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Ecosystem Health Assessments of Changwon Stream as a Preliminary Diagnosis for Aquatic Ecosystem Restoration

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In this study, we applied 10-metric health assessment model, based on the Index of Biological Integrity (IBI) during 2006 in the Changwon Stream, which is located in the Changwon city, Gyeongnam province, S. Korea, and then compared with water quality data. The Index of Biological Integrity (IBI) in the Changwon Stream varied from 18 to 38 in the watershed depending on the sampling location and averaged 30.3 (n=6) during the study. Analysis of tolerance guilds showed that the proportion of sensitive species was 13%, but tolerant and intermediate species were 34% and 53%, respectively. Qualitative Habitat Evaluation Index (QHEI) averaged 43.3 (range: 65-104, n=6) indicating non-supporting condition, based on the criteria of U.S. EPA (1993). Values of QHEI showed a typical longitudinal decreases from the headwater reach to the downstream location, except for Site 1 with a low QHEI value by artificial habitat by concrete construction. Minimum QHEI was found in Site 4 where fish diversity was minimal. Conductivity increased continuously along the gradients and especially showed abrupt increases in the downstream sites along with turbidity. Stream ecosystem health of IBI matched to the values of QHEI except for S6. Low IBI values in the sites 4 and 5 was considered to be a result of combined effects of chemical pollutions and habitat degradations. Our results support the hypotheses of Plafkin *et al.* (1989) that physical habitat quality directly influences the trophic structure and species richness, and is closely associated with IBI values.

Key words : ecosystem health, biological integrity, QHEI, ecosystem restoration, water quality

INTRODUCTION

Rapid urbanization and wide spread of land utilization close to the city in S. Korea have caused the degradation of ecological health in stream watershed. Especially, streams nearby the metropolitan city hardly maintain their ecological health because of physico-chemical degradations in company with habitat deteriorations such as artificial changes of stream embeddedness and bank construction with concretes. Various biological assessments and monitoring methods, based on multi-metric approaches using various bioindicators, have been developed in order to prevent these degradations and protect the environmental health.

Recently, new evaluation methodology using bioindicators are widely introduced to assess the integrative aquatic health, not just with chemical assessment of water quality and also habitat evaluation methods to monitor physical degradation of stream itself (Barbour *et al.*, 1999; U.S. EPA, 2002). Such approaches, thus, have been adapted to various types of aquatic environments to recover and restore their ecological functions in the watershed (Woo and Kim, 2000; MEK, 2004, 2005; An and Kim, 2005). Especially, multi

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-metric assessments using fish assemblages among the various biota reflect not only chemical water quality in stream but the status of physical habitat. In addition, the assessments reflects energy flow through the trophic interations and material cycling in the ecosystem (An *et al.*, 1992; Lee, 2001) and were sometimes modified by regional climate changes (An, 2000, 2001). Thus, biological health assessment have been adapted to many countries and applied as stream management tools.

In recent case of S. Korea, health assessments methodology using biota such as periphyton (Hwang *et al.*, 2006), macroinvertebrate (Won *et al.*, 2006) and fish (An *et al.*, 2006) have been introduced to evaluate the aquatic ecosystem by Ministry of Environment, S. Korea in 2006. The ecosystem health assessments in S. Korea using fish assemblage developed by An *et al.* (2006) was originally based on approaches of Karr (1981) and Barbour *et al.* (1999). Now, Korean government started a national monitoring program of stream ecosystem health assessments in July 2007. This program may have significant roles to keep clean aquatic environments and to restore stream health impacted in the major watershed, S. Korea. For a successful restoration in watersheds, researches should conduct a comparative analysis of past and present health conditions of aquatic environments and also predict the future conditions.

Our study was to determine the ecosystem health in the six sites of Changwon Stream, which is supposed to restore the stream ecosystem for sustainable conservation in 2008. For the study, we used multi-metric health assessment model, which was developed by An *et al.* (2005a) and calibrated by An *et al.* (2006). The results of our study will provide key dataset of stream health conditions prior to the stream restorations in terms of physical habitat and biota, and after the restoration construction, this research also will act as a important criteria in determining whether the stream was restored or not.

MATERIALS AND METHODS

1. Descriptions of sampling sites and periods

Studies were conducted at six selected sites in the Changwon Stream, a warm-water system, which is located in the Changwon city, Gyeongnam province, S. Korea (Fig. 1). Changwon Stream is merged with Nam Stream near the downstream reach of 7.5 km from Site 1 (S1) and flow out to Masan Bay.

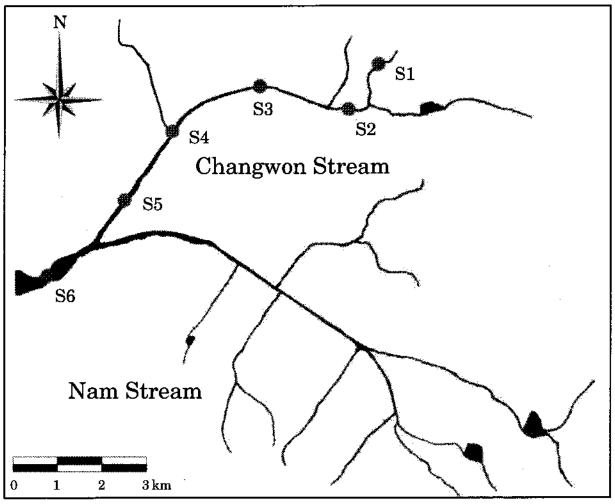

Fig. 1. Sampling sites in Changwon Stream.

Fish samples were collected, based on catch per unit of effort (CPUE; Ohio EPA, 1989), in September 2006 when it was hydrologically stable conditions, compared to the summer monsoon of heavy flood. All types of the habitats riffle, run, and pool reaches were included for the fish sampling. Physical conditions in each sampling site are summerized as follows: the mean depth and width in the Site 1 (S1) are 5-10 cm and 3-4 m, respectively, and epifaunal substrate is mainly covered with artificial concrete structure. Site 2 (S2) is 15-20 cm in depth, 3-4 m in width, and is also covered by concrete structures. Site 3 (S3) is influenced by commercial area and dense residential area. Site 4 (S4) is merged with Naedong Stream, which is directly influenced by dense residential populations and municipal sewage water. Sites 5 and 6 (S5, S6) is located in the eastury area with high dark silts in the bottom and high salts in the water. All sites are located in the Changwon City, Gyeongnam province, S. Korea. The detail sampling sites (Site=S) are as follows;

S1: Enterance of Changwon National University, 9 Sarim-dong
S2: Toechon 3rd bridge, Sarim-dong
S3: Changwon 1st bridge, Banji-dong

S4: Daewon bridge, Daewon-dong
S5: Youtong bridge, Daewon-dong
S6: Bongam bridge, Sinchon-dong

In addition to the regular sampling, we also surveyed 30 reference stations, based on the approach of Hughes (1995) and derived maximum species richness lines (MSRLs) against stream orders using the dataset. Maps of 1 : 15,000 were used for the selection of candidate reference stations, and the determination of stream order was based on the methodology of Strahler (1957). The MSRLs were determined by empirical methods of Karr and Dionne (1991) and 1st order regression analysis of Rankin and Yoder (1999).

2. Sampling methods and sampling gears

At each sampling location, stream distance sampled was 100 m and the sampling time elapsed was 60 minutes according to the quantitative sampling method (Barbour *et al.*, 1999). We used various sampling gears such as electrofishing method, casting net, and kick net for the fish sampling. Electrofishing was designed as 12 volt and 24 ampere (An and Kim, 2005; An *et al.*, 2005b), and were kept within effective range of the electrical field by electric stimulus and fish were immobilized making it possible to pick them up with long-handled dip net. The mesh sizes of casting net and kick net were 5 × 5 mm and 4 × 4 mm, respectively. The sampling gears were applied to the all sampling sites, and the fish samplings were conducted toward the upstream direction. Fish species collected were identified according to the methods of species identification (Nelson, 1994; Kim and Park, 2002).

3. Model applications of index of biological integrity and metric determinations

In this study, we adapted 10-metric index of biological integrity (IBI) which was developed for regional applications in S. Korea by An *et al.* (2006). The metrics (M) were composed of three major groups such as species richness and composition, trophic and tolerance guilds, and fish abundance and health condition. Trophic guilds as a energy flow in the food web in the aquatic ecosystems, were categorized as omnivore, insectivore (or invertevore), carnivore (pisivore), and herbivore species, but in this IBI model, we used the metrics of omnivore, insectivore, and carnivore species. Also, trophic guilds were divided into three categories of sensitive, tolerant, and intermediate species and this classification followed the approach of U.S. EPA (1993). Species richness and compositions were composed of four metrics such as a number of native species (M_1), riffle-benthic species (M_2), number of sensitive species (M_3), and the proportion of tolerant species (M_4). Trophic compositions were composed of three metrics including the proportion as a number of omnivore species (M_5), proportion as a number of carnivore species (M_6), and the proportion as a number of insectivore species (M_7). And fish abundance and health conditions were composed of three metrics of total number of individual (M_8), the proportion as a number of exotic species (M_9), and the proportion as a number of abnormal individuals (M_{10}). Metric scores of 1, 3, or 5 were assigned to each of the raw metric values after the approach of U.S. EPA. These scores were then summed to obtain a site-specific model value that ranged from 10 to 50, and four ranks (Excellent, 46-50; Good, 36-40; Fair, 26-30; Poor, 16-20 and Very poor, < 10) were used for the evaluation.

4. Water quality and habitat quality assessments

In addition to the fish sampling, we measured water quality such as water temperature, dissolved oxygen (DO), pH, conductivity, turbidity, and salinity using YSI 6600 Model in the field. Also, we evaluated physical habitat conditions using a qualitative habitat evaluation Index (QHEI; U.S. EPA, 1983; Plafkin *et al.*, 1989) in the Changwon Stream. Eleven habitat parameters were selected for the assessments of QHEI, based on the references widely used (Bartholow, 1989). The metrics used for analysis of habitat quality in the sampling sites of Changwon Stream are as follows; M_1: substrate/instream cover, M_2: embeddedness, M_3: flow velocity/depth combination, M_4: bottom scouring and sediment deposition, M_5: channel flow status, M_6: channel alteration, M_7: frequency of riffles or bends, M_8: bank stability, M_9: bank vegetative protection, M_{10}: riparian vegetative zone width, and M_{11}: dam construction impact. Each parameter was divided into four categories of "Excellent (182-220): Ex", "Good (128-168): G", "Fair (66-110): F", and "Poor (8-52): P" conditions, based on the criteria of U.S.

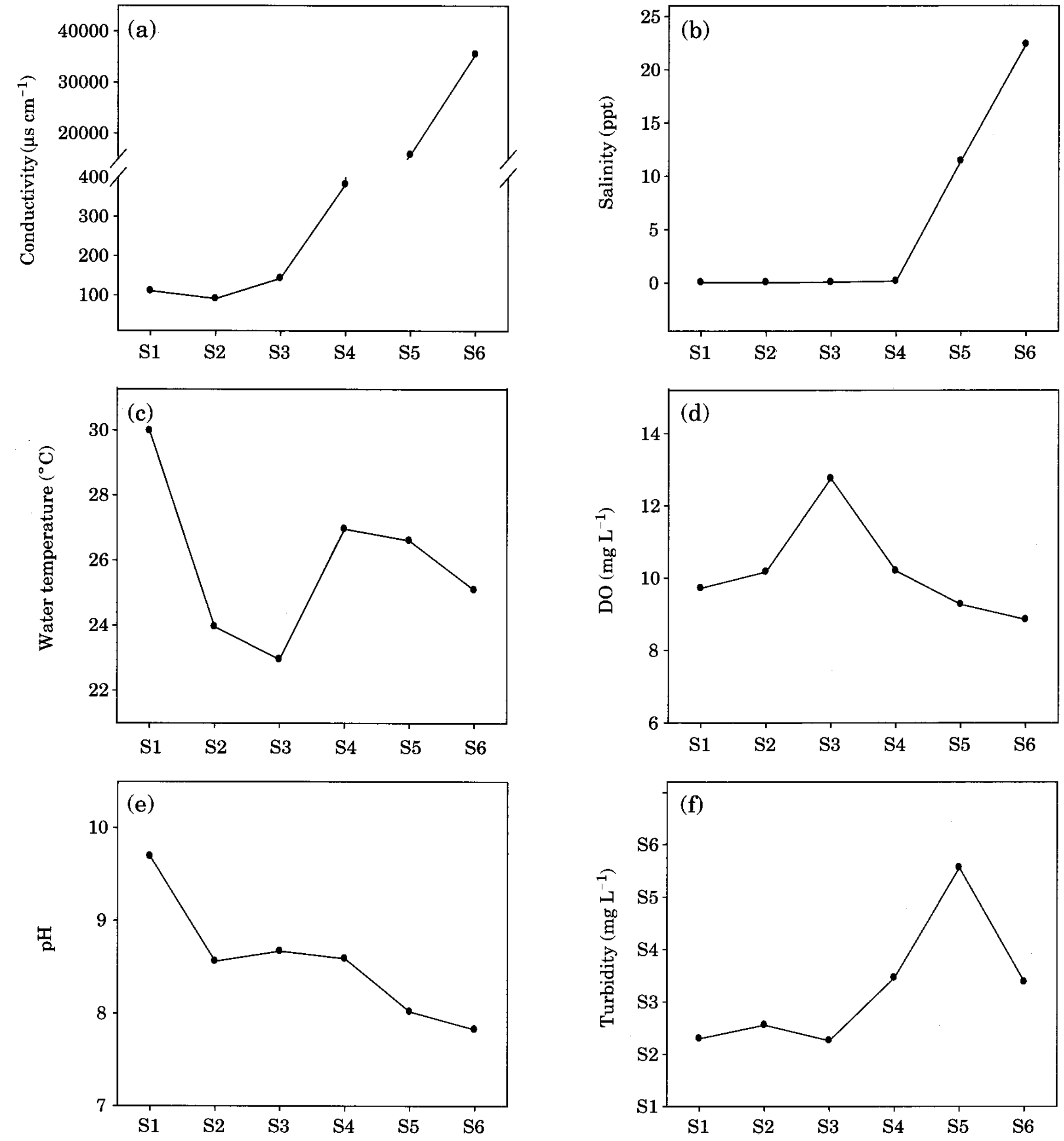

Fig. 2. Conventional water quality of conductivity, salinity, water temperature, dissolved oxygen (DO), pH, and turbidity in the sampling sites.

EPA (1983). The health conditions of the habitat were assessed by sum of scores obtained from the 11 metrics.

RESULTS AND DISCUSSION

1. Physical and chemical conditions

Physico-chemical properties in the Changwon Stream showed a typical longitudinal gradient along the axis of the upstream-to-downstream; conductivity increased continuously along the gradients and especially showed abrupt increases in the downstream sites of S5 and S6, which was considered as a nutrient rich estuary ecosystem (Fig. 2a). Salinity was almost same in the reach of S1-S4, but showed abrupt increases in S5-S6 (Fig. 2b). Water temperature was greatest in the Site 1 (S1) where water volume was mini-

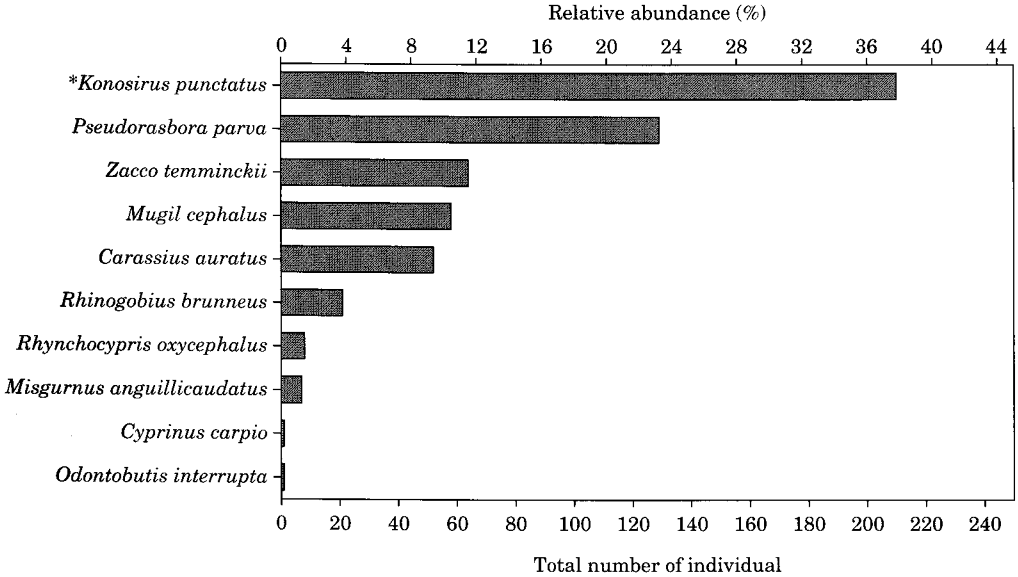

Fig. 3. Dominant species (*), expressed as a relative abundance, in Changwon Stream.

Table 1. Tolerance guild and trophic guild in Changwon Stream.

Species	Tol. G	Tro. G	Hab. G	S1	S2	S3	S4	S5	S6
Zacco temminckii	SS	I		5	46	13			
Misgurnus anguillicaudatus	TS	H			1	6			
Rhinogobius brunneus	IS	I	RB	2	12	6	1		
Rhynchocypris oxycephalus	SS	I				8			
Carassius auratus	TS	O				51	1		
Mugil cephalus	TS	H						24	33
Odontobutis interrupta	IS	C	RB		1				
Cyprinus carpio	TS	O				1			
Konosirus punctatus	IS	C						34	176
Pseudorasbora parva	TS	O				129			
Total number of species				2	4	7	2	2	2
Total number of individual				7	60	214	2	38	209

Tol. G=Tolerance Guild, Tro. G=Trophic Guild, Hab. G= Habitat Guild, SS=Sensitive Species, IS=Intermediate Species, TS=Tolerant Species, O=Omnivore, I=Insectivore, C=Carnivore, H=Herbivore, RB=Riffle-Benthic species

mal in the sampling sites (Fig. 2c). In the all sampling sites, concentrations of dissolved oxygen (DO) were >8 mg L^{-1} and pH values were >7.0, implying no impacts of oxygen and pH on the fish populations in all sites (Fig. 2d, 2e). Turbidity increased continuously from 6.5 NTU at the Site 1 to 22.8 NTU at the Site 5, which was maximum, and then declined 11.9 NTU at the Site 6 (Fig. 2f). We suggest that it caused by conflux of Naedong Stream at the site 4, which is directly influenced by dense residential populations and municipal sewage water.

2. Fish compositions and tolerance guilds

In the Changwon Stream, total number of species sampled was 10 species (9 family) with 550 individuals and varied from 2 to 7 species depending on the sampling sites (Table 1). We could not compare the fish fauna sampled in this study with previous data due to no reports, although some researches of Bae *et al.* (1979), Bae *et al.* (1980), Lee *et al.* (1981), and Lee *et al.* (1984) reported chemical water quality in the stream. Dominant species in the estuary reach (S6) was *Konosirus punctatus* (Family Clupeidae) and in

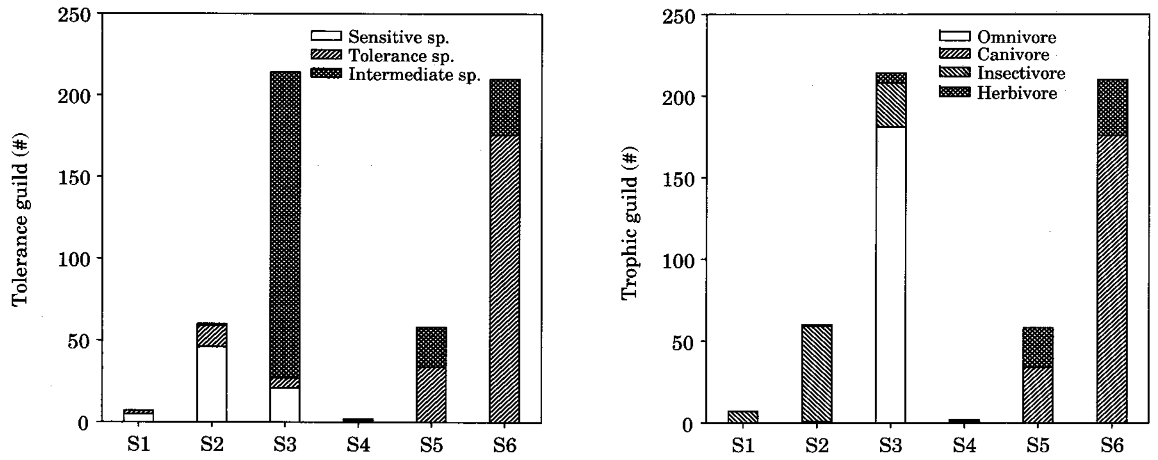

Fig. 4. Analysis of tolerance guilds and trophic guilds.

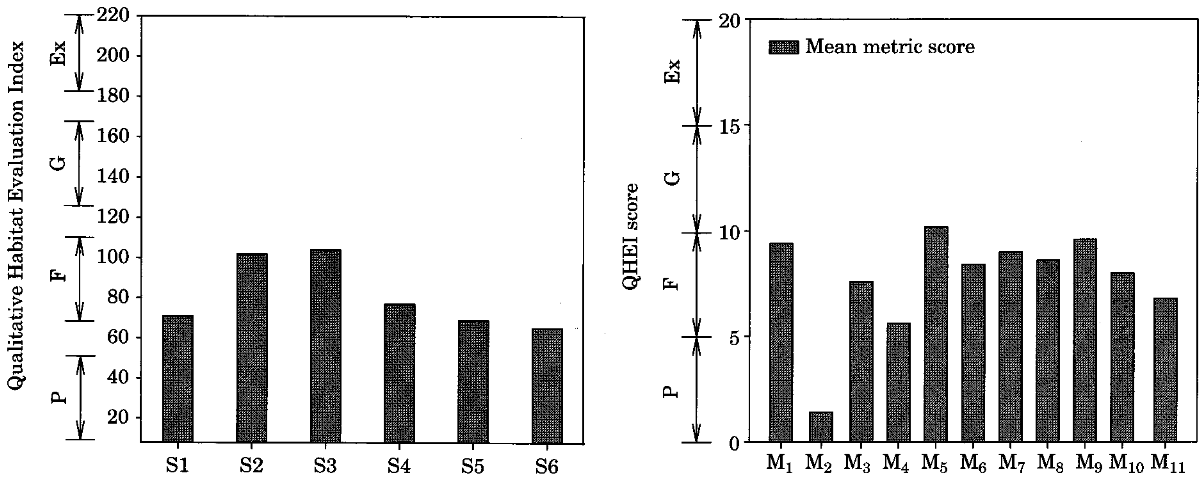

Fig. 5. Qualitative Habitat Evaluation Index (QHEI) and their metric analysis.

other reaches, *Pseudorasbora parva* dominated (23.5%, 129 individuals) the community (Fig. 3). Korean endemic species was only one, *Odontobutis interrupta* among the fishes sampled, while endanged species and natural monument species were not observed in the study periods.

Jeon (1980) and Choi *et al.* (2000) reported that richness in the endemic fish species may be a good barometer for judging the environmental health and that the numbers decreases rapidly as stream habitats degradate. These results imply that water environment of Chongwon Stream may be impacted by various factors. Especially, only two species were appeared in the Site 4 where organic matter and nutrient pollution were severe, as shown in the research of water quality by Yoon *et al.* (1998). In fact, analysis of tolerance guilds showed that the proportion of sensitive species was 13% (72 individuals), but tolerant and intermediate species were 34.4% (189 individuals) and 53% (289 individuals), respectively. The compositions indicate the dominance of tolerant or intermediate species in the stream, indicating an ecological disturbance (Fig. 4). In spite of the degradations, exotic species were not observed in the all stream sites, indicating no influence of introduced species such as large-mouth bass.

3. Physical habitat health

The Qualitative Habitat Evaluation Index

(QHEI), conducted in the Changwon Stream, averaged 43.3 (range: 65-104, n=6, Fig. 5), indicating non-supporting condition (rank: IV) of four ranks, based on the criteria of U.S. EPA (1993). Values of QHEI showed a typical longitudinal decreases from the headwater reach to the downstream location, except for Site 1 with low QHEI value. The low QHEI in the headwater site (S1) was mainly attributed to artificial habitat by concrete construction, so the vegetation coverage was very low, compared to other habitats. Maximum QHEI occurred in the Site 3 (104) and the minimum value was found in Site 4 where fish diversity was minimal. Thus, stream ecosystem health, measured as the Index of Biological Integrity (IBI), matched to the values of QHEI except for Site 6. In other words, QHEI values in the Sites 4 and 5 were low, compared to values of upstream-sites (S1-S2) and also the IBI values were low, even if the IBI values even lower than expected by the QHEI values. These results indicate that low IBI values in the Sites 4 and 5 may be a result of combined effects of chemical pollutions and habitat degradations. Our results support the hypotheses of Plafkin *et al.* (1989) that physical habitat quality directly influences the trophic structure and species richness, and is closely associated with IBI values (Table 2).

In the metric analysis of QHEI, the metric of M_2, as an embeddedness, was 1.4, indicating severe degradations by sand or silts. Also, the metric of vegetation coverage showed low values as shown in the Fig. 5. These characteristics reflected high proportions of concrete substrate in the stream sites, especially 100% in the Site 1 (S1). Overall, each metric values in the all sites did not greater than 10, indicating a severe degradations of the stream habitat.

4. Stream ecosystem health

The Index of Biological Integrity (IBI) in the Changwon Stream varied from 18 to 38 in the watershed depending on the sampling location and averaged 30.3 (n=6) during the study (Fig. 6). The ecosystem health was judged as a fair condition, based on the modified criteria of U.S. EPA (1993). In this case of fair conditions, generally

Table 2. Qualitative Habitat Evaluation Index (QHEI) at four sampling locations in the Changwon Stream.

Site	Substrate structure and vegetation coverage					Channel characteristics			Bank characteristics and structure			QHEI score (Criteria)
	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}	M_{11}	
S1	1	1	1	1	3	1	1	0	0	0	6	15 (P)
S2	6	6	6	1	3	1	1	0	0	0	1	25 (P)
S3	6	1	8	10	5	3	1	0	0	0	3	37(P)
S4	10	1	6	8	6	5	1	0	0	0	6	43 (P)
S5	6	1	1	8	10	11	1	12	15	0	10	75 (F)
S6	3	1	1	6	10	3	1	7	10	10	15	67 (F)

M_1=Substrate/Instream cover, M_2=Embeddedness, M_3=Flow velocity/Depth combination, M_4=Bottom scouring & Sediment deposition, M_5=Channel flow status, M_6=Channel alteration, M_7=Frequency of riffles or bends, M_8=Bank stability, M_9=Bank vegetative protection, M_{10}=Riparian vegetative zone width, M_{11}=Dam construction impact

Table 3. The Stream Ecosystem Health Assessments (SEHA), based on the 10 metric models in the Changwon Stream.

Sampling site	TNS	RBS	SS	TS	OS	IS	CS	TNI	XT	AI	Total
S1	2 (3)	1 (3)	1 (1)	0 (5)	0 (5)	100 (5)	0 (1)	7 (1)	0 (5)	0 (5)	34 (II-III)
S2	4 (3)	2 (3)	1 (1)	1.670 (5)	0 (5)	96.67 (5)	1.67 (3)	60 (3)	0 (5)	0 (5)	38 (II)
S3	70 (5)	1 (1)	2 (3)	87.38 (1)	84.58 (1)	12.62 (1)	0 (1)	214 (5)	0 (5)	5.14 (1)	24 (III-IV)
S4	2 (1)	1 (1)	0 (1)	50 (1)	50 (1)	50 (5)	0 (1)	2 (1)	0 (5)	50 (1)	18 (IV)
S5	2 (1)	0 (1)	0 (1)	41.38 (1)	0 (5)	0 (1)	58.62 (5)	58 (1)	0 (5)	1.72 (1)	22 (III-IV)
S6	2 (1)	0 (1)	0 (1)	0 (5)	0 (5)	0 (1)	84.21 (5)	209 (5)	0 (5)	0 (5)	34 (II-III)

TNS=Total # of native species, RBS=# of riffle benthic species, SS=# of sensitive species, TS=% individuals as tolerant species, OS=% individuals as omnivores, IS=% individuals as native insectivores, CS=% individuals as native carnivores, TNI=Total # of individual, XT=% individuals as exotics, AI=% individuals with anomalies

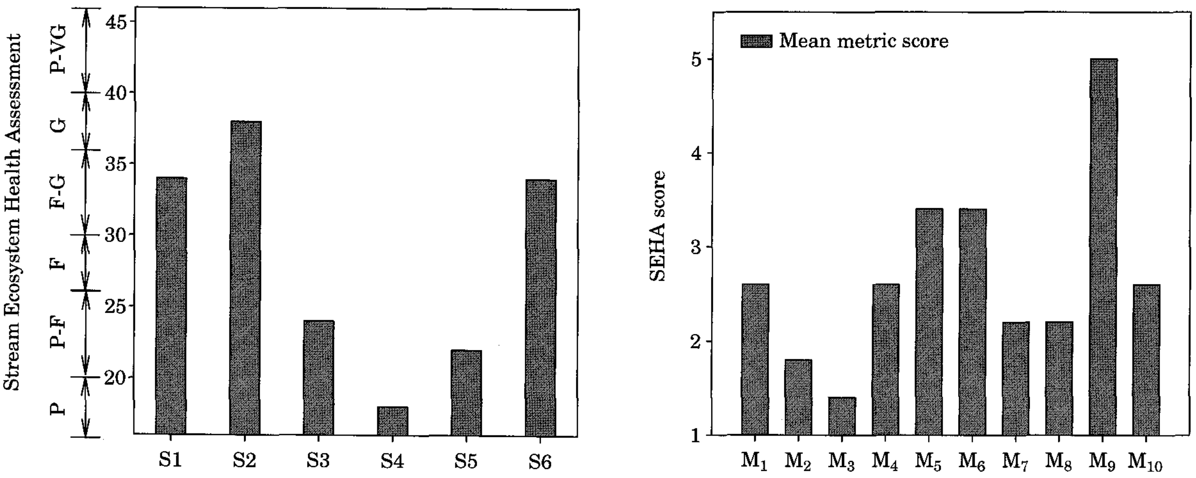

Fig. 6. Stream Ecosystem Health Assessments (SEHA) and their metric analysis.

species are composed of low sensitive species, high omnivore and tolerant species. This trend in the species compositions and trophic guilds was evident in the study. Especially, low IBI values were found in the Sites 4 and 5 where pollutions of nutrients and organic matter were severe and QHEI values were lowest. Thus, the reduced IBI in the Sites 4 and 5 reflected the chemical degradations and habitat modifications. Ecosystem health, based on the IBI model of fish, was similar to the previous studies of urban streams (Kap Streams, An *et al.*, 2001a) but showed large difference, compared to a mountainous stream (Pyungchang River, An *et al.*, 2001b). We believe that degradation in the ecosystem health is highly associated with habitat conditions and chemical pollutions, but also, flow volume in the stream was one of the important factors influencing the biological health. Each metric analysis showed that each metric values of M_2 as a number of riffle-benthic species and M_3 as a number of sensitive species averaged 1.7 and 1.3, respectively and this values were minimum compared to other metric values. This result indicates that the riffle zone, mainly composed of pebble and grabble, was not formed or rare in the streams (Table 3).

CONCLUSION

Korean government started a national monitoring program in 2007 using the multi-metric model, applied in this study, for the evaluations of stream ecosystem health. Our study may have significant roles to keep clean the stream environments and to restore stream health impacted. For a successful restoration in the watersheds, researches should conduct a comparative analysis of past and present health conditions of stream environments and also predict the future conditions. Recently, USA (Karr and Dionne, 1991) and many other developed countries including France (Oberdorff and Hughes, 1992; Oberdorff and Porcher, 1994), Japan (Koizumi and Matsumiya, 1997), and Australia (Harris, 1995) have adapted the multi-metric model for evaluation of water environments. Our study determined the ecosystem health in the six sites of Changwon Stream, which is supposed to restore the stream ecosystem for sustainable conservation in 2008. We believe that this study will provide key dataset of stream health conditions prior to the stream restorations in terms of physical habitat and biota, and will be an important criteria in determining whether the stream was restored or not.

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