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Original article

Efficiency comparisons of fish sampling gears for a lentic ecosystem health assessments in Korea

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A B S T R A C T

The key objective of this study was to analyze the sampling efficiency of various fish sampling gears for a lentic ecosystem health assessment. A fish survey for the lentic ecosystem health assessment model was sampled twice from 30 reservoirs during 2008–2012. During the study, fishes of 81 species comprising 53,792 individuals were sampled from 30 reservoirs. A comparison of sampling gears showed that casting nets were the best sampling gear with high species richness (69 species), whereas minnow traps were the worst gear with low richness (16 species). Fish sampling efficiency, based on the number of individual catch per unit effort, was best in fyke nets (28,028 individuals) and worst in minnow traps (352 individuals). When we compared trammel nets and kick nets versus fyke nets and casting nets, the former were useful in terms of the number of fish individuals but not in terms of the number of fish species.

Introduction

The abundance, composition, and distribution of fishes in lake ecosystems are key components in understanding the ecosystem functions and structures for aquatic ecologists and lake managers. Previous studies of lentic ecosystems have analyzed: (1) fish biomass, production, and size–frequency distribution (Ryder 1965; Hanson and Leggett 1982); (2) relationships between species and habitat characteristics (Hinch et al 1991); (3) composition of assemblages and community structure (Werner et al 1977; Jackson et al 1992; Rundle and Jackson 1996) in relation to various physical and chemical conditions (Tonn and Magnuson 1982; Rahel 1984; Somers and Harvey 1984; Jackson and Harvey 1993, 1997); (4) the fish community as a measure of “ecosystem health” (Minns et al 1994); and (5) biogeographical characteristics of fishes (Jackson and Harvey 1989; Tonn et al 1990; Mandrak and Crossman 1992).

Such analyses were largely determined by sampling effects. Also, there is considerable variation in the degree of sampling effort used to determine the various estimates of fish abundance or presence in entire lakes. In some studies, as few as five or six sampling gears were used for a single night to sample the fish community of lakes, whereas the other end of the sampling spectrum is represented by the use of multiple sampling gears over many nights resulting in hundreds of units of sampling efforts across habitats. Integrating the catch data from various gears for different species is also challenging in studies using fish abundance. One approach simply is to add the various catches together (Hinch et al 1991; Weaver et al 1993). Although there is such a wide range of approaches to sampling and the type of data collected, there is little to guide us on whether the degree of sampling is sufficient to provide good quantitative or even qualitative estimates of fish abundance.

The accurate estimation of biotic assemblage attributes (e.g. species richness and composition, relative abundances, functional metrics) is required in environmental monitoring and assessments (Cao et al 2003; Kennard et al 2006). For samplings of fish assemblages in the world, a variety of catching methods are available (Cowx 1996; Murphy and Willis 1996). However, catching effectiveness—including species selection and size selectivity patterns—may differ for each gear, making it difficult to determine whether these differences allow for accurate characterization of assemblage attributes. Hence, there is a need for a more intensive evaluation of between-gear variations to determine their relative efficiency (Jackson and Harvey 1997; Olin and Malinen 2003; Goffaux et al 2005). Fish assemblage metrics are being intensively

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used to determine the ecological status of lakes (Randall and Minns 2002; Gassner et al 2003; Drake and Valley 2005), and fish as a group is one of the key biotic elements for such evaluation under the water Framework Directive of the European Union (2000).

In this study, new methods to estimate the abundance of fish species across numerous Korean reservoirs were tested. Given the recognized bias associated with fish sampling gears, how do various gears compare in estimating the relative abundance of species? When using different gears, do we get similar estimates in the average abundance or in the pattern of covariation in species abundance across reservoirs—i.e. if two species are positively correlated with abundance for one gear, is this consistent for all gears? In a more qualitative approach, how well do different gears identify the composition of fish communities present and how much effort is required with different gears to sample adequately for various species? Although there is an urgent need for a standardized fishing protocol for Korea's reservoir habitats, such a methodology is still under development in Korea.

Materials and methods

Sampling periods and sites

Fish samplings were conducted twice a year during a 5-year period (2008–2012) in 30 reservoirs within Han River (12), Geum River (6), Nakdong River (7), and Yeongsan River (5) watersheds. The sampling sites are as follows: Togyo Reservoir, Giljeong Reservoir, Soyang Reservoir, Yangyang Reservoir, Chuncheon Reservoir, Paldang Reservoir, Hwajinpo Reservoir, Pyeongtaek Reservoir, Wangsong Reservoir, Yonggye Reservoir, Idong Reservoir, Daeryong Reservoir, Masan Reservoir, Wonnam Reservoir, Daecheong Reservoir, Sinchon Reservoir, Buan Reservoir, Yedang Reservoir, Jusan Reservoir, Woonmun Reservoir, Upo Wetland, Jinyang Reservoir, Yeoncho Reservoir, Gucheon Reservoir, Byeokgye Reservoir, Bulgap Reservoir, Geumpung Reservoir, Dongbok Reservoir, Yeonku Reservoir, and Susan Reservoir.

The fish data were collected between 2008 and 2012 from 30 South Korea reservoirs (Figure 1). The reservoirs were selected using a probability design to be representative of regional conditions (Larsen et al 1994). Five or six crews were employed to sample in six reservoirs each year. The fish samples were collected twice a year: in the premonsoon season (May to June) and in the postmonsoon season (September to October).

Sampling gears and methods

Fish assemblages were sampled with overnight sets of fyke nets (FN), gill nets (GN), trammel nets (TN), minnow traps (MT), casting nets (CN), and kick nets (KN) were conducted in the daytime in the littoral zones of the reservoirs. A standardized level of effort, as a logarithmic function of reservoir size, ranged from one to three sets of each passive gear and three to nine of each active gear sites (Baker et al 1997; US EPA 1998). The sampling objective was to collect a representative sample of the fish assemblage at each reservoir, without regard to any particular species, or concentrated sampling of species-rich habitats. Fishes were identified to species level and counted. All voucher specimens were preserved in 10% formalin and returned to the laboratory for identification (Kim and Park 2002; Lee and No 2006).

Various sampling gears such as GN, FN, TN, MT, KN, and CN were used along the shorelines of the reservoirs. FN (20 m long and 2.4 m high, 5 mm mesh size), GN (100 m long and 2.0 m high, mesh size 45 mm), TN (50 m long and 1.0 m high, mesh size 12 mm), and MT (0.6 m long and 0.3 m high, 4 mm in mesh size) were set up at different depths in the profundal and the littoral zones. CN and KN were used in the nearshore area as well as the offshore zones of the reservoirs. FN, GN, TN, and MT were set up along the shorelines using a small boat and 25 HP motor (YAMAHA 2-Stroke, 25 MHS, tiller type). The littoral zones with 0.5–1 m depths were sampled using CN (38.5 m^2 capturing area, 7 mm in mesh size) and KN (1.6 m^2 capturing area, 4 mm in mesh size). CN was mainly used in the open water around the littoral area and KN was used in the shallow region with hydrophytes and water weeds. At each sampling location, the sampling distance was 200 m and the sampling time elapsed was 60 minutes according to the quantitative sampling method described by Barbour et al (1999).

Data analysis

Values of richness and abundance standardized per unit effort of capture (the number of fishes captured was divided by the number of hours or replicates of each sampling technique on each sampling site) were compared using analysis of variance (ANOVA). A factorial ANOVA (Zar 1999) was performed on richness and abundance of fish standardized per unit effort of capture, with sampling gears (CN, KN, FN, TN, GN, and MT) as factors, to test for the presence of interaction among gears. In the absence of interaction and to locate possible sources of differences in the variable of interest (sampling methods), analysis of simple effects was performed with one-way ANOVA, followed by *posthoc* multiple comparisons using Tukey's honest significant difference test (significance level of 0.05). All differences were declared to be statistically significant at a 0.05. Statistical tests were performed using 20 IBM SPSS Statistics 20 for Windows (IBM, SPSS Inc., Chicago, IL), and the results were expressed as mean values. Simple regression analysis and Pearson's correlation analysis were conducted using environmental factors (lake surface area and watershed area) and fish community data of 30 sampling reservoirs. In addition, cluster analysis was conducted by the dendrogram approach (PC-ORD; McCune and Mefford 1999) using similarity coefficients between the functional distances.

Results

We ran a cluster analysis using six variables estimating the physical environmental factors of the 30 reservoirs. According to the result, we divided the reservoirs into three large groups: Group I (D_c, S_y), Group II (W_m, D_b, B_a, Y_d, P_d, J_y, P_t, C_c, T_g, I_d, B_g), and Group III (S_s, U_p, G_j, Y_c, H_j, G_c, Y_d, W_n, G_p, M_s, Y_g, J_s, B_k, W_s, D_r, Y_k, S_c). Group I reservoirs, with more than 50 km^2 surface area, were deep and relatively wide, having a shore road with special physical topography or Shore Development Index, etc., and were considered large-size reservoirs. Group II reservoirs, with surface areas $3 \leq x < 50$ km^2, are midsize reservoirs, and Group III reservoirs, those with less than 3 km^2 lake area, low depth, small area, and low Shore Development Index, were considered small reservoirs (Figure 2).

During the study, fishes of 81 species (comprising 53,792 individuals) were sampled from 30 reservoirs. Comparisons of sampling gears showed that CN were the best sampling gear with high species richness (69 species), whereas MT were the worst performing gear with low richness (16 species). Fish sampling efficiency, based on the number of individual catch per unit effort (CPUE), was best in FN (28,028 individuals) and worst in MT (352 individuals). When we compared TN and KN versus FN and CN, the former were useful in terms of the number of fish individuals but not in terms of the number of fish species. Both GN and MT had the lowest sampling efficiencies in the number of species and number of individuals (Table 1).

The following 17 species have been collected over 50% by CN: *Squalidus gracilis majimae*, *Acheilognathus rhombeus*, *Rhinogobius*

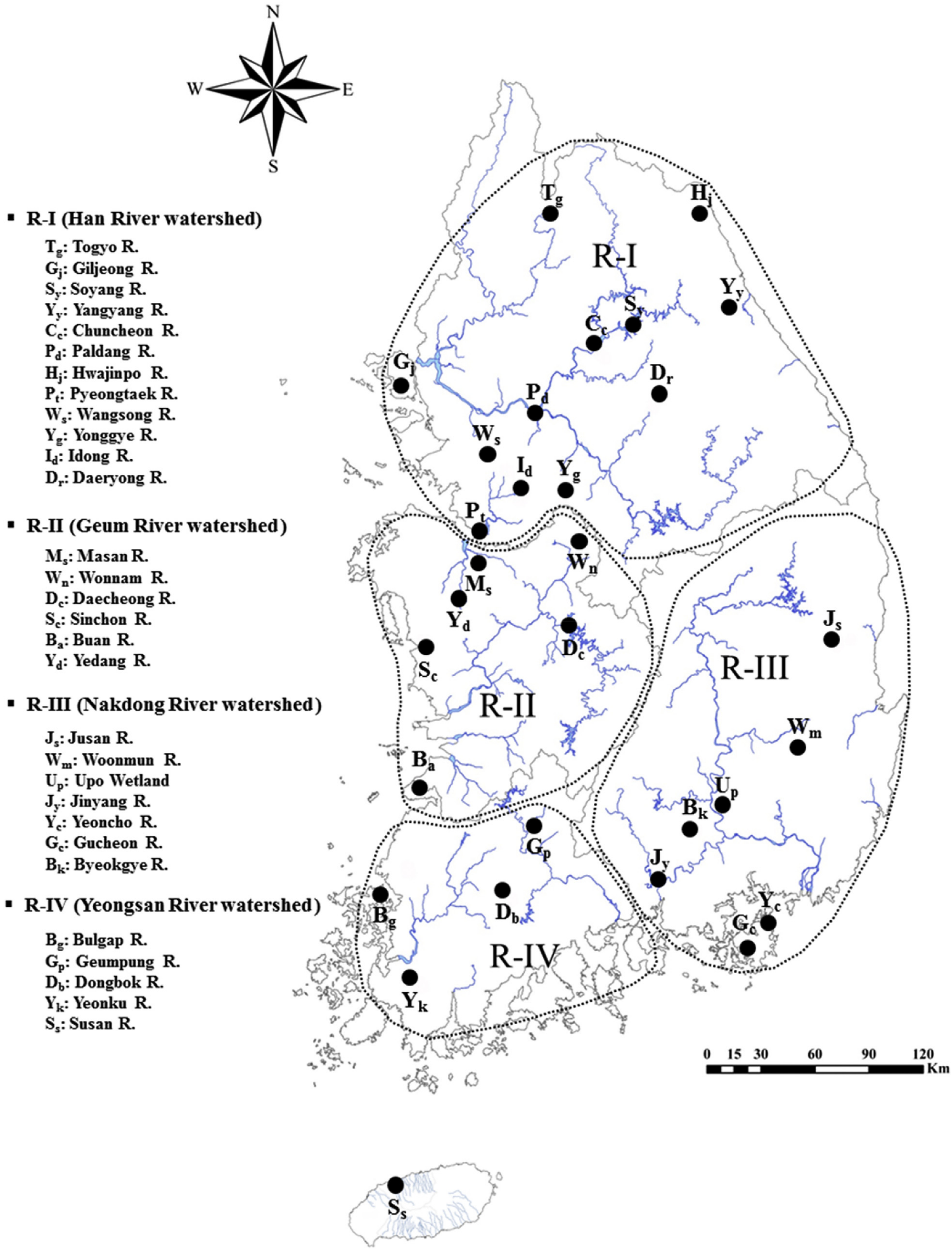

Figure 1. Locations of 30 reservoirs in Korea. Dark dotted lines represent ecoregion limits. R-I, Han River watershed; R-II, Geum River watershed; R-III, Nakdong River watershed; R-IV, Yeongsan River watershed.

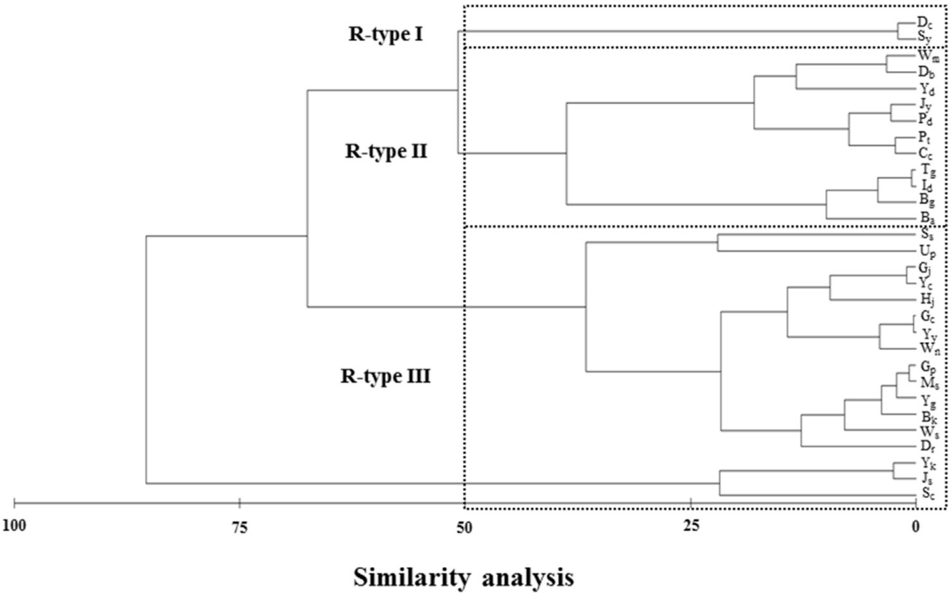

Figure 2. Cluster analysis using six environmental parameters of 30 reservoirs in Korea.

brunneus, *Pseudorasbora parva*, *Cobitis lutheri*, *Acheilognathus yamatsutae*, *Squalidus chankaensis tsuchigae*, *Pseudogobio esocinus*, *Carassius auratus*, *Acheilognathus koreensis*, *Cyprinus carpio*, *Pseudobagrus fulvidraco*, *Coreoperca herzi*, *Rhodeus notatus*, *Tridentiger brevispinis* Katsuyama. Furthermore, the following five species were collected over 50% by FN: *Zacco platypus*, *Erythroculter erythropterus*, *Acheilognathus lanceolatus*, *Hypomesus nipponensis*, *Pungtungia herzi*. TN collected over 50% *Acanthorhodeus macropterus* only but had a lower collecting efficiency than CN and FN in other species collection (Table 2). By analyzing the species composition of collected fishes, CN and FN were found to be highly efficient in collecting schooling fishes, carps such as *Z. platypus*, *Hemiculter eigenmanni*, *S. gracilis majimae*, *Squalidus curriculus*, and *P. herzi*, and also in collecting big fishes, such as skin carp (*Hemibarbus labeo*). The benthic fishes that inhabit the bottom or rock crack of a lake—*R. brunneus*, *C. lutheri*, *P. esocinus*, *C. herzi*, and *T. brevispinis* Katsuyama—were collected by CN only rather than by FN and TN, so CN presents high collecting efficiency in collecting

Table 1. Sampling efficiencies of six fishing gears based on the number of fish species and individuals in 30 reservoirs during 2008–2012.

Classification	Reservoir	CN		FN		TN		GN		MT		KN		Total	
		S	I	S	I	S	I	S	I	S	I	S	I	S	I
Large-size reservoirs	S_y	12	241	10	454	4	14	—	—	1	2	12	217	23	4,450
	D_c	25	1,922	13	1,748	12	223	6	24	—	—	18	327	32	4,244
Midsize reservoirs	P_d	11	139	5	1,552	6	75	1	5	—	—	14	113	19	1,884
	J_y	28	3,567	15	3,054	14	582	8	118	6	59	5	95	29	7,475
	C_c	4	75	4	25	9	132	8	46	—	—	8	60	18	428
	P_t	25	2,525	12	82	15	589	14	628	6	15	10	91	27	3,930
	D_b	17	365	8	2,562	7	29	6	38	5	40	4	9	17	3,043
	B_a	9	524	8	117	5	7	4	15	—	—	6	35	12	698
	B_g	15	2,378	11	2,680	6	56	4	38	1	2	—	—	18	5,154
	Y_d	27	2,733	20	3,556	18	179	3	38	7	213	—	—	33	6,719
	I_d	17	744	4	47	10	198	3	9	—	—	4	11	19	1,009
	W_m	18	851	14	2,830	9	91	5	15	—	—	7	92	21	3,955
	T_g	11	164	4	30	6	55	4	11	—	—	—	—	15	260
Small-size reservoirs	B_k	3	54	1	3	1	3	0	0	—	—	—	—	3	60
	M_s	15	2,774	10	3,881	7	512	3	92	—	—	11	254	15	7,513
	W_s	4	32	6	2,503	6	124	3	65	1	1	6	96	9	3,788
	Y_g	8	97	—	—	4	6	3	17	—	—	—	—	8	120
	J_s	3	110	—	—	3	233	1	54	—	—	—	—	4	397
	G_p	5	964	4	65	1	56	1	9	3	10	9	89	11	1,193
	W_p	15	385	9	92	—	—	—	—	—	—	15	153	23	630
	Y_y	6	364	7	2,209	8	174	1	28	—	—	—	—	9	2,775
	H_j	13	2,700	8	5,136	7	113	3	6	2	10	—	—	16	7,965
	S_c	15	705	10	915	6	35	1	6	4	300	2	21	17	1,988
	D_r	9	1,568	7	7,213	5	84	—	—	1	44	2	33	11	8,943
	W_n	17	787	18	322	12	315	6	45	—	—	5	31	23	1,500
	Y_k	11	359	7	155	6	95	4	18	—	—	4	23	13	650
	G_c	12	763	12	321	3	28	2	7	4	13	10	230	16	1,362
	Y_c	11	837	6	743	1	42	1	9	10	628	4	5	12	2,264
	S_s	3	818	3	8	3	4	3	16	—	—	—	—	5	846
	G_j	10	71	2	3	7	88	3	16	2	5	4	30	13	213

CN = casting net; FN = fyke net; GN = gill net; I = individuals; KN = kick net; MT = minnow trap; S = species; TN = trammel net.

Table 2. Sampling efficiencies of six fishing gears based on fish fauna and compositions in 30 reservoirs during 2008–2012.

Species	Ab	% *N*	Fr	CN	FN	TN	GN	MT	KN
		(*n* = 72,009)	(*n* = 30)	(*n* = 103)	(*n* = 38)	(*n* = 38)	(*n* = 38)	(*n* = 38)	(*n* = 103)
Zacco platypus	*Z. pla*	12.5	18	45.9	51.4	0.77		0.11	1.77
Pseudorasbora parva	*P. par*	11.1	18	23.1	67.9	1.23		4.60	3.19
Lepomis macrochirus†	*L. mac*	10.7	11	52.2	39.5	5.50	0.90	0.08	1.75
Micropterus salmoides†	*M. sal*	9.52	16	54.1	40.7	2.61	0.99	0.58	1.05
Zacco koreanus	*Z. kor*	7.35	7	9.18	84.8	2.91			3.12
*Squalidus gracilis majimae**	*S. gra*	7.13	13	17.0	81.3	0.80		0.29	0.60
*Hemiculterei genmanni**	*H. eig*	7.05	10	36.1	29.2	22.1	10.8		1.97
Hypomesus nipponensis	*H. nip*	5.40	14	52.6	46.1	1.26	0.03		
Konosirus punctatus	*K. pun*	4.63	1	1.41	98.0	0.54	0.03		
Carassius auratus	*C. aur*	3.21	20	45.2	25.5	18.2	9.65		1.47
Rhodeus ocellatus	*R. oce*	3.11	4	58.1	39.4	0.89		1.52	0.04
*Squalidus chankaensis tsuchigae**	*S. cha*	2.10	4	16.1	79.7	1.13		2.91	0.20
Carassius cuvieri†	*C. cuv*	1.89	17	58.2	13.6	8.30	14.3		5.66
*Squalidus japonicus coreanus**	*S. jap*	1.83	8	20.9	73.8	2.35	0.30	2.65	
*Rhodeus uyekii**	*R. uye*	1.25	4	9.08	86.8	0.00		3.54	0.55
Erythroculter erythropterus	*E. ery*	1.23	5	31.1	42.2	16.8	9.29		0.57
Rhodeus notatus	*R. not*	0.95	4	9.09	78.6			12.3	
Rhinogobius brunneus	*R. bru*	0.85	16	51.7	15.3			3.92	29.0
Tribolodonha konensis	*T. hak*	0.81	1	8.45	89.7	1.55	0.34		
Hemibarbus labeo	*H. lab*	0.62	9	24.6	3.79	64.5	7.14		
Synechogobius hasta	*S. has*	0.58	1	64.5	16.4	16.2	0.71	2.14	
Acheilognathus lanceo latus	*A. lan*	0.54	4	27.2	66.2	4.62		0.26	1.79
Pseudogobioes ocinus	*P. eso*	0.50	10	49.4	3.89	42.5	1.39		2.78
Rhinogobiu sgiurinus	*R. giu*	0.38	9	54.9	16.0			1.09	28.0
Cyprinus carpio	*C. car*	0.33	17	58.5	12.3	5.51	16.9		6.78
Acheilognathus rhombeus	*A. rho*	0.31	2	72.1	26.1	1.77			
*Acanthorhodeus gracilis**	*A. gra*	0.29	6	67.3	1.42	25.1			6.16
Acanthorhodeus macropterus	*A. mac*	0.26	6	20.5	6.84	71.6	1.05		
Opsarichthys uncirostris amurensis	*O. unc*	0.25	8	49.7	41.9	5.59	0.56		2.23
Oryzias sinensis	*O. sin*	0.23	3	60.9	20.7				18.3
Hemiculter leucisculus	*H. leu*	0.22	5	6.79	70.4	22.8			
Tridentiger brevispinis‡	*T. bre*	0.22	5	17.8					82.2
Plecoglossus altivelis altivelis	*P. alt*	0.21	1	2.01	98.0				
Acanthogobius lactipes	*A. lac*	0.18	1	100					
Rhynchocypris oxycephalus	*R. oxy*	0.18	5	82.9		11.6			5.43
Tridentiger bifasciatus	*T. bif*	0.16	1	96.6	3.39				
Pseudobagrus fulvidraco	*P. ful*	0.16	13	37.9	19.0	15.5	4.31		23.3
Gymnogobius urotaenia	*G. uro*	0.16	4	72.3	24.1				3.57
*Abbottina springeri**	*A. spr*	0.13	3	48.5	51.5				
Acanthogobius flavimanus	*A. fla*	0.12	1	78.4	21.6				
Cobitis lutheri	*C. lut*	0.12	5	100					
Mugilce phallus	*M. cep*	0.11	1	82.5		17.5			
Silurus asotus	*S. aso*	0.11	8	32.9	2.63	56.6	5.26		2.63
Pungtungia herzi	*P. her*	0.10	8	55.4	27.0	9.46			8.11
Oreochromis niloticus†	*O. nil*	0.09	1	63.6	6.06	22.7	4.55	3.03	
Oryzias latipes	*O. lat*	0.08	1	95.1					4.92
*Acheilognathus yamatsutae**	*A. yam*	0.08	4	67.2		3.45			29.3
*Odontobutis interrupta**	*O. int*	0.08	8	64.9	1.75	8.77	1.75	1.75	21.1
*Cobitis tetralineata**	*C. tet*	0.07	3	94.2					5.77
Siniperca scherzeri	*S. sch*	0.06	4	65.2	13.0	2.17	19.6		
Takifugu niphobles	*T. nip*	0.06	1		97.8	2.22			
Misgurnus mizolepis	*M. miz*	0.06	7	2.50	10.0			7.50	80.0
Misgurnus canguilliaudatus	*M. ang*	0.05	10	2.78	13.9	2.78		11.1	69.4
Hemibarbus longirostris	*H. lon*	0.05	7	61.8	2.94	29.4			5.88
Channa argus	*C. arg*	0.04	7	30.0	56.7	3.33	3.33		6.67
*Coreoperca herzi**	*C. her*	0.04	2	17.2	72.4	10.3			
Abbottina rivularis	*A. riv*	0.02	4	68.8	25.0	6.25			
Rhynchocypris steindachneri	*R. ste*	0.02	1	26.7	26.7	46.7			
*Odontobutis platycephala**	*O. pla*	0.02	5	50.0			8.33	8.33	33.3
*Iksookimia koreensis**	*I. kor*	0.02	2	16.7					83.3
Hyporhamphus sajori	*H. saj*	0.02	2	27.3	72.7				
*Koreocobitis rotundicaudata**	*K. rot*	0.02	1						100
Gymnogobius castaneus	*G. cas*	0.01	1	100					
Tridentiger obscurus	*T. obs*	0.01	1	100					
*Acheilognathus koreensis**	*A. kor*	0.01	1	66.7	33.3				
*Pseudobagrus koreanus**	*P. kor*	0.01	2	50.0					50.0
Aphyocypris chinensis	*A. chi*	0.01	1	100					
Culter brevicauda	*C. bre*	0.004	2		33.3		66.7		
Trachidermus fasciatus	*T. fas*	0.004	1	100					
Squaliobarbus curriculus	*S. cur*	0.004	1	100					
*Microphysogobio yaluensis**	*M. yal*	0.003	2						100
Monopterus albus	*M. alb*	0.003	1						100
Lefua costata	*L. cos*	0.001	1						100

Table 2 (*continued*)

Species	Ab	% *N*	Fr	CN	FN	TN	GN	MT	KN
		(*n* = 72,009)	(*n* = 30)	(*n* = 103)	(*n* = 38)	(*n* = 38)	(*n* = 38)	(*n* = 38)	(*n* = 103)
Cyprinus carpio†	*C. car-1*	0.001	1		100				
*Sarcocheilichthys variegatus wakiyae**	*S. var*	0.001	1			100			
*Liobagrus andersoni**	*L. and*	0.001	1						100
Total no. of species				68	55	45	24	19	44
Total no. of individuals				26,110	38,370	3,834	1,299	715	1,681

CN = casting net; FN = fyke net; Fr = frequency; GN = gill net; KN = kick net; MT = minnow trap; TN = trammel net; * = Korean endemic species; † = introduced species.

benthic fishes (Table 2). As a whole, whereas among three kinds of fishing gears CN can collect species from various inhabited environments, FN and TN collected certain species that lived mainly at the middle layer and the surface. Therefore, FN and TN cannot present the data that represent the various inhabited environments of Jinyang Reservoir. This result shows that CN is an active gear used to collect various species in different inhabited environments, whereas FN and TN are passive gears because they are installed at the high mobility point of fish species. This characteristic of fishing gears is relevant to species composition, especially in a number of species. All common species were captured by CN; however, endemic species, such as *Koreocobitis rotundicaudata*, *Microphysogobio yaluensis*, and *Liobagrus andersoni* were captured by KN.

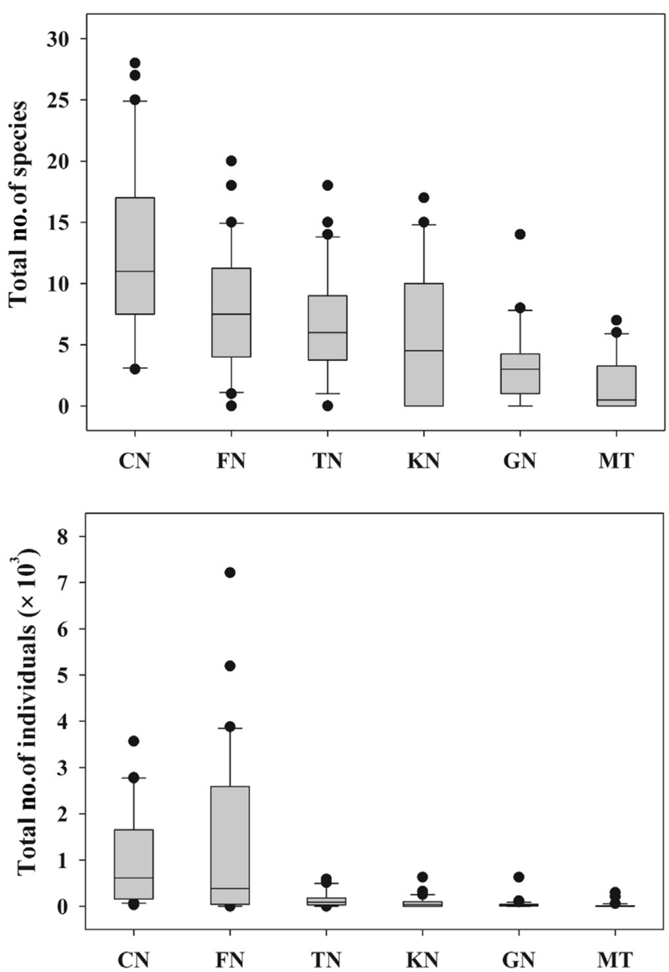

Figure 3. The number of fish species and the number of individuals captured by different sampling gears in 30 reservoirs. CN, casting nets. FN, fyke nets. GN, gill nets. KN, kick nets. MT, minnow traps. TN, trammel nets.

Sampling efficiency analysis of fish species by each sampling gear showed that most species were sampled by CN, followed by KN, FN, etc., in the sampling order. In the meantime, GN and MT were less effective gears compared with other fishing gears. Similar results were shown in sampling efficiency, based on the individual number of fish. CN and TN were shown to have sampled the highest number of individuals. GN, MT, KN, and TN were, however, less efficient in fish sampling (Figure 3). Overall, the data suggest CN was the most efficient gear for fish sampling in the target reservoirs in terms of the number of species/individual collections, the time lapsed for the sampling, and the cost (money) spent for sampling (Figure 3).

Optimal sampling distance, time, and casting number using CN for coast sampling have shown some variation depending on the reservoir size. According to sampling results through over 20 times casting with each 5-m distance in the littoral zone, for large-size reservoirs (surface area of more than 50 km^2), 120-m distance and 60 minutes were optimal for the study with no accumulated species after 15 times casting. For midsize reservoirs, with surface area ranging from 3 to 50 km^2, 10-m distance and 50 minutes were optimal without accumulated species after 13 times casting, and for small-size reservoirs (less than 3 km^2), 70-m distance and 40 minutes with nine times casting were optimal (Figure 4).

To analyze optimal sampling time in the coastal region of the artificial reservoir with FN, the sampling species and individuals with time lapse were figure out and the results were compared with fish mortality. In this study, a sampling place was selected for Bulgap reservoir and an FN was placed within a 1-day period within a total of 3 days. From the results of FN sampling, eight species were sampled in a 1-day lapsed FN and nine accumulated species in a 2-day lapse, as well as the same nine species in a 3-day lapse without any significant difference in 1-day lapsed FN result. However, in the aspect of individual number analysis, a significant difference along

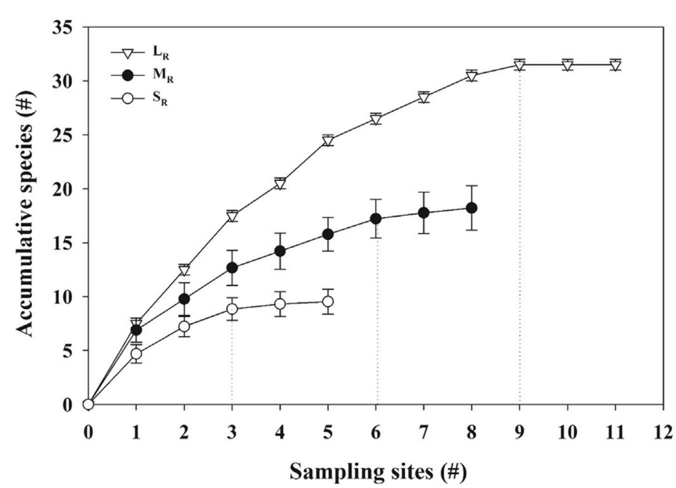

Figure 4. The optimal number of sampling sites for fish sampling using casting net depending on the reservoir size. LR, large-size reservoirs. MR, mid-size reservoirs. SR, small-size reservoirs.

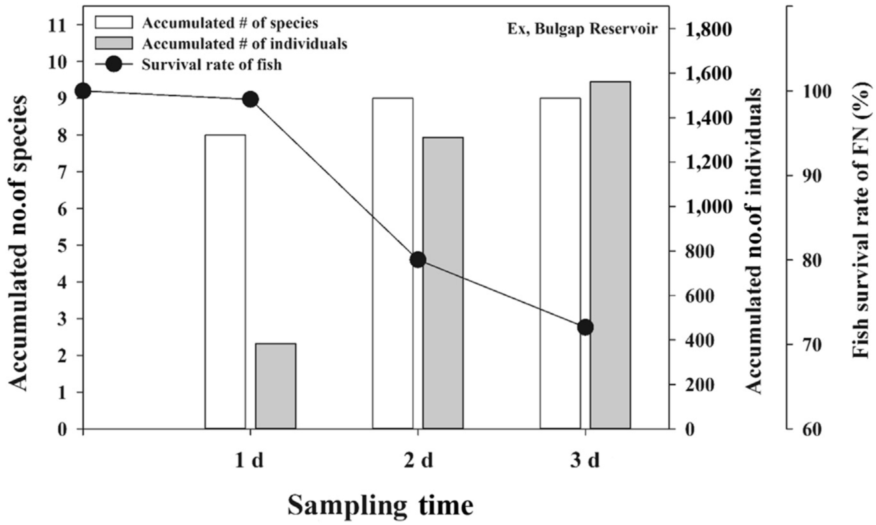

Figure 5. Comparisons of fish survival rates, accumulated the number of species and individuals among the sampling times by fyke net (FN).

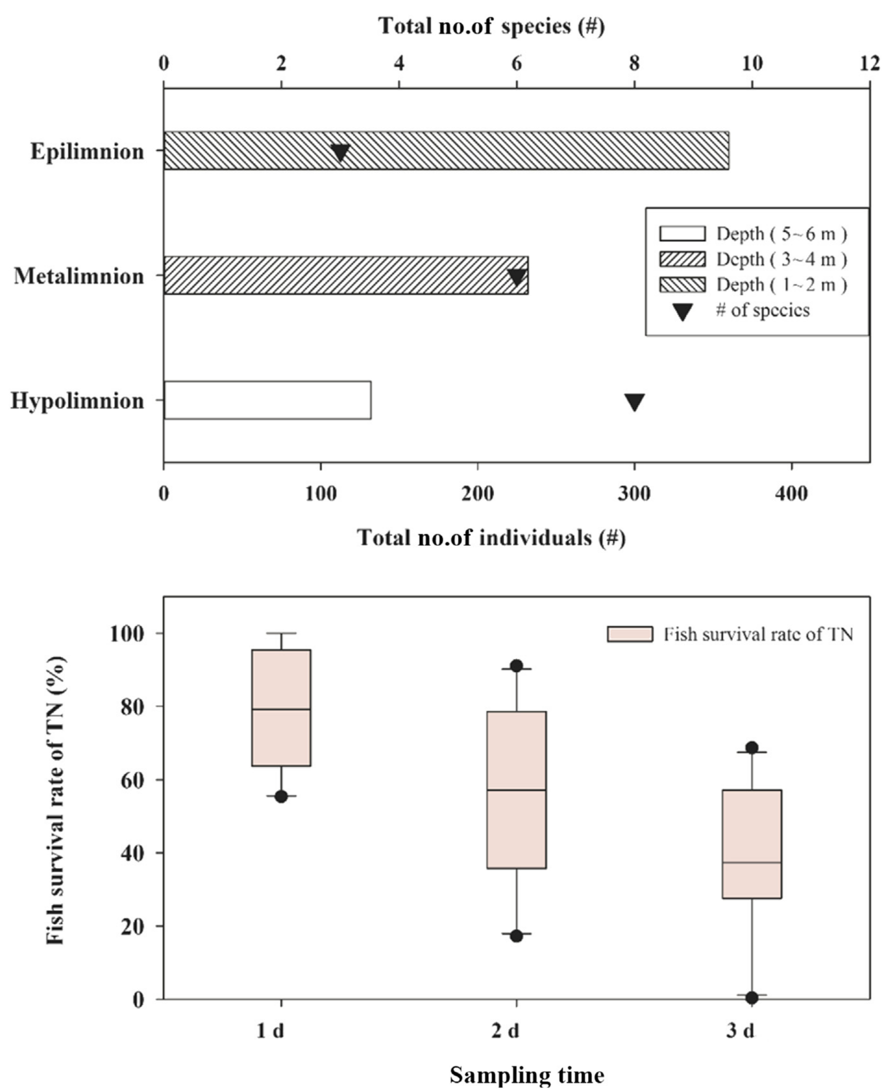

Figure 6. Comparisons of a number of species and individuals along the vertical distributions and fish survival rates among the sampling times by trammel net (TN). Upper panel: fish sampling efficiency of TN along the vertical distributions; lower panel: fish survival rate of TN.

with time lapse was noted. Meanwhile, in fish mortality analysis along with time lapse in FN sampling, 1-day lapsed FN sampling showed the highest survival rate (99%) but the rate was reduced to less than 80% after a 2-day lapse (Figure 5). Considering the efficiency of time, cost, and mortality to assess fish health, 1 day (24 hours) was considered optimal for FN analysis rather than 2- or 3-day lapse.

To analyze the efficiency of fish sampling using TN through depths in the artificial reservoir, fish species composition was analyzed along with reservoir depth in Masan reservoir. According to the analysis, up to eight species were found in the lower depth, and at least three species were found in the surface of the reservoir. However, individual number analysis yielded completely opposite results, as most were found in the surface and the least in the lower depth (Figure 6A). The high biodiversity in the lower depth was derived from the sampling of benthic species, such as Korean bullhead (*P. fulvidraco*), which mainly inhabited the substrate area in the bottom, and the high species richness in the surface area was derived from schooling species such as Sharpbelly (*H. eigenmanni*). Thus, to sample more various species, lower depth (bottom area) is recommended as the most effective area for TN sampling. To figure out the optimal sampling time using TN in the coastal region of the reservoir, we tried using the time lapse analysis as in FN analysis. TN analysis based on time lapse showed similar results as in FN analysis, which showed no significant differences against 1-day lapse TN sampling. However, significant differences against 1-day time lapse in fish mortality were noted between TN and FN. According to the mortality analysis, there was a high survival rate (80%) in 1-day lapsed TN, but only 56% in 2-day lapsed TN and less than 45% in 3-day lapsed TN (Figure 6B). Considering the efficiency of time, cost, and mortality to assess fish health, 1-day (24 hours) lapsed TN was considered the most efficient.

According to a comparative analysis of the fish composition in reservoirs based on the lake surface area from 30 reservoirs, the fish

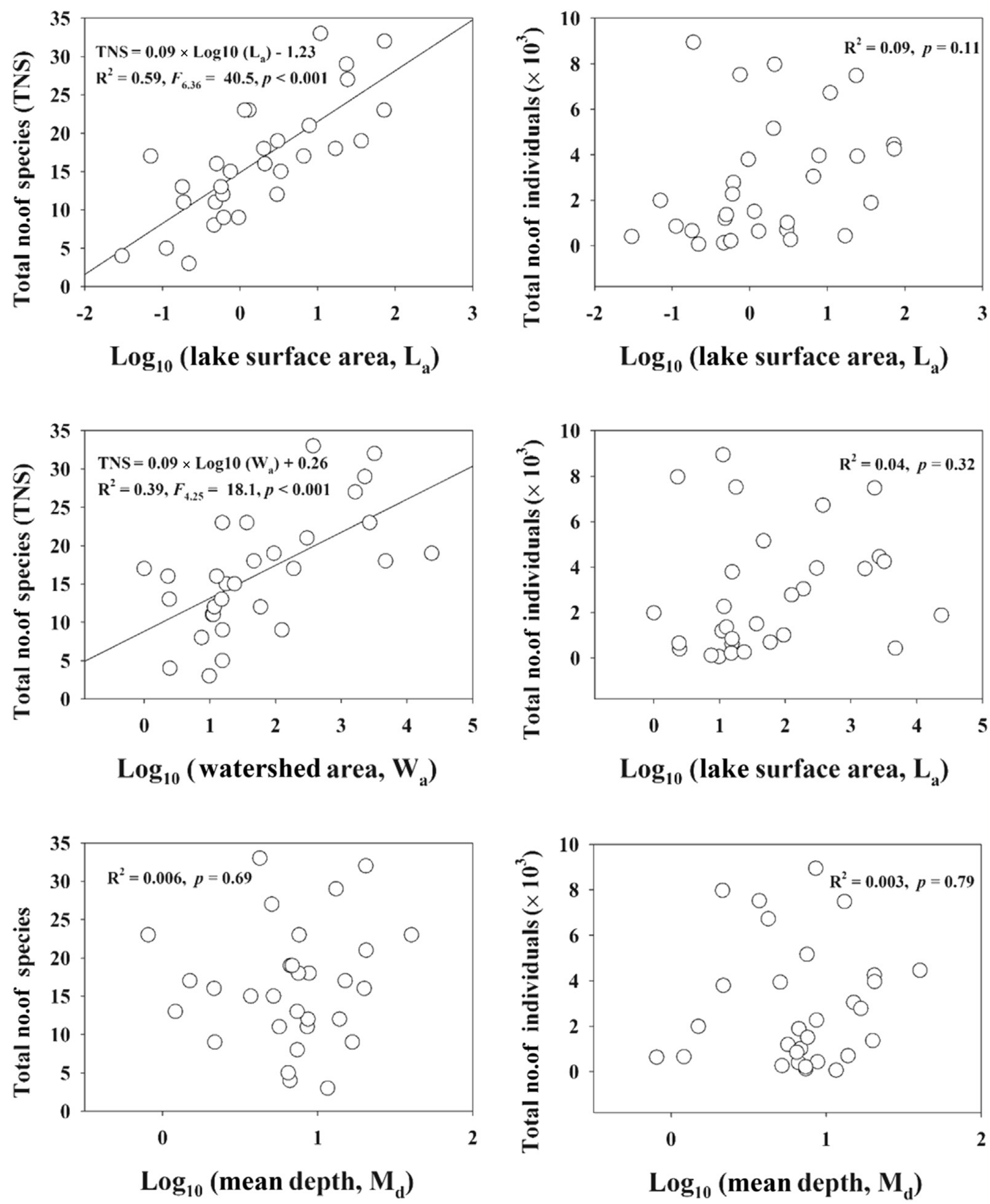

Figure 7. Regression analysis among the number of species and individuals within environmental factors (lake surface area and watershed area).

assemblage was significantly related to lake surface area in the reservoir (Figure 7). Sampling species relatively tended to increase in relation to the surface area of the reservoir. Sampling in reservoirs with larger surface areas showed 52 species (range, 14–29) and 20,848 individuals (range, 239–7513). In contrast, in smaller reservoirs, only 34 species (range, 2–23) and 13,868 individuals (range, 54–78,513) were recorded.

The analysis of fish tolerance guilds indicated that there were distinct differences in tolerant and sensitive fish groups along the trophic gradients of mesotrophic, eutrophic, and hypereutrophic states in the reservoirs. The mesotrophic group (I) consisted of eight reservoirs and the eutrophic group (II) comprised 16 reservoirs. The eutrophic group (III) comprised six reservoirs. In these reservoirs, sensitive species decreased from a mesotrophic to eutrophic state, and the proportions of tolerant species increased with eutrophication in the reservoirs. Also, trophic guild analysis showed that the proportions of omnivore species increased as the trophic state of the reservoirs increased, whereas the proportions of insectivore and carnivore species decreased as the trophic level rose (Figure 8).

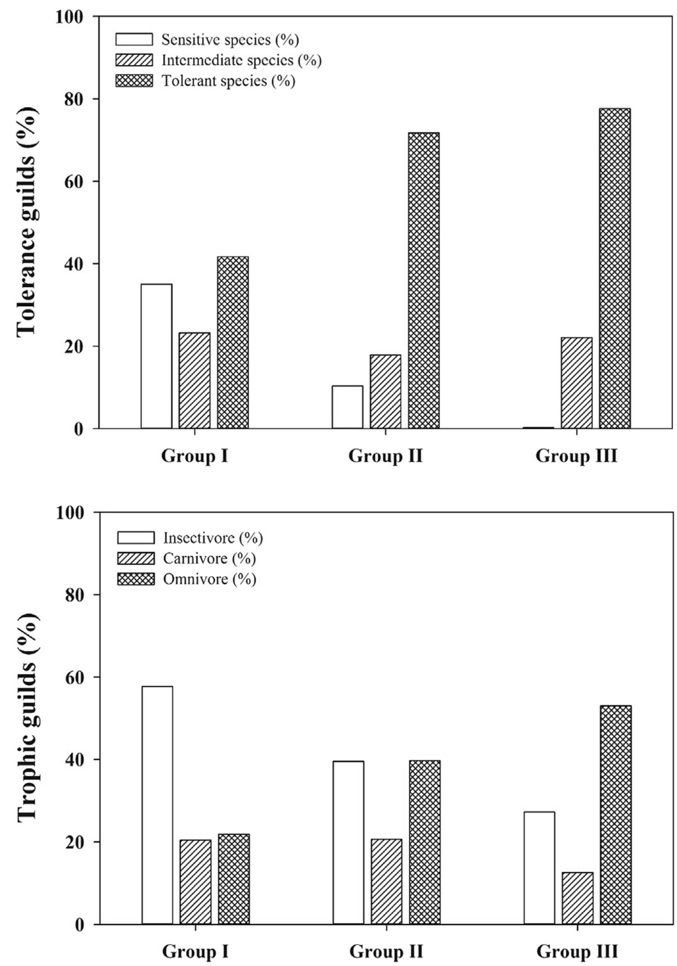

Figure 8. Comparisons of tolerant guilds and trophic guilds among the groups: Group I, mesotrophy. Group II, eutrophy. Group III, hypereutrophy.

Discussion

Fish sampling gears are some of the most useful tools available to fisheries managers and researchers for the appraisal of sport or commercial fisheries or assessment of environmental effects on stocks of aquatic animals (Allen et al 1960; Hocutt and Stauffer 1980; Bonar et al 2009). However, problems with sampling variability and gear selectivity are universal. Standardization of sampling devices and strict sampling protocols are necessary to reduce variation among samples and to detect possible changes in stocks that are the result of management efforts or environmental effects (Committee 1992; Bonar and Hubert 2002; Hubert and Fabrizio 2007). The American Fisheries Society has published Standard Methods for Sampling North American Freshwater Fishes (Bonar et al 2009) in an effort to standardize sampling gears and protocols across North America. A serious problem associated with many passive entanglement and entrapment gears is the continued capture of animals by the gear if it is lost, a process called ghost fishing (Guillory 1993).

A continued effort is needed to incorporate more biodegradable material or other technologies into the construction of fish sampling gears used in commercial fisheries and fish population assessments. A concern with the use of fish sampling gears is the unintended spread of invasive species while sampling (Jacks et al 2009). Measures to decontaminate sampling gear, boats, and other equipment used in sampling prior to moving among water bodies are advised. Efforts have been made to identify standard sampling gears for fish in various habitats (Bonar et al 2009), but such standards are not yet widely adopted. We have provided a decision tree to assist in the selection of possible gears for sampling fish in various habitats. The decision tree identifies potential gears for use in sampling fish in differing inland and marine habitats, but it does not identify gears that are selective for various fish species. When selecting gear and designing a sampling protocol, knowledge of life history and habitat selection by individual species and life stages must be coupled with gears that may be applicable in the habitats used by the targeted fish. It is important to have a sampling design that uses the same gear over time and among locations, and to sample at the same locations and same times each year when monitoring fish populations (Hubert and Fabrizio 2007). Generally, sampling designs are developed to minimize variation in CPUE that is caused by factors other than the true abundance of fish rather than to maximize CPUE. Fish sampling gears have a long tradition of use for sampling and assessing fish stocks, and their utility will be enhanced in the future with standardization of gears and effective sampling designs.

Conflicts of interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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