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Ecological Comparisons of Stream Conditions Between the Unimpacted and Impacted Sites: Case Study

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The purpose of this study was to analyze chemical water quality, fish trophic guilds, tolerance indicators, and fish community conditions in the Gap Stream and to compare the stream conditions between the unimpacted site and impacted site. This study was conducted in the physically stable season (May 2008) to minimize physical impacts such as flow and hydrological disturbance, and applied the study in the Gap Stream with two sites of unimpacted upstream site (Unim-S), mainly surrounded by forested area and impacted site (Im-S), influenced by the wastewater disposal plants and industrial complex in the urban region. Chemical data analysis showed that the degree of organic matter pollution, based on BOD, and COD, was 2~3 fold greater in the Im-S than the Unim-S, and that TP, as eutrophication indicators, was 4.7 fold greater in the Im-S. Also, NH_3-N was in 8.2 fold greater in the Im-S (6.25 mg L^{-1}) than the Unim-S (0.76 mg L^{-1}), indicating a massive influence of wastewater from the disposal plant. Similar results were found in other chemical parameters. Thus, chemical impacts in the Im-S were evident, compared to the unimpacted site. Evaluations of tolerant indicator species indicated that sensitive species were dominant in the Unim-S (23.9%) and tolerant species were dominant (97.8%) in the Im-S. Condition factor (CF) was averaged 0.95 (0.68~1.18) in the Unim-S and 1.08 (0.93~1.22) in the Im-S. Fish community in the Unim-S and Im-S was categorized as *Zacco*-community and *Hemibarbus*-community, respectively, and the community diversity index (*H'*) was significantly ($p<0.05$) higher in the Unim-S (0.810) than the Im-S (0.466). Overall, our results suggest that the comparison approach of various chemical and ecological indicators provide important information in identifying multiple stressors in the stream ecosystems.

Key words : Impacted site, stream, tolerance guild, trophic guild, community index

INTRODUCTION

Recent studies of stream ecosystems reported that water quality is rapidly degradiated by various sources of pollutions such as industrial complex effluents (Ra *et al.*, 2007; Yeom *et al.*, 2007), municipal discharges, agricultural wastes, and urban non-point pollutants (Lee and An, 2007b). These pollutions resulted in nutrient enrichment of nitrogen and phosphorus (An and Park, 2002), increases of toxicant and heavy metals (Lee and An, 2007a; Lee *et al.*, 2008), habitat degradations by sediment pollutions (Judy *et al.*, 1984; An and Kim, 2005), and low biodiversity of fish, producing a poor ecological health in stream ecosystems (An and Choi, 2003). These phenomena are widely reporting in urban streams (An *et al.*, 2001a), agricultural streams (An *et al.*, 2001b), and lowland estuary streams (Cho *et al.*, 1999).

For this reason, researchers have tried to identify various stressors, especially on fishes, in the

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stream ecosystems for stream conservations and protections. Main scope of earlier studies as a key factor for stream pollution was on chemical contaminations (Yeom *et al.*, 2000) along with modifications of physical habitats (An and Kim, 2005). Recent publications, however, pointed out that chemical and physical approaches are not enough to assess the ecological stream health (Karr, 1981) and that biological monitoring is required to detect the conditions of ecosystem health (An *et al.*, 2006). Also, numerous studies suggest some problems in the conventional biological methodologies such as counting of simple diversity index without considering the stream size (order) (Strahler, 1957), one or two parameter analysis of species number and/or individual number in the sampling sites and comparisons of relative abundance on dominant or rare species (An *et al.*, 1992). Such studies did not give much information and key clues on the fish stressor and symptoms in the stream ecosystems.

Recently, "Stressor Identification Guidance Document (SIGD)", published in 2000 by US EPA, provides various information on how to identify the stream fish stressors in the various organizations, diagnose the stream health using the multi-level fish analysis, and also organize the scientific evidence supporting the conclusions of health assessments (US EPA, 2000). Little is known about the multi-level fish stressor analysis in the stream ecosystems and its application to Korean streams. In this study, we determined the chemical conditions, based on conventional water quality parameters, and analyzed the differences in the fish trophic and tolerance guilds between the unimpacted site (Unim-S) and impacted site (Im-S) along with analysis of condition factors (CF) and community structure with comparison of the conventional community analysis to describe the present condition. This data will provide some clues which parameters were largely impacted in the sites influenced by the wastewater disposal plants.

MATERIALS AND METHODS

1. Sampling sites and periods

Sampling sites were selected on 2 sites which can represented the unimpacted site (Unim-S) in upstream and impacted site (Im-S) in downstream in the Gap Stream, a tributary of the Geum River Watershed in May 2008 (Fig. 1). The Unim-S was located in out of urban area, minimal artificially effected conventional natural stream. It also surrounded by forests near the stream and partially covered some paddy and ordinary field beside the stream banks. The Im-S was mostly influenced by point sources such as Daejeon industrial complex and wastewater disposal plant (WWDP) and also merged with Yudeung Stream running through the Daejeon metropolitan city, just 3 km ahead. Especially, the WWDP of Daejeon discharged about 9×10^5 m^3 day^{-1} of treated effluents to the Im-S of the Gap Stream directly. Both sites were located in the Daejeon metropolitan city and detail information with the stream order (Strahler, 1957) were described as follows:

Unim-S (E36°15′09″, N127°19′20″):
Bongoek 2nd bridge, Bongoek-dong, Seo-gu, Daejeon (3rd order).

Im-S (E36°24′17″, N127°24′47″):
Gapcheon bridge, Jeonmin-dong, Daedeok-gu, Daejeon (5th order).

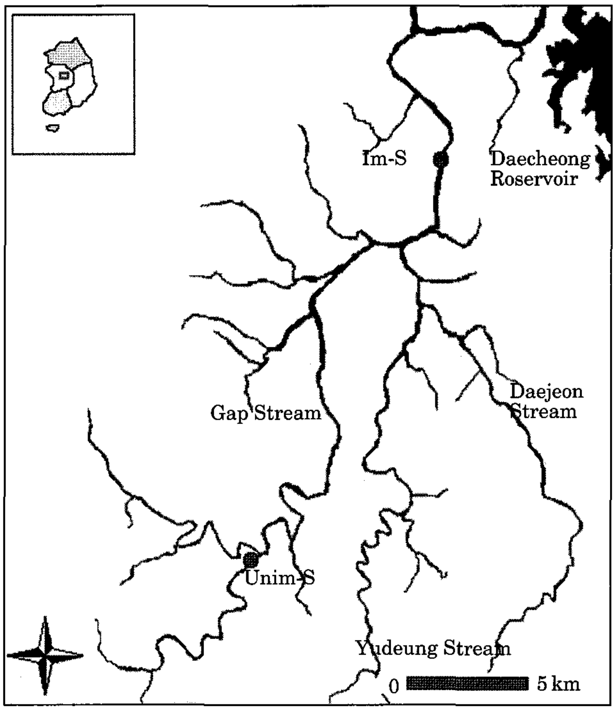

Fig. 1. The map showing the sampling sites in the Gap Stream (Unim-S: Unimpacted site, Im-S: Impacted site).

2. Fish collection and population and community analysis

Fishes were collected by modified wading method (Ohio EPA, 1989) applied by An *et al.* (2006), based on the catch per unit of effort (CPUE). It was also considered 60 minutes sampling to apply all habitat types such as riffle, pool, and run area in the stream and approximately 200 m stream segments were sampled at each site. Sampled fishes were identified by following the key of Kim and Park (2002) and returned to their natural habitats except sentinel species, *Zacco platypus* for further study. We used cast net (mesh 5 × 5 mm) and kick net (4 × 4 mm) for the sampling, the most common sampling gears of wading stream for the fish study in Korea. Cast net was used for the habitats such as open water without any obstructions in riffle, pool and slow run. However, kick net was used at places influenced by fast current regime and many obstructions, where hardly could use a cast net.

3. Physiochemcial water quality

For the analysis of physiochemical water quality, we used the data from water quality monitoring stations of the ministry of environment, Korea (MEK) where the same sites we surveyed. All data we used in water quality were March to May in the recent 5 years which can reflect the condition of stable waterbody stage as premonsoon period. To analyze the site specific characteristics of water quality, 6 parameters were diagnosed as follows; biological oxygen demand (BOD), chemical oxygen demand (COD), total phosphorus (TP), ammonia nitrogen (NH_3-N), most probable number of coliform (MPN, Coliform colony / 100 mL) and the suspended solids (SS) were analyzed.

4. Population and community analysis

Among the sampling, collected sentinel species, *Z. platypus* were carried to the laboratory alive and then, measured the size (total length) and weight for population analysis including calculation of condition factor (CF) (Anderson and Neumann, 1996). Also, we used community analysis using the sampling fishes as follows; dominance (Simpson, 1949), species richness (Margalef, 1958), evenness (Pielou, 1975), species diversity (Shannon-Weaver, 1963).

RESULTS AND DISCUSSION

1. Physiochemical water quality

From the analysis of 6 parameters in physiological water quality, biological oxygen demand (BOD), chemical oxygen demand (COD) were analyzed for organic matter influences. Total phosphorus (TP) and ammonia nitrogen (NH_3-N) were examined for nutrients effect analysis. Most probable number of coliform (MPN, Coliform colony / 100 mL) and the suspended solids (SS) were analyzed for pathological and turbidity effects, respectively (Table 1). BOD was averaged 5.42 mg L^{-1}, indicating class IV, relatively poor condition on the basis of present MEK water quality standard, issued on January 2007. There were averaged 2.48 mg L^{-1} in the Unim-S, whereas, it was averaged 8.24 mg L^{-1} in the Im-S in downstream reach, indicating almost 3.3 fold higher than the Unim-S. Besides, COD also have a similar tendency with BOD's and almost 2.2 fold higher in the Im-S. This could show that organic inflow from the point sources such as wastewater treatment plant and industrial complex near the downstream reach could caused the organic disturbance to the stream ecosystem.

In case of TP and NH_3-H, the difference between the Unim-S and Im-S was distinct that showed aggravations in Im-S were obvious. While, MPN were averaged 51,487 (Total coliform colony/100 mL), almost 10 times fold higher than MEK standards (below 5,000). Especially, it had a strong longitudinal variation that dowstream (Im-S)

Table 1. Chemical parameters to indicate stressor effects in the Gap Stream.

		Unim-S			Im-S		
		Mean	Max.	Min.	Mean	Max.	Min.
Chemical indicator	BOD (mg L^{-1})	2.48	3.7	1.5	8.24	10.9	6.5
	COD (mg L^{-1})	4.33	6.6	3.4	9.77	12.9	7.9
	TP (mg L^{-1})	0.23	0.54	0.075	1.08	1.48	0.54
	NH_3-N (mg L^{-1})	0.76	2.04	0	6.25	13.11	0.63
	MPN	1,424	7,000	130	98,133.3	170,000	5,000
	SS (mg L^{-1})	4.7	7.8	2	10.54	15.6	6.4

Unim-S: unimpacted site, Im-S: Impacted site were 98,133 much higher than upstream (Unim-S, 1,424). Thus, downstream region was not only affected by pollutants influenced directly to the stream but indirect pathogenic damage to the organisms living in their habitats could be occurred, so strong management to the stream environment especially for point sources were essentially necessary to control these factors.

Suspended solids were 6.96 mg L^{-1} indicating fair condition with the score below the MEK standards. Overall physiochemical water quality was characterized as typical urban stream and tends to be degraded along with the gradient of up to downstream, mostly caused by effluents containing enriched organic and inorganic nutrients from the wastewater treatment plants and industrial complex as well as living waste sewages from residential region. It indicated the Im-S in downstream was directly exposed by water pollution in association with strong human activities in urban region.

2. Fish fauna and community analysis

Total number of species and individuals in the Gap stream, based on CPUE were 17 species and 167 individuals from the sampling (Table 2). *Z. platypus* were dominant species with relative abundance (RA), 40.1% (67 individuals). Among these species, 6 species including *Iksookimia koreensis* were found to be Korean endemic species (15.5% RA). It appeared only in Unim-S (20.7% RA), regarded as lacked at Im-S in downstream reaches.

According to the previous report (Jeon, 1980; Choi *et al.*, 2000), endemic species could tend to be suddenly decreased by the habitat destruction. In this case, habitat in downstream site was located inside of the city mainly effected with artificial disturbances such as channel modification, substrate degradation, and point sources effluents, and then caused the decrease of endemic species as a result.

3. Guild characteristics analysis of ecological indicators

Analysis of tolerance guilds showed that relative proportion of tolerant species was 66.5% (111 individuals), higher than 5.8% (29 individuals) of sensitive species in the entire survey (Table 3). This result could follow to previous studies (Karr, 1981; US EPA, 1991), reported that tolerant species and omnivore species were increased according to physiochemical habitat degradation such as organic pollution and habitat destruction. Thus, the Gap Stream we surveyed was urban stream which flows through the Daejeon metropolitan city. Especially, artificial interf-

Table 2. Fish fauna and compositions, based on tolerance, trophic, and habitat guilds in the Gap Stream.

Species	Tolerance guild	Trophic guild	Habitat guild	Unim-S	Im-S	Total	RA (%)
Odntobutis platycephala	S	C	RB	12	0	12	7.19
Pungtungia herzi	S	I	RB	1	0	1	0.60
Iksookimia koreensis⋆	S	I	RB	2	0	2	1.20
Hemibarbus longirostris	S	I	–	4	0	4	2.40
Acheilognathus lanceolatus	S	O	–	3	0	3	1.80
Zacco temminckii	S	I	–	7	0	7	4.19
Odontobutis interrupta⋆	I	C	RB	7	0	7	4.19
Pseudogobio esocinus	I	I	–	3	0	3	1.80
Acheilognathus koreensis⋆	I	O	–	8	0	8	4.79
Squalidus gracilis majimae⋆	I	I	–	7	0	7	4.19
Rhodeus uyekii⋆	I	O	–	1	0	1	0.60
Sarcocheilichthys nigripinnis morii⋆	I	I	–	0	1	1	0.60
Zacco platypus	T	O	–	60	7	67	40.12
Hemibarbus labeo	T	I	–	0	30	30	17.96
Carassius auratus	T	O	–	1	4	5	2.99
Pseudorasbora parva	T	O	–	5	0	5	2.99
Cyprinus carpio	T	O	–	0	4	4	2.40
Total number of species				14	5	17	
Total number of individual				121	46	167	100

⋆: Endemic species, Tolerance guild (S: Sensitive, I: Intermediate, T: Tolerance), Trophic guild (I: Insectivore, O: Omnivore, C: Carnivore), Habitat guild (RB: Riffle- Benthic), Unim-S: Unimpacted site, Im-S: Impacted site, RA: Relative abundance erences to the stream environment was going to be severe by point sources such as sewages from industrial complex and residential area along with the main axis from the upstream to downstream. In addition, Im-S were mainly affected by effluents of wastewater treatment plant, treated 9,000 ton of sewages daily and conflux effects from the Yudeung Stream exposed by physical habitat disturbance from stream bank construction. 97.8% (45 individuals) of tolerant species was appeared without any sensitive species in Im-S (Table 3). It indicated the downstream ecosystem was directly exposed by water pollution itself.

According to the trophic guild analysis, omnivore species (55.7%, 93 individuals) were more dominant than insectivore species (32.9%, 55 individuals), indicating that the habitat degradation as urban stream was occurred. However, this analysis could not show the significant differences between the Unim-S and Im-S as like as tolerance guild analysis (Table 3). On the contrast, it was happened decreased omnivore either increased insectivore in Im-S. It was owing to relatively less sampled in Im-S compared to Unim-S in spite of increase stream order. Moreover, 30 individuals (65%) of *Hemibarbus labeo* affected relatively high insectivore proportions among the entire 46 sampled individuals in Im-S. Besides, it was not appeared for riffle-benthic species in Im-S despite 18% appearances in Unim-S. Thus, habitat guild analysis also showed the similar result as well as tolerance guild analysis reflecting influences from habitat degradation and water pollution nearby downstream reach.

DELT species among collected fish were resulted in one individual in Unim-S (*Z. platypus*, RA 2.17%), and one in downstream (*H. labeo*, RA 2.17%), have a tendency to increase along the gradient to the downstream (Table 3). Deformity species was presented caused by physical impacts in Unim-S. However, anomalies with bleeding caused by skin erosion were observed in Im-S. Thus, abnormal fish tend to increase because 2nd microbial infection from the pathogen was occurring without any healing after physical damages on external organ such as skin, mainly caused by nutrient enrichment and MPN increase from point sources along with Im-S in downstream reach.

Table 3. Guilds and anormality parameters to indicate stressor effects in the Gap Stream.

		Unim-S	Im-S
Tolerance guild indicator	Tolerant sp. (%)	54.5	97.8
	Sensitive sp. (%)	23.9	0
Trophic guild indicator	Ominivore sp. (%)	64.4	32.6
	Insectivore sp. (%)	19.8	67.3
Morphological anormality	DELT (%)	0.83%	2.17%

4. Species abundance analysis

From the species abundance analyses from the sampling species, only 5 species were presented in Im-S relatively lower in a comparison with 14 in Unim-S. According to maximum species richness line following the stream order, based on reference stream study (An *et al.*, 2001a), it was presented max. 9 species in 3rd order and 15 in 5 th order, respectively (Table 4). So, there were

Table 4. Population and community parameters to indicate stressor effects in the Gap Stream.

		Unim-S			Im-S		
		Mean	Max.	Min.	Mean	Max.	Min.
Species-Individual:	Species # (%)		14 (155%)			5 (33%)	
	Individual # (%)		121 (66%)			46 (14.3%)	
Size distribution indicator	Total length (cm)	7.41	15.6	4.9	12.47	15.6	10.9
	Weight (g)	5.8	42.08	1.21	23.26	49.23	12.09
	CF	0.95	1.18	0.68	1.08	1.22	0.93
Community indicator	Group		*Zacco*-community (50%)			*Hemibarbus*-community (65%)	
	Richness (d)		2.711			1.045	
	Evenness (J')		0.706			0.666	
	Dominance (λ)		0.275			0.464	
	Diversity (H')		0.810			0.466	

Species and individual percentages were against maximum species richness line based on stream order, d=Margalef's species richness index, J'=Pielou's evenness index, H'=Shannon-Weaver diversity index, λ=Simpson's dominance index more species presented in Unim-S but only 33% was presented in Im-S in comparison with reference 5 th order stream. According to the individual analysis from the sampling, Im-S had the lowest 46 individuals compared to Unim-S (121). In comparison with the maximum individuals (183 in 3rd and 321 in 5th order stream) in the reference based on the stream order (An *et al.*, 2001a), it was appeared only 14% in Im-S, though over 66% was observed in Unim-S compared to the references. Consequently, it was appeared abundantly in the Unim-S in upstream reach for the species with indiviuals but appeared relatively lower in species and individuals compared to the reference. Especially, Im-S in downstream supposed to be appear more variously abundant fish species and individuals according as the stream size/order increased. However, Im-S in the urban was more affected by ecological disturbances derived from water pollution and artificial habitat modification including chennelization had less species and individuals so more efforts to support and protect for habitat conservation and maintenance were necessary.

5. Population and community analysis

According to distributions of total length and weight against *Z. platypus* population, it was increased in average length and weight but decreased in distribution range in the comparsion of up and downstream reaches (Table 4). It means averaged length and weight in Unim-S showed lower but size variation between big and small individuals was wider, indicating that more various individuals in size and weight were appeared in upstream reach. However, big and heavy individuals were only appeared in Im-S so that the size distribution in downstream reach was relatively limited compared to upstream region. Condition factor (CF) analysis, usually indicating fish health condition including nutrition and obesity also had a similar pattern with size and weight distribution and appeared higher in Im-S compared to Unim-S (Table 4). Moreover, distribution in Im-S was relatively limited than Unim-S's, so it may cause that more effects by enriched organic pollutants from point source in downstream region can make CF higher than other site. Overall analyses of *Z. platypus* population through size (total length), weight and CF pointed out that Im-S showed significant increase compared to upstream site. Especially, it was well reflected ecological disturbances at Im-S influenced by incoming enriched nutrients such as N and P from nearby wastewater treatment plant (Table 1).

From the community analysis, fish community in the Unim-S and Im-S could be categorized as *Zacco*-community and *Hemibarbus*-community with over 50% RA in the site, respectively (Table 4) and the community diversity index (H') was significantly ($p < 0.05$) higher in the Unim-S (0.810) than the Im-S (0.466) (Table 4). Generally, conventional concepts for community index analysis described that the polluted stream by habitat degradation and eutrophication may have a limitation for the distribution of various fish species so that may decrease species diversity. On contrast, species diversity index may increase following by stabilized habitat condition (Choi *et al.*, 2000). Thus, Unim-S was more stable and healthier than Im-S and this status was caused by habitat stabilization mainly affected to the species diversity.

Overall speaking followed by all types of analyses including physiochemical, ecological indicators, Unim-S in upstream reach, well developed natural vegetation beside stream was relatively less impacted by human activities including point sources. While, Im-S in downstream reach, heavily affected by point sources were gradually degraded the stream environment especially by organic and inorganic enriched nutrients along with currents from up to downstream. Moreover, it was also complicated for pathological effect by bacterial activities with those organic matters and nutrients so that might cause to affect structural changes of fish fanua and ecological indicator's guilds accompany with severe habitat deterioration. Various parameters which were used for these analyses could indicate these degradation and destruction well especially in Im-S. In particular, population analysis could suggest that it was affected to the ecological stabilities through distributional changes of fish size and weight along with CF variances by nutrient exposures between Unim-S and Im-S. Community analysis get through by community index was also reflected the overall ecological condition as urban stream. Thus, our approaches applying various parameters may be used as an effective tool to identify individual - to - community level stressors for the diagnosis the integrative stream environment and can be applied as useful prewarning techniques before water pollution occurs.

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