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Tolerance Range Analysis of Fish on Chemical Water Quality in Aquatic Ecosystems

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In this study, we analyzed fish tolerance guilds in mainstems and tributaries of 65 streams and rivers and their relations to water quality using dataset sampled from April to November, 2009. For the study, water quality parameters including biochemical oxygen demand (BOD), electric conductivity (EC), total nitrogen (TN), total phosphorus (TP), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N) and phosphate phosphorus (PO_4-P) were analyzed in the laboratory and also tolerance ranges in 3 category fishes of sensitive, intermediate, and tolerant species with high abundance were analyzed. According to fish guild analysis, tolerant species was 58% of the total community and the proportion of omnivore species was 63% of the total, indicating a degradation of habitats and water quality. Water quality was shown typical longitudinal gradients from the headwater to the down-river; TN and TP increased toward the down-rivers except for the big point-source area and ionic contents, based on, electric conductivity showed same pattern. Tolerance guild analysis of 9 major species with high abundance indicated that sensitive groups had narrower tolerance range in the water quality than the groups of intermediate and tolerant species. In contrast, tolerant groups including *Zacco platypus*, *Carassius auratus*, and *Opsarichthys uncirostris amurensis* had wider tolerance ranges than the groups of sensitive and intermediate species. Thus, each group was evidently segregated from the tolerance levels. Principal Component Analysis (PCA) employed for the relations of water quality to fish species in each groups suggests that water quality had highest eigenvalues with fish species in the 1st axis of the PCA and nitrogen (TN, NH_3-N, NO_3-N) and phosphorus (TP) were key components differentiating three groups of sensitive, intermediate and tolerance guilds.

Key words : tolerance guild, water quality, fish, PCA, nutrient

INTRODUCTION

Previous numerous studies for aquatic environments have mainly focused on chemical water quality for assessing environmental impacts (Barbour *et al.*, 1999; An and Yang, 2007). Such studies have shown that chemical water quality is considered as one of the most important parameters and this was most frequently used as a measure diagnozing the health of aquatic environment. For this reasons, simple measurements of biological oxygen demand and chemical oxygen demand as an indicator of organic matter pollutions, and total nitrogen (TN) and total phosphorus (TP) as an indicator of organic matter pollutions were most frequently used for water environments. Such measurements, however, have been pointed out that water quality varies too largely depending on season, and location, and even water quality

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had high differences within a same site depending on sampling depth and persons sampled in the microhabitats. In spite of these facts, these measurements have provided water quality management and conservation strategies of streams and rivers. In addition, biological studies have been used for the diagnosis of aquatic environments. The key indicators such as fish, macroinvertebrate, and periphyton were frequently surveyed for the distributions, abundances, and community analysis. Such outcomes indirectly gave some implications on influences of chemical water quality to the biota.

In recent, biological water quality concepts using fish have been widely used in aquatic studies (Barbour *et al.*, 1999; An *et al.*, 2001). The concepts are mainly based on multi-metric fish model, which is originated from the concept of Index of Biological Integrity (Karr, 1981) and has been used as a tool of efficient stream and river managements. This concept has emphasized biological or ecological health than a concept of simple fauna or distribution (An *et al.*, 2001). From the multi-metric model, tolerance guild concept was used as one of 12 metrics determining the ecological health of the aquatic ecosystems (US. EPA, 1993). Tolerance in this study refers to the ability of fish species to thrive in degraded environmental conditions and Karr (1981) developed the concept. Jones *et al.* (2005) pointed that fish is a representative organisms in the food chain of aquatic ecosystem and had log life history, so the fish is widely used as an key indicator species for diagnosis of water quality conditions. However, little is known about specific fish tolerance guilds and their relations of chemical water quality in Korean ecosystems as well as North America and European waterbodies.

Recently, Simpson (1998) emphasized that the measures such as tolerance levels of sensitive, intermediate and tolerant fish must be sensitive to the environmental conditions being monitored. In addition, the response range (Sensitivity) of the measure should be suitable for the intended applications and this concept is basically based on the tolerance raw of Shelford (1912). In this study, we analyzed chemical water quality and fish tolerance guilds in 65 sampling streams and rivers along with fish abundance and fauna. We defined three major groups of fishes, tolerant guilds and then analyzed 3 species with highest abundance from each groups for analyzing the tolerance effects of fishes to the chemical water quality. In the paper we have discussed in tolerance range of selected fishes along the gradients of nitrogen and phosphorus nutrients with principal component analysis (PCA).

MATERIALS AND METHODS

1. Descriptions of sampling locations and sampling periods

Fish sampling and water quality were measured in 65 streams and rivers of the Geum-River watershed from April~November 1999. The watershed has three large dams; Yeoungdam Dam in the up-river Dam in the mid-river region, and Estuary Dam in the down-river region. The main tributaries inflowing into the mainstem are three in up-river regions (Namdae Stream, Yeoungdong Stream, and Byochung), three in mid-river regions (Gap Stream, Miho Stream, and Yugu Stream), and two in down-river regions (Seoksung Stream and Nonsan Stream). We collected the fish and water samples from 14 mainstem and 51 tributary sites, respectively. In the river, the largest point-sources are located in the Gap Stream and Miho Stream, which influence the downstream water quality of main-river. The specific sampling sites are as follows:

1) Mainstem sites of Geum-River (14)

Up-river region (5 sites), mid-river region (5 sites), and down-river region (4 sites)

2) Tributary sites of Geum-River (51)

Jinan Stream (5 sites), Muju-Namdae Stream (1 site), Yeongdong Stream (5 sites), Cho Stream (3 sites), Bocheong Stream (5 sites), Sooak Stream (1 site), Whaein Stream (1 site), Joowon Stream (1 site), Gap Stream (9 sites), Woecheon Stream (1 site), Miho Stream (19 sites), Yongsoo Stream (1 site), Daegyo Stream (1 site), Jeongan Stream (1 site), Yoogu Stream (1 site), Ji Stream (1 site), Eunsan Stream (1 site), Geum Stream (1 site).

2. Chemical analysis

Dissolved oxygen (DO), electrical conductivity (EC), and pH were measured in the field using a YSI-6600 multi-parameter analyzer. For the chemical analysis, we collected surface waters from 65 streams and rivers within the Geum-River watershed. Dissolved oxygen (DO) was one of the most important chemical parameter for inhabited fish. it was tend to increase just after sunrise in the natural stream where process the eutrophication condition and in contrast, to decrease suddenly after sunset. Hence, the data of DO which measured in 9~10am was applied and analyzed in this study. Total nitrogen (TN) was measured by second derivative method after a persulfate digestion and phosphorus (TP) was determined using the ascorbic acid method after persulfate oxidation. Filtered water was used for analysis of PO_4-P and the analysis followed after the ascorbic acid method. Ammonia nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), and biochemical oxygen demand (BOD) were measured by the methods of APHA (1995). Nutrient analyses were performed in triplicate. Chlorophyll-*a* (Chl-*a*) concentration, as an estimate of algal biomass was measured by using a spectrophotometer (Bechman Model DU-65) after extraction in hot ethanol.

3. Fish sampling and taxa identification

Fish samples were collected at the sixty five sites of Geum-River watershed, according to the method of the catch per unit of effort (CPUE; Ohio EPA, 1989). The sampling gears used in this survey were casting net (5 × 5 mm) and deep net (4 × 4 mm). All habitat types including riffle, run, pool were sampled in an upstream direction for a distance of at least 200 m with 50 minutes. All specimens were preserved in 10% formalin and returned to the lab to identify the taxa (Kim and Park, 2002).

4. Indicator species analysis

In the Geum-River watershed, we analyzed tolerance guilds and trophic guilds to elucidate the relations of water quality to the fish guilds. Tolerance guilds of fish were categorized as three types based on US. EPA (1993) and Barbour *et al.* (1999); sensitive species (SS), intermediate species (IS), tolerant species (TS). The sensitive species (SS) was designated as a species which disappear rapidly as water quality or habitat degrades in the lotic ecosystem. The tolerant species (TS) was designated as a species which the abundance increases in spite of degradation of water quality or habitat conditions in the ecosystem. The intermediate species (IS) are not included in the SS and TS. We also categorized trophic guilds as three types based on Ohio EPA (1989); omnivore species (O), insectivore species (I), carnivore species (C), and herbivore species (H). According to the Barbour *et al.* (1999), the proportions of omnivore species increase as water quality is getting worse, while the proportions of insectivore species decrease as water quality is getting worse. These characteristics of the indicator guilds may be used as a key tool assessing the biological water quality in lotic ecosystems.

5. Statistical data analysis

Statistical package of PC-Ord (Ver. 4.25 for windows; McCune and Mefford, 1999) was used for principal components analysis (PCA). Using the PCA, we have analyzed relationship between fish guilds and water quality (nitrogen, phosphorus, and BOD).

RESULTS AND DISCUSSION

1. Water quality characteristics

Water quality varied largely in Geum River with season (Table 1). Electrical conductivity (EC), ammonia nitrogen (NH_3-N), and phosphate phosp-

Table 1. Water quality observed (n=65) in the 56 tributaries and mainstem sites of Geum River.

Physicochemical variables	Mean	Minimum ~ Maximum
Dissolved oxygen (DO, mg L^{-1})	13.98	7.30 ~ 17.5
Electric conductivity (EC, μs cm^{-1})	427	13 ~ 1,981
pH	8.19	5.5 ~ 9.8
Biochemical oxygen demand (BOD, mg L^{-1})	2.5	0.1 ~ 9.1
Total nitrogen (TN, mg L^{-1})	2.08	0.29 ~ 6.61
NH_3-N (mg L^{-1})	0.16	0.01 ~ 2.51
Total phosphorus (TP, mg L^{-1})	0.07	0.005 ~ 0.58
PO_4-P (mg L^{-1})	0.03	0.003 ~ 5.37
NO_3-N (mg L^{-1})	1.51	0.10 ~ 5.37
Chlorophyll-*a* (Chl-*a*, μg L^{-1})	20.3	0.7 ~ 153.3

horus (PO_4-P), and chlorophyll-*a* (Chl-*a*) showed differences of >100 fold between minima and maxima depending on the sampling location. The large difference was mainly attributed to the influence by the presence or absence of point-sources near the sampling locations, and the maxima occurred in wastewater disposal plants and urban regions. The polluted streams observed were Gap Stream and Miho Stream, which directly influenced water quality in the mainstems of Geum River. In the mean time, nutrients of total nitrogen (TN) and nitrate nitrogen (NO_3-N) showed less variation than those of other parameters (Table 1). In addition, we compared the organic matter and nutrients between tributary and mainstrem sites in which the watershed BOD, EC, TP, TN, and NH_3-N showed greater variations in the tributaries than the mainstems (Fig. 1), and average water quality was better in the tributaries than the mainstem. Mean BOD was greater in the mainstem (2.69 mg L^{-1}) than the tributaries (2.4 mg L^{-1}), while mean conductivity was less in the mainstem (337 μs cm^{-1}) than the tributaries (450 μs cm^{-1}). In the mean time, maximum conductivity (1,981 μs cm^{-1}) was observed in the Miho Stream, which was directly influenced by waste water discharged from Chungju Industrial Complex (CIC). Mean TN showed little difference between the mainstem (1.990 mg L^{-1}) and tributary (2.110 mg L^{-1}) but the tributary of Gap-Stream (6.600 mg L^{-1}) and Yudung Stream (6.270 mg L^{-1}) largely differed from the mainstem of Geum River. The difference between the two systems was same as NH_3-N, suggesting that the tributary is directly influenced by the wastewater treatment plants and dense-population urban. Our results are supported by the previous studies (An *et al.*, 2001; An and Yang, 2007) that such distinct differences in the organic matter and nutrients between the tributary and mainstem were mainly due to the point-sources such as wastewater treated facilities.

2. Fish compositions and relative abundance

Overall, 61 fish species (13 family) were collected during the survey periods in 2009 (Table 2). According to abundance analysis at family level, Cyprinidae had 38 species, that showed the highest abundance (89%). The next as followed by five species of Cobitidae, three species of Bagridae, and two species of Osmeridae, Gobiidae, Odontobutidae, and Centropomidae, Entrarchidae, respectively, only one species was found in Siluridae, Amblycipitidae, Channidae, Synbranchidae, and Belontiidae, respectively (Table 2). The highest abundance of Cyprinidae is accorded or accordance with previous study by Jeon (1980). *Zacco platypus* in the Cyprinidae showed highest in number of individuals (number=10,530, abundance=40%) in the river and highest constancy value as level (the site number of observed/total number).

Endemic species observed in the watershed were 24 species and the abundance was made of 39.3% in total communities (Table 2). It is relatively higher compared to proportion found in Korean peninsula (Nam, 1996). Two exotic species were collected, *Lepomis macrochirus* and *Micropterus salmoides* (Table 2). Those are rapidly spreading in the Geum River watershed. Especially, *Micropterus salmoides* may seriously influence on the ecosystem health by predation Korean native species and endangered species (Kim *et al.*, 1993; Lee *et al.*, 2009). One of the endangered and national monument species, *Iksookimia choii* was only observed in two sites of Gap Stream and Miho Stream. Its relative abundance based on the number of individual was getting decreased (Table 2). The abundances of two endangered species of *Liobagrus obesus* and *Pseudopungtungia nigra* were rare (Table 2), the protection program will be required in the watershed. Analysis of external anormality of fishes such as skin abrasion and fin erosion were frequently observed (0.16%, 43 number of individual) in the urban streams (i.e., Deajeo Stream, Gap Stream, and Miho Stream) where wastewater disposal plants (WDPs) directly influenced. This impact of the WDPs on the fish anormality is already reviewed by previous study (Lee, 2001).

3. Fish tolerance guilds and trophic guilds

According to the analysis of fish tolerance guilds in the Geum River watershed, the proportion of sensitive, intermediate, and tolerant species were 8.4% (2,215), 33.5% (8,828), and 58% (15,280), respectively (Fig. 2). Comparing the relative abundance of sensitive and tolerant species in the river, tolerant species dominated the community, suggesting that river health condition is getting degraded (US. EPA, 1993; Barbour *et al.*, 1999). The rate of the tolerant species was higher in Gap Stream and Miho Stream than other streams. Out result is agreed with the previous study of

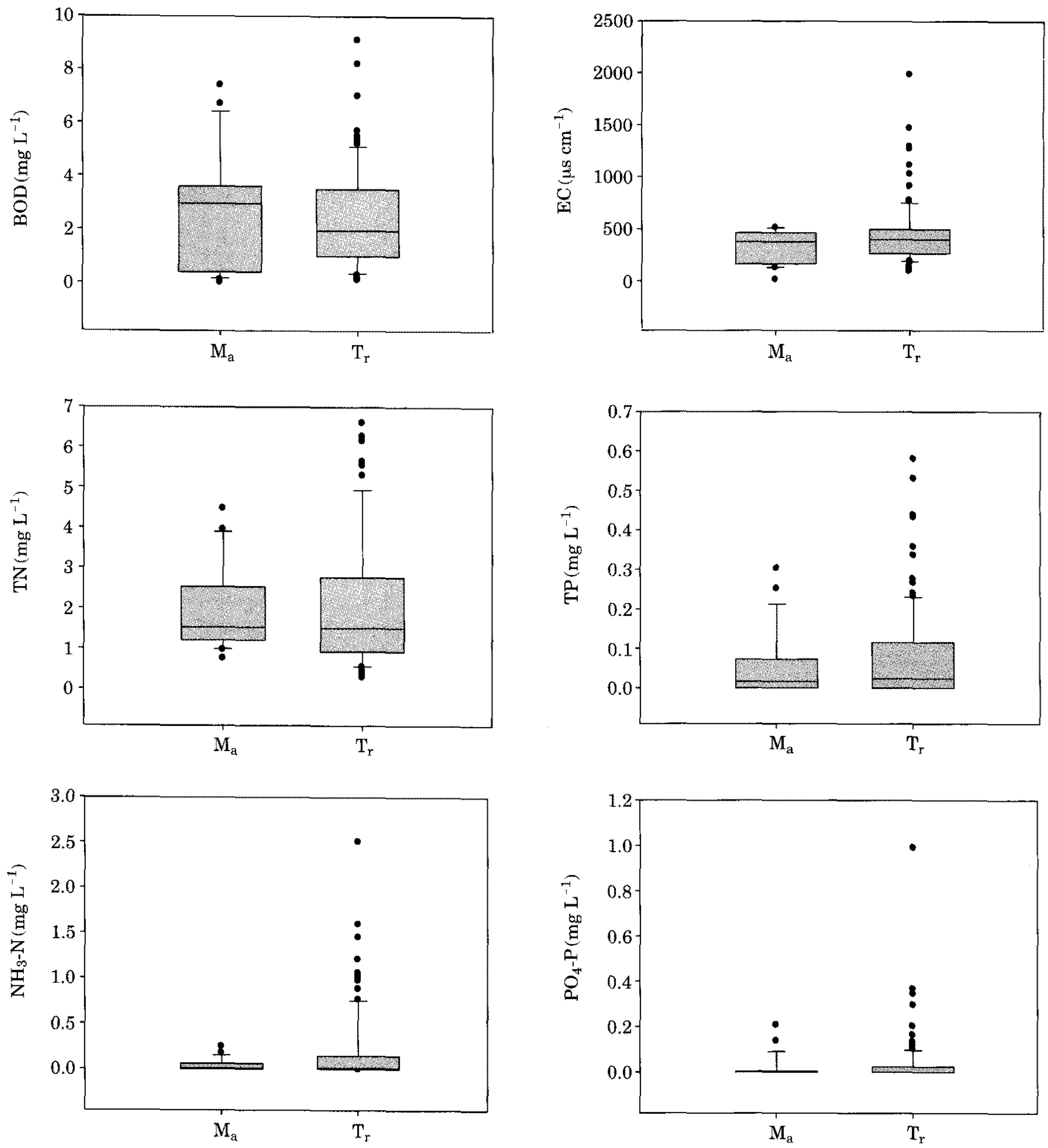

Fig. 1. Comparisons of biochemical oxygen demand (BOD), electric conductivity (EC), total nitrogen (TN), total phosphorus (TP), NH_3-N and PO_4-P in the mainstems (M_a) vs. tributaries (T_r) of the Geum River watershed.

An *et al.* (2001).

As results of trophic guilds the proportion of omnivore species (O), carnivore species (C), insectivore species (I), and herbivore species (H), were 62.7% (16,516), 6.3% (1,669), 30.9% (8,130), and 0.03% (8), respectively (Fig. 2). According to the Barbour *et al.* (1999), the proportions of omnivore and insectivore species are reversely correlated with water quality. Omnivore species one increased in degraded condition, while insectivore species are decreased. For these reasons, tow different guilds were frequently used as a key factor explaining the biological water quality in lotic ecosystems.

4. Species tolerance range on chemical water quality

To determine species tolerance range on chemi-

Table 2. Fish compositions and guild analysis (T_oG=tolerance guilds, T_rG=trophic guild) in 13 mainstem (M_a) and 52 tributaries (T_r) streams of Geum River watershed. Tolerance guilds (SS: sensitive species, IS: intermediate species, TS: tolerant species), trohic guilds (O: Omnivore, I: Insectivore, C: Carnivores, H: Herbivores) are shown in the columns. In the table, SA indicate species abbreviation and total number of individual, respectively.

Family/Species	SA	T_oG	T_rG	M_a	T_r	TNI
Cyprinidae						
Cyprinus carpio	Ccl	TS	O	3	85	88
Carassius auratus	Can	TS	O	36	1,036	1,072
Carassius cuvieri	Cct	TS	O	1	11	12
Rhodeus ocellatus	Rok	IS	O	1	2	3
Rhodeus uyekii	Rum	IS	O	24	71	95
Rhodeus notatus	Rnn	IS	O	1	16	17
Acheilognathus lanceolatus	Alt	IS	O	179	951	1,130
Acheilognathus koreensis	Akk	IS	O	189	336	525
Acheilognathus yamatsutae	Aym	IS	O	121	140	261
Acheilognathus rhombeus	Art	IS	O	9	92	101
Acanthorhodeus macropterus	Amb	IS	O	4	38	42
Acanthorhodeus gracilis	Agr	IS	O	7	33	40
Pseudorasbora parva	Ppt	TS	O	39	222	261
Pungtungia herzi	Phh	IS	I	189	434	623
Pseudopungtungia nigra	Pnm	SS	I	60	89	149
Coreoleuciscus splendidus	Csm	SS	I	65	84	149
Sarcocheilichthys variegatus wakiyae	Svw	SS	I	89	30	119
Sarcocheilichthys nigripinnis	Snm	IS	I	7	36	43
Gnathopogon strigatus	Gar	IS	I		192	192
Squalidus gracilis majimae	Sgm	SS	I	22	172	194
Squalidus japonicus coreanus	Sjc	TS	O	596	402	998
Squalidus chankaensis tsuchigae	Sct	IS	O	14	102	116
Hemibarbus labeo	Alp	TS	I	234	412	646
Hemibarbus longirostris	Hir	IS	I	151	471	622
Pseudogobio esocinus	Pet	IS	I	279	1,654	1,933
Abbottina rivularis	Arb	TS	O		33	33
Abbottina springeri	Asb	TS	O		28	28
Gobiobotia macrocephala	Gmm	SS	I	1	23	24
Gobiobotia brevibarba	Gbm	SS	I	11	8	19
Microphysogobio yaluensis	Mym	IS	O	92	426	518
Microphysogobio jeoni	Mjk	IS	I	225	10	235
Rhynchocypris oxycephalus	Ros	SS	I		70	70
Zacco koreanus	Zkk	SS	I	474	822	1,296
Zacco platypus	Zpt	TS	O	1,285	9,245	10,530
Opsarichthys uncirostris amurensis	Oua	TS	C	378	356	734
Squaliobarbus curriculus	Scr	IS	O	59	40	99
Erythroculter erythropterus	Eeb	TS	C	34	21	55
Hemiculter eigenmanni	Hej	TS	O	25	235	260
Cobitidae						
Misgurnus anguillicaudatus	Mac	TS	O	17	213	230
Misgurnus mizolepis	Mmg	TS	O	2	55	57
Iksookimia koreensis	Ikk	IS	I	16	114	130
Iksookimia choii	Ick	SS	I		6	6
Cobitis lutheri	Clr	IS	I	3	68	71
Bagridae						
Pseudobagrus fulvidraco	Pfr	TS	I	10	23	33
Pseudobagrus koreanus	Pku	SS	I	21	55	76
Leiocassis ussuriensis	Lud	IS	I		5	5
Siluridae						
Silurus asotus	Sal	TS	C	2	16	18

Table 2. Continued.

Family/Species	SA	T_oG	T_rG	M_a	T_r	TNI
Amblycipitidae						
Liobagrus obesus	Los	SS	I	1		1
Osmeridae						
Hypomesus nipponensis	Hnm	IS	I		1	1
Plecoglossus altivelis altivelis	Paa	IS	H		8	8
Synbranchidae						
Monopterus albus	Maz	TS	C		1	1
Centropmidae						
Siniperca scherzeri	Sss	SS	C	36	20	56
Coreoperca herzi	Chh	SS	C	44	21	65
Centrchidae						
Lepomis macrochirus	Lmr	TS	I	1	67	68
Micropterus salmoides	Msl	TS	C	9	137	146
Odontobutidae						
Odontobutis platycephala	Opi	SS	C	46	139	185
Odontobutis interrupta	Oil	IS	C	45	355	400
Gobiidae						
Rhinogobius brunneus	Rbt	IS	I	132	774	906
Tridentiger brevispinis	Tbk	IS	I	51	467	518
Belontiidae						
Macropodus ocellatus	Moc	TS	I		1	1
Channidae						
Channa argus	Cac	TS	C		9	9
Total number of specises				50	60	61
Total number of individuals				5,340	20,983	26,323

cal water quality, we selected nine species based on previous studies and literatures (3 species of each guild). Selected species were categorized as three groups; sensitive, intermediate, and tolerant guilds. The sensitive group was *Zacco koreanus* (Zkk), *Odontobutis platycephala* (Opi), and *Pseudobagrus koreanus* (Pku), intermediate group was *Pseudogobio esocinus* (Pet), *Odontobutis interrupta* (Oil), and *Hemibarbus longirostris* (Hir). Finally, tolerant group was *Zacco platypus* (Zpt), *Carassius auratus* (Can), and *Opsarichthys uncirostris amurensis* (Oua). The constancy values in nine species were >0.5, which indicates high occurrence and abundance in the watershed. And then we determined water quality ranges of BOD, EC, TN, TP, NH_3-N, and PO_4-P on each tolerance guilds of nine fishes (Fig. 3).

Vertical box plots of selected nine fishes showed different response for chemical water quality (Fig. 3) The ranges of water quality for sensitive species was much narrow compared to these of tolerant species. Sensitive species of *Zacco koreanus* (Zkk), *Odontobutis platycephala* (Opi), and *Pseudobagrus koreanus* (Pku) showed that BOD values were <2.0 mg L^{-1} and conductivity values were <375 μs cm^{-1}, while TN values were <1.5 mg L^{-1} and TP values were <0.1 mg L^{-1}. These tolerance ranges in the sensitive fish guilds were much lower than the ranges of water quality in the intermediate and tolerant species.

Mean BOD values in the sensitive guilds of *Zacco koreanus* (Zkk), *Odontobutis platycephala* (Opi), and *Pseudobagrus koreanus* (Pku) were 6 mg L^{-1}, 1.7 mg L^{-1} and 2.0 mg L^{-1}, respectively. In the mean time, mean BOD values in the intermediate guilds of *Pseudogobio esocinus* (Pet), *Odontobutis interrupta* (Oil), and *Hemibarbus longirostris* (Hlr) were 2.5 mg L^{-1}, 2.4 mg L^{-1} and 2.3 mg L^{-1}, respectively, which were classified as II-rank (i.e., fair condition) by the criteria of the WQME. Mean BOD values in the tolerant guilds of *Zacco platypus* (Zpt), *Carassius auratus* (Can), and *Opsarichthys uncirostris amurensis* (Oua) were 2.4 mg L^{-1}, 2.4 mg L^{-1} and 2.7 mg L^{-1}, respectively. Maxi-

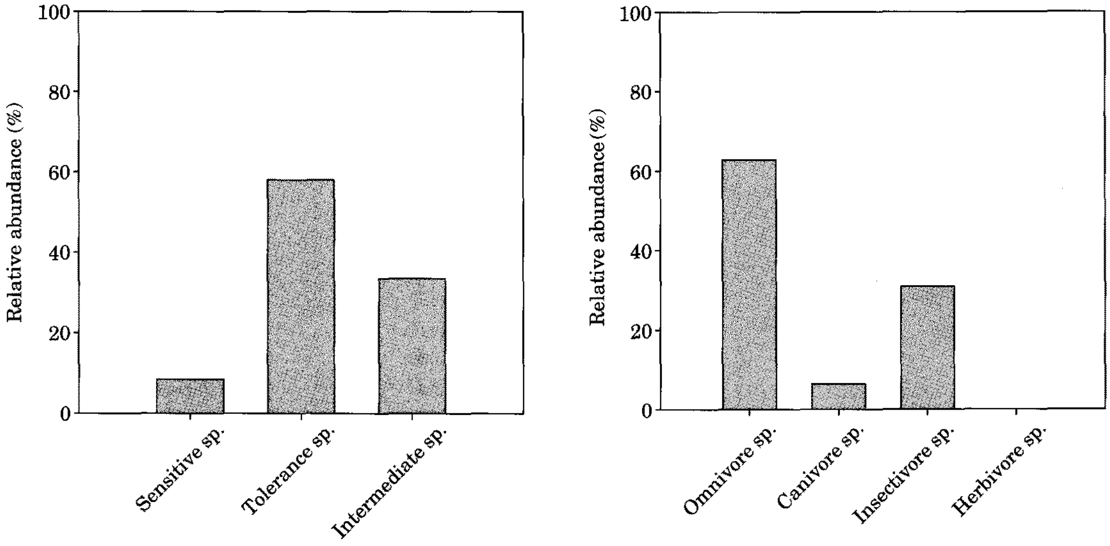

Fig. 2. The relative abundance expressed as proportion of the total numbers of individual trophic and tolerant guilds in the Geum River watershed.

mum BOD in the tolerant three guilds (Zpt, Can, Oua) was 9.1 mg L^{-1}, 9.1 mg L^{-1}, 7.4 mg L^{-1}, respectively, and these values were similar to the maxima (9.1 mg L^{-1}) in the tolerant guilds. Thus, chemical water quality, based on these mean BOD values, was Ib-rank, which is good conditions, after the criteria of water quality of the Ministry of Environment (WQME), Korea. Maximum ranges of BOD in the sensitive guilds of the three species were <7.0 mg L^{-1}, whereas maximum ranges of BOD in the intermediate and tolerant guilds increased up to 9.1 mg L^{-1}. The resulted of our experiment suggest that sensitive species have narrow and lower BOD ranges, compared to the ranges of intermediate and tolerant guilds.

Maximum electrical conductivity in the sensitive guilds of *Zacco koreanus* (Zkk), *Odontobutis platycephala* (Opi), and *Pseudobagrus koreanus* (Pku) was <775 μs cm^{-1}, and the maxima in the intermediate and tolerant guilds increased up to 1,981 μs cm^{-1}, suggesting that conductivity in the sensitive was much lower than ranges in the intermediate and tolerant guilds. We believe that the conductivity may be a useful parameter identifying the tolerance guilds of fish in the ecosystem.

Nutrient of total nitrogen (TN), as an indicator of eutrophication or trophic conditions in the waterbodies, was compared among three types of tolerance guilds. Mean TN values in the sensitive guilds of *Zacco koreanus* (Zkk), *Odontobutis platycephala* (Opi), and *Pseudobagrus koreanus* (Pku) were 1.3 mg L^{-1}, 1.4 mg L^{-1} and 1.5 mg L^{-1}, respectively, which were classified as Ia-rank (i.e., excellent condition) by the criteria of the WQME. Maximum TN in the sensitive guilds was <5.5 mg L^{-1}, and these values were lower than the mean maxima (6.6 mg L^{-1}) in the intermediate and tolerant guilds. *Carassius auratus* turned out as a species surviving in most polluted water. Mean and maxima of electrical conductivity (487 μs cm^{-1}, 1,981 μs cm^{-1}), TN (2.3 mg L^{-1}, 6.6 mg L^{-1}), and TP (0.1 mg L^{-1}, 0.6 mg L^{-1}) in *Carassius auratus* were much greater than values in two other tolerant species (Opi, Pku). The result based on 56 streams and rivers, suggests that *Carassius auratus* may be a good experimental fish representing most tolerant and abundant species in the stream environments. According the result of external anormality, occurrence frequency of *Carassius auratus* was comprised of 70% of the total abnormal individuals (43) and this species were most frequently observed in the severe polluted rivers and streams, indicating that the abnormality comes from the polluted water (high BOD, TN, TP) and the high abundance in the polluted water indicates high chemical tolerance of the species.

Overall box plot analysis on three levels of fish tolerance guilds indicated that three species of *Zacco koreanus* (Zkk), *Odontobutis platycephala* (Opi), and *Pseudobagrus koreanus* (Pku), selected

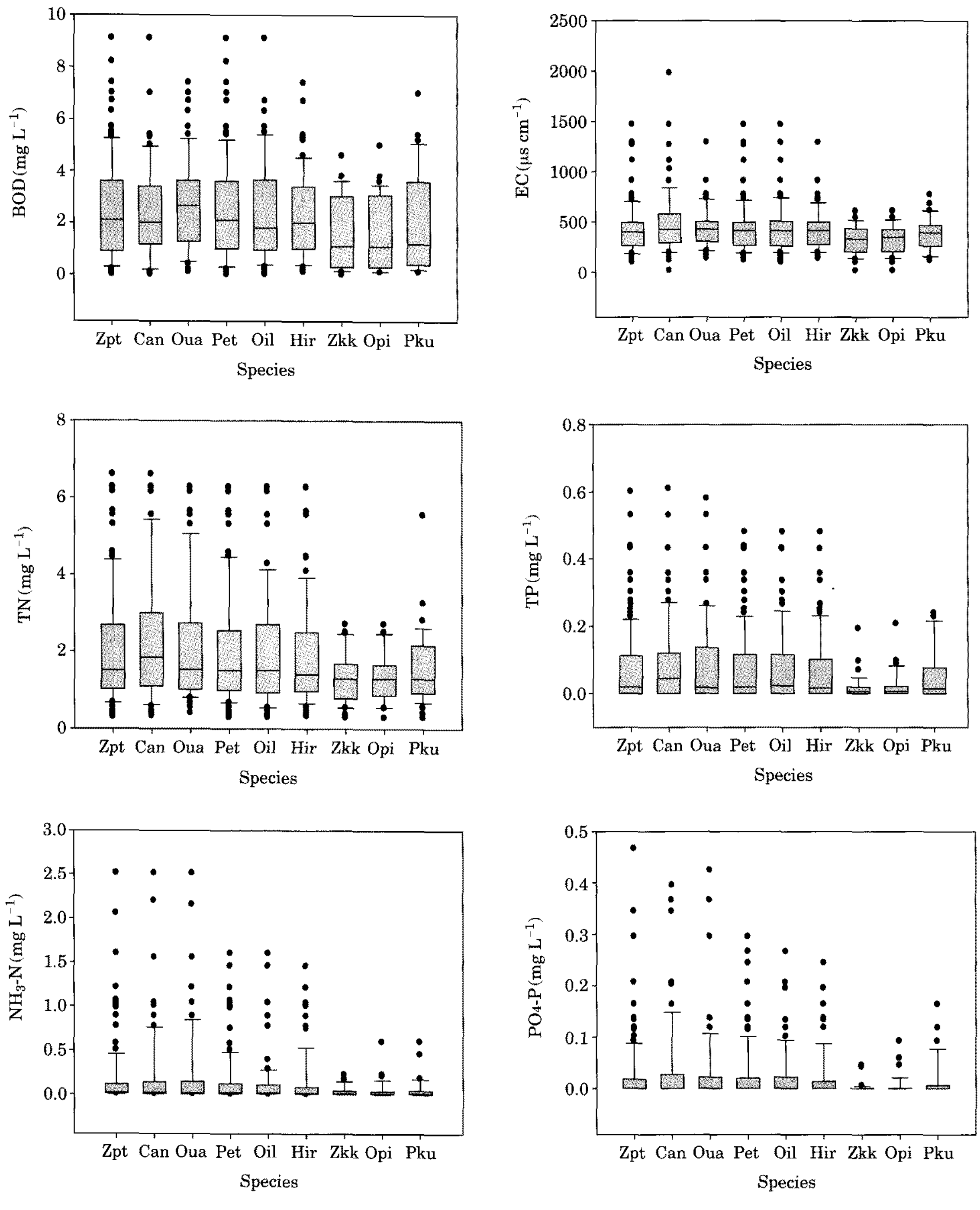

Fig. 3. Vertical box plots of selected nine fishes on the chemical water quality parameters. For the analysis, abundant fish in the watershed in terms of sensitive, intermediate, and tolerant guilds were selected as follows: *Zacco koreanus* (Zkk), *Odontobutis platycephala* (Opi), *Pseudobagrus koreanus* (Pku), *Pseudogobio esocinus* (Pet), *Odontobutis interrupta* (Oil), *Hemibarbus longirostris* (Hir), *Zacco platypus* (Zpt), *Carassius auratus* (Can), and *Opsarichthys uncirostris amurensis* (Oua).

as sensitive species and one species of *Carassius auratus* (Can) selected as tolerant species were accorded with the classification system of tolerance guilds designated by the Ministry of the Environment Korea. In the mean time, mean and maxima water quality ranges for *Pseudogobio esocinus*

Table 3. Principal component analysis (PCA) using physicochemical variables. The data were loaded on axes I, II, and III and the values indicate correlation coefficients. Bold numbers indicate high significant values of ≥|0.35|.

Physicochemical variable	Axis I	Axis II	Axis III
Total nitrogen (TN)	**−0.467**	−0.016	−0.074
NH_3-N	**−0.382**	−0.141	−0.291
Total phosphorus (TP)	**−0.382**	0.114	−0.007
NO_3-N	**−0.456**	0	−0.087
Dissolved oxygen (DO)	0.086	**0.521**	−0.053
pH	0.209	**0.406**	−0.26
Chlorophyll-*a* (Chl-*a*)	−0.129	**0.499**	0.118
Electric conductivity (EC)	−0.235	0.052	**0.564**
Biochemical oxygen demand (BOD)	−0.281	0.278	**−0.376**
PO_4-P	−0.156	−0.082	**0.492**

(Pet), *Odontobutis interrupta* (Oil), and *Hemibarbus longirostris* (Hir) designated as intermediate tolerance guilds by the Ministry of the Environment Korea did not show much differences with tolerant species. Further study should be done for the elucidating the tolerance category of these species using more dataset covering major four river watersheds in Korea.

5. Relations of fish tolerance on water quality parameters

Principal components analysis (PCA) plots of axes-I and axes-II based on a PCA of tolerance indicator values for 61 fish species classified as SS (sensitive species), IS (intermediate species), TS (tolerant species) is shown in Fig. 4. Water quality parameters used for the PCA analysis were DO, pH, BOD, conductivity, TP, TN, NH_3-N, and PO_4-P. Three axis of I, II, and III in the PCA analysis covered up to 75.8% of the variation as shown in Table 3. Axis-I explained 34.6%, based on criteria of factor loading ≥|0.35| by the water quality variables of total nitrogen (TN), ammonia nitrogen (NH_3-N), total phosphorus (TP), and nitrate nitrogen (NO_3-N), while axis-II explained 24.2%, based on criteria of factor loading ≥|0.35| by two water quality variables of dissolved oxygen (DO), pH, and chlorophyll-*a* (Chl-*a*). The axis-III on the fish tolerance explained 16.8% by two varables of biochemical oxygen demand (BOD) and phosphate phosphorus (PO_4-P).

The dendrogram analysis of fish species as a function of distance (objective function) on water quality parameters of TN, NH_3-N, TP, and NO_3-N is shown in Fig. 5. The hierarchical cluster analysis indicated that fish species categorized as two groups of sensitive and non-sensitive species (more like tolerant species) in the Geum River watershed rather than three groups of sensitive, intermediate, and tolerant species (Fig. 5). Fish species such as *Iksookimia choii* (Ick), *Siniperca scherzeri* (Sss), *Pseudobagrus koreanus* (Pku) were included Group II (G-II), which is classified as a sensitive guild by the Ministry of Environment, Korea. When we considered only water quality in this study, fish species such as *Pungtungia herzi* (Phh), *Acheilognathus koreensis* (Akk), *Acheilognathus yamatsutae* (Aym), *Iksookimia koreensis* (Ikk) should be shifted from the intermediate guilds to sensitive guilds. Currently, these species were classified as the intermediate guild by the Ministry of Environment, Korea. According to the classification criteria of Ministry of Environment

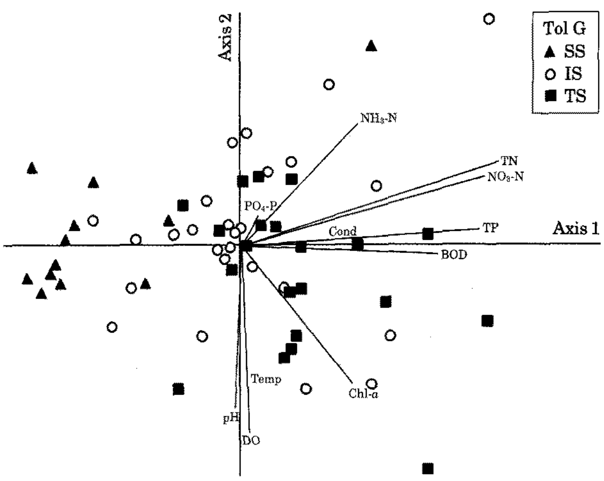

Fig. 4. Principal components analysis (PCA) plot of axes-I and axes-II, based on a PCA of tolerance indicator values for 61 fish species classified as SS (sensitive species), IS (intermediate species), and TS (tolerant species).

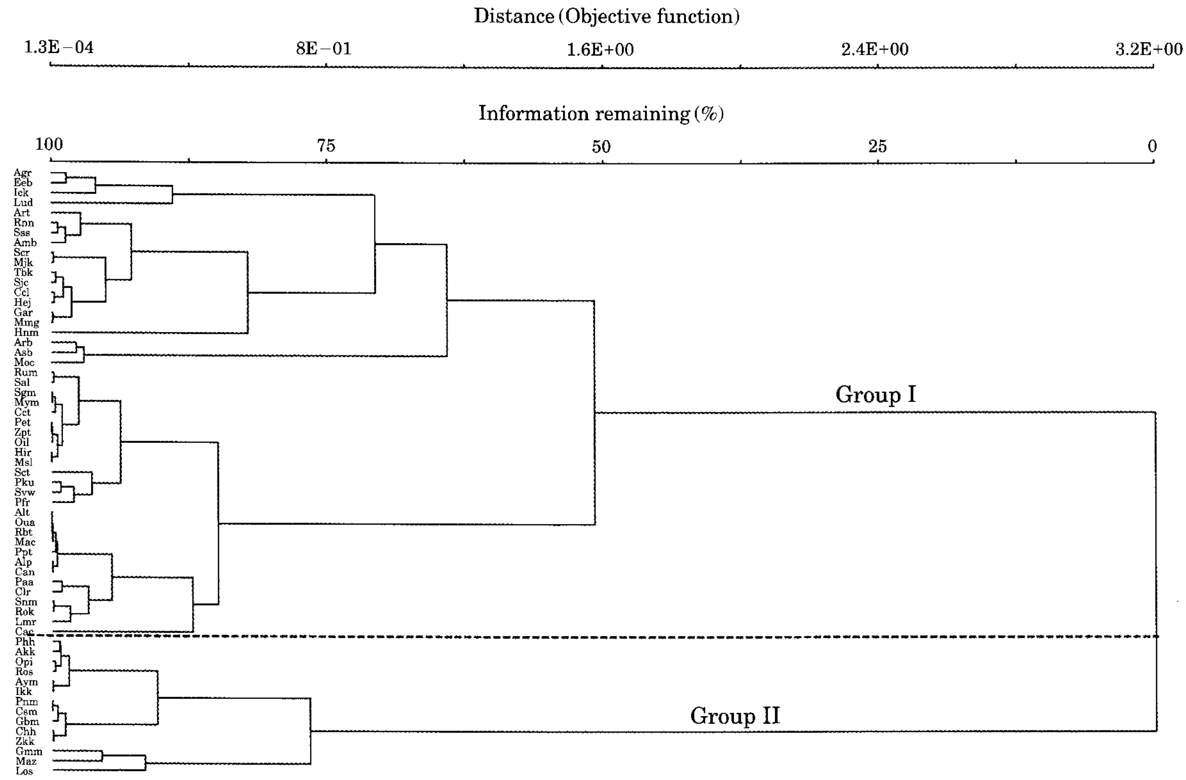

Fig. 5. Dendrogram of fish species, as a function of distance (objective function) on water quality parameters of TN, NH_3-N, TP, and NO_3-N in the Geum River watershed.

on tolerance guilds, the number of sensitive species, intermediate species, and tolerant species were 13 (8.4%), 21 (33.5%), and 21 (58%), respectively in Geum River watershed. In contrast, fish tolerance guild categories, based on dendrogram analysis, showed that nine species were accord with the classification criteria of Ministry of Environment on tolerance guilds and that the accordance rate was 64.3%. In contrast, Group I (G-I) of tolerant guilds did not show a difference with intermediate guilds by the Ministry of Environment, Korea. In Fig. 4, one species of tolerant guilds and two species of intermediate guilds were *Macropodus ocellatus* (Moc), *Leiocassis ussuriensis* (Lud), and *Hypomesus nipponensis* (Hnm), respectively and these three species were located far from both axis-I and axis-II. This was mainly attributed to low frequency of occurrence and low number of observation in the survey, so more data were required for the reliable results. Our results indicated that most important key parameters influencing the axis-I among the variables used here were TN, NH_3-N, TP, and NO_3-N and these variables made clearly the difference between sensitive guilds and tolerant guilds. Factors such as water temperature, dissolved oxygen, and pH may not be as important in distinguishing between tolerant and intolerant classifications, but may segregate species classified as moderate. So the parameters may be effectively used for categorization of fish tolerance guilds. For the reliable results, more large dataset including other major rivers of Han-River, Nakdong-River, and Yeongsan/Seomjin River watersheds.

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