Int. J. Environ. Res., 7(3):659-668,Summer 2013
ISSN: 1735-6865

Ecological Health Assessments of an Urban Lotic Ecosystem Using a Multi-metric Model along with Physical Habitat and Chemical Water Quality Assessments

Kim, J.H.[1], Oh, H.M.[2], Kim, I.S.[3], Lim, B.J.[4], and An, K.G.[1*]

[1] Department of Biological Science, College of Bioscience and Biotechnology, Chungnam National University, Daejeon 305-764, South Korea

[2] Environmental Biotechnology Research Center, Korea Research Institute of Bioscience & Biotechnology, Daejeon 305-806, South Korea

[3] Institute of Environmentally-Friendly Agriculture, College of Agriculture and Life Sciences, Chonnam National University, Gwangju 500-757, South Korea

[4] Yeongsan River Water Research Center, Gwangju 500-480, South Korea

Received 2 Oct. 2012; Revised 17 Dec. 2012; Accepted 10 March 2013

ABSTRACT: The objective of this study was to diagnose integrative ecological health of an urban stream, which is located in the Asian temperate region. The research approach was primarily based on the Index of Biological Integrity (IBI) using fish assemblage and a Qualitative Habitat Evaluation Index (QHEI). And these indexes were compared with long-term conventional chemical dataset during 1996-2005. For the experiment, four sampling sites were chosen from the stream and wading method was used for fish collection during 2004-2005. We developed a stream health assessment model (SHA model) for the regional application. Stream health conditions, based on the SHA model, averaged 23 indicating a fair-poor condition, and varied from 18 to 40 depending on the sampling stations. Values of QHEI varied from 55 (fair-poor condition) to 112 (good-fair condition) and the values were significantly lower in the down stream than the headwater. Water quality, based on COD, BOD, TN and TP declined from the upstream to downstream reach. The proportion of sensitive species showed a negative linear function with BOD and the tolerant was vise versa. Values of SHA model reflected the chemical and physical habitat conditions and this result was clearly evident in the downstream reach. These outcomes were supported by principal component analysis (PCA) of IBI vs. other factors. Overall these results suggest that the impacts to the health of this stream are due to the combined effects of both chemical and habitat degradation.

Key words: Stream health assessment, Fish assemblage, Habitat evaluation, Water quality, Biological integrity

INTRODUCTION

Recently, numerous studies (Trautwein *et al.*, 2012; Teng *et al.*, 2011; Brown *et al.*, 2009; Cunico 2012) pointed out that urbanization is rapidly expanding in regional watersheds and caused a rapid degradation of stream water environment. Many urban channels were designed for flood control and sediment transport without ecological consideration (Morley and Karr, 2002), resulting in physical degradation of the streams throughout habitat modifications such as dam constructions and dredging (Sullivan, 2000; Casatti, 2006). Also, urban stream runoff carries toxic contaminants (Yuan *et al.*, 2001), nutrients (Jones *et al.*, 1999), and organic matter (Casey, and Rasmussen, 2006) along with sediments (Jones *et al.*, 1999). These alternations in physical channel structures and water chemistry also change in the composition of the biotic community inhabiting the stream, usually with a reduction in the species diversity (Boon, 2000). Further, these decrease biological health lead to local dominance of tolerant species (Desiree *et al.*, 2006; Walton *et al.*, 2007), increased proportion of omnivore taxa (Barbour *et al.*, 1999) and exotic species (Leidy and Fiedler, 1985), and increased anormalities of aquatic biota (An *et al.*, 2004).

To diagnose such various symptoms, chemical measurements are frequently used as a primary tool to evaluate the degree of water pollution (Yoder *et al.*, 2000). One of the major problems in the chemical approach is a large variability caused by the measuring time, sampling

*Corresponding author E-mail:kgan@cnu.ac.kr

sites, weather conditions, and sampling techniques (Richard *et al.*, 1999). Chemical approaches also fail to account for certain types of degradation, such as channelization, barriers, exotic species, and altered flow regimes (Fore *et al.*, 1993). For these reasons, aspects of the various biological, ecological, and geo-morphological approaches are reviewed in effective stream managements (Gore, 1985; Boon, 2000). US EPA established Rapid Bioassessment Protocol (Barbour *et al.*, 1999) for the assessment of stream health using various biotas including fish. The Water Framework Directive (WFD), in the European Union (EU) also adopted the multi-metric bioassessment models using fish assemblages for an effective management and conservation in European streams and rivers (EU, 2000). These bioassessment programs have been used as a key tool for restoration of urban rivers and stream ecosystems and become a recent world-wide methodology for health assessments of aquatic environments (Karr and Chu, 2000). The restoration and maintenance of 'healthy' ecosystems has become important objectives of stream conservation and management (Gore, 1985; Karr, 1991; Rapport, 1991).

Korean government invested 58.7 billion dollars in the ecological restoration of sixty-four streams in forty-eight administrative districts in 2004. But, the government still has no appropriate methodology and the model for the regional applications. The establishing an overall assessment model about stream health by measuring not only chemical conditions but also indicator species characteristics is urgent for the multilateral restoration of lotic ecosystems. The objectives of this study were to establish a multi-metric model for urban stream management and restoration in this watershed, and evaluate current health conditions of the stream.

MATERIALS & METHODS

This study was conducted in a wadable, 2^{nd} - 3^{rd} order stream (Daejeon stream) which is located in the temperate region (South Korea). The stream is located in one of the most densely populated and industrialized metropolitan regions in South Korea. It has an altered flow regime, because the stream flows through the center of a commercial area, and receives sewage and industrial effluents. Four sampling sites were selected to assess the stream health (Fig. 1). Site 1 (S1) is located in the suburban area with resident (67%) and forest cover (25%), and other sites (S2-S4) are in the 100% commercial and urban. S1 has well-developed riffle-pool morphology with gravel as the dominant substratum. Stream bed morphological alterations are minimum in the headwater reach, while habitat structure is more degraded in the downstream sites due to stream engineering activities such as channelization and barrier construction. Especially, S4 is also influenced by a tributary stream with industrial inputs, and runoff from urban roads and domestic sewage. At the four sites, fish collections were conducted during August 2004 - September 2005 according to the wading method (EPA, 1989). All habitat types including riffles, runs, and pools were sampled in an upstream direction for a distance of at least 150–200 m for 60 min. At each site, a hand net (5 × 5 mm), casting net (8 × 8 mm), and electrofishing (25A, 12 V) gear where used to collect fishes. Most fishes were identified and released at the sampling sites, but some ambiguous specimens were preserved in 10% formalin and identified in the lab. Sensitive and tolerant species were classified based on the previous studies (An *et al.*, 2002).

We adapted a 10-metric index of biological integrity (IBI) which was modified for a regional application in Korean watershed (An, *et al.*, 2002). The metrics (M) were composed of three major groups: species richness and composition, trophic composition, and fish abundance and health condition. Species richness and composition were composed of four metrics: number of native species (M_1), riffle-benthic species (M_2), number of sensitive species (M_3), and proportion of tolerant species (M_4). Trophic compositions were composed of three metrics: proportion as a number of omnivore species (M_5), proportion as a number of carnivore species (M_6), and proportion as a number of insectivore species (M_7). Fish abundance and health condition were composed of three metrics: total number of individual (M_8), proportion as a number of exotic specie (M_9), and proportion as a number of abnormal individual (M_{10}). Metric scores of 1, 3, or 5 were assigned to each of the raw metric values after the approach of Barbour et al. (1999). These scores were then summed to obtain a site-specific model value that ranged from 10 to 50, and four rank (excellent, 46–50; good, 36–40; fair, 26-30; poor, 16-20; and very poor, <10) were used for the evaluation (An *et al.*, 2002). The habitat conditions were measured during 2004-2005, and the Qualitative Habitat Evaluation Index (QHEI; U.S. EPA, 1993; Plafkin *et al.*, 1989) was used to score habitat quality. We selected eleven habitat parameters, based on the references (U.S. EPA, 1993; Barbour *et al.*, 1999). Each of the habitat attributes assessed is summarized in Table 1. For the habitat assessments, we included in-stream substrate type, flow condition, channel modification and bank characteristics. The health conditions of the habitat were assessed by sum of scores obtained from the eleven parameters and were categorized as 4 ranks of excellent (182-220), good (124-168), fair (66 - 110) and poor (8-52). Chemical dataset were measured by the national water quality monitoring program of the Ministry of Environment Korea (MEK) during 1996-2005. The parameters

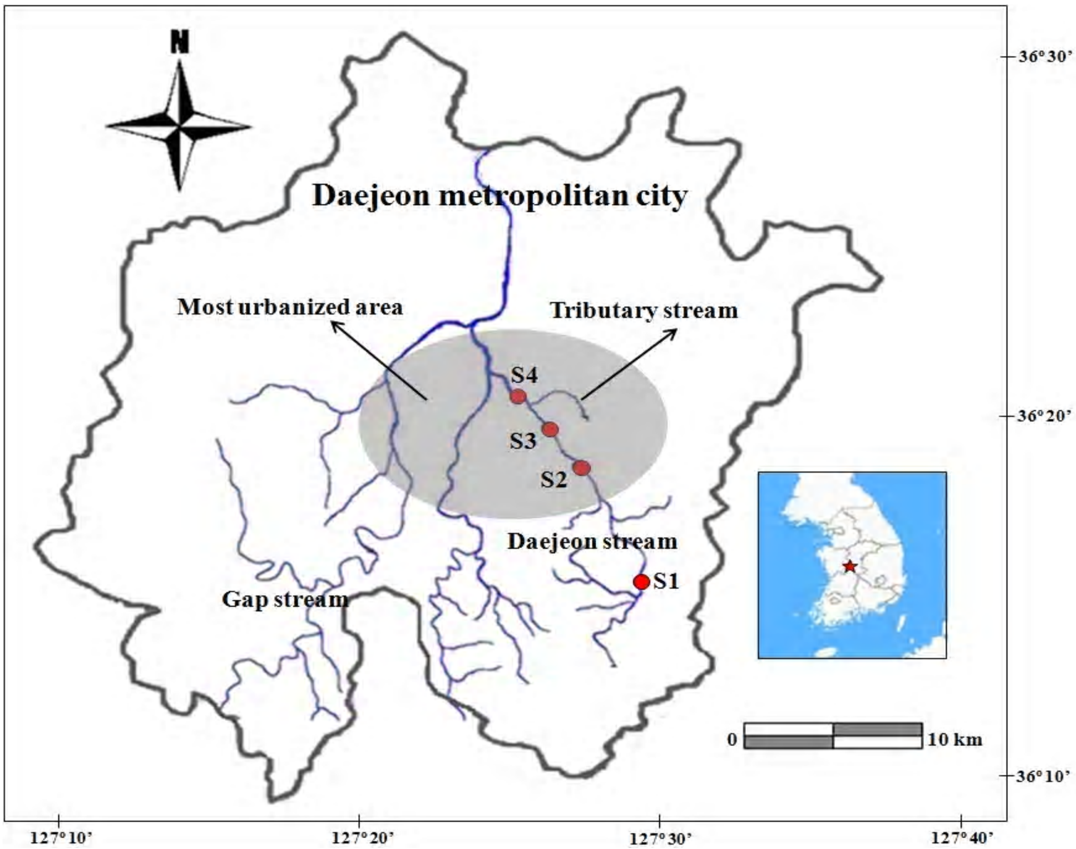

Fig. 1. The map showing four sampling sites (S1-S4) in Daejeon stream, South Korea

Table 1. Qualitative Habitat Evaluation Index (QHEI) at four sampling sites in Daejeon stream, South Korea

Habitat Parameters	Sampling Locations			
	S1	S2	S3	S4
M_1 Epifaunal Substrate/ Available cover	14	10	5	6
M_2 Embeddedness	15	10	3	5
M_3 Velocity/Depth Combination	14	12	7	8
M_4 Sediment deposition	12	9	11	7
M_5 Channel flow status	12	6	4	4
M_6 Channel alteration	6	1	1	3
M_7 Frequency of riffles or bends	12	8	3	5
M_8 Bank stability	14	14	14	13
M_{19} Bank vegetative protection	4	1	1	6
M_{10} Riparian vegetative zone width	10	1	1	4
M_{11} Existence of small-scale dams	6	1	2	11
Model Score (Criteria of US EPA)	121 (Good - Fair)	74 (Good - Fair)	52 (Poor)	73 (Good - Fair)

analyzed were biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP). We analyzed spatial and temporal patterns of chemical water quality.

RESULTS & DISCUSSION

Long-term chemical data during 1996-2005 showed that stream water quality improved over the last ten years (Fig. 2). In 1996, BOD averaged 4.5 mg/L and increased up to 5.8 mg/L, which was maximum during the study (Fig 2-a). Minimum concentration of BOD occurred in 2003 when the annual precipitation was greater than last two years from 2003, indicating a dilution of stream water by rainwater. Concentrations of COD followed inter-annual variation and minimal-maximal trend in the BOD (Fig. 2-b). Total nitrogen (TN) also showed a typical linear decline ($y=6.2-0.145x$, $p<0.05$) from 1996 to 2005, except for 2003 (Fig. 2-d). Mean TP was highest in 1996 and the variation ranged between 24 and 880 μg/L (Fig. 2-c). Long-term trend of TP did not follow the patterns of BOD, COD, and TN, but the mean and minimum-maximum range showed large decreases, compared to the previous years. Improvements in water quality in recent years were linked to the concentrations of wastewater disposal plants after 1997.

Spatial trend of water quality was evident: BOD and COD had a positive linear increase from the headwater to downstream (Fig. 3-a, b). Thus, BOD and COD was highest in the downstream (S4), TP increased abruptly in the downstream and the minimum-maximum range was greater than other sites (Fig. 3-c). The rapid degradation of water quality in the downstream reflected the urban's land use (Park *et al.*, 2003). Mean TN was >5.0 mg/L in the all sites, indicating a highly eutrophic condition (Fig. 3-d). Qualitative Habitat Evaluation Index (QHEI) showed that habitat quality

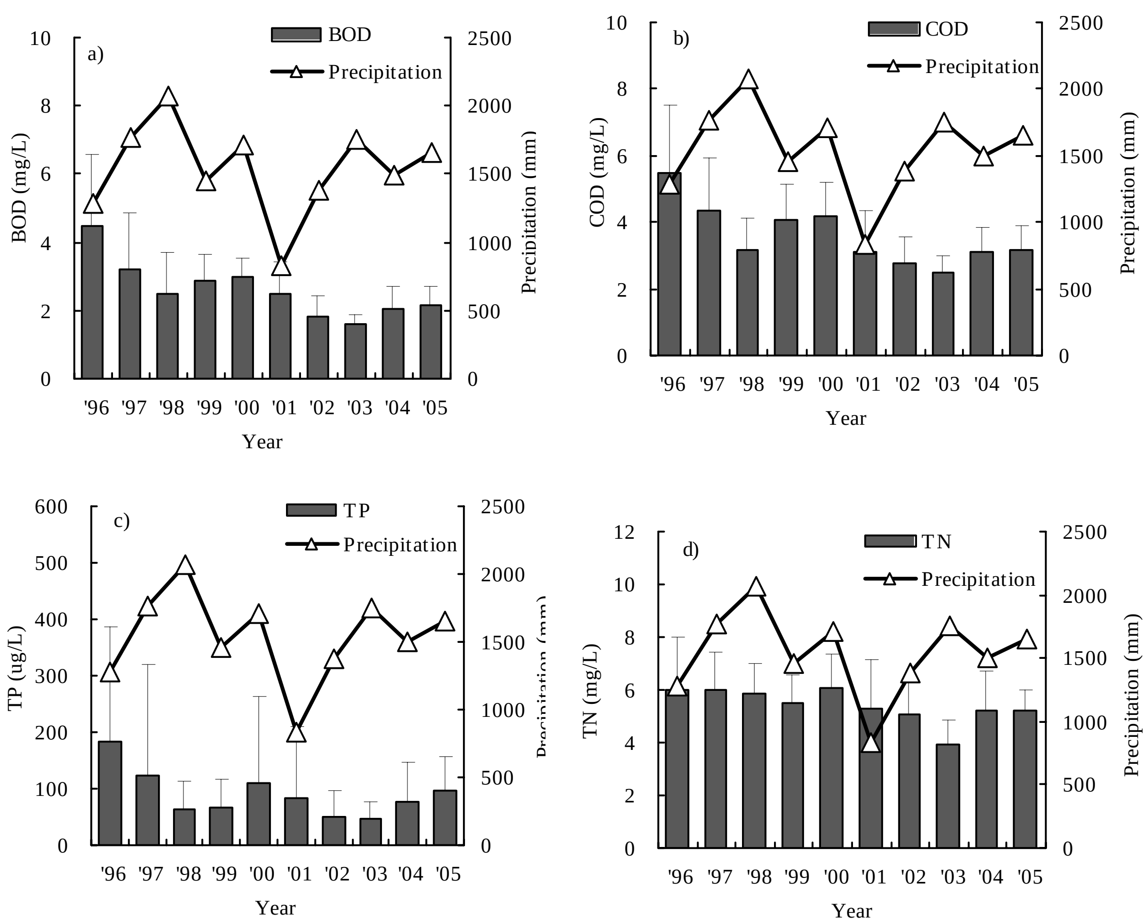

Fig. 2. Long-term changes of BOD, COD, TP, and TN during 1996 – 2005 in Daejeon stream, South Korea

declined from the headwater of the suburban to downstream near the most commercially developed areas. Mean QHEI was 121 in the headwater (S1), indicating a fair - good condition by the criteria of U.S. EPA (1993, Table 1). In contrast, QHEI in the site 3 averaged 52, indicating a poor condition and the value was a half of the headwater. Metric component analysis, based on Relative Habitat Quality (RHQ), showed that substrate/instream cover, embeddedness, channel flow status, and frequency of riffles or bend degraded rapidly from 67% (range: 58-76%) in the upstream to 25% (range: 18-31%) in the downstream (Fig. 4). Also RHQ in the flow velocity/depth, bottom scouring & sediment deposition, channel alteration, bank stability, and riparian zone width metrics declined from 56% (range: 32-70%) to 20% (range: 6-29%) along the headwater to downstream (Fig. 4). Based on the trophic guild analysis of the collected species, omnivores dominated at all sites by 65-93 %. It was far more dominant than insectivores and carnivores (Fig. 5). Furthermore, the relative abundance of omnivores at urbanized area (S2-S4) increased up to 98-100% as going downstream. US EPA (1993) and Barbour et al. (1999) found that as the nutrient pollution in the stream ecosystem increases, trophic guild of insectivores is eliminated and the omnivores dominated the community, resulting in an ecological trophic unbalance. Therefore, the predominance of omnivore in our stream indicates the biological degradation. Such compositional changes in the trophic guild matched well to tolerance guilds. The proportion of tolerant species in the downstream was increased by 95% and was closely associated ($r=0.983$, $p<0.05$, $n=10$) with fish abnormalities (Fig. 5).

Ecological stream health, based on the Index of Biological Integrity (IBI), varied depending on the locations sampled and seasons. Overall IBI values raged from 14 to 40 and averaged 24 ($n = 20$). Thus, the stream health was judged as fair or poor condition according to the criteria of Barbour et al. (1999). Mean IBI in the headwater stream was 32, indicating a good or fair condition (Fig. 6). In contrast, the health condition was judged as poor in the downstream (S4). Values of IBI (by site) reflected physical habitat and chemical conditions. Qualitative Habitat Evaluation

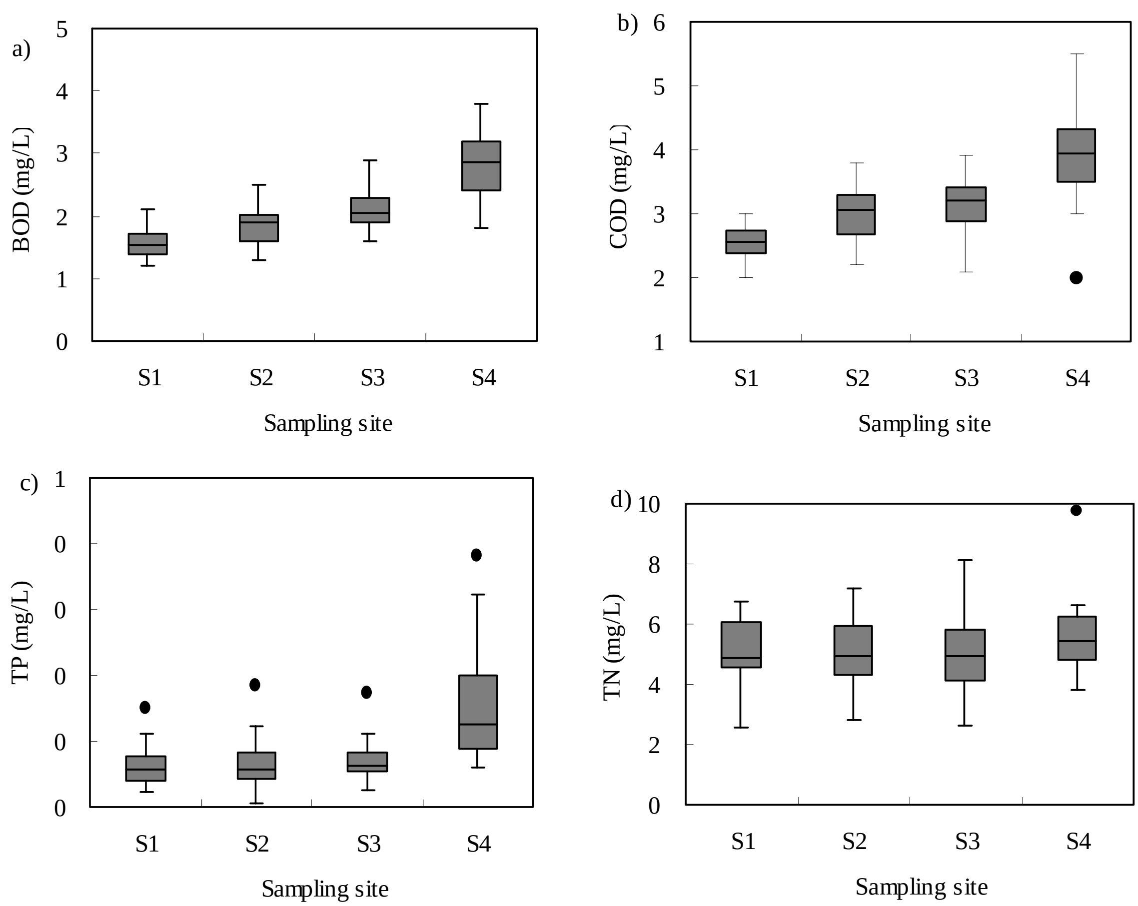

Fig. 3. Spatial variations of chemical conditions (BOD, COD, TP, and TN) in Daejeon stream, South Korea

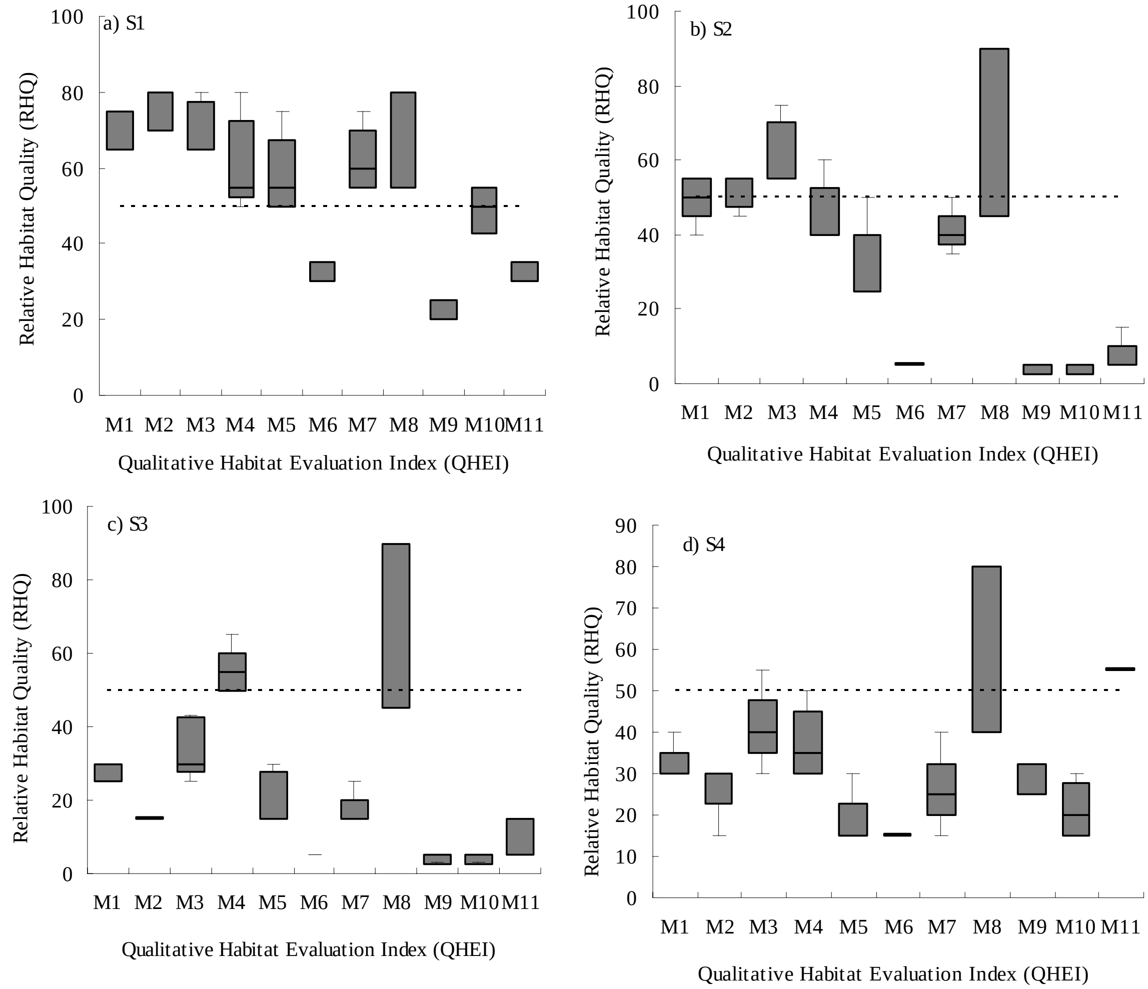

Fig. 4. Relative Habitat Quality (RHQ) of each parameter in the sampling sites. Values of RHQ were calculated as a proportion of each habitat index measured divided by maximum QHEI values

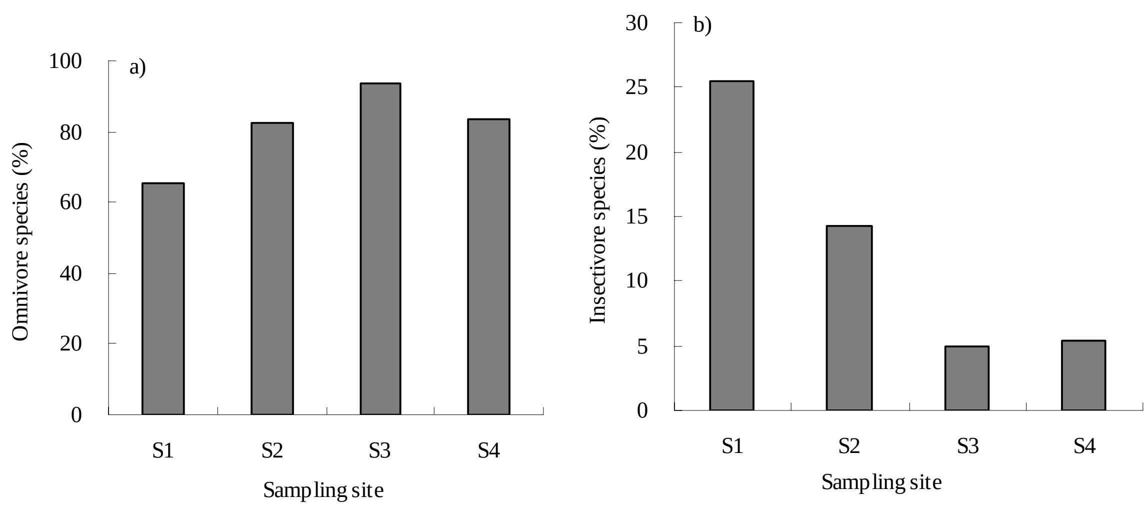

Fig. 5. Spatial variations of biological compositions in Daejeon stream, South Korea

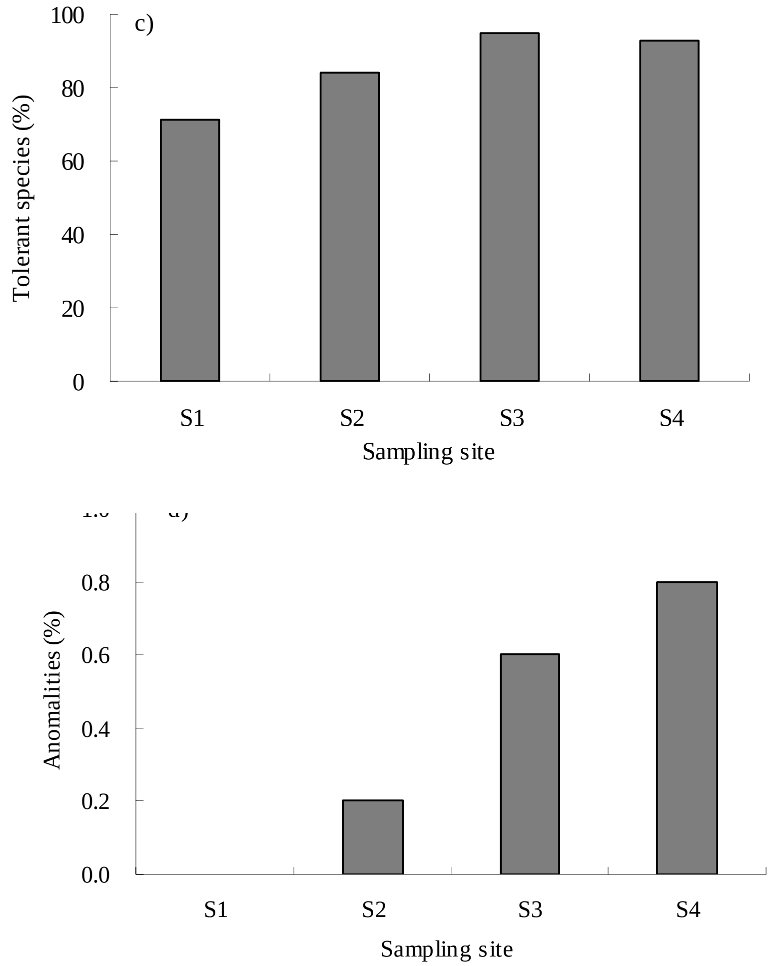

Fig. 5. Spatial variations of biological compositions in Daejeon stream, South Korea

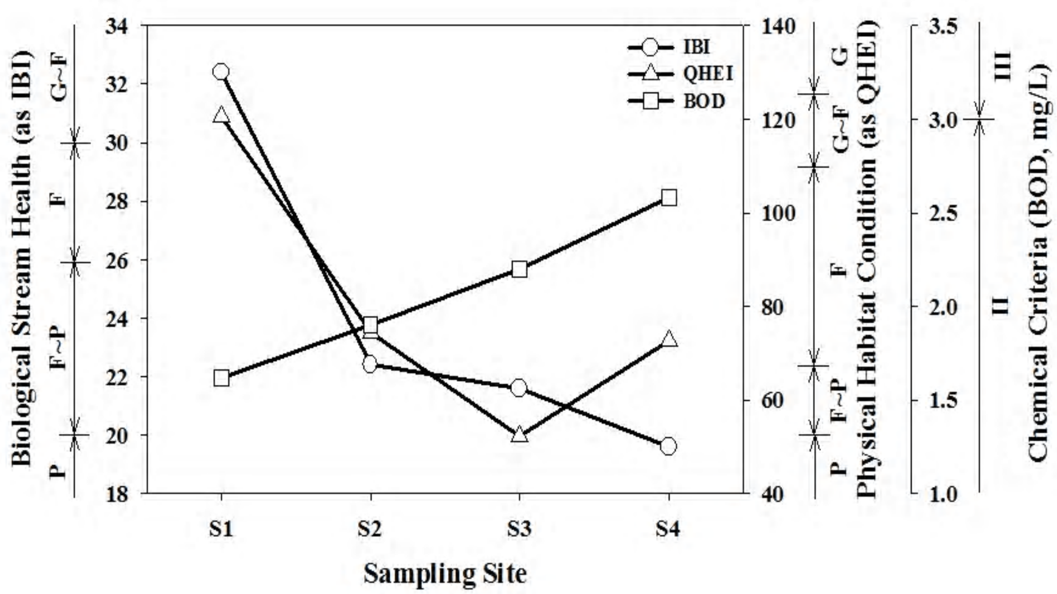

Fig. 6. Biological stream health using the Index of Biological Integrity (IBI), physical habitat health, based on Qualitative Habitat Evaluation Index (QHEI), and chemical conditions (BOD)

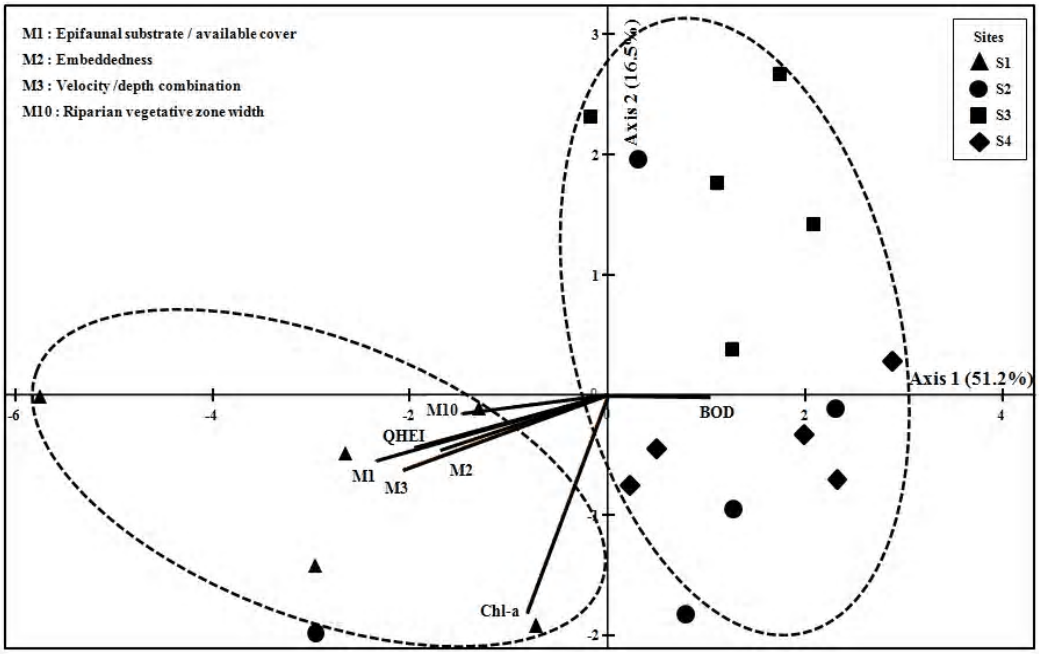

Fig. 7. Principal component analysis (PCA) of the Index of Biological Integrity (IBI) on the chemical and habitat metrics with sampling sites
The abbreviations in the figure are as follows; M1 = epifaunal substrate/available cover, M2 = embeddedness, M3 = velocity/depth combination, M10 = riparian vegetative zone width, Chl-a = Chlorophyll-a

Index (QHEI) showed an abrupt decreasing in the mid-stream, so the values was minimum 53 in the site 3 which was judged as poor condition in the habitat health. Thus, the positive functional relations between QHEI and IBI were evident. Also, IBI values decreased as BOD values increased, indicating that the downstream with low IBI was impacted by organic chemical pollution. Values of IBI were higher correlations (QHEI, $r=0.663$, $p<0.01$, $n=20$) with habitat conditions than the chemical conditions (BOD, $r=-0.576$, $p<0.01$, $n=20$). Thus, we believe that in this stream, physical habitat disturbance was more important than chemical conditions on account of the difference of the IBI between sites. Principal component analysis (PCA) in the sampling site supported the impact of chemical and habitat parameters on the stream health. Similarly, seasonal data of PCA showed a distinct segregation among the three seasons (Fig. 7).

Overall this study suggests that degradation of stream health was a combined effect of chemical pollution (i.e. wastewater treatment plant in the downstream) and habitat disturbance (concrete structure and channel modification). Consequently, it is urgent to reduce effluents of the point source in the watershed and restore the natural habitat by eliminating the artificial concreted structure in the stream for an efficient stream management.

CONCLUSIONS

Overall, our results were consistent with previous studies that urbanization has a negative association with biological integrity of streams (Steedman, 1988; May et al,. 1997; Karr and Chu 2000; Yoder *et al.*, 2000), and that spatial interactions with wastewater disposal plants of the urban are important determinants of variability in trophic compositions of stream biota. Our urban stream was degraded and this was supported by the poor condition of IBI, based on the criteria of Karr (1981). Such conditions were also supported by trophic unbalance of low proportion of insectivores and high proportion of omnivores in this urban stream. Chemical data suggested that nutrient enrichments were severe, especially in the downstream reach and the eutrophication probably resulted in greater fish anormalies and trophic modifications of fish communities. These outcomes suggest that the reduced IBI was not a result of impacts by single factor but is a combined effect of several factors. It is hard to identify the specific potential factor influencing the reduced IBI in this study because of simultaneous degradations of chemical and habitat quality. It is evident that the stream health was influenced by the combined impacts of chemical stressors and habitat degradations. Under these degrading conditions, efficient stream management is urgent for conservation of the ecosystem health. The present evaluation methodology of IBI may be served as a key tool for ecological restoration of wadable streams in the future.

ACKNOWLEDGEMENT

This work was supported by the CAER (Center for Aquatic Ecosystem Restoration) of Eco-STAR project, the Ministry of Environment, Korea (MEK).

REFERENCES

An, K. G., Kim, D. S., Kong, D. S. and Kim, S. D. (2004). Integrative assessments of a temperate stream based on a multimetric determination of biological integrity, physical habitat evaluations, and toxicity tests. Bull. Environ. Contam. Toxicol., **73**, 471-478.

An, K. G., Park, S. S. and Shin, J. Y. (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.

Barbour, M. T., Gerritsen, J., Snyder, B. D. and Stribling, J. B. (2nd Eds.) (1999). Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish. EPA841-B-99-002. US EPA Office of Water, Washington DC USA.

Boon, P. J. (2000). The development of integrated methods for assessing river conservation value. Hydrobiologia, **422**, 413-428.

Brown, L. R., Gregory, M. B. and May, J. T. (2009). Relation of urbanization to stream fish assemblages and species traits in nine metropolitan areas of the United States. Urban Ecosyst., **12**, 391-416.

Casatti, L., Langeani, F. and Ferreira, C. P. (2006). Effects of physical habitat degradation on the stream fish assemblage structure in a pasture region. Environ. Manage., **38**, 974-982.

Casey, J. L. and Rasmussen, T. J. (2006). Occurrence of organic wastewater compounds in effluent-dominated streams in Northeastern Kansas. Sci. Total Environ., **371**, 258-269.

Cunico, A. M., Ferreira, E. A., Agostinho, A. A., Beaumord, A. C. and Fernandes, R. (2012). The effects of local and regional environmental factors on the structure of fish assemblages in the Pirapo basin, Southern Brazil. Landscape and Urban Planning, **105**, 336-344.

Desiree, D. T, David, L. P. and Gregory, D. J. (2006). Development and application of a bioindicator for benthic habitat enhancement in the North Carolina Piedmont. Ecological Engineering, **27**, 228-241.

EPA, (1989). Biological criteria for the protection of aquatic life (Vol III); Standardized biological field sampling and laboratory method for assessing fish and macroinvertebrate communities. USA.

EU WFD (2000). Water Framework Directive, Directive of the European parliament and the council 2000/60/EC, a framework for community action in the field of water policy, Official J Europe Com., 22: 12.

Fore, L. S., Karr, J. R. and Conquest, L. L. (1993) Statistical properties of an index of biological integrity used to evaluate water resources. Can. J. Fish Aquat. Sci., **51**, 1077-1087.

Gore, J. A. (Ed) (1985). The Restoration of rivers and streams. (pp. 280) Butterworth: Stoneham.

Jones, E. B. D., Helfman, G. S. Harper, J. O. and Bolstad, P. V. (1999). Effects of riparian forest removal on fish assemblages in Southern Appalachian streams. Conserv. Biol., **13**, 1454-1465.

Karr, J. R. (1981). Assessment of biotic integrity using fish communities. Fisheries, **6**, 21-27.

Karr, J. R. (1991). Biological integrity: a long neglected aspect of water resource management. Ecol. Appl., **1**, 66-84.

Karr, J. R. and Chu, E. W. (2000) Sustaining living rivers. Hydrobiol., **422/423**, 1-14.

Leidy, R. A. and Fiedler, P. L. (1985). Human disturbance and patterns of fish species diversity in the San Francisco Bay Drainage. Biol. Conserv., **33**, 247-267.

May, C. R., Horner, J. Karr, B. Mar, B. W. and Welch, E. (1997) Effects of urbanization on small streams in the Puget Sound low land ecoregion. Water Protect Tech., **2**, 483-494.

Morley, S. A. and Karr, J. R. (2002). Assessing and restoring the health of urban streams in the Puget Sound basin. Conserv. Biol., **16**, 1498-1509.

Plafkin, J. L., Barbour, M. T., Porter, K. D., Gross, S. K. and Hughes, R. M. (1989). Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrate and fish. EPA/444/4-89-001. Office of water regulations and standards USEPA, Washington DC, USA.

Rapport, D. J. (1991). Myths in the foundations of economics and ecology. Bio. J. Linn. Soc. **44**, 185-202.

Richard, H.N. and Martin, C.T. (1999) What is river health?. Freshwater Biol., **41**, 197-209.

Steedman, R. J. (1988). Modification and assessment of an index of biotic integrity to quantify stream quality in southern Ontario. Can. J. Fish Aquat. Sci., **45**, 492-500.

Sullivan, N. (2000). The use of agitation dredging, water injection dredging and side casting: Result of a survey of ports in England and Wales. Terra. Aqua., **78**, 11 20.

Teng, Y., Tang, J., Zuo, R. and Wang, J. (2011). Impact of urbanization and industrialization upon surface water quality: a pilot study of Panzhihua mining town. J. Earth Science, **22**, 658-668.

Trautwein, C., Schinegger, R. and Schmutz, S. (2012). Cumulative effects of land use on fish metrics in different types of running waters in Austria. Aquat. Sci., **74**, 329-341.

USEPA, (1993). United States Environmental Protection

Agency, Fish field and laboratory methods for evaluating the biological integrity of surface waters. EPA 600-R-92-111. Environmental Monitoring systems laboratory - Cincinnati Office of Modeling, Monitoring systems, and quality assurance Office of Research Development, USEPA, Cincinnati, Ohio, USA.

Walton, B.M., Salling, M., Wyles, J. and Wolin, J. (2007) Biological integrity in urban streams: Toward resolving multiple dimensions of urbanization. Landscape Urban Plan, **79,** 110-123.

Yoder, C. O., Miltner, R. and White, D. (2000). Using biological criteria to assess and classify urban streams and develop improved landscape indicators. EPA/625/R-00/001. USEPA, Environmental Protection Agency, Cincinnati, Ohio.

Yuan, Y., Hall, K. and Oldman, C. (2001). A preliminary model for predicting heavy metal contaminant loading from an urban catchment. Sci. Total Environ., **226**, 299-307.