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Physicochemical tolerance ranges and ecological characteristics in two different populations of *Carassius auratus* and *Cyprinus carpio*

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Abstract

The objectives of this research were to determine mean and maximum tolerance ranges of *Carassius auratus* (C_a) and *Cyprinus carpio* (C_c) populations on various physico-chemical parameters and ecological indicator metrics. Little is known about chemical tolerance ranges of the two species, even though these species are widely distributed species in aquatic ecosystems. Maximum tolerance ranges of C_a-population to total nitrogen (TN) and total phosphorus (TP) were 20.3 mg L^{-1} and 2.0 mg L^{-1}, respectively. Optimal ranges of TN and TP in the C_a-population were 1.7-5.0 mg L^{-1} and 0.06-0.30 mg L^{-1}, respectively. Such nutrient regimes of the C_a-population were evaluated as hypereutrophy, indicating high tolerance limits. The C_c-population had similar ecological characteristics to C_a-population, but the mean tolerance ranges of TN, TP, BOD, and COD were significantly ($p < 0.05$) greater than the C_a-population. Ecological patterns of trophic composition and tolerance guilds in the C_a-population were similar to those of the C_c-population. The model value of Index of Biological Integrity (IBI) of the habitat where *C. auratus* and *C. carpio* co-occurred averaged 15.0 ± 4.3 and 12.9±3.6, respectively. Based on the modified criteria of the United States Environmental Protection Agency (Klemm et al. 1993), it indicated poor ecological health of both species. These results suggest that both species are highly tolerant to chemical and physical habitat conditions of waterbodies, and that the chemical tolerance range of C_c-population was higher than C_a-population.

Key words: *Carassius auratus*, chemical tolerance, *Cyprinus carpio*, ecological guild, water quality

INTRODUCTION

In Korean streams and rivers, organic matter and nutrient pollution are nationwide problems, and are key issues in ecosystem health assessment and ecological management. This phenomenon is caused mainly due to rapid industrialization, urbanization, human population increase, and intensive farming (Limburg and Schmidt 1990, Ricciardi and Rasmussen 1999, Baer and Pringle 2000). Especially dredging, flow alteration, and channelization in the urban streams accelerated the degradation of physical habitat health (Paul and Meyer 2001, Allan 2004). Such anthropogenic disturbances influence biodiversity of various aquatic biota including fish, and disrupt food chains from the nutrient regime to top-carnivores in the lotic environment. For these reasons, the United

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States Environmental Protection Agency (Klemm et al. 1993) and the European Union (Didier et al. 1995, Oberdorff et al. 2002) developed an ecological health assessment system based on numerous multi-metric biological models and implemented the model for regional assessment. The fish models of the ecological multi-metric approach were originally based on the concept of “index of biological integrity” (IBI) to evaluate physical habitat, chemical, and biological conditions in lotic ecosystems (Karr 1981). This approach has been applied to streams and rivers of the U.S. (Karr et al. 1986), France (Oberdorff and Hughes 1992, Oberdorff et al. 2002) Australia (Harris 1995), India (Ganasan and Hughes 1998), Japan (Koizumi and Matsumiya 1997), and Korea (An et al. 2001, An et al. 2002, Choi et al. 2011, Lee and An 2014). One of the problems in the regional model applications, however, was the classification and class categorization of fish tolerance guilds and trophic guilds.

Fish are an ecological indicator to measure the chemical tolerance and assess habitat modifications in lotic ecosystems. The biological response or tolerance range differs depending on the magnitude of the pollution or ecological disturbances (United States Environmental Protection Agency 1988, Van Putten 1989). Especially, the presence or absence, and the abundance of regional fish fauna are frequently influenced by chemicals in the water. The tolerance based guild classification used in the biological integrity models is based only on fish dictionaries or experiences of fish ecologists or taxonomists. The classification of the tolerance guild into tolerant, intermediate or sensitive species (Klemm et al. 1993) is ambiguous, and an analysis based on quantitative data rather than simple field experiences is needed. In fact, the ecosystem health assessment model, which uses a metric of tolerance guild based on the subjective aspects and traditional experiences, were widely applied in national streams and rivers (Choi 1989, Kim 1997). The model values, thus, obtained from the multi-metric health assessments may be ambiguous in diagnosing the ecological health (Meador and Carlisle 2007). In spite of these facts, little is known about the tolerance ranges or magnitude of fish species in developed countries and Korea.

Each fish species has a set of optimal, sub-optimal, or lethal tolerance range in terms of temperature (thermal tolerance), physical habitat (habitat tolerance), water quality (chemical tolerance), and ecological relevance (ecological tolerance), and one or two factors in the tolerance level are critical to some fishes. Generally, physical hydrological factors such as water temperature (Beitinger et al. 2000), land use patterns (Wang et al. 2001), stream morphology (Wang et al. 2003), and flow regime (Bunn and Arthington 2002) are known to be important factors influencing the level of fish tolerance in aquatic ecosystems. Also, chemical parameters such as organic matter pollutant (Dyer et al. 2000), toxic chemicals (Brian et al. 2005), ionic content or salinity (Le François et al. 2004) or nutrients (N, P) are other key factors that control fish tolerance in the waterbodies of geographic regions. In addition, fish tolerance may also be associated with biological factors such as predation (Brown et al. 2005). The physical, hydrological and chemical preferences and needs for a certain type of stream condition greatly influence the regional distribution of fish species (Lee and An 2014). In real stream environments, multiple abiotic and biotic factors simultaneously influence any given fish species, which causes problems when quantifying the tolerance range of the fish.

The two target species, *Carassius auratus* and *Cyprinus carpio,* selected in this study are cyprinidae. They are widely distributed in Korean aquatic ecosystems, and well known as commercial fish species with high scientific value (Kim and Park 2002). These two species are categorized as omnivore species in the trophic guilds (Choi 1987, Kim et al. 2005, Lee and Noh 2006), and their major habitats are mainly stagnant regions of weirs, reservoirs, and rivers with slow current velocity and large amounts of sediments in the bottom (Kim et al. 2005). Little is still known about how these species tolerate various environmental stress caused by chemicals. Determination of tolerance ranges of different species for different environmental factors is a key issue for ecologists working in ecosystem health assessment. In this study, tolerance ranges of two fish populations (C_a-population and C_c-population) were determined on the basis of land use pattern, stream morphology, chemical quantity in water, habitat parameters, ecological indicators (trophic/tolerance compositions) of co-occurring fishes, and multi-metric assessment of stream health.

MATERIALS AND METHODS

Sampling methods and sampling gears

Fishes were collected by a modified wading method applied by An et al. (2006) based on the catch per unit effort (CPUE; Klemm et al. 1993). Fish sampling were conducted at 720 streams and rivers of the Han River watershed (river length (RL) = 514 km; basin area (BA) = 26,219 km^2), the Nakdong River watershed (RL: 525 km, BA: 23,860

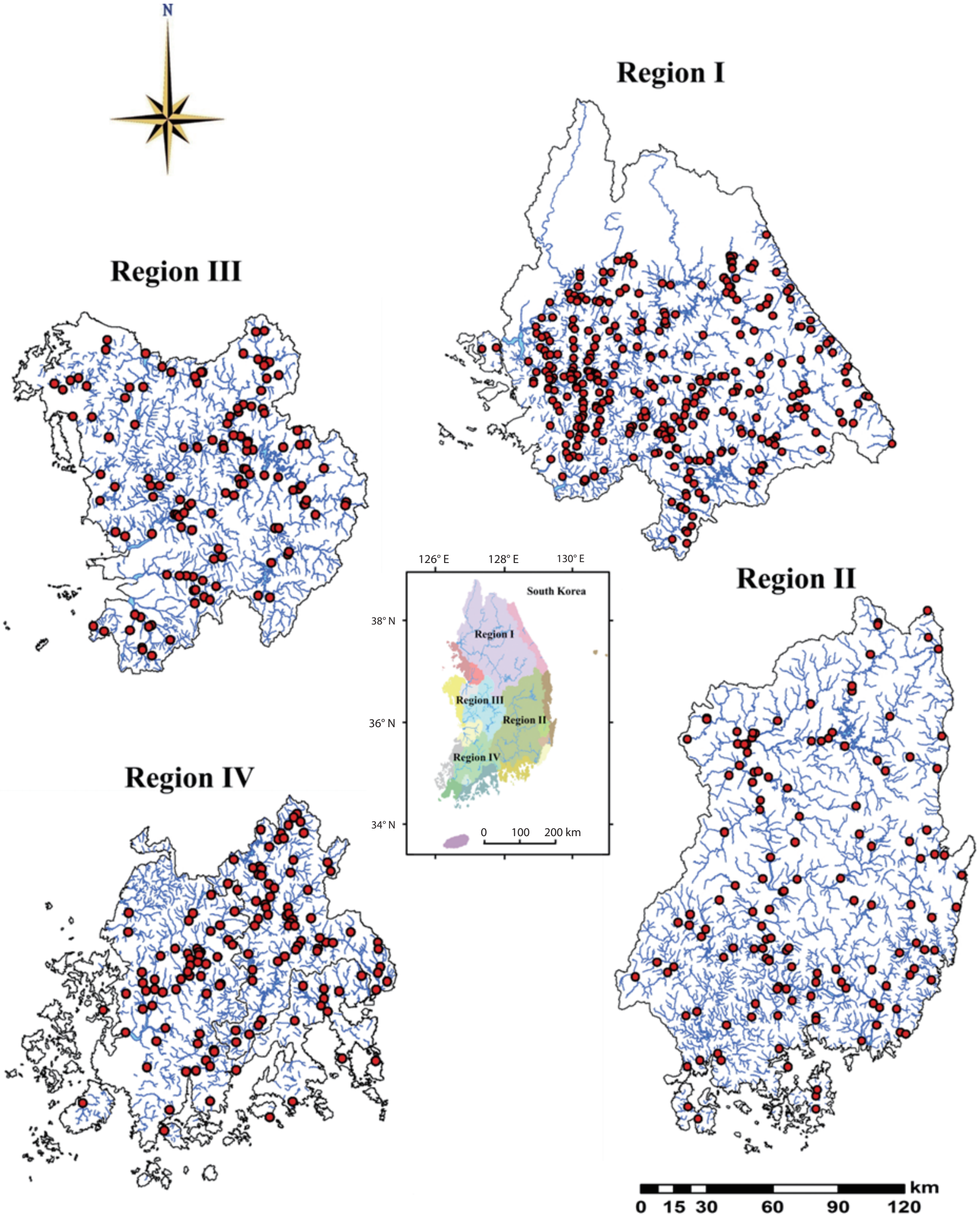

Fig. 1. Maps showing the sampling sites in four major Korean river watersheds of Han River (Region I), Nakdong River (Region II), Geum River (Region III) and Yeongsan/Sumjin River (Region IV).

km^2), Geum River watershed (RL: 414 km, BA: 9,886 km^2), Yeongsan/Sumjin River watershed (RL: 348 km, BA: 8,267 km^2) during 2008-2009 (Fig. 1). The time lapse for fish sampling was 60 minutes and all habitat types such as riffle, pool, and run area were included in 200m stream segments.

Sampled fishes were identified by using an IBI-approach developed by An et al. (2006) and returned to their natural habitats. Some ambiguous specimens were preserved in 10% formalin to identify the taxa in the laboratory. All fishes were examined for external anomalies of DELT, namely deformities (D), erosion (E: skin, barbells), lesion (L: open sores, ulcerations), and tumors (T)on the basis of the criteria developed by Sanders et al. (1999). Casting nets (mesh 7 × 7 mm) and kick nets (4 × 4 mm), which are the most common sampling gears in Korea, were used for fish sampling. The casting net was used for open water fish habitats without any obstructions like riffles, pools, and slow runs, whereas, the kick net was used at places with fast currents and many obstructions where one could hardly use a casting net.

Reference sampling sites

In addition to regular sampling, thirty-four reference sites were chosen from the watershed to calculate maximum species richness lines (MSRLs) against stream orders by following the approach of Hornig et al. (1995). Each reference stream number from the 1st to 5th order streams in the survey of reference sites were 3, 4, 3, 11, and 13, respectively. A 1:15,000 map was used to select candidate reference locations and determine stream order based on the methodology of Strahler (1957). The MSRL was determined by empirical methods developed by Karr (1981) and 1st order regression analysis developed by Rankin and Yoder (1999).

Physico-chemical analysis

A total of eight parameters that include biological oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN), nitrate-nitrogen (NO_3-N), total phosphorus (TP), phosphate-phosphorous (PO_4-P), suspended solids (SS), and electric conductivity were analyzed in this study. We analyzed monthly datasets that were obtained from the Ministry of Environment, Korea (MEK) from January 2008 to December 2009. The criteria of physico-chemical water quality were based on a 7-rank system set by the Ministry of Environment, Korea.

Stream ecosystem health model

Fish samples were first analyzed according to the Index of Biological Integrity (IBI) developed by Karr (1981) and Barbour et al. (1999) and run through an ecological health assessment model. The samples were collected from four major watersheds of the Han River, Nakdong River, Geum River, and Yeongsan/Sumjin River during 2008-2009. The metrics (M) reflected three major ecological characteristics: species richness and composition, trophic composition, and fish abundance and health condition. The three groups each consisted of eight metrics: M_1, total number of native species; M_2, number of riffle-benthic species; M_3, number of sensitive species; M_4, proportion of individuals as tolerant species; M_5, proportion of individuals as omnivores; M_6, proportion of individuals as native insectivores; M_7, total number of individual native species; and M_8, proportion of abnormal individuals. The four metrics (M_1, M_2, M_3, and M_7) were evaluated using the maximum species richness line (MSRL) with stream orders. Each metric was given 1, 3, or 5 points respectively. The points were then summed up to determine 4 class criteria that ranged from excellent (A: 40-36), good (B: 35-26), fair (C: 25-16), and very poor (D: $\leq$ 15). Detailed descriptions with specific characteristics and scoring criteria of the model have been previously reported by An et al. (2006).

Physical habitat parameters

Habitat assessments were modified according to the Qualitative Habitat Evaluation Index (QHEI) described by Plafkin et al. (1989). Six habitat parameters chosen from widely used references (Hamilton and Bergersen 1984, Lafferty 1987, Bartholow 1989), were used for assessing QHEI: epifaunal substrate/available cover (Q_1), embeddedness (Q_2), channel flow status (Q_3), dam construction impact (Q_4), channel alteration (Q_5), and sediment deposition (Q_6). Each of the assessed habitat attributes was summarized and divided into 4 categories: “optimal (20, 18, 16),” “sub-optimal (15, 13, 11),” “marginal (10, 8, 6),” and “poor (5, 3, 1).”

Statistical analysis

SPSS ver. 18.0 (SPSS Inc., Chicago, IL, USA) was used to test significant differences between C_a-population (n = 479) and C_c-population (n = 145) by using datasets from four major rivers and streams. Two independent sample *t*-tests were conducted to compare water quality parameters, physical habitat variables, and ecological indicators between C_a-population (n = 479) and C_c-population (n = 145). In addition, SYSTAT 7.0 (Wilkinson 1997) was used for sample linear regression analyses and spearman-correlation analyses.

RESULTS AND DISCUSSION

Impact of stream morphology and land use patterns on C_a-population and C_c-populations

An analysis of stream morphology and land use patterns were carried out at sites where C_a-population and C_c-populations were sampled (Table 1). Stream width, stream order, and altitude were used as key variables for stream morphology. Three categories were set up to differentiate land use patterns, namely urban land, agricultural land, and forestry. The C_a-population occurred in habitats with a mean stream width of 73.3m (range: 1-550), mean stream order of 3.35 (1-6), and mean altitude of 38.2m (0-359), while the C_c-population occurred in habitats with a mean stream width of 89.6m (range: 1.1-625), mean stream order of 3.48 (1-6), and mean altitude of 30.9m (0-175; Table 1). Two statistically independent sample *t*-tests on stream morphology between C_a-population and C_c-population (Table 1) showed that there were no significant differences ($p > 0.05$) in stream width and stream order, but differences were found in altitude.

Analysis of land use pattern showed that occurrence frequency of the C_a-population was 50.3% (1.5-100%) in the forestry region, 31.8% (1.0-86.8%) in the agricultural region, and 20.8% (0.5-100%) in the urban region. In the meantime, occurrence frequency of the C_c-population was 42.5% (7.1-88.5%) in the forestry region, 30.9% (2.0-82.7%) in the agricultural region, and 31.2% (1.1-100%) in the urban region. Two statistically independent sample *t*-tests on land use patterns between the two populations showed that there were significant differences ($p < 0.001$) in the urban and forestry regions, but not in the agricultural region. When compared to the C_a-population, the C_c-population was more widely distributed in the urban region and less widely distributed in the forestry region.

Statistical tests in the C_a-population and C_c-population indicated that stream morphology agreed with land use patterns in both populations. Both C_a-population and C_c-populations had a significant probability of $p < 0.05$ in the altitude (stream morphology), and fish occupancy of $p < 0.001$ in the urban and forestry region. The C_c-population was distributed in lower altitude regions (downstream) and urban regions, where point and non-point pollution sources are denser when compared to the C_a-population. These results indicate that the tolerance of C_a-population for stream morphology and land use pattern is greater than the C_c-population.

Chemical tolerance of C_c-population and C_a-population for water quality

The chemical tolerance ranges of the C_c-population and C_a-population were determined after assessing water chemistry factors such as biological water quality (BOD), chemical oxygen demand (COD), total nitrogen (TN),

Table 1. Means, range (maximum-minimum) and quartile (1/4 quartile, median and 3/4 quartile) on stream morphologic parameters and land use pattern in streams and rivers where C_a-population and C_c-population was sampled

Parameters		C_a-Population							C_c-Population							*t*-value	*p*-value
		n	Mean ± SD	Min	1/4 Quartile	Median	3/4 Quartile	Max	n	Mean ± SD	Min	1/4 Quartile	Median	3/4 Quartile	Max		
Stream morphology	Stream width (m)	474	73.3 ± 91.6	1	20	40	90	550	145	89.6 ± 113.5	1.1	26	50	100	625	-0.009	0.993
	Stream order	479	3.35 ± 1.17	1	3	3	4	6	145	3.48 ± 1.1	1	3	4	4	6	-1.175	0.240
	Altitude (m)	471	38.2 ± 40.6	0	13	26	52	359	144	30.9 ± 26.1	0	13	25	41.3	175	2.542	0.011
Land use pattern	Urban (%)	465	20.8 ± 22	0.5	5	11.8	27.9	100	144	31.2 ± 24.7	1.1	9.1	26.2	45.4	100	-4.789	< 0.001
	Agriculture (%)	457	31.8 ± 19.3	1	17.5	27.4	44	86.8	134	30.9 ± 20.3	2	13.6	25.2	45	82.7	0.535	0.593
	Forest (%)	471	50.3 ± 22.6	1.5	30.3	52.4	68.3	100	138	42.5 ± 20.6	7.1	25.5	40.1	60.9	88.5	3.632	< 0.001

C_a, *Carassius auratus*; C_c, *Cyprinus carpio*; Max, maximum; Min, minimum; n, number of sample nitrate-nitrogen (NO_3-N), total phosphorus (TP), phosphate-phosphorus (PO_4-P), total suspended solids (SS), and electric conductivity (Table 2; Figs. 2 and3). Mean and maximum tolerance ranges for organic matters of BOD in the C_a-population were 3.71 mg L^{-1} and 24.4 mg L^{-1}, respectively, and the tolerance values for COD were 7.14 mg L^{-1} and 27.3 mg L^{-1}. Mean and maximum tolerance ranges for TP were 0.24 mg L^{-1} and 2 mg L^{-1} in the C_a-population, respectively. In the meantime, mean and maximum tolerance ranges for BOD in the C_c-population were 5.1 mg L^{-1} and 24.4 mg L^{-1}, respectively, and the tolerance values for COD were 8.07 mg L^{-1} and 27 mg L^{-1}. Mean and maximum tolerance ranges for TP were 0.39 mg L^{-1} and 1.9 mg L^{-1} in the C_c-population. Two statistically independent sample *t*-tests showed that fish tolerance for BOD, COD, and TP, except SS, were significantly ($p < 0.05$) greater in the C_c-population than the C_a-population (Table 2). These outcomes suggest that chemical tolerance of organic matter pollution and nutrient enrichment was greater in the C_c-population than the C_a-population.

In addition, optimal peak ranges for two fish populations were determined by using quartile analysis (Table 2, Figs. 2 and 3). As shown in Figs. 2 and 3, the tolerance range for chemical parameters were wide in both the C_c-population and C_a-population, and the mean values for BOD, COD, and TP fell in the high chemical concentrations, indicating that both the C_c-population and the C_a-population are tolerant fish species along the chemical gradients. The chemical ranges of one-fourth and three-fourths, based on the quartile, were a major distribution of the fish populations, and were also compared with criteria of stream water quality according to the Ministry of Environment, Korea (2006). Major distribution of the C_a-population on BOD was 1.5-4.5 mg L^{-1}, indicating that the stream chemical health, based on BOD, was judged as a little fair (III) to good health condition (Ib) according to the criteria of MEK (2006). Similarly, the major distribution range of the C_a-population on COD was 4.5-9 mg L^{-1} and the distribution range on TP was 0.06-0.3 mg L^{-1}, indicating poor (IV) to good health (Ib) condition. Also, the C_a-population from 479 sampling sites were observed and 156 sites out of 479 sites turned out to be in very poor condition (BOD > 10 mg L^{-1}; COD > 11 mg L^{-1}; TP > 0.5 mg L^{-1}), and unfit for the survival of the C_a-population. Also, the C_a-population was observed in the clean environment (Ia), indicating that the fish can distribute in pristine conditions, even though the C_a-population is widely known as a tolerant fish population (Kim and Park 2002, Lee and Noh 2006).

Major distribution of the C_c-population on BOD

Table 2. Means, range (maximum-minimum) and quartile (1/4 quartile, median and 3/4 quartile) on water quality in streams and rivers where C_a-population and C_c-population was sampled

Parameters	C_a-Population							C_c-Population							*t*-value	*p*-value
	n	Mean ± SD	Min	1/4 Quartile	Median	3/4 Quartile	Max	n	Mean ± SD	Min	1/4 Quartile	Median	3/4 Quartile	Max		
BOD (mg L^{-1})	473	3.71 ± 3.35	0.1	1.5	2.6	4.5	24.4	140	5.1 ± 4.16	0.3	2.3	3.9	6.4	24.4	-3.610	< 0.001
COD (mg L^{-1})	385	7.14 ± 3.76	1.1	4.5	6.4	9	27.3	118	8.07 ± 3.69	1.7	5.8	7.4	10.2	27	-2.363	0.019
TN (mg L^{-1})	473	3.92 ± 3.21	0.1	1.7	2.9	5	20.3	140	5.64 ± 4.11	0.7	2.3	4.3	8.2	20.3	-4.555	< 0.001
NO_3-N (mg L^{-1})	466	2.07 ± 1.58	0.02	1	1.7	2.7	11.8	140	2.63 ± 2.07	0.02	1.3	2.4	3.2	11.8	-3.001	0.003
TP (mg L^{-1})	467	0.24 ± 0.30	0.01	0.06	0.1	0.3	2	139	0.39 ± 0.39	0.01	0.1	0.2	0.5	1.9	-4.212	< 0.001
PO_4-P (mg L^{-1})	429	0.16 ± 0.23	0.001	0.02	0.07	0.2	1.7	131	0.29 ± 0.3	0.001	0.06	0.14	0.4	1.3	-4.408	< 0.001
SS (mg L^{-1})	437	14.50 ± 13.40	0.5	6	11.1	18.1	95.5	129	16.2 ± 13.5	1.2	6.9	12.7	20.4	78	-1.216	0.224
Electric Conductivity (μS cm^{-1})	385	376.8 ± 238.6	70	219	311	464	1821	118	442.9 ± 272.7	107	256.5	375	518.8	1529	-2.543	0.011

C_a,*Carassius auratus*; C_c, *Cyprinus carpio*; Max, maximum; Min, minimum; BOD, biological oxygen demand; COD, chemical oxygen demand; TN, total nitrogen; NO_3-N, nitrate-nitrogen; TP, total phosphorus; PO_4-P, phosphate-phosphorous; SS, suspended solids; n, number of sample

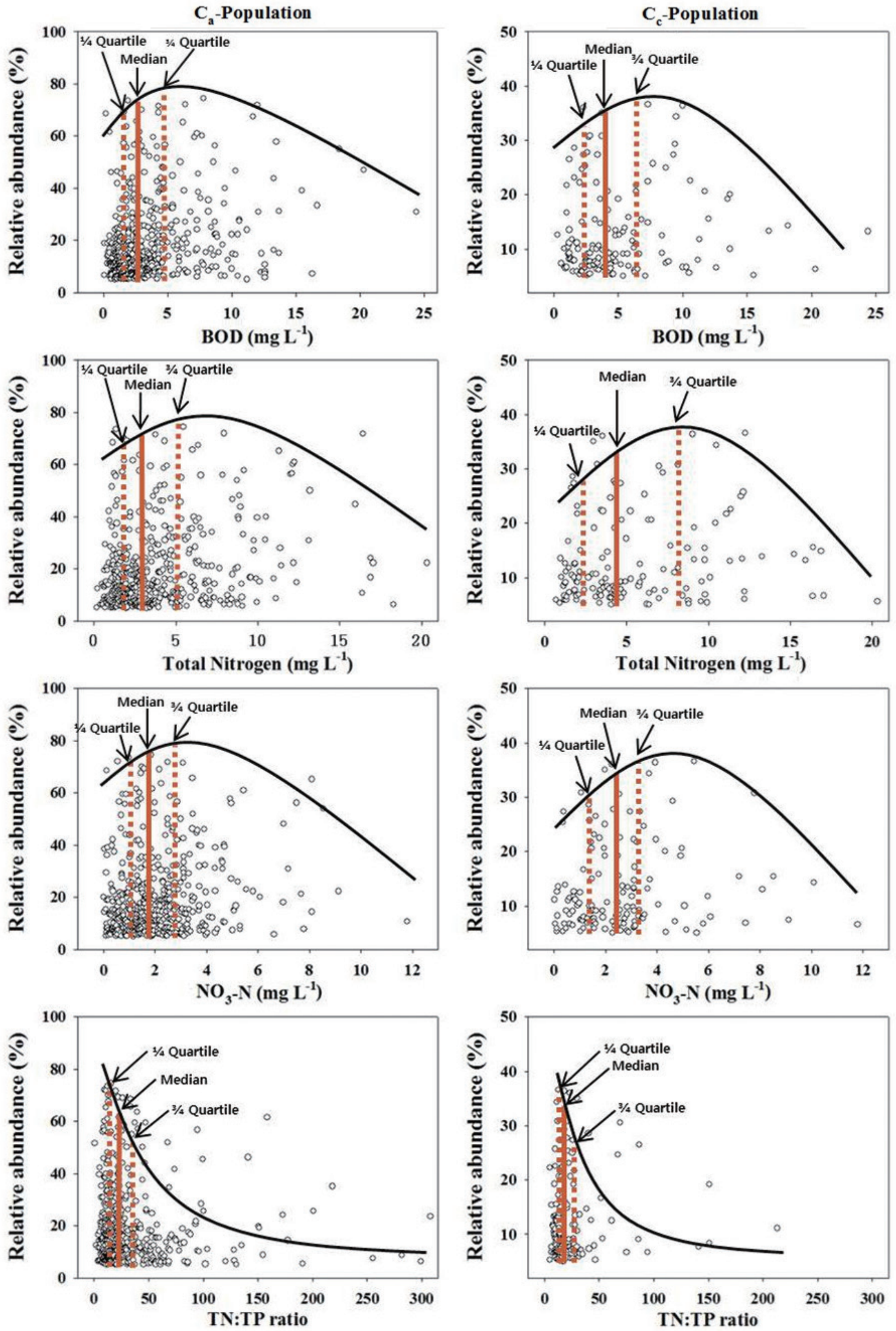

Fig. 2. Relative abundance (%) as a function of oxygen demand (organic matter), N nutrients in C$_a$-population (*Carassius auratus*) and C$_c$-population (*Cyprinus carpio*).

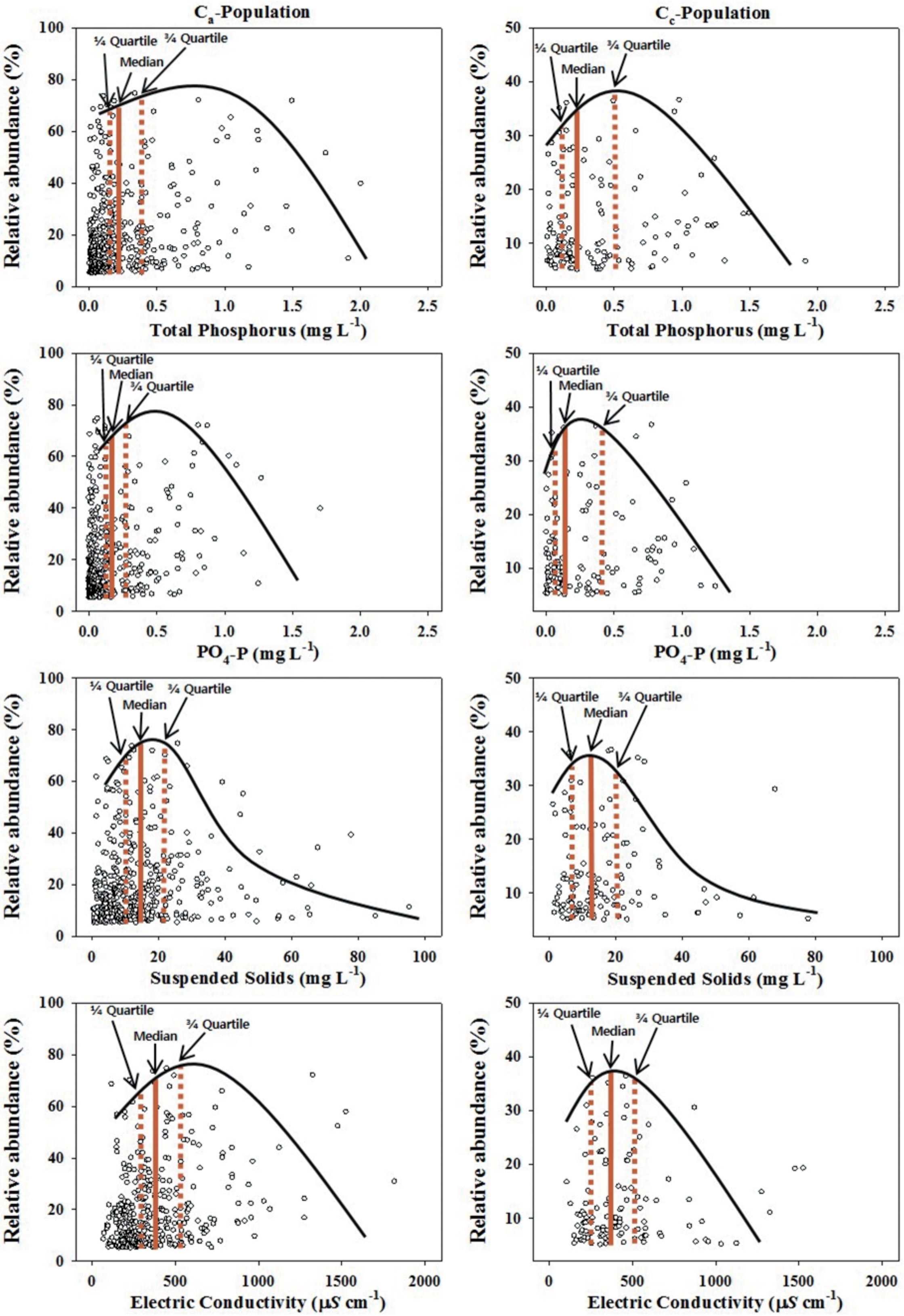

Fig. 3. Relative abundance (%) as a function of P nutrients, suspended solids and ionic content (Cond) in C_a-population (*Carassius auratus*) and C_c-population (*Cyprinus carpio*).

was 2.3-6.4 mg L^{-1}, indicating that the stream chemical health, based on BOD, was judged as poor (IV) to somewhat good health condition (II) according to the criteria of MEK (2006). Similarly, the major distribution range of the C_c-population on COD was 5.8-10.2 mg L^{-1}, and the distribution range on TP was 0.1-0.5 mg L^{-1}, indicating a poor (V) to somewhat good health (II) condition. Also, the C_c-population from 145 sampling sites were observed and 53 sites out of 367 sites turned out to be in very poor condition (VI), unfit for survival of the C_c-population. Only 9% (13 of 145 sampling sites) of the C_c-population was observed in a clean environment (Ia), indicating that C_c-population was generally distributed in fairly poor quality water than in clean environments.

All analysis of the chemical tolerance range indicated that both fish populations had wide range of tolerance in major chemical parameters. However, the C_a-population was distributed in both polluted regions and clean regions, while the C_c-population was distributed more widely in severely polluted regions than the clean regions. These results suggest that the C_c-population has adapted more to the polluted region than the C_a-population, and that *Carassius auratus* was classified as a tolerant species as shown in conventional classifications of tolerance guild (An et al. 2006). In addition, the two populations were observed less frequently in clean environments as shown in the Figs. 2 and 3.

Statistical tests of two populations in relation to the water quality variables

Regression analysis on relative abundance of the C_a-population and the C_c-population to the water chemical parameters are shown in Figs. 4 and 5. The data analysis was conducted by dividing the intervals of water quality data uniformly. The maximum relative abundance (Max R_a) values of the fish population were obtained from the intervals of water quality (Figs. 4 and 5). These two populations were statistically significant in all water chemical parameters in the level of p = 0.05, and especially statistically significant in the level of $p < 0.001$. The C_a-population had TN, NO_3-N, TN:TP ratio, and SS, and the C_c-population had BOD, TN, NO_3-N, and electric conductivity. Determinant coefficients of the C_a-population in the linear regression analysis were suspended solids (SS: $R^2 = 0.543$), NO_3-N ($R^2 = 0.479$), total nitrogen (TN: $R^2 = 0.433$), TN:TP ratio ($R^2 = 0.412$), total phosphorus (TP: $R^2 = 0.34$), BOD ($R^2 = 0.264$), electric conductivity ($R^2 = 0.21$) and PO_4-P ($R^2 = 0.15$) (Figs. 4 and 5). This outcome indicates that suspended solids, dissolved phosphate and nitrogen in water columns are key determinants that cause variation in abundance of the C_a-population, and these factors were closely associated with the habitat of *Carassius auratus* (Kim and Park 2002, Lee and Noh 2006). The determinant coefficients of the C_c-population were electric conductivity ($R^2 = 0.456$), NO_3-N ($R^2 = 0.402$), TN ($R^2 = 0.366$), suspended solids ($R^2 = 0.353$), PO_4-P ($R^2 = 0.344$), TP ($R^2 = 0.329$), BOD ($R^2 = 0.296$) and TN:TP ratio ($R^2 = 0.282$) (Figs. 4 and 5). Regression analysis of the C_c-population suggests that electric conductivity, dissolved nitrogen and phosphorus and suspended solids in the water column are primary components that influence the abundance of the C_c-population. Overall, this data suggests that dissolved phosphate, and volatile and non-volatile suspended solids are key determinants for the abundance of the two populations.

Trophic / tolerance preference tests of two populations in the co-occurring fish

Trophic preferences of two fish populations were analyzed by comparing insectivore and omnivore species, and also, tolerance preferences were analyzed by studying sensitive and tolerant species (Fig. 6). Barbour et al. (1999) pointed out that trophic guild and tolerance guild of fish are closely associated with water chemistry parameters such as organic matter and nutrient (N, P) pollution. Previous research on biological integrity of fish showed that omnivore species and tolerant species are frequently observed in the polluted regions, while insectivore species and sensitive species are frequently observed in the clean riffle regions (An et al. 2001, An et al. 2006, Choi et al. 2011, Lee and An 2014). These attributes of the fish compositions are usually used for classification of fish guilds (Karr 1981, Klemm et al. 1993). As shown in Fig. 6, the relative abundance of the C_a-population decreased with the percentage of insectivore and percentage of sensitive species and increased with the percentage of omnivores and the percentage of tolerant species. The relative abundance of the C_c-population also decreased with the percentage of insectivore and percentage of sensitive species and increased with the percentage of omnivores and percentage of tolerant species, even when the distribution range of the C_a-population was wider than the C_c-population (Fig. 6).

Ecological indicator analysis of C_a-population and C_c-population

According to the analysis of ecological indicators co-

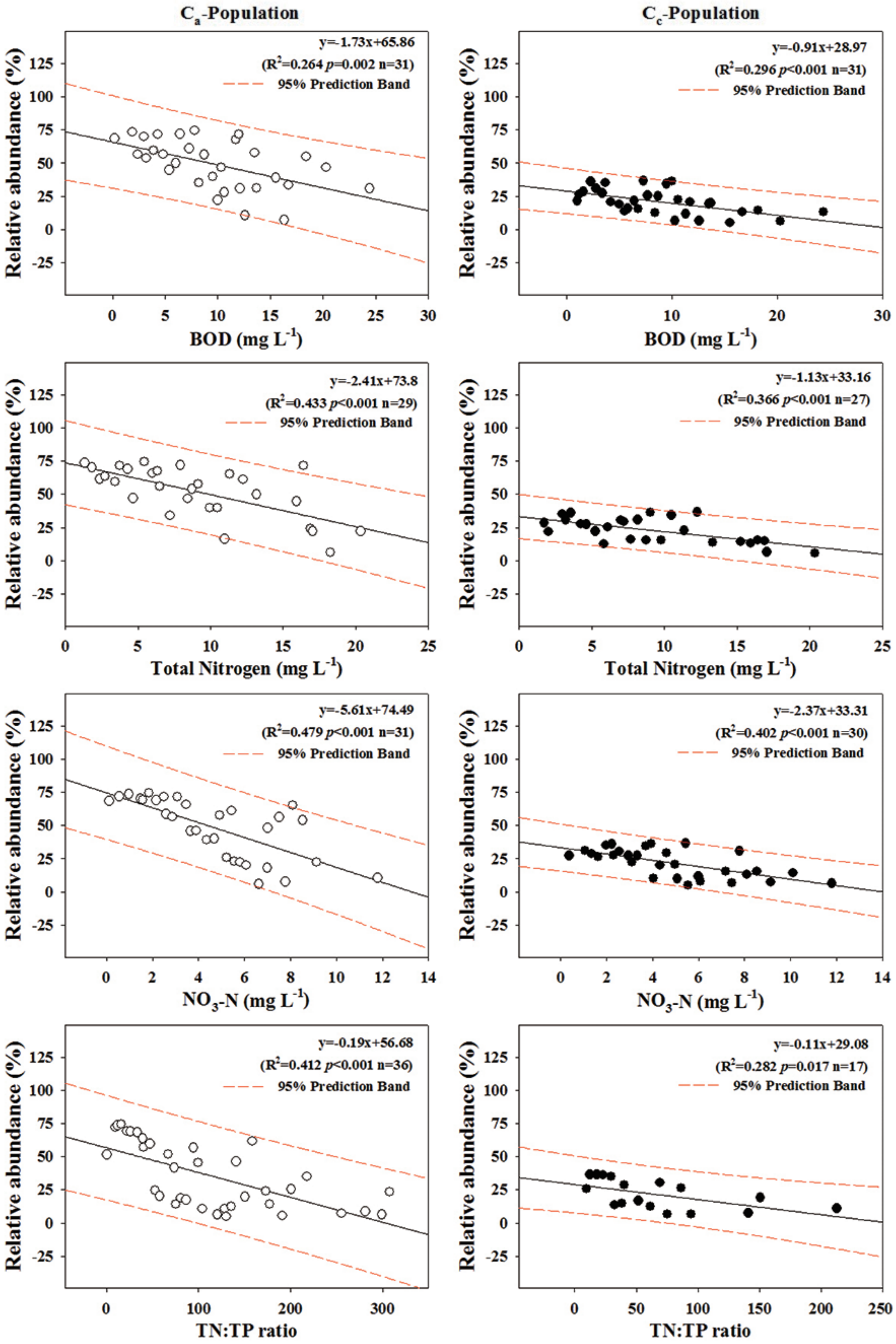

Fig. 4. Linear regression analysis on water quality parameters for oxygen demand (organic matter), N nutrient and the maximum relative abundance in C_a-population (*Carassius auratus*) and C_c-population (*Cyprinus carpio*).

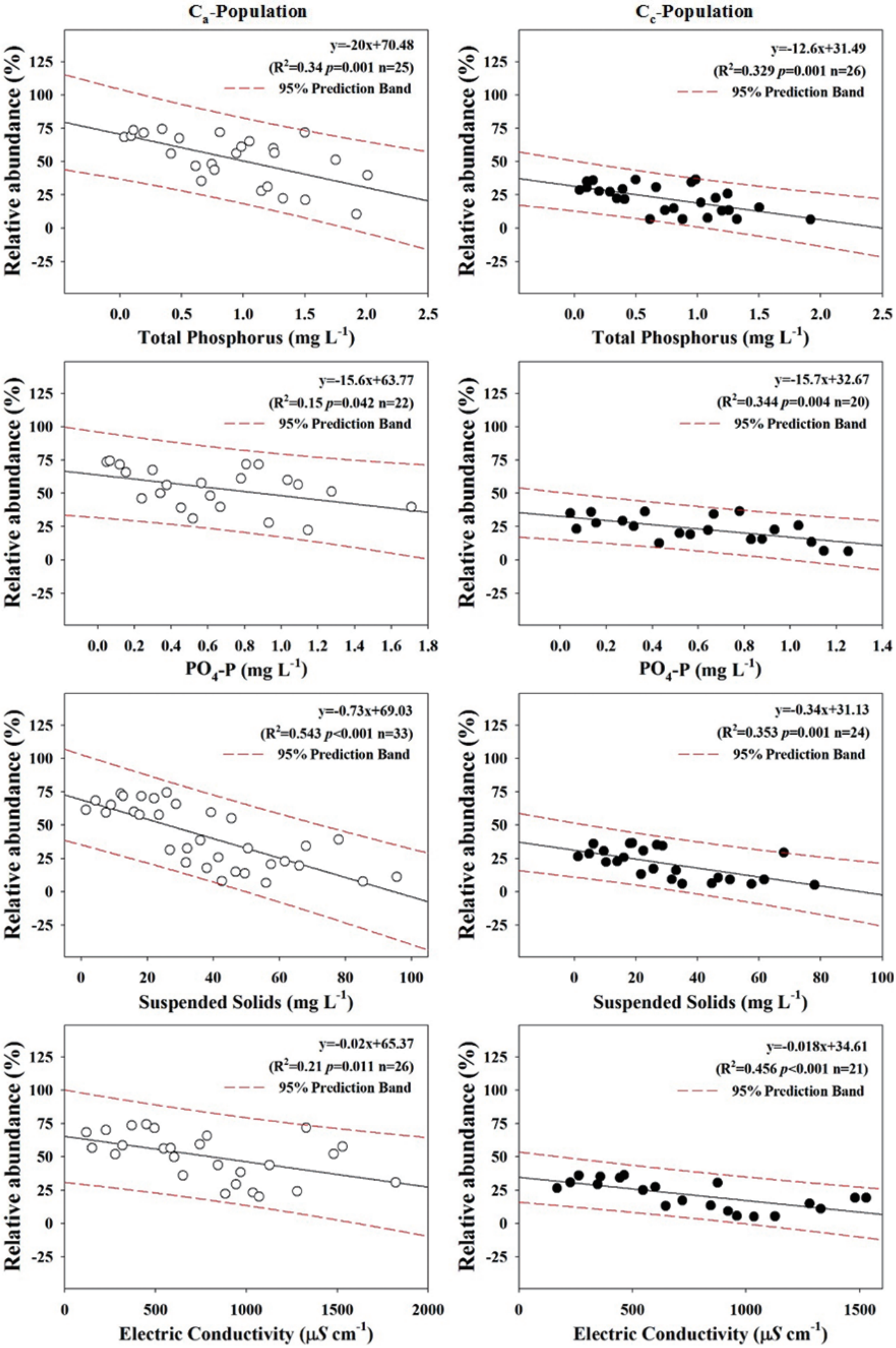

Fig. 5. Linear regression analysis on water quality parameters of P nutrient, suspended solids, ionic content (Cond) and the maximum relative abundance in C_a-population (*Carassius auratus*) and C_c-population (*Cyprinus carpio*).

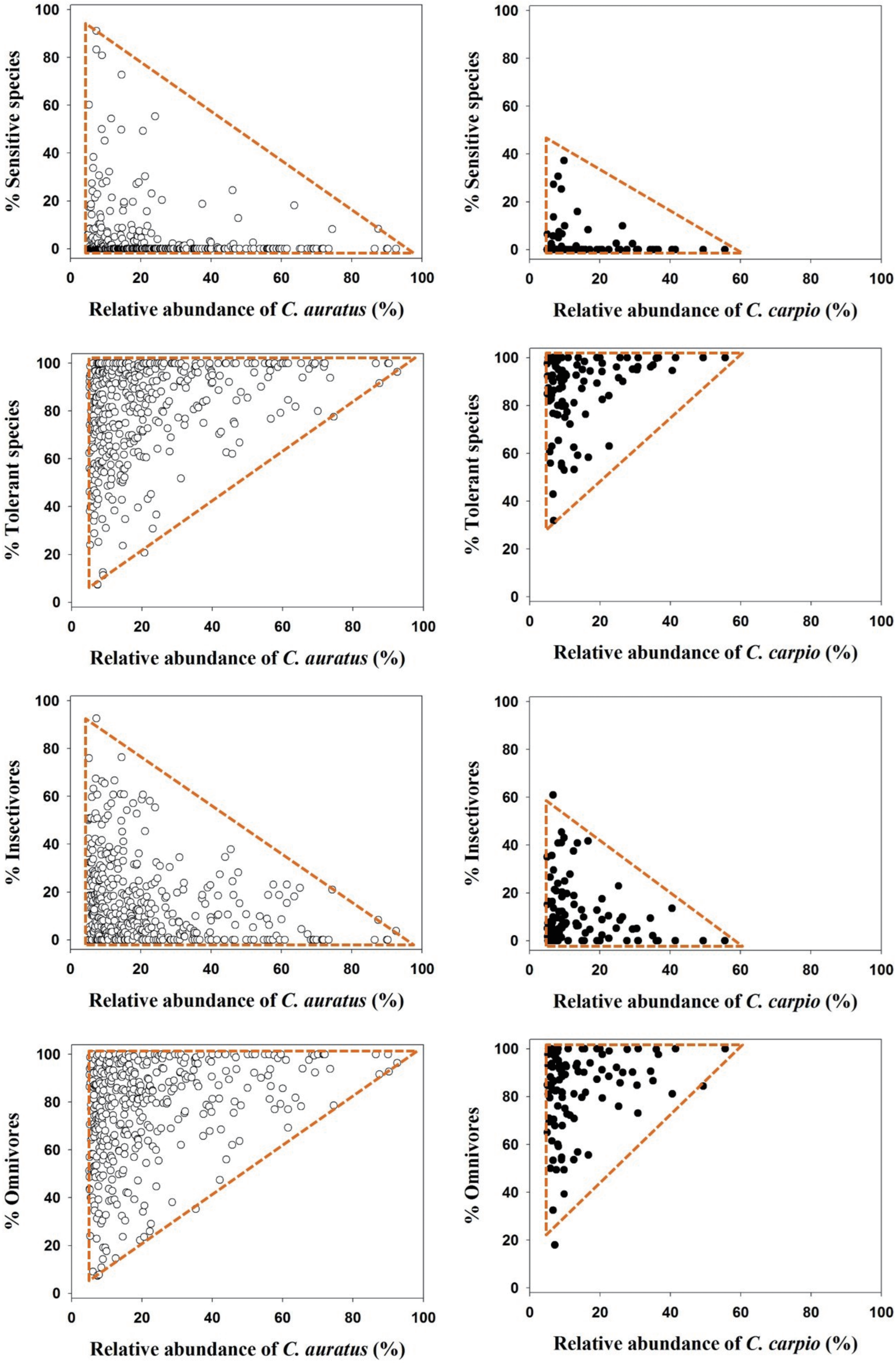

Fig. 6. Tolerance gradients of sensitive and tolerant species (%) and trophic gradients of insectivore and omnivore species (%) co-occurring with *Carassius auratus* and *Cyprinus carpio*.

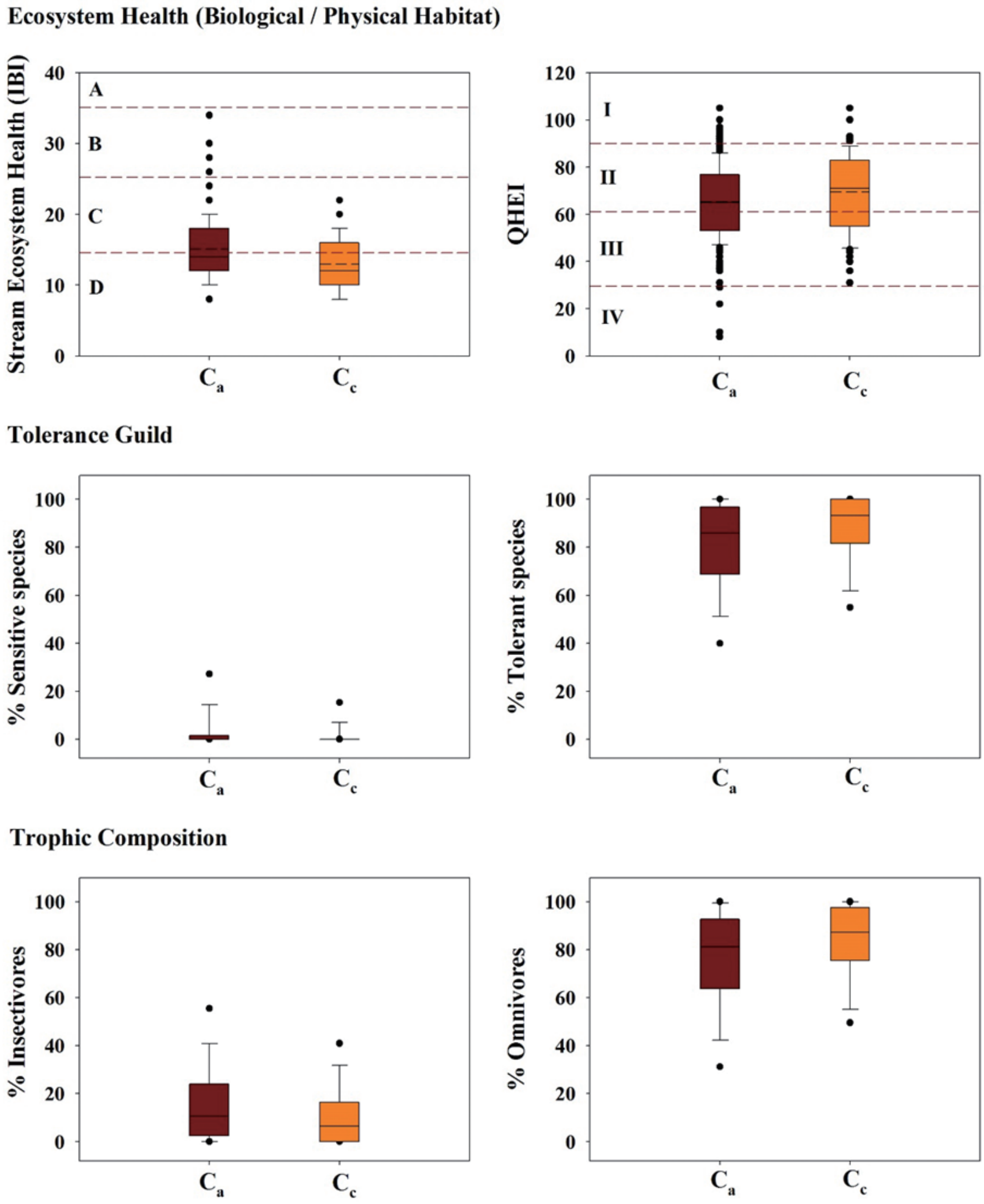

Fig. 7. Comparison between streams with C_a-population (*Carassius auratus*) and C_c-population (*Cyprinus carpio*) on ecosystem health, tolerance guild and trophic composition (Number of sample in C_a=416, C_c=105).

occurring in the two populations (Fig. 7), the relative abundance of tolerant species co-occurring with the C_a-population and C_c-population was 80.2% and 89.1%, respectively. In contrast, the relative abundance of sensitive species that co-occurred with the C_a-population and C_c-population was only 4.5% and 1.7%, respectively (Fig. 7). Numerous studies of tolerance guild metric (Karr 1981, Klemm et al. 1993, Barbour et al. 1999) showed that the tolerance guild of fish is closely associated with water chemistry parameters such as organic matter and nutrient (N, P) pollution. So, tolerant species tend to increase in polluted streams while sensitive species decrease in polluted streams.

Analysis of the trophic guild indicator co-occurring in the two populations showed that the relative abundance of omnivore and insectivore species that co-occurred with the C_a-population was 74.5% and 16.4%, respectively (Fig. 7). In contrast, the relative abundance of omnivore and insectivore species that co-occurred with the C_c-population was only 79.8% and 11.9%, respectively (Fig. 7). These outcomes suggest that omnivore species dominated the community in both fish populations and the magnitude of omnivore dominance was greater in the C_c-population than the C_a-population. Thus, based on the trophic indicator (omnivore, insectivore), biological tolerance was greater in the C_c-population than the C_a-population. Our results are supported by the fact that the predominance of omnivore species in the fish community is a typical example of water pollution (Klemm et al. 1993) and a good indicator for ecological disturbance in the stream environment (Shin et al. 2013). Both C_a-population and C_c-population groups were considered to be tolerant species in the stream regions with organic matter pollution.

Ecological health analysis in the distribution of C_a-population and C_c-population

The model value of the Index of Biological Integrity (IBI) in habitats co-occurring with *C. auratus* and *C. carpio* averaged 15.0 ± 4.3 and 12.9 ± 3.6, respectively (Table 3). This indicated a fairly healthy condition in the C_a-population and poor health condition in the C_c-population according to the modified criteria of US EPA (Klemm et al. 1993). Thus, the ecological health degraded in the streams of two fish populations, and the magnitude of degradation of ecological health was greater in the C_c-population than the C_a-population (Table 3). The multi-metric indicator analysis showed that metric values of seven (except M_4) out of eight metrics (M_1- M_8) were lower in the C_c-

Table 3. Comparison of fish community metrics according to Index of Biological Integrity (IBI) between streams and rivers with C_a-population and C_c-population

Category	Metrics	Stream Location		*t*-value	*p*-value
		Stream/River with C_a-Population (n=479)	Stream/River with C_c-Population (n=145)		
Species composition	M_1. Total number of native species	3.0 ± 1.4	2.4 ± 1.3	4.351	< 0.001
	M_2. Number of riffle-benthic species	1.2 ± 0.6	1.1 ± 0.3	2.645	0.008
	M_3. Number of sensitive species	1.1 ± 0.5	1.0 ± 0.2	2.082	0.038
	M_4. Proportion of individuals as tolerant species	1.0 ± 0.2	1.0 ± 0.0	2.663	0.008
Trophic composition	M_5. Proportion of individuals as omnivores	1.3 ± 0.9	1.2 ± 0.8	1.763	0.079
	M_6. Proportion of individuals as native insectivores	1.8 ± 1.3	1.5 ± 1.0	3.198	0.002
Fish abundance and condition in sample	M_7. Total number of individuals as native species	2.2 ± 1.6	1.8 ± 1.4	2.785	0.006
	M_8. Proportion of abnormal individuals	3.4 ± 1.9	2.8 ± 2.0	2.751	0.006
		15.0 ± 4.3 (Fair-Poor)	12.9 ± 3.6 (Poor)	5.993	< 0.001

C_a, *Carassius auratus*; C_c, *Cyprinus carpio*; M, metric; n, number of sample

Table 4. Comparison of habitat parameters according to Qualitative Habitat Evaluation Index (QHEI) between streams and rivers with C_a-population and C_c-population.

Category	Metrics	Stream Location		*t*-value	*p*-value
		Stream/River with C_a-Population (n=479)	Stream/River with C_c-Population (n=145)		
Habitat parameters	Q_1. Epifaunal substrate / Available cover	10.1 ± 4.4	10.1 ± 4.3	0.049	0.961
	Q_2. Embeddedness	10.1 ± 4.1	10.6 ± 3.9	-1.269	0.205
	Q_3. Channel flow status	11.4 ± 3.7	11.9 ± 3.2	-1.311	0.191
	Q_4. Dam construction impact	11.1 ± 4.5	11.6 ± 4.5	-1.215	0.225
	Q_5. Channel alteration	10.3 ± 3.7	10.4 ± 4.0	-0.084	0.933
	Q_6. Sediment deposition	10.3 ± 3.7	12.5 ± 4.3	-2.190	0.029
		64.7 ± 16.2	67.0 ± 16.7	-1.517	0.130

C_a, *Carassius auratus*; C_c, *Cyprinus carpio*; Q, Qualitative Habitat Evaluation Index (QHEI); n, number of sample population than the C_a-population.

The largest difference (≥ 0.3) in the metric values between the C_a-population and the C_c-population was seen in metrics M_6, M_7, and M_8. These metric values suggest that both species are categorized as highly tolerant species in the waterbodies, and the magnitude of tolerance (pollution) based on the multi-metric model, was greater in the C_c-population than the C_a-population. Statistically independent sample *t*-tests showed distinct differences in metric values between the C_a-population and C_c-populations at a probability level of 0.05 in the seven metrics, except M_5, and at the level of 0.01 in the six metrics.

Physical habitat health analysis of C_a-population and C_c-population

Qualitative Habitat Evaluation Index (QHEI) in the C_a-population and C_c-population were evaluated as shown in Table 4. The model value of QHEI co-occurring with *C. auratus* and *C. carpio* averaged 64.7 and 67 respectively, (Table 4), indicating that the physical habitat health was in good condition according to the modified criteria of US EPA (Klemm et al. 1993; Table. 4, Fig. 7). The most significant difference in mean habitat metric values between the C_a-population and the C_c-population was seen for sediment deposition (Q_6), which was 10.3 and 12.5 respectively (Table 4). But, the remaining mean habitat metric values were similar for both species. Epifaunal substrate/available cover (Q_1), embeddedness (Q_2), and channel alteration (Q_5) ranged 10.1-10.3 and 10.1-10.6, respectively. The physical habitat of the C_a-population and C_c-population was assessed to be in fair condition (Table 4). In the meantime, mean habitat metric values of the C_a-population and C_c-population for channel flow status (Q_3) and dam construction impact (Q_4) ranged from 11.1-11.4 and 11.6-11.9 respectively, (Table 4). The physical habitat of C_a-population and C_c-populations was judged to be in good condition.

To determine differences in physical habitats between the two populations, statistical tests were conducted under the assumption of equal variance on all metrics. According to the results of habitat health, values of probability (*P*) ranged from 0.19 to 0.96, indicating no significant difference in habitat conditions between the C_a-population and C_c-population. The probability (*P*) value in the epifaunal substrate/available cover (Q_1) was the highest among the six habitat metrics and the metric reflects the artificial habitat constructions and habitat simplification as well. These results indicate that the C_a-population and C_c-population reflected characteristics of tolerant species very well. Both populations occupied similar habitats with slow current velocity or dams and reservoirs with sediment deposition (Kim and Park 2002, Lee and Noh 2006).

CONCLUSION

Tests on overall tolerance range showed that both the C_a-population and C_c-population can be classified as tolerant groups after the analysis of land use-pattern, stream morphology, chemical water quality, habitat parameters, and ecological indicators (trophic compositions and tolerance guilds) of co-occurring fish along with the multi-metric ecological health model. The magnitude of the tolerance range, however, was greater in the C_c-population than the C_a-population, and this was evident in chemical variables such as organic matter pollutants (BOD, COD), nutrients (TP, TN), suspended solids, and ionic contents. In the past, all research just categorized these two species as tolerant species using empirical methods such as simple descriptions of fish habitat, chemical conditions and fish dictionaries. International or domestic references with quantitative analysis based on land use pattern, stream morphology, chemical water quality, habitat parameters, ecological indicators, and ecological integrity model values did not exist. This research provides a clear-cut evaluation of tolerance ranges or guild classification of the C_a-population and C_c-population in relation to physical, chemical, and ecological indicators, which are closely associated with external tolerance in the aquatic environment.

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LITERATURE CITED

Allan JD. 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. Annu Rev Ecol Evol Syst 35: 257-284.

An KG, Lee JY, Bae DY, Kim JH, Hwang SJ, Won DH, Lee JK, Kim CS. 2006. Ecological assessments of aquatic environment using multi-metric model in major nationwide stream watersheds. J Korean Soc Water Environ 22: 796-

804.

An KG, Park SS, Shin JY. 2002. An evaluation of a river health using the index of biological integrity along with relations to chemical and habitat conditions. Environ Int 28: 411-420.

An KG, Yeom DH, Lee SK. 2001. Rapid bioassessments of Kap Stream using the index of biological integrity. Korean J Environ Biol 19: 261-269.

Baer KE, Pringle CM. 2000. Special problems of urban river conservation: the encroaching megalopolis. In: Global Perspectives on River Conservation: Science, Policy and Practice (Boon PJ, Davies BR, Petts GE, eds). John Wiley& Sons Ltd, Chichester, pp 385-402.

Barbour MT, Gerritsen J, Snyder BD, Stribling JB. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish, 2nd ed. United States Enivironmental Protection Agency, Office of Water, Washington, DC. Report No.: EPA 841-B-99-002.

Bartholow JM. 1989. Stream temperature investigations: field and analytical methods. Instream flow information paper no. 13. Biological Report 89. Fish and Wildlife Service, US Department of the Interior, Washington D.C.

Beitinger TL, Bennett WA, McCauley RW. 2000. Temperature tolerances of North American freshwater fishes exposed to dynamic changes in temperature. Environ Biol Fish 58: 237-275.

Brian JV, Harris CA, Scholze M, Backhaus T, Booy P, Lamoree M, Pojana G, Jonkers N, Runnalls T, Bonfa A, Marcomini A, Sumpter JP. 2005. Accurate prediction of the response of freshwater fish to a mixture of estrogenic chemicals. Environ Health Persp 113: 721-728.

Brown C, Gardner C, Braithwaite VA. 2005. Differential stress responses in fish from areas of high-and low-predation pressure. J Comp Physiol B 175:305-312.

Bunn SE, Arthington AH. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environ Manage 30: 492-507.

Choi JW, Kumar HK, Han JH, An KG. 2011. The development of a regional multimetric fish model based on biological integrity in lotic ecosystems and some factors influencing the stream health. Water Air Soil Poll 217: 3-24.

Choi KC. 1987. Nature of Chungnam Province. Freshwater fishes. Korea Foundation for the Advancement of Science and Technology, Jeongmun Publishing Co., Seoul.

Choi KC. 1989. Freshwater Fish in Korea. Seomun Publishing Co., Ltd, Seoul.

Didier J, Kestemont P, Micha JC. 1995. Indice Biotique d'Integrite Piscicole pour Evaluer la Qualite Ecologique des Ecosystemes Aquqtiques. Unite de Recerche en biologie des Organismes, Facultes Universitairies N.D.la Paix, Namur, Belgium report (n 3) to the Ministere de la Region wallonne (MRW-DGTRE).

Dyer SD, White-Hull CE, Shephard BK. 2000. Assessments of chemical mixtures via toxicity reference values overpredict hazard to Ohio fish communities. Environ Sci Technol 34: 2518-2524.

Ganasan V, Hughes RM. 1998. Application of an index of biological integrity (IBI) to fish assemblages of the rivers Khan and Kshipra (Madhya Pradesh), India. Freshw Biol 40: 367-383.

Hamilton K, Bergersen EP. 1984. Methods to Estimate Aquatic Habitat Variables. Colorado Cooperative Fishery Research Unit, Colorado State University, Fort Collins, CO.

Harris JH. 1995. The use of fish in ecological assessments. Aust J Ecol 20: 65-80.

Hornig CE, Bayer CW, Twidwell SR, Davis JR, Kleinsasser RJ, Linam GW, Mayes KB. 1995. Development of regionally based biological criteria in Texas. In: Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making (Davis WS, Simon TP, eds). CRC Press, Boca Raton, FL, pp 145-152.

Karr JR. 1981. Assessment of biotic integrity using fish communities. Fisheries 6: 21-27.

Karr JR, Fausch KD, Angermeier PL, Yant PR, Schlosser IJ. 1986. Assessing biological integrity in running waters: a method and its rationale.Illinois Natural History Survey, Champaign, IL.

Kim IS. 1997. Illustrated Encyclopedia of Fauna and Flora of Korea. Vol. 37, Freshwater Fishes. Ministry of Education, Korea, Seoul.

Kim IS, Choi Y, Lee CY, Lee YJ, Kim BJ, Kim JH. 2005. Illustrated Book of Korean Fishes. Kyo-Hak Publishing Co., Ltd., Seoul.

Kim IS, Park JY. 2002. Freshwater Fishes of Korea. Kyo-Hak Publishing Co., Ltd., Seoul.

Klemm DJ, Stober QJ, Lazorchak JM. 1993. Fish field and laboratory methods for evaluating the biological integrity of surface waters. Environmental Monitoring Systems Laboratory – Cincinnati Office of Modeling, Monitoring Systems, and Quality Assurance, Office of Research and Development, US Enironmental Protection Agency, Cincinnati, OH. Report No.: EPA 600-R-92-111.

Koizumi N, Matsumiya Y. 1997. Assessment of stream fish habitat based on index of biotic integrity. Bull Jpn Soc Fisher Oceanogr 61:144-156.

Lafferty B. 1987. A procedure for evaluating buffer strips for stream temperature protection under the Forest Practices Act. In: Managing Oregon's Riparian Zone for Timber, Fish, and Wildlife. National Council of the Paper

Industry for Air and Stream Improvement, New York, NY, pp 70-77.

Lee JH, An KG. 2014. Integrative restoration assessment of an urban stream using multiple modeling approaches with physical, chemical, and biological integrity indicators. Ecol Eng 62: 153-167.

Lee WO, Noh SY. 2006. The Freshwater Fish of Korean Peninsula-With Looking Characteristics. Jisung Publishing Co., Ltd., Seoul.

Le François NR, Lamarre SG, Blier PU. 2004. Tolerance, growth and haloplasticity of the Atlantic wolffish (*Anarhichas lupus*) exposed to various salinities. Aquaculture 236: 659-675.

Limburg KE, Schmidt RE. 1990. Patterns of fish spawning in Hudson River tributaries: response to an urban gradient? Ecology 71: 1238-1245.

Meador MR, Carlisle DM. 2007. Quantifying tolerance indicator values for common stream fish species of the United States. Ecol Indic 7: 329-338.

Ministry of Environment, Korea. 2006. Researches for integrative assessment methodology of aquatic environments (III): development of aquatic ecosystem health assessment and evaluation system. National Institute of Environmental Research (NIER), Incheon.

Oberdorff T, Hughes RM. 1992. Modification of an index of biotic integrity based on fish assemblages to characterize rivers of the Seine Basin, France. Hydrobiologia 228:117-130.

Oberdorff T, Pont D, Hugueny B, Porcher JP. 2002. Development and validation of a fish-based index for the assessment of ‘river health’ in France. Freshw Biol 47: 1720-1734.

Paul MJ, Meyer JL. 2001. Streams in the urban landscape. Annu Rev Ecol Syst 32: 333-365.

Plafkin JL, Barbour MT, Porter KD, Gross SK, Hughes RM. 1989. Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrates and fish. Office of Water, United States Environmental Protection Agency, Washington, DC; Report No.: EPA/444/4-89-001.

Rankin ET, Yoder CO. 1999. Methods for deriving maximum species richness lines and other threshold relationships in biological field data. In: Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities (Simon TP, ed.). CRC Press, Boca Raton, FL, pp. 611-624.

Ricciardi A, Rasmussen JB. 1999. Extinction rates of North American freshwater fauna. Conserv Biol 13: 1220-1222.

Sanders RE, Miltner RJ, Yonder CO, Rankin ET. 1999. The use of external deformities, erosion, lesion, and tumors (DELT anomalies) in fish assemblages for characterizing aquatic resources: a case study of seven Ohio streams. In: Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities (Simon TP, ed.). CRC Press, Boca Raton, FL. pp 225-245.

Shin EJ, Choi JW, An KG. 2013. Ecological characteristics and chemical gradients in two different loach populations - *Misgurnus anguillicaudatus* and *Koreocobitis rotundicaudata*. Korean J Environ Biol 31: 419-428.

Strahler AN. 1957. Quantitative analysis of watershed geomorphology. Eos Trans Am Geophys Un 38: 913-920.

United States Environmental Protection Agency. 1988. WQS draft framework for the water quality standards program. Office of Water, United States Environmental Protection Agency, Washington, DC; Report No.: Draft 11-8-88.

Van Putten M. 1989. Issues in applying water quality criteria. In: Water Quality Standards for the 21st Century (Flock GH, ed). Office of Water, United States Environmental Protection Agency, Washington, DC, pp 175-177.

Wang L, Lyons J, Kanehl P. 2001. Impacts of urbanization on stream habitat and fish across multiple spatial scales. Environ Manage 28: 255-266.

Wang L, Lyons J, Rasmussen P, Seelbach P, Simon T, Wiley M, Kanehl P, Baker E, Niemela S, Stewart PM. 2003. Watershed, reach, and riparian influences on stream fish assemblages in the Northern Lakes and Forest Ecoregion, U.S.A. Can J Fish Aquat Sci 60: 491-505.

Wilkinson L. 1997. SYSTAT: new statictics, version 7.0, SPSS Inc. Chicago, Illinois, USA.