Multiple Ecological Parameters Analysis in Streams and Rivers

SANG-JAE LEE[1], EUI-HAENG LEE[2], MD. MAMUN[1], KWANG - GUK AN[1]

[1]Department of Biological Science, College of Biological Sciences and Biotechnology, Chungnam National University, Daejeon 34134, South Korea

[2]Korea Rural Community Corporation, Naju 58327, South Korea

E-mail: wangmommyson@hanmail.net   http://sbb.cnu.ac.kr/bk21plus/eng/

Abstract: - We evaluated multiple ecological parameters of streams and rivers within a same watershed for a diagnosis of physical, chemical, and biological conditions. Water quality such as nutrients (N, P), BOD, suspended solids, and specific conductivity were analyzed to detect a chemical pollution. Physical habitat conditions were determined by Qualitative Habitat Evaluation Index (QHEI), and the biological conditions were determined by fish analysis, based on the multi-metric fish model of the Index of Biological Integrity (IBI) for evaluations of the biological stream health. In addition, we analyzed fish fauna and compositions in the streams and rivers along with the analysis of tolerance and trophic guilds. Ecological stream/rivers health were analyzed using the all dataset of physical habitat, chemical, and biological components. These approach may be provide a key data for an ecological restoration of impaired lotic ecosystems.

Keywords: - Multiple parameter analysis, stream habitat, water quality, biological integrity

1 Introduction

Recently, streams and rivers are rapidly degradated by physical habitat degradations of habitat as well as various sources of organic or inorganic pollutants. Also, urban developments and expending resulted in more constructions of wastewater treatment plants and also modified stream habitat structures such as channel shapes and substrate composition and flow regimes of stream ecosystems. As a result, ecological degradations in the streams and rivers have been frequently reported in regional aquatic ecosystems [1].

Most of these degradations were diagnosed on the basis of conventional chemical water pollution theory so far [2]. However, it could not reflect integrative effects from channelization, barriers, exotic species, and altered flow regimes, all complex factors happening in stream ecosystem. Most of chemical approaches could detect specific types of degradation, only associated with chemical sources like as eutrophication and toxicant effects, but did not reflect the habitat alterations of stream environments [3]. For these reasons, integrated approaches using biological, chemical, and physical parameters were required for efficient stream health monitoring and management [4].

Recently in Korea, stream health assessment methodology using biota such as periphyton, macroinvertebrate and fish was developed to evaluate the aquatic ecosystem by the government in 2006. This monitoring methodology has a key role to diagnose stream health degradations [5]. It also provides standards how to manage and restore the stream health impacted in the major watersheds in Korea. For some successful managements to keep watersheds clean, researches should be conducted through comparative analysis between past and present health conditions of aquatic environments and also predict the future.

In this study, we applied various approaches of multi-metric assessment model, based on Index of Biological Integrity (IBI), physical habitat health, based on Qualitative Habitat Evaluation Index (QHEI), and chemical water quality analysis to evaluate the integrative stream ecosystem health in Geum River Watershed, Korea

2 Materials and Methods

2.1 Sampling sites and Sampling Methods

This study was conducted in Geum-River watershed, which is located in the temperate region of South Korea. Fish sampling were conducted at multiple sites in the watershed including mainstream and tributaries, according to the modified wading method to adapt the Korean aquatic ecosystem. We also sampled 39 reference streams and determined the stream order after the methodology of Strahler [6] using a map scale of 1:120,000.

2.2 Chemical Analysis

Chemical dataset were obtained from the National Water Quality Monitoring Program (NWQMP), the Ministry of Environment, Korea (MEK). The parameters used in the study were biological oxygen demand (BOD), total suspended solids (TSS), electric conductivity (EC), and total phosphorus (TP).

2.3. Physical Habitat Analysis

The habitat health was evaluated by Qualitative Habitat Evaluation Index (QHEI) which was developed by Plafkin *et al*. [7]. We selected eleven habitat parameters, based on the previous references widely used. For the habitat assessments, we included primary, secondary, and tertiary components to the habitat model and the metrics are substrate structure and vegetation coverage, channel characteristics, bank characteristics and bank structure. All metric characteristics were described in the previous research by An *et al.* [8]. The health conditions of the habitat were judged by the summation of scores obtained from the eleven parameters and were ranked as excellent (A, 182 − 220), good (B, 124 − 168), fair (C, 66 − 110), and poor (D, 8 − 52) conditions.

Total mercury concentrations in various fish tissues such as liver, kidney, gill, vertebra, and muscle were analyzed by direct mercury analyzer (DMA-80, US EPA Method 7473), and the target fish was *Zacco platipus*.
The method 7473 of US EPA was known as a spectroscopic analytical method which has no pre-treatments of samples and directly ignite at high temperatures. Samples of fish tissues were analyzed by the DMA-80, based on thermal decomposition, catalytic reduction, and amalgamation desorption. The fish tissues were initially dried in the oxygen stream passing through a quartz tube located inside a controlled heating coil under the condition of oxygen supplies as a carrier gas to each cylinder. The mercury content was determined using a single beam spectrophotometer with two sequential, flow-through measurement cells under the condition of 254 nm.

2.4. Biological Integrity Model

In this study, we adapted eight metric model, which is the Index of Biological Integrity (IBI) instead of 12 metrics, originally suggested by Karr[4]. We modified the model for the regional application of Geum River Watershed. The metrics (M) were composed of three major groups such as ecological characteristic and species composition, trophic composition, and fish abundance and health condition. Metric scores of 1, 3, or 5 were assigned to each of the raw metric values after the approach of US EPA. Each metric and criteria characteristics were described in the previous research by An et al. (2006) [8]. These scores were then summed to obtain a site-specific model value that ranged from 8 to 40, and categorized with four ranks (Excellent, A, 36 − 40; Good, B, 26 − 35; Fair, C, 16 − 25; Poor, D, 8 − 15) to be used.

3 Results and Discussion

3.1. Stream Water Quality

Data analysis of chemical water quality showed that (Fig. 1), BOD as a measure of usually organic pollution averaged 2.1 ㎎ L^{-1} and ranged between 0.1 and 12.9 ㎎ L^{-1} (n = 1188), indicating relatively good condition by the criteria of MEK showed a large variation along the longitudinal gradients of upstream to downstream. BOD in the upstream area was below 1 ㎎ L^{-1} but BOD in some sites (G15) was＞ 6.0 ㎎ L^{-1} due to the industrial complex and waste water treatment plant. Also the stream of G21 was greatly degraded, just after by the confluence of Mi-ho Stream and Gap Stream in the aspect of Geum River. Then, it was averaged about 3 ㎎ L^{-1} except a few sites. Thus, organic pollution was getting worse in gradient from up to downstream reach.

Total phosphorus (TP), as an indicator of trophic state, averaged 0.149 ㎎ L^{-1} and ranged between 0.000 and 3.216 ㎎ L^{-1} depending on the presence of the point- and nonpoint sources. TP also was low in upstream reach as shown in the BOD (TP < 0.5 ㎎ L^{-1}).

3.2. Physical Habitat Health

In the mainstream of Geum River, overall, it tends to be degrading slowly for habitat condition along the gradient from up to downstream. QHEI value in mainstream was averaged 155 (n = 12), showing higher than QHEI average of entire survey. It was scored mean 174 (n = 6) with excellent - good condition indicating that physical habitat maintained well until G16. However, it was averaged 120 (n = 6) with good - fair condition indicated minor habitat disturbance from G21 to G32. Particularly, downstream (G32) was proceeded severe habitat simplification derived from sedimentation of silt and organic matters and was constructed to be park along waterside area reflecting artificial disturbances by human activities (Table 1).

In tributaries of Geum River, QHEI value was averaged 138 (n = 21), caused by habitat deterioration from several sites. G03 (QHEI: 110) was maintained well in habitat condition but affected by disturbances from human activity such as weir and some recreational parks, located in the stream. In Gap Stream (G13 – G15), typical urban stream, it was proceeded organic sedimentation and disturbances occurred by residential effluents and recreational park in G14 (QHEI: 101). In G17 (101) and G18 (96), it was simplified by sand for stream substrate and was affected by flow reduction related to seasonal factors.

3.3. Total Mercury Concentrations in *Zacco platypus*

Tissue analysis (liver, gill, kidney, vertebra, muscle) of *Zacco platypus*, sampled from 33 streams showed that the mercury levels were different with the regional characteristics in the watershed. When [Hg] levels in each tissue were converted to the relative proportion to compare differences among 5 tissues (Fig. 2).

According to the tissue sample analysis, the mean level of [Hg] was the highest in the muscle (34.9%) and the lowest in the gill (7.1%).

In our study, there was no high correlation ([Hg] vs IBI, r = 0.371, p = 0.034) between total [Hg] and IBI values. However, high levels of [Hg] were observed where IBI values were high Therefore, [Hg] concentrations in fish tissue was not directly related with IBI value for ecological health assessments, QHEI values for habitat evaluations and chemical water quality. In fact, [Hg] levels in our study did not affect fish individual itself when we compared the level with [Hg] standard of US EPA guideline. Hence, this [Hg] parameter could not respond with evaluation method under the fish community level and standard water quality assessment.

3.4. Biological Health Using Fish Model

Multi-metric fish model values of the Index of Biological Integrity (IBI) averaged 24.4 (range: 12 - 34, n = 33) and categorized as a “fair condition” in the biological health (Table 2). In this study, pristine streams were rare and meso-eutrophic conditions were general. However, two streams of Gap stream and Miho stream, passing through the urban area, were more degradated, compared to the streams of upper regions (Fig. 3). Thus, stream channelization and nutrient enrichments directly influenced the stream degradations in the urban area. Thirteen streams, located in the lowland area were categorized as a fair - poor condition except a few streams. Though there were some regional differences, consequently, the habitats and water quality in the upper streams and rivers were maintained well and the degration sites were rare. In contrast, the mid- to down-streams and rivers, influenced by rurban area and industrial complex had large dedegradations [9]. We found that fish compositions and fauna were influenced by human activities and habitat simplification with sand sedimentation in the watershed. Overall, our study suggests that the stream/river degradation is a combined effect of physical habitat modifications (disturbance) and chemical pollutions.

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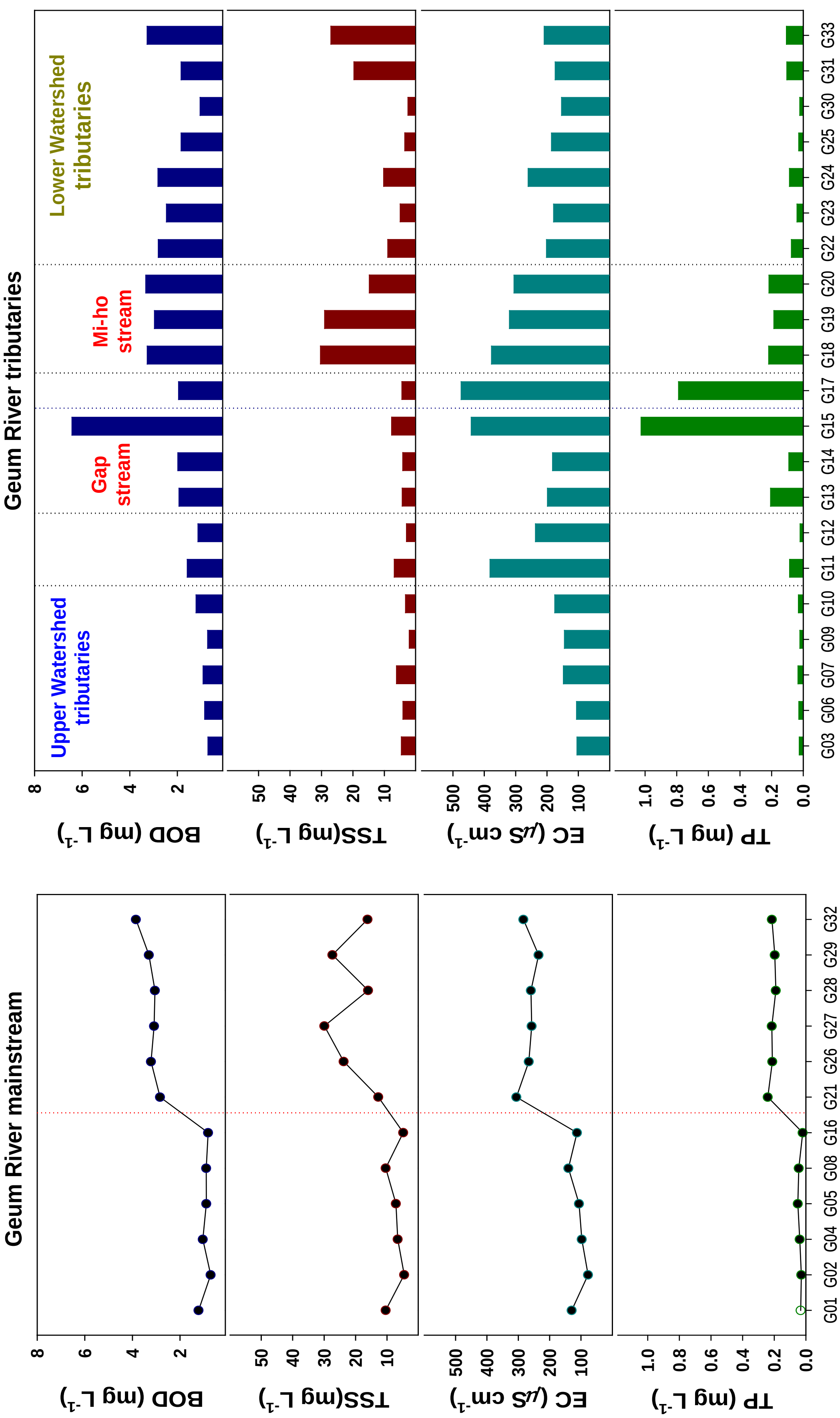

Fig. 1 Chemical analysis of water quality along with entire sites in Geum River Watershed

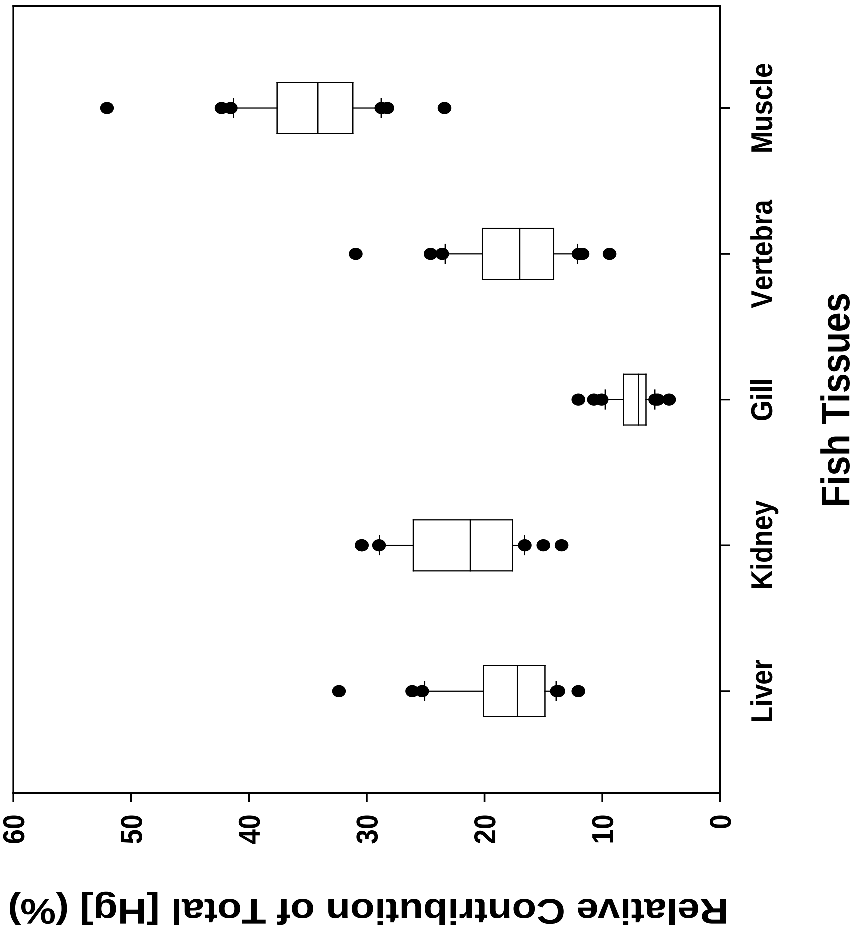

Fig. 2 Relative contribution of total [Hg] in sentinel species (*Zacco platypus*) among each tissue

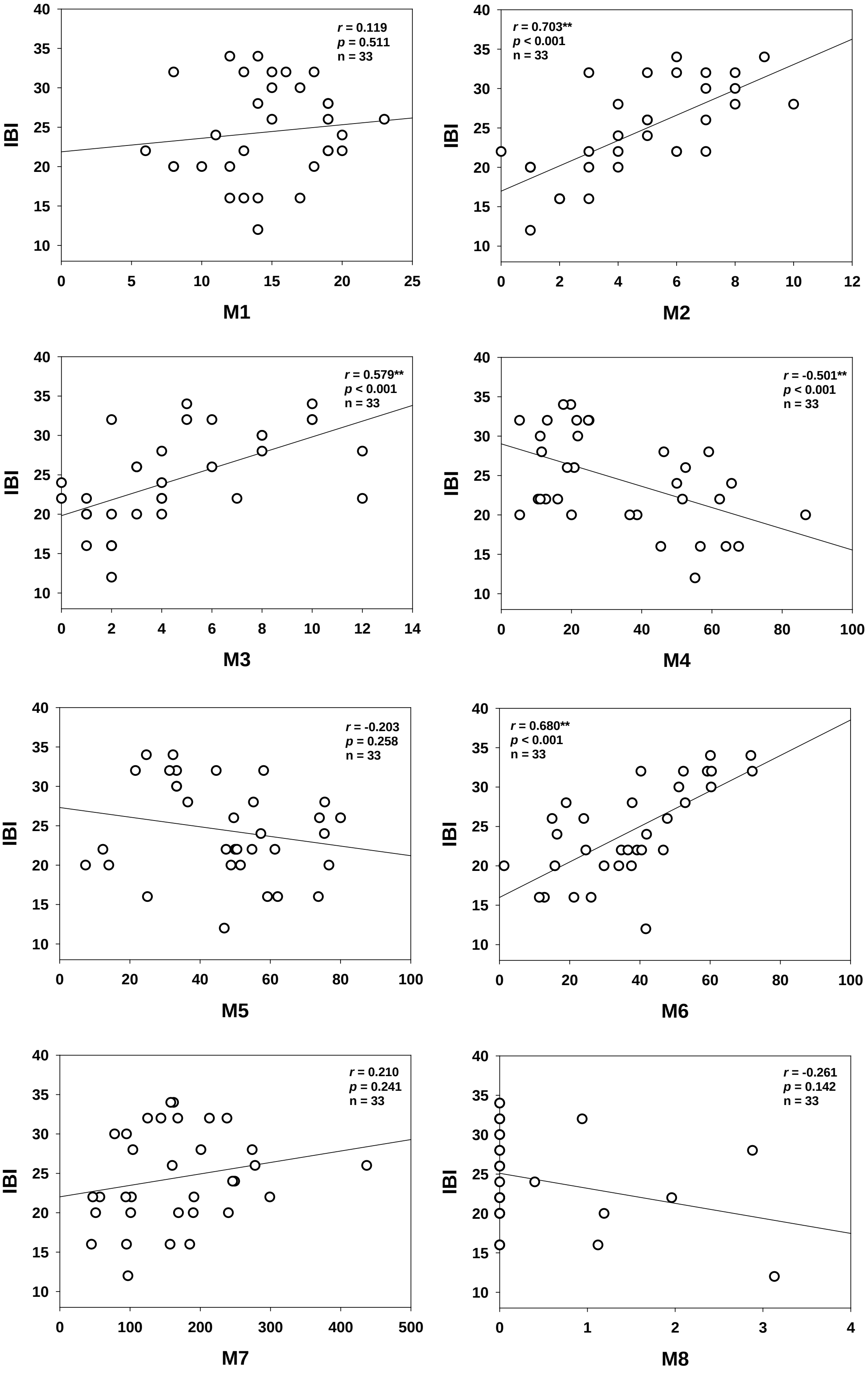

Fig. 3 Relations of the IBI to each model metric

Table 1. Qualitative Habitat Evaluation Index (QHEI) based on 11-metrics in Geum River Watershed

	Habitat Parameters	Sampling Locations																
		G01	G02	G03	G04	G05	G06	G07	G08	G09	G10	G11	G12	G13	G14	G15	G16	G17
H1	Epifaunal Substrate / Available cover	18	20	15	20	18	18	20	16	18	16	18	20	16	10	11	15	8
H2	Embeddedness	16	18	16	18	13	16	20	18	16	18	16	18	13	11	11	15	8
H3	Velocity /Depth Combination	16	20	16	16	13	18	20	15	20	18	18	10	15	11	13	15	8
H6	Sediment deposition	18	15	16	16	18	13	13	15	10	13	13	5	10	18	18	16	16
H4	Channel flow status	13	13	15	15	18	11	10	13	8	11	15	8	8	18	15	18	10
H5	Channel alteration	18	18	6	13	15	15	15	15	18	20	13	13	15	5	6	18	8
H7	Frequency of riffles or bends	15	15	8	10	6	8	15	8	13	13	13	18	13	5	8	6	8
H8	Bank stability	20	20	4	10	18	18	14	17	19	16	15	8	10	4	12	15	7
H9	Bank vegetative protection	20	20	4	19	20	20	14	18	20	17	18	14	16	6	8	18	20
H10	Riparian vegetative zone width	16	20	4	16	13	14	15	16	16	15	12	10	6	5	2	16	2
H11	Existence of small-scale dams	15	11	6	15	13	8	15	15	15	15	8	6	5	8	8	20	6
	Model Score (Criteria)	185 (A)	190 (A)	110 (C)	168 (B)	165 (B)	159 (B)	171 (A-B)	166 (B)	173 (A-B)	172 (A-B)	159 (B)	130 (B)	127 (B)	101 (C)	112 (B-C)	172 (A-B)	101 (C)

	Habitat Parameters	Sampling Locations															
		G18	G19	G20	G21	G22	G23	G24	G25	G26	G27	G28	G29	G30	G31	G32	G33
H1	Epifaunal Substrate / Available cover	5	11	10	13	16	8	6	18	8	5	10	5	16	20	6	5
H2	Embeddedness	3	15	13	15	13	6	11	13	11	11	11	6	16	20	6	3
H3	Velocity / Depth Combination	8	16	16	15	15	13	18	18	15	15	15	15	20	18	15	8
H6	Sediment deposition	6	15	13	16	15	13	11	13	18	13	18	18	13	16	16	16
H4	Channel flow status	8	13	13	15	13	10	10	10	15	8	18	18	10	15	15	15
H5	Channel alteration	13	15	13	10	16	15	13	15	13	18	16	15	8	13	8	18
H6	Frequency of riffles or bends	11	8	6	6	8	16	10	13	6	6	6	6	6	6	6	5
H8	Bank stability	8	16	6	10	18	16	12	14	10	18	11	14	10	18	10	18
H9	Bank vegetative protection	15	16	10	13	20	18	16	18	15	18	10	18	10	20	6	20
H10	Riparian vegetative zone width	13	14	16	14	13	16	10	16	15	12	8	11	2	10	6	10
H11	Existence of small-scale dams	6	13	11	15	6	11	20	15	20	15	13	20	6	13	11	13
	Model Score (Criteria)	96 (C)	152 (B)	127 (B)	142 (B)	153 (B)	142 (B)	137 (B)	163 (B)	146 (B)	139 (B)	136 (B)	146 (B)	117 (B-C)	169 (A-B)	105 (C)	131 (B)

A = Excellent, B = Good, C = Fair

Table 2. The Index of Biological Integrity (IBI), based on 8 metric models after Karr (1981) at thirty-three sampling sites in Geum River Watershed

Code	Sampling locations	Stream order	Ecological Characteristics: Species Composition				Trophic Composition		Fish Abundance and Health Condition		IBI score
			TNS (M1)	RB (M2)	SS (M3)	TS (M4)	O (M5)	I (M6)	TNI (M7)	AN (M8)	
G01	Geum River 01	4th	14 (5)	8 (5)	8 (5)	46.3 (1)	55.2 (1)	37.8 (3)	201 (3)	0.0 (5)	28
G02	Geum River 02	4th	15 (5)	7 (5)	10 (5)	5.2 (3)	33.3 (3)	59.2 (5)	213 (3)	0.9 (3)	32
G03	Muju-namdae Stream	4th	13 (5)	8 (5)	10 (5)	25.0 (1)	44.6 (3)	52.4 (5)	168 (3)	0.0 (5)	32
G04	Geum River 03	5th	16 (5)	7 (5)	8 (3)	11.1 (3)	33.3 (3)	51.1 (5)	90 (1)	0.0 (5)	30
G05	Geum River 04	5th	13 (3)	4 (3)	7 (3)	10.5 (3)	47.4 (1)	24.6 (3)	57 (1)	0.0 (5)	22
G06	Cho River 01	4th	14 (5)	9 (5)	10 (5)	19.8 (3)	24.7 (3)	71.6 (5)	162 (3)	0.0 (5)	34
G07	Cho River 02	5th	19 (5)	10 (5)	12 (5)	11.5 (3)	36.5 (3)	52.9 (5)	104 (1)	2.8 (1)	28
G08	Geum River 05	6th	19 (5)	7 (3)	12 (5)	12.7 (3)	50.0 (1)	39.2 (3)	102 (1)	2.0 (1)	22
G09	Bo-cheong Stream 01	3rd	12 (5)	6 (5)	5 (5)	17.7 (3)	32.3 (3)	60.1 (5)	158 (3)	0.0 (5)	34
G10	Bo-cheong Stream 02	4th	15 (5)	8 (5)	8 (5)	21.8 (1)	33.3 (3)	60.3 (5)	78 (1)	0.0 (5)	30
G11	So-oak Stream	3rd	17 (5)	6 (5)	6 (5)	13.1 (3)	58.1 (1)	40.3 (3)	236 (5)	0.0 (5)	32
G12	Hoe-in Stream	2nd	8 (5)	3 (5)	2 (3)	24.8 (1)	21.6 (3)	72.0 (5)	125 (5)	0.0 (5)	32
G13	Gap Stream 01	3rd	16 (5)	5 (5)	5 (5)	21.5 (1)	31.3 (3)	60.4 (5)	144 (3)	0.0 (5)	32
G14	Gap Stream 02	4th	13 (5)	2 (1)	2 (1)	64.0 (1)	65.1 (1)	12.8 (1)	86 (1)	0.0 (5)	16
G15	Gap Stream 03	5th	16 (5)	3 (1)	2 (1)	67.6 (1)	73.7 (1)	21.2 (3)	179 (3)	1.1 (1)	16
G16	Geum River 06	6th	13 (3)	2 (1)	2 (1)	56.7 (1)	59.2 (1)	26.1 (3)	157 (1)	0.0 (5)	16
G17	Woe-chun Stream	2nd	8 (5)	1 (1)	1 (1)	86.7 (1)	76.7 (1)	1.3 (1)	240 (5)	0.0 (5)	20
G18	Mi-ho Stream 01	3rd	10 (5)	4 (5)	0 (1)	50.0 (1)	57.3 (1)	41.9 (3)	248 (5)	0.4 (3)	24
G19	Mi-ho Stream 02	4th	18 (5)	5 (3)	4 (3)	65.6 (1)	75.4 (1)	16.4 (1)	244 (5)	0.0 (5)	24
G20	Mi-ho Stream 03	5th	18 (5)	6 (3)	4 (1)	51.6 (1)	50.5 (1)	34.7 (3)	190 (3)	0.0 (5)	22
G21	Geum River 07	6th	20 (5)	6 (3)	4 (1)	62.2 (1)	54.8 (1)	40.5 (3)	299 (3)	0.0 (5)	22
G22	Yong-soo Stream	3rd	19 (5)	7 (5)	6 (5)	52.5 (1)	80.0 (1)	15.0 (1)	160 (3)	0.0 (5)	26
G23	Dae-gyo Stream	2nd	19 (5)	4 (5)	4 (5)	59.1 (1)	75.5 (1)	19.0 (1)	274 (5)	0.0 (5)	28
G24	Jeong-an Stream	4th	17 (5)	3 (3)	4 (3)	38.7 (1)	48.8 (1)	29.8 (3)	168 (3)	1.2 (1)	20
G25	Yoo-gu Stream	4th	12 (5)	4 (3)	3 (1)	36.6 (1)	51.5 (1)	37.6 (3)	101 (1)	0.0 (5)	20
G26	Geum River 08	6th	13 (3)	1 (1)	2 (1)	55.2 (1)	46.9 (1)	41.7 (3)	96 (1)	3.1 (1)	12
G27	Geum River 09	6th	8 (1)	1 (1)	1 (1)	20.0 (3)	14.0 (5)	34.0 (3)	50 (1)	0.0 (5)	20
G28	Geum River 10	6th	10 (3)	1 (1)	2 (1)	5.3 (3)	7.4 (5)	15.8 (1)	190 (1)	0.0 (5)	20
G29	Geum River 11	6th	11 (3)	2 (1)	1 (1)	45.5 (1)	25.0 (3)	11.4 (1)	44 (1)	0.0 (5)	16
G30	Non-san Stream 01	4th	15 (5)	5 (3)	3 (1)	20.5 (1)	49.6 (1)	47.8 (5)	278 (5)	0.0 (5)	26
G31	Non-san Stream 02	4th	21 (5)	5 (3)	3 (1)	18.8 (3)	74.0 (1)	24.0 (3)	430 (5)	0.0 (5)	26
G32	Geum River 12	6th	6 (1)	0 (1)	0 (1)	13.3 (3)	13.3 (5)	46.7 (5)	45 (1)	0.0 (5)	22
G33	Gil-san Stream	3rd	18 (5)	3 (3)	1 (1)	16.1 (3)	61.3 (1)	36.6 (3)	93 (1)	0.0 (5)	22