOD, COD, TP, and TN in each fish species such as *Erythroculter erythropterus* (*E.e*), *Opsarichthys uncirostris* (*O.u*), *Hamibarbus labeo* (*H.l*), *Rhodeus notatus* (*R.n*), *Misgurnus mizolepis* (*M.m*), *Rhinogobius brunneus* (*R.b*), *Pseudorasbora parva* (*P.p*), *Carassius auratus* (*C.a*) and *Hemiculter eigenmanni* (*H.e*).

low maximum BOD values of <2.6 mg L^{-1} for *Erythroculter erythropterus* (*E.e*), *Opsarichthys uncirostris* (*O.u*), *Hamibarbus labeo* (*H.l*) and another group had high maximum BOD values of 8.5 mg L^{-1} for *Carassius auratus* (*C.a*), *Pseudorasbora parva* (*P.p*), *Hemiculter eigenmanni* (*H.e*) (Fig. 6). Thus, there were BOD differences of >3-fold between the two groups. The pattern of the groups, based on the BOD, was similar to fish analysis, based on COD values in the reservoirs (Fig. 6).

The mean range of TP in all fish species sampled in the reservoirs varied from 10 μg L^{-1} in *Rhinogobius brunneus* (*R.b*) to 320 μg L^{-1} in *O. sinensis* and averaged 85 μg L^{-1} (Fig. 6). Mean TP of most species, except for two species (*A. macropterus*, *O. sinensis*), were less than 100 μg L^{-1} (Fig. 6), indicating a low variation in each species. The maxima of TP, however, showed large differences between the two groups; one group had low maxima TP values of <140 μg L^{-1} for *E. erythropterus*, *O. uncirostris*, *H. labeo*, and another group had high maximum TP values of 320 μg L^{-1} for *C. auratus*, *P. parva*, *H. eigenmanni* (Fig. 6). The distinct differences of fish in maximum TP were similar to those of maximum BOD and COD, and also that of TN. These results indicate that two groups may be different in terms of tolerance guilds in relation to water quality. In more polluted or eutrophicated reservoir, species composition and evenness value are lower than relatively clean reservoir (Yang and Chae, 1994; Seong *et al.*, 1997). Also fishes such as *R. brunneus* (*R.b*), *P. parva* (*P.p*) and *C. auratus* (*C.a*) have wide distribution in each water quality parameter. So, these fishes appeared clean water or polluted water (Seo *et al.*, 2006). This result, however, may be varied or modified by the reservoir sites and seasons sampled because of large spatial water quality variations depending on the types of the reservoirs and the temporal dynamics of water quality

Table 1. TN : TP ratio. TN, TP values are calculated based on annual TN, TP mean (2000～2007) in each reservoir. In all reservoirs, TN : TP ratios over 17. In reservoirs, based on TN : TP ratios, limiting factor is determined.

Reservoir	TN	TP	TN : TP ratio
Namyang	3.7±2.2	0.10±0.12	3.7 : 0.10=37
Youngsan	5.1±2.1	0.20±0.16	5.1 : 0.20=25.5
Daechung	1.6±0.4	0.02±0.01	1.6 : 0.02=80
Chungju	2.4±0.4	0.02±0.01	2.4 : 0.02=120
Chungpyung	2.4±1.2	0.04±0.05	2.4 : 0.04=60
Paldang	2.5±0.7	0.06±0.06	2.5 : 0.06=41.7

TN=Total nitrogen, TP=Total phosphorus

during the summer monsoon. Also, this pattern of fish in relation to the water quality in reservoir systems, in other words, lentic ecosystems, may be different from the streams/or rivers, in other words, lotic ecosystems due to the structural and functional differences between the two systems (Adams *et al*., 2000).

Based on TN/TP ratios, limiting factor is determined in lakes. TN/TP ratio >17, P is working as limiting factor (P-limited). When 10<TN/TP ratio <17, N and P have correlation (co-limited) and TN/TP ratio showed less than 10, N is working as limiting factor (Forsberg and Ryding, 1980). In this study, TN, TP values are calculated based on annual mean (2000～2007). All reservoirs showed that TN/TP ratios are more than 17. The range of TN/TP ratios are 25.5～120. In Chungju Reservoir (C_jR), TN/TP value is the highest (120), but in Youngsan Reservoir (Y_sR) value is the lowest (25.5). So, it is explains that P working as limiting factor in all reservoirs in this study (Table 1).

ACKNOWLEDGEMENTS

This study was supported by the CAER (Center for Aquatic Ecosystem Restoration) of Eco-STAR project from MOE (Ministry of Environmet, Republic of Korea).

LITERATURE CITED

Adams, W.J., J.E. Toll, K.V. Brix, L.M. Tear and D.K. DeForest. 2000. Site-specific approach for setting water quality criteria for selenium: difference between lotic and lentic system. Proceedings mine reclamation symposium: seleniun session; sponsored by ministry of energy and mines, Williams lake, British Columbia, Canada, p. 21-22.

An, K.G. 2000. The impact of monsoon on seasonal variability of basin morphology and hydrology. *Korean J. Limnol.* **33**(4): 342-349.

An, K.G. and I.C. Shin. 2005. Influence of the Asian monsoon on seasonal fluctuations of water quality in a mountainous stream. *Korean J. Limnol.* **38**(1): 54-62.

An, K.G., J.Y. Lee, D.Y. Bae, J.H. Kim, S.J. Hwang, D.H. Won, J.K. Lee and C.S. Kim. 2006. Ecological assessments of aquatic environment using multimetric model in major nationwide stream watersheds. *J. Korean Soc. Water Qual.* **22**(5): 796-804.

An, K.G., Y.P. Hong, J.K. Kim and S.S. Choi. 1992. Studies on zonation and community analysis of freshwater fish in Kum-river. *Korean J. Limnol.* **25**(2): 99-112.

Barbour, M.T., J. Gerritsen, B.D. Snyder and J.B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, bentic macroinvertebrates and fish, 2nd Ed, EPA 841-B-99-002. U.S. EPA office of water, Washington, D.C., USA.

Carlson, R.E. 1977. A trophic state index for lakes. *Limnol. Oceanogr.* **22**: 361-369.

Choi, J.S., J.K. Kim, Y.S. Jang, K.Y. Lee, H. Ryu, J.Y. Jeong and B.C. Kim. 2006. Characteristics of fish community on six lakes located in Gyeonggi. *Korean J. Limnol.* **39**(2): 178-186.

Choi, J.S. 2005. Fish fauna and community in Cheongpyeong Reservoir. *Korean J. Limnol.* **38**(1): 63-72.

Choi, K.H., S.J. Hwang, H.S. Kim and M.S. Han. 2003. Temporal changes of limiting nutrients and phytoplankton growth rate in lake Paldang. *Korean J. Limnol.* **36**(2): 139-149.

Downing, J.A., C. Plante and S. Lalonde. 1990. Fish production correlated with primary productivity, not the morphoedaphic index. *Can. J. Fish. Aquat. Sci.* **47**: 1929-1936.

Drenner, R.W., J.D. Smith and S.T. Threlkeld. 1996. Lake trophic state and the limnological effects of omnivorous fish. *Hydrobiol.* **319**(3): 213-223.

Eklöv, A.G., L.A. Greenberg, C. Brönmark, P. Larsson and O. Berglund. 1998. Response of stream fish to improved water quality: a comparison between the 1960s and 1990s. *Freshwater Biology* **40**(4): 771-782.

Forsberg, C. and S.V. Ryding. 1980. Eutrophication parameters and trophic state indices in 30 Swedish waste-receiving lakes. *Arch. Hydrobiol.* **89**: 189-207.

Han, J.H. and K.G. An. 2008. Applications and assessments of a multimetric model to Namyang Reservoir. *Korean J. Limnol.* **41**(2): 228-236.

Ion, N., A.D. Buijse and M. Staras. 2002. Effects of hydrology and water quality on the fish community in Danube Delta lakes. *Internat. Rev. Hydrobiol.* **87**(2-3): 329-248.

Kent, W.T., B.L. Kimmel and F.E. Payne. 2002. Reservoir limnology. Shingwang, p. 66-169.
Kerr, S.R. and R.A. Ryder. 1988. The applicability of fish yield indices in freshwater and marine ecosystems. *Limnol. Oceanogr.* **33**(4): 973-981.
Keum, J.D. and H.J. Yang. 2002. The fish fauna and its community structure in the Nam River, Nakdong River system, Korea. *Korean J. Limnol.* **35**(3): 220-231.
Kim, H.S. and S.J. Hwang. 2004. Effects of nutrients and N/P ratio stoichiometry on phytoplankton growth in an eutrophic reservoir. *Korean J. Limnol.* **37**(1): 36-46.
Kim, H.S., D.S. Kong and S.J. Hwang. 2005. Characteristic community dynamics of phyto- and zooplankton in a shallow eutrophic reservoir. *Korean J. Limnol.* **38**(1): 18-29.
Kim, J.S., H. Heo, H. Noh, H. Yang and M.S. Han. 2003. Relationship between limnological characteristics and algal bloom in lake-type and river-type reservoirs, Korea. *Korean J. Limnol.* **36**(2): 124-138.
Kong, K.H., J.H. Lee and K.G. An. 2009. The analysis of water quality and suspended solids effects against transparency of major artificial reservoirs in Korea. *Korean J. Limnol.* **42**(2): 221-331.
Kratzer, C.R. and P.L. Brezonic. 1981. A Carlson-type trophic state index for nitrogen in Florida lakes. *Water. Res. Bull.* **17**: 713-715.
Krenkel, P.A., G.F. Lee and R.A. Jones. 1979. Effects of TVA impoundments on downstream water quality and biota, p. 289-309. *In*: The Ecology of Regulated Streams (Ward, J.V. and J.A. Stanford, eds.). Plenum Press, New York.
Leach, J.H., L.M. Dickie, B.J. Shuter, U. Borgmann, J. Hyman and W. Lysack. 1987. A review of methods for prodiction of potential fish production with application to the great lakes and lake Winnipeg. *Can. J. Fish. Aquat. Sci.* **44**(2): 471-485.
Lee, J.Y., J.H. Lee, K.H. Shin, S.J. Hwang and K.G. An. 2007. Trophic state and water quality characteristics of Korean agricultural reservoirs. *Korean. J. Limnol.* **40**(2): 223-233.
Macan, T.T. 1974. Freshwater ecology, 2nd ed. London: Longmans, viii. p. 343.
Matuszek, J.E. 1978. Empirical predictions of fish yields of large north American lakes. *Trans. Amer. Fish. Soc.* **107**: 385-394.
McConnell, W.J., S. Lewis and J.E. Olson. 1977. Gross photosynthesis as an estimator of potential fish production. *Trans. Amer. Fish. Soc.* **106**(5): 417-423.
McQueen, D.J. 1998. Freshwater food web biomanipulation: A powerful tool for water quality improvement, but maintenance is required. *Lakes & Reserv. Research. Manage.* **3**(2): 83-94.
Melack, J.M. 1976. Primary productivity and fish yields in tropical lakes. *Trans. Amer. Fish. Soc.* **105**(5): 575-580.
Ministry of Environment, Korea (MEK). 2001. The general report of investigation technique development for limnological environment in Korea, p. 28.
Ministry of Environment, Korea (MEK). 2008. Survey and evaluation of aquatic ecosystem health in the Han River.
Nelson, J.S. 1994. Fishes of the world (3th ed.). John Wiley & Sons, New York.
Oglesby, R.T. 1977. Relationships of fish yield to lake phytoplankton standing crop, production and morphoedaphic factors. *J. Fish. Res. Board Can.* **34**: 2271-2279.
Ohio EPA. 1989. Biological criteria for the protection of aquatic life (Vol III); Standardized biological field sampling and laboratory method for assessing fish and macroinvertebrate communities. USA.
Park, H.J. and K.G. An. 2007. Trophic State Index (TSI) and empirical models, based on water quality parameters in Korean reservoirs. *Korean. J. Limnol.* **40**(1): 14-30.
Park, J.G. 2005. Water environmental factors and trophic states in lake Daecheong. *Korean. J. Limnol.* **38**(3): 382-392.
Quirós, R. 1995. The effects of fish assemblage composition on lake water quality. *Lake and Reserv. Manage.* **11**(4): 291-298.
Rada, R.G. and J.C. Wright. 1979. Factors affecting nitrogen and phosphorus levels in canyon Ferry reservoir, Monata, and its effluent waters. *Northwest Sci.* **53**(3): 213-220.
Ranta, E. and K. Limdstoröm. 1993. Theory on fish yield versus water quality in lakes. *Ann. Zool. Fennici* **30**: 71-75.
Rawson, D.S. 1952. Mean depth and the fish production of large lakes. *Ecology* **33**(4): 513-521.
Rawson, D.S. 1955. Morphometry as a dominant factor in the productivity of large lakes. *Int. Ver. Theor. Angew. Limnol. Verh.* **12**: 164-175.
Rounsefell, G.A. 1946. Fish production in lakes as a guide for estimating production on proposed reservoirs. *Copeia* **1**: 29-40.
Ryder, R.A. 1965. A method for estimating the potential fish production of north-temperate lakes. *Trans. Amer. Hish. Soc.* **94**: 214-218.
Ryder, R.A. 1982. The morphoedaphic index-use, abuse, and fundamental concepts. *Trans. Amer. Fish. Soc.* **111**: 154-164.
Ryder, R.A., S.R. Kerr, K.H. Loftus and H.A. Regier. 1974. The morphoedaphic indies, a fish yield estimator-review and evaluation. *J. Fish. Resear. Can.* **31**: 663-688.
Seo, J.W., I.S. Lim and H.S. Lee. 2006. Distribution of eight abundant fish species in relation with water quality. conference book of Korean society of water and wastewater and Korean society on water quality's autumn academic convention, Daegu convention center, Daegu, 2006. p. 71-75.
Seong, C.N., K.S. Baik, J.H. Choi, H.W. Cho and J.H. Kim. 1997. Water quality and fish community in

streamlets of Juam reservoir. *Korean J. Limnol.* **30**(2): 107-118.

Thornton, K.W. 1990. Perspectives on reservoir limnology, p. 1-4. *In*: Reservoir Limnology: Ecological Perspectives (Thornton, K.W., F.E. Payne and B.L. Kimmel, eds.). John Wiley & Sons, New York.

U.S. EPA. 1993. Fish field and laboratory methods for evaluationg the biological integrity of surface waters. EPA 600-R-92-111. Environmental monitoring systems laboratory-cincinnati office of modeling, monitoring systems, and quality assurance office of research development, U.S EPA, Cincinnati, Ohio 45268, USA.

U.S. EPA. 2003. Fish field and laboratory methods for evaluating the biological integrity of surface waters. EPA 600-R-92-111. Environmental monitoring systems laboratory-cincinnati office of modeling, monitoring systems, and quality assurance office of research development, U.S. EPA, Cincinnati, Ohio 45268.

Wetzel, R.G. 1990. Reservoir ecosystems: conclusions and speculations, p. 227-238. *In*: Reservoir Limnology: Ecological Perspectives (Thornton, K.W., F.E. Payne and B.L. Kimmel, eds.). John Wiley and Sons, New York.

White, D.L., D.E. Porter and A.J. Lewitus. 2004. Spatial and temporal analyses of water quality and phytoplankton biomass in an urbanized versus a relatively pristine salt marsh estuary. *J. Exp. Mar. Biol. Ecol.* **298**(2): 255-273.

Yang, H.J. and B.S. Chae. 1994. The water environment and limnological study the river system around the megalopolis The ichthyofauna and structure of fish community in the Kumho River. *Korean. J. Limnol.* **27**(2): 177-188.

Yang, H.J., B.S. Chae and M.M. Nam. 1991. The ichthyofauna in autumn at upper reach of Hongchon River. *Korean. J. Limnol.* **24**(1): 37-44.

(Manuscript received 4 November 2009,
Revision accepted 9 December 2009)