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Integrative Assessments of a Temperate Stream Based on a Multimetric Determination of Biological Integrity, Physical Habitat Evaluations, and Toxicity Tests

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US EPA (1992) defined "ecological risk" as a likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors. In aquatic ecosystems, the adverse ecological effects included all modifications of biotic and abiotic components by undesirable or artificial factors. During the past several decades, however, ecological effects were frequently evaluated by chemical measurements, one of the abiotic components, such as toxic chemicals, biochemical oxygen demand, and nutrients. This approach was considered as a surrogate for achieving the goal of ecological integrity in ecosystems (Yoder, 1991). Simple chemical monitoring, however, may not detect an integrative health condition of aquatic environments due to physical habitat degradations, hydrological variations, and inconsistent responses of regional biota on the chemicals. For this reason, the importance of physical habitat has been emphasized in the ecological risk assessments of streams because of its direct influences on the biological compositions and diversity (US EPA, 2000). Recently, Barbour et al. (1999) established a "Rapid Bioassessment Protocol" (RBP) for evaluations of aquatic ecosystem health, based on the original concept of the index of biological integrity (IBI; Karr, 1981) and physical habitat evaluation index (Plafkin et al., 1989). The RBP is recognized as a new approach to evaluate integrative ecological health in streams (Karr, 1981; Yoder, 1991) and is also known as a stressor - response analytical methodology for ecological risk assessments (Davis and Simon, 1995). In this study, we developed the IBI metric model, based on natural fish assemblages, and physical habitat index for application of regional streams, and then evaluated the integrative ecological health using the indices and toxicity tests of standard test species. Also, we identified the key component influencing the stream health impacts for the ecosystem management and restoration.

MATERIALS AND METHODS

This study was conducted at five stations within the temperate Keum River Watershed, Korea (36° 20' N, 127° 25'E) during May - October of 2001 - 2003. The sampling stations were chosen on the basis of point-source locations and land use patterns: Stations I and II are located in the upstream reach, which is mainly surrounded by forest (80%) and rural farms (> 20%), and Site III is located near

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Table 1. The ecological stream health model, based on the index of biological integrity. The metrics with asterick were modified from the original model of Karr (1981).

Category	Metrics	Scoring Criteria		
		5	3	1
Species composition	M_1: Total number of native fish species	>67%	33-67%	<33%
	M_2: Number of riffle benthic species*	>67%	33-67%	<33%
	M_3: Number of water column species*	>67%	33-67%	<33%
	M_4: Number of sensitive species	>67%	33-67%	<33%
	M_5: % individuals as tolerant species	<5%	5-20%	>20%
Trophic composition	M_6: % individuals as omnivore	<20%	20-45%	>45%
	M_7: % individuals as native insectivore*	>45%	20-45%	<20%
	M_8: % individuals as native carnivore*	>5%	1-5%	<1%
Fish abundance and condition	M_9: Total number of individuals	>67%	33-7%	<33%
	M_{10}: % individuals as exotic species*	0%	0-1%	>1%
	M_{11}: % individuals with disease, tumors, fin damage and other anomalies*	0%	0-1%	>1%

the city center (> 85%). Stations IV and V are located in the downstream reach that is directly influenced by industrial wastewater treatment plants (IWTP) and domestic disposal plants (DDP) with an average effluent discharge of 0.6 million tons per day. Fish samples were collected from the five sampling stations to develop the index of biological integrity (IBI). The sampling strategy followed the method of catch per unit of effort (US EPA, 1993). We also surveyed 34 reference stations within the watershed, 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 (1981) and 1st order regression analysis of Rankin and Yoder (1999).

Ecological river health was evaluated, based on the index of biological integrity (IBI) using natural fish assemblages (Barbour et al., 1999). As shown in Table 1, eleven-metric model was developed for the river health evaluations. Six metric attributes (M_2, M_3, M_7, M_8, M_{10}, M_{11}) were modified from the model suggested by Karr (1981), and one metric of long-lived fish species was removed from the model due to difficulties in the regional application. Ratings of 5, 3, and 1 were assigned to each metric according to whether its value approximates, deviates somewhat from, or deviates greatly from the value expected at the eleven metric ratings. The sum of those ratings (5, 3, 1) provided an IBI value at each station. Overall, ecological river health was expressed as five integrity classes of excellent (53 - 55), good (43 - 47), fair (35 - 39), poor (23 - 29), and very poor conditions (8

- 17). Also, physical habitat health was evaluated using the Qualitative Habitat Evaluation Index (QHEI) developed by Plafkin et al. (1989) and US EPA (1993). Six habitat parameters were chosen for the quantitative habitat assessments. The health conditions of the habitat were assessed by sum of scores obtained from the parameters and were categorized as 4 levels of "comparable to reference (> 90% ; score > 108)", "supporting (55-75%; 66-90)", "partially support (30-50%; 36-60)" and "non-support (< 25%, 0-30)".

General water quality evaluations and toxicity tests were conducted to examine whether chemical impacts on the river health are present. Five day biological oxygen demand (BOD_5) and chemical oxygen demand (COD_5) were measured as duplicate by standard methods (APHA, 1985). Total nitrogen (TN) and total phosphorus (TP) was measured as triplicate by second derivative method after a persulfate digestion and the ascorbic acid method after persulfate oxidation, respectively. Also, toxicity tests were conducted as triplicate for standard test species of fish (*Oryzias latipes*), daphnia (*Daphnia magna*), and lemna (*Lemna gibba*) using the waters sampled from five stations during premonsoon (June) and monsoon period (August). Toxicity test endpoints were as follows: Fish = motality at 96-h, Daphnia = immobility at 96-h, *Lemna* = growth at 168-h. Test species and conditions followed the test guidelines of US EPA (1991). Values of LC_{50} (lethal concentration) and EC_{50} (effective concentration) were determined for fish and daphnia, respectively, and the growth rate was measured as dry weight per day for lemna.

RESULTS AND DISCUSSION

Overall IBI values in the stream averaged 36 (range: 17 - 49), based on all sampling stations during the study. Thus, the ecological health was identified as a "fair condition". However, there were large variations in the IBI values among the five study stations. The IBI values at stations I, II, and III were 49 (good – excellent), 45 (good), and 41 (fair), respectively. In contrast, IBI values at stations IV and V were 25 and 26, indicating a "poor condition". Especially, the minimum IBI of < 20, judged as "very poor condition", occurred at Station IV during the premonsoon (dry season) when the water level was low.

BOD_5 and COD_5 averaged 5.1 mg L^{-1} (range: 1.2- 14.0 mg L^{-1}) and 5.2 mg L^{-1} (1.8 - 11.8 mg L^{-1}), respectively (Figure 1). Regression analysis of BOD_5 against the distance from the upstream showed that oxygen demand increased as a rate of 0.13 ($R^2 = 0.81$, $p < 0.05$) over the distance. Similar spatial pattern was found in COD_5. Thus, paired-sample *t*-test showed that the annual means in the downstream reach were significantly higher (p values < 0.05, t =4.36 for BOD_5, t=7.07 for COD_5), and seasonal variability by station, measured as the coefficient of variation (CV), was higher in the downstreams than the upstreams. Thus, during the monsoon floods, BOD_5 and COD_5 values in the downstreams declined by 2-3 fold. Maximum BOD_5 and COD_5 were observed in the station IV during premonsoon when water level was low. Total phosphorus (TP) and total nitrogen (TN) averaged 0.46 mg L^{-1} (range: 0.11- 1.12 mg L^{-1}) and 6.4 mg L^{-1} (1.2 – 18.0

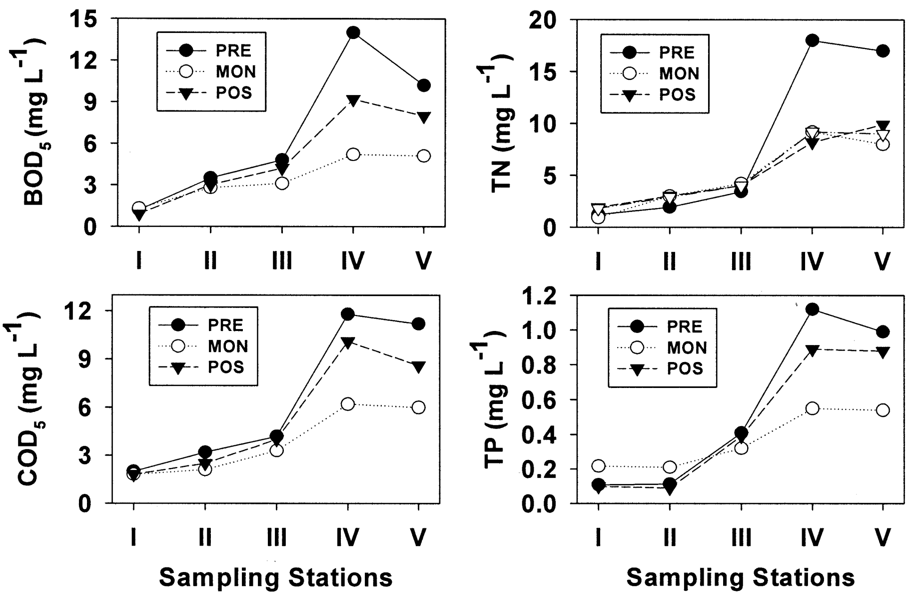

Figure 1. Chemical analyses in the five sampling stations during three seasons (PRE = premonsoon, MON = monsoon, POS = postmonsoon).

mg L^{-1}), respectively, indicating a hyper-eutrophic condition, based on conventional water quality measures. The longitudinal gradients and maximal values in TN and TP followed the patterns of BOD_5 and COD_5 at sites. During the monsoon period, TN and TP values in the downstreams declined more than 2 fold, compared to the premonsoon samples (Figure 1), indicating a nutrient dilution by monsoon flood water. Also, mean mass ratios of TN:TP in the downstream reach was 15, which was similar to a typical ratio (14) from sewage water (Kalff, 2002). Greater oxygen demands and nutrients in the downstream reach were evidently due to excessive nutrient inputs from the point sources of IWTE and DDP, implying that low IBI in the station IV may be partially associated with rapid eutrophication. Simultaneously, other hazard chemicals may be also responsible for the reduced IBI in the station IV. This fact is supported by previous GC-FID profiling dataset and Ames tests analyzed from Station I (upstream location) and Station IV (downstream location) of the same stream in 1999 (Kim et al., 2001). According to this study, the number of chemical peaks, based on acetonitrile fraction, was more than 3 fold greater in the downstream (mean = 38.7) than upstream (12.1) and the Ames tests using S9 mixture showed positive reactions in the downstream but not in the upstream. Also, Kim et al. (2001) found 1-5 fold greater toxicity in the upstream station based on Microtox toxicity tests using a methanol fraction, and two time greater PAHs (ethylacetate fraction) in the downstream (70. 61 ηg L^{-1}) than the upstream (36.89 ηg L^{-1}). These results indicate that other toxic chemicals associated with point and non-point source pollution also had an equal or greater effect on the low IBI than the variables.

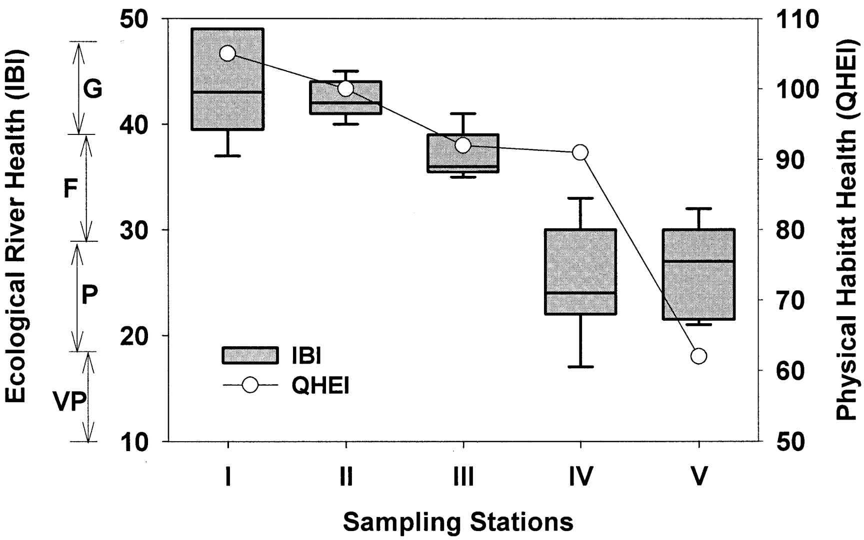

Figure 2. Ecological river health, based on the IBI, and the physical habitat health, based on the QHEI. In the figure, G (good), F (fine), P (poor), and VP (very poor) indicate the integrity class.

Physical habitat health, measured as Qualitative Habitat Evaluation Index (Plafkin et al. (1989) was judged as a supporting condition (90) according to the criteria (Barbour et al, 1999). Habitat health (as QHEI) was correlated with fish IBI values, particularly at Stations I, II, and III (Figure 2, Table 2). While the QHEI value at Station IV was comparable to those at Stations I through III, the IBI at this station was considerably lower. The lowest QHEI value was measured at Station V, and this station also had a lower IBI value. We believe that the impact of the ecological river health in the station IV was more associated with hazard chemical contaminations than habitat degradations. This supposition is demonstrated well through significant downstream impacts in terms of previous various ecotoxicity tests such as GC-FID profiling, Ames tests, Microtox toxicity, and PAHs analysis (Kim et al., 2001). Correlation analysis between conventional water quality parameters and IBI indicated that river health in the impacted station IV was also partially associated with eutrophication through nutrient enrichments from the point- and non-point sources. As shown in Table 2, fish IBI had strong negative correlation (r range: - 0.83 ~ -0.93, p < 0.01) with water quality parameters along with a positive correlation (r= 0.80, p < 0.05) with the QHEI. In the mean time, the low mean IBI (26, "poor condition") in the station V was observed when the habitat health, measured as the QHEI, was "partially supporting condition" (62; Figure 2), which is not suited for aquatic organisms", based on the criteria of US EPA (1993), and also chemical contents, measured as BOD5, COD5, and nutrients, were high (Figure 1). These results indicate that the low IBI in the station V is a combined impact of chemical and habitat disturbance

Table 2. Pearson's correlation coefficients (r) and probability values (p) for various parameters measured from the stream.

	Coeff.	IBI	QHEI	BOD	COD	TN	TP
IBI	r	1.00					
	p						
QHEI	r	.80*	1.00				
	p	.011					
BOD	r	-.87**	-.82**	1.00			
	p	.000	.004				
COD	r	-.89**	-.89**	.97**	1.00		
	p	.000	.001	.000			
TN	r	-.83**	-.78*	.93**	.94**	1.00	
	p	.001	.02	.000	.000		
TP	r	-.93**	-.92**	.96**	.98**	.93**	1.00
	p	.016	.000	.000	.000	.000	

*: Significant at the 0.05 level, **: Significant at the 0.01 level.

According to stressor identification guidelines of US EPA (2000), major candidate causes for the biological impairment in streams and rivers were identified as excess toxic chemicals, excess BOD, high total suspended solids, excess nutrients, sedimentation, excess algal growth, reduced DO, and habitat degradation. In the present study, however, our data is not sufficient to determine exactly which ones among above eight factors are key stressors in the system.

Significantly greater motality of *Daphnia magna* was observed in samples from Stations IV and V during the pre-monsoon season, and some fish (*Oryzias latipes*) motality was observed in samples from Station IV during this season (Table 3). No toxicity to either fish or daphnia was observed at any station during monsoon sampling. Reduced toxicity during the monsoon may have been due to dilution of chemical contamination during flooding, as shown in the decreases of nutrients,

Table 3. Toxicity tests of fish, daphnia, and lemna using the waters sampled from five sites (I – V). LC_{50} and EC_{50} values (mean ± standard error) were measured for fish and daphnia, respectively, while growth rate was determined for the lemna.

Toxicity test (Test species)	Fish (*Oryzias latipes*)		Daphnia (*Daphnia magna*)		Lemna (*Lemna gibba*)	
End Point	Mortality (%)		Immobilization (%)		Growth Rate (d^{-1})	
Test Hour	96 hr		48 hr		168 hr	
Sample Date	PRE	MON	PRE	MON	PRE	MON
Control	4±3.58	0	8±2.50	0	0.07±0.01	0.13±0.01
I	0	0	0	0	0.08±0.03	0.15±0.06
II	0	0	0	0	0.09±0.03	0.19±0.07
III	0	0	0	0	0.18±0.02*	0.21±0.08
IV	14±5.82*	0	29±4.79**	0	0.25±0.03**	0.18±0.08
V		0	20±4.08**	0	0.22±0.07*	0.22±0.07

PRE = premonsoon, MON = monsoon, *: $p < 0.05$, **: $p < 0.01$

BOD_5, and COD_5 (Figure 1). Such chemical dilution effect by the monsoon flooding is also supported by previous studies (Yeom et al., 2000). Growth rate of *Lemna gibba*, however, was significantly greater ($p < 0.05$) in the stations of III, IV, and V. We believe that higher growth in these stations was due to greater ambient nutrient concentrations supplied from the effluents of the IWTP and DDP.

Overall data suggest that the ecological river health in the stream is influenced by the combined impacts of chemical stressors and habitat degradations. Future studies should be designed to identify key stressors regulating the integrative ecosystem health using US EPA methods (2000; eg. more comprehensive chemical analysis, toxicity identification evaluations, detailed habitat assessment, fish pathology studies, etc.). Once the important stressors are identified, appropriate management actions may be implemented to improve habitat quality and reduce chemical contamination in this system, with the goal of reducing toxicity and improving fish community health.

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