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RESEARCH PAPER

Ecological Health Assessments of 72 Streams and Rivers in Relation to Water Chemistry and Land-Use Patterns in South Korea

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Abstract

This research was conducted as an ambitious eco-project of "National Ecological Health Assessments in South Korea" to diagnose the ecological health of 72 streams and rivers in Geum river watershed by an Index of Biological Integrity Model (IBI_{KW}) based on fish assemblages. The objectives of this study were to know the systematic impacts on the health of the biological systems, identification of impairment and take a snap-shot of the biological community structure. The IBI_{KW} model consists of eight fish assemblages attributes, termed as metrics, that are related to environmental quality, ecosystem integrity and biodiversity of the Geum river watershed streams and rivers: number of native species, number of riffle benthic species, number of sensitive species, proportion of tolerant species, proportion of omnivore species, proportion of native insectivore species, total number of native individuals and proportion of anomalies. Physico-chemical water quality parameters and fish species compositions were greatly influenced by land-use patterns. According to the IBI_{KW}, one stream was classified as ecologically good, nine streams as fair, 61 streams as poor, and one as very poor. Analysis of trophic and tolerance guilds revealed that tolerant species were dominant in polluted regions, whereas sensitive species preferred less polluted areas. Nutrients and organic matter were responsible for the production of algae in the waterbodies, and total phosphorus (TP) was the major key factor. Overall, the ecosystem health assessment by IBI_{KW} gives a clear insight into the biological condition of Korean watersheds and could play a significant role in regular bioassessments, postrestoration assessments, successful management and conservation.

Keywords: Ecosystem health, trophic and tolerance guilds, IBI index, land-use pattern, water quality parameters.

Introduction

The crop production and drinking water quality depend on freshwater ecosystem health which indirectly affects the survivability of human society (Cairns & Niederlehner, 1995). The degradation of the freshwater aquatic ecosystems and assessments of the health are the major key issues for ecologist, limnologist, and other scientists and its mechanism are complex and not easy to measure their combined effects on the systems (Simon & Lyons, 1995). Stream fish can be used as an important tool to assess the effects of multiple stressors to the aquatic environments and health of lotic ecosystems (Karr, 1981; EPA, 2002). Fish community structure are closely related to land-use patterns (Karr, Fausch, Angermerier, Yant, & Schlosser, 1986), physical habitat quality (Fausch, Karr, & Yant, 1984), chemical water quality (Fausch *et al*., 1984; Karr *et al*., 1986), and biological interactions (Steedman, 1988; Allan, Erickson, & Fay, 1997).

Evaluations of ecological health have used the fish multimetric model of Index of Biological Integrity as a reliable source of information. The multimetric fish model has been widely used to evaluate the ecological status of bodies of water. It is constructed based on biological indicators and physical habitat conditions. To evaluate stream health, Karr (1981) constructed a model known as an IBI model. The model combines 12 fish assemblage attributes or metrics that are classified into three groups: species richness and composition, trophic composition, and fish abundance and health. The IBI model accumulates information from the individual, population, assemblage, and ecosystem levels into a single numerical indicator and gives a quality rating for aquatic ecosystems (Karr *et al*., 1986). The major advantage of the IBI model is that it is very cost effective and relies on quantitative and multimetric approaches rather than a single-parameter approach (Karr & Dionne, 1991; Barbour, Gerritsen, Snyder, & Stribling, 1999). Thus, the IBI has emerged as a key tool for the restoration (Karr, 1991), mitigation

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(Yoder & Rankin, 1998), and conservation (Barbour *et al*., 2000) of degraded aquatic ecosystems.

Approximately 70% of the land in Korea is mountainous. Agricultural and urban-dominated streams are becoming polluted because of intensified urbanization and agricultural practices that greatly influence the water chemistry and fish compositions of the water. Thus, the IBI model was modified regionally by An *et al*. (2006) to give it the flexibility to assess national stream health conditions compared to areas such as North America (Karr & Dionne, 1991; EPA, 1993), Europe (Hughes & Oberdorff, 1999), South America (Lyons, Navarro-Perez, Cochran, Santana, & Guzman-Arroyo, 1995), and Africa (Hugueny, Camara, Samoura, & Magassouba, 1996). To successfully assess the health of Korean watersheds, the IBI model has been developed and categorized into eight metrics (An *et al*., 2006) and 10 metrics (Wang *et al*., 2008; An *et al*., 2010).

This paper gives a clear idea about the ecological health of rivers and streams in the Korean Geum River watershed based on the IBI_{KW} model and outlines the relationship among trophic composition, tolerance guilds, and land-use patterns and evaluates the effects of nutrients and organic matter on fish assemblages in the watershed.

Materials and Methods

Study Sites

This study was conducted in the Geum River watershed which is located between 35° 34′ 47″ to 37° 03′ 03″ latitude and 126° 40′ 25″ to 128° 03′ 53″ longitude (Geum River Basin Environmental Office, 2007). The total area of the Geum river watershed is 17,537 km^2 (Ministry of Land, Transport, & Maritime Affairs, 2009). Fish and water quality data were collected from 72 sampling sites in 2012 (Figure 1), which were divided into agricultural, urban, and forestry-dominated regions.

Analysis of Water Quality Parameters

Important Physico-chemical water quality parameters were determined as follows- electrical conductivity was determined using a portable multiparameter analyzer (YSI Sonde Model 6600), total nitrogen (TN), biological oxygen demand (BOD), and chemical oxygen demand (COD) were measured using the chemical testing method standardized by the Ministry of the Environment (MOE, 2006), total phosphorus (TP) was determined using the ascorbic acid method after the chemical testing method standardized by the Ministry of the Environment (Korea), total suspended solids (TSS) were filtered from the water through preweighted Whatman GF/C filters and then weighed after drying at 103°C for 1 h (MOE, 2006), and the chlorophyll-*a* (CHL) concentration was measured using a spectrophotometer (Bechman Model DU-65) after extraction in hot ethanol (Marker, Crowther, & Gunn, 1980). Nutrient analyses were performed in triplicate whereas Chl was measured in duplicate.

Sampling Equipment and Methods

Fish assemblages were sampled overnight from the Geum River using sets of fyke nets (FN), gill nets (GN), trammel nets (TN), minnow traps (MT), cast nets (CN), and kick nets (KN). The trammel net (50 m long and 1.0 m high, mesh size 12 × 12 mm), gill net (50 m long and 2 m high, mesh size 45 × 45 mm), fyke net (20 m long and 2.4 m high, mesh size: 5 × 5 mm), cast net (mesh size: 7 × 7 mm), kick net (mesh size: 4 × 4 mm), and minnow trap (0.6 m long and 0.3 m high, 4 mm mesh size) were used in the open water at different depths. The cast net and kick net were used in nearshore as well as offshore waters of the Geum River. The fyke net, gill net, trammel net, and minnow trap were installed along the shoreline using a small boat. The littoral zone was sampled at a 0.5-1 m water depth using the cast net (38.5 m^2 capture area) and kick net (1.6 m^2 capture area). The cast net was mainly used in the open water around the littoral area, and the kick net was used in shallow regions with hydrophytes and weeds. At each sampling location, the sampling distance was 200 m and the elapsed sampling time was 60 min by following the quantitative sampling method of Barbour *et al*. (1999). After collecting the samples, the fish was identified and any abnormalities in those fish were also noted. Trophic and tolerance species analyses were conducted using previous regional studies (An, Kim, Kong, Kim, 2004).

Data Analyses

Data were analyzed using Sigma Plot version 10.00 (Systat Software Inc.) and PC-ORD software (McCune & Mefford, 1999).

Results and Discussion

Chemical Water Quality in Relation to Land-Use Patterns

Nutrients, organic matter, and sestonic chlorophyll were directly determined by land-use patterns in the watershed (Table 1). Water quality was lowest in agricultural regions compared to urban and forestry regions. Mean TN and TP were higher in agricultural regions than in the other types of regions, and organic matter pollution (based on BOD and COD) showed the same pattern as nutrients. The high levels of nutrients and organic matter in agricultural regions were mainly attributable to the massive use of crop fertilizers by intensive farms. By contrast, concentrations of TP, TN, BOD, COD, SS, and EC were lowest in forest regions, which indicates pristine

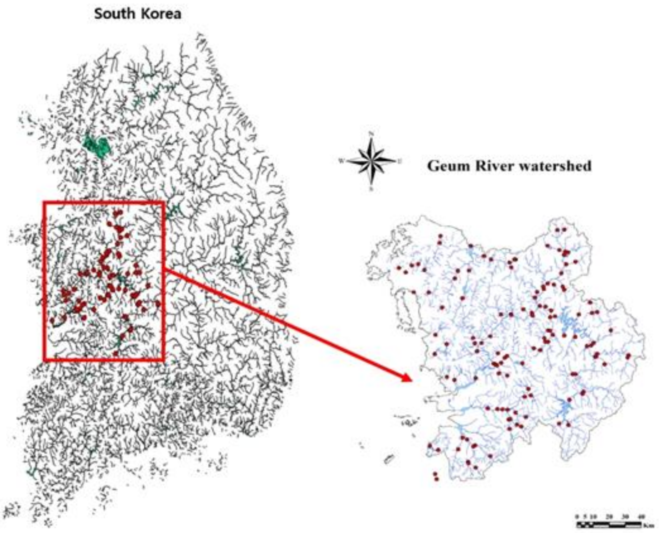

Figure 1. Sampling sites of Geum river watershed which was located in the middle-west part of South Korea.

Table 1. Chemical water quality in relation to the land-use pattern of the Rivers and Streams in the Geum River watershed. The land-use pattern was categorized as agricultural dominated region (Ag-D Reg.), urban dominated region (Ur-D Reg.) and forestry dominated region (Fr-D Reg.)

Chemical Parameter	Land-use Pattern		
	Ag-D Reg. Mean±SE (Min-Max)	Ur-D Reg. Mean±SE (Min-Max)	Fr-D Reg. Mean±SE (Min-Max)
Total phosphorus (µgL^{-1})	134.05±17.69	133.66±69.59	19.33±3.71
	(21.0-319.0)	(17.0-669.0)	(5.0-30.0)
Total nitrogen (mgL^{-1})	3.54±0.46	2.66±1.00	1.39±0.07
	(1.12-7.19)	(0.96-10.56)	(1.19-1.60)
Chlorophyll (µgL^{-1})	27.08±6.74	17.24±6.57	3.35±1.08
	(0.16-103.1)	(0.5-63.13)	(0.1-6.63)
Biological oxygen demand (mgL^{-1})	5.07±0.79	3.02±0.59	1.01±0.10
	(0.8-15.26)	(1.1-6.56)	(0.63-1.36)
Chemical oxygen demand (mgL^{-1})	9.04±0.91	5.72±0.93	3.41±0.48
	(3.03-18.3)	(3.2-12.3)	(1.73-4.6)
Suspended solids (mgL^{-1})	18.73±2.64	6.02±1.37	4.37±1.48
	(2.5-42.1)	(1.03-15.16)	(0.76-10.53)
Electrical conductivity (µScm^{-1})	384.23±35.41	271.66±31.77	139.33±11.53
	(196-791.66)	(175.33-495.66)	104.66-187.33)

water quality conditions. These low nutrient levels were due to no point sources or nonpoint sources being located in the forest region. The low nutrients resulted in low concentrations of sestonic chlorophyll, although chlorophyll was also affected by high current velocity and vegetation shading in the forest region. By contrast, chlorophyll was highest in the agricultural region, mainly because of the high supply of N and P from fertilizer runoff. Yoon, Cho, Choi, and Son (2006) pointed out that excessive amounts of fertilizer have been used in paddy fields, providing an important source of nitrogen and phosphorus.

Fish Trophic and Tolerance Guilds in Relation to Land-Use Patterns

Trophic and tolerance preferences were closely associated with land-use patterns. Land-use patterns greatly affected the distribution of fish species in the water (Figure 2). The percentage of tolerant fish species (*Micropterus salmoides, Zacco platypus* etc.) were increased linearly with increasing agricultural (R^2 = 0.76, $P<0.007$) and urban area (R^2 = 0.36, $P<0.007$). By contrast, the abundance of tolerant species decreased linearly with increasing forest area (R^2 = 0.72, $P<0.01$). Sensitive species were positively related to forest area. The proportion of sensitive species increased linearly with increasing forest area (R^2 = 0.57, $P<0.07$). Sensitive species (*Zacco temminckii*, *Pseudobagrus brevicorpus* etc) had an inverse relationship with the amount of urban (R^2 = 0.17, $P<0.03$) and agricultural land (R^2 = 0.82, $P<0.01$). This study supports the suggestion that tolerant species can persist in polluted regions,

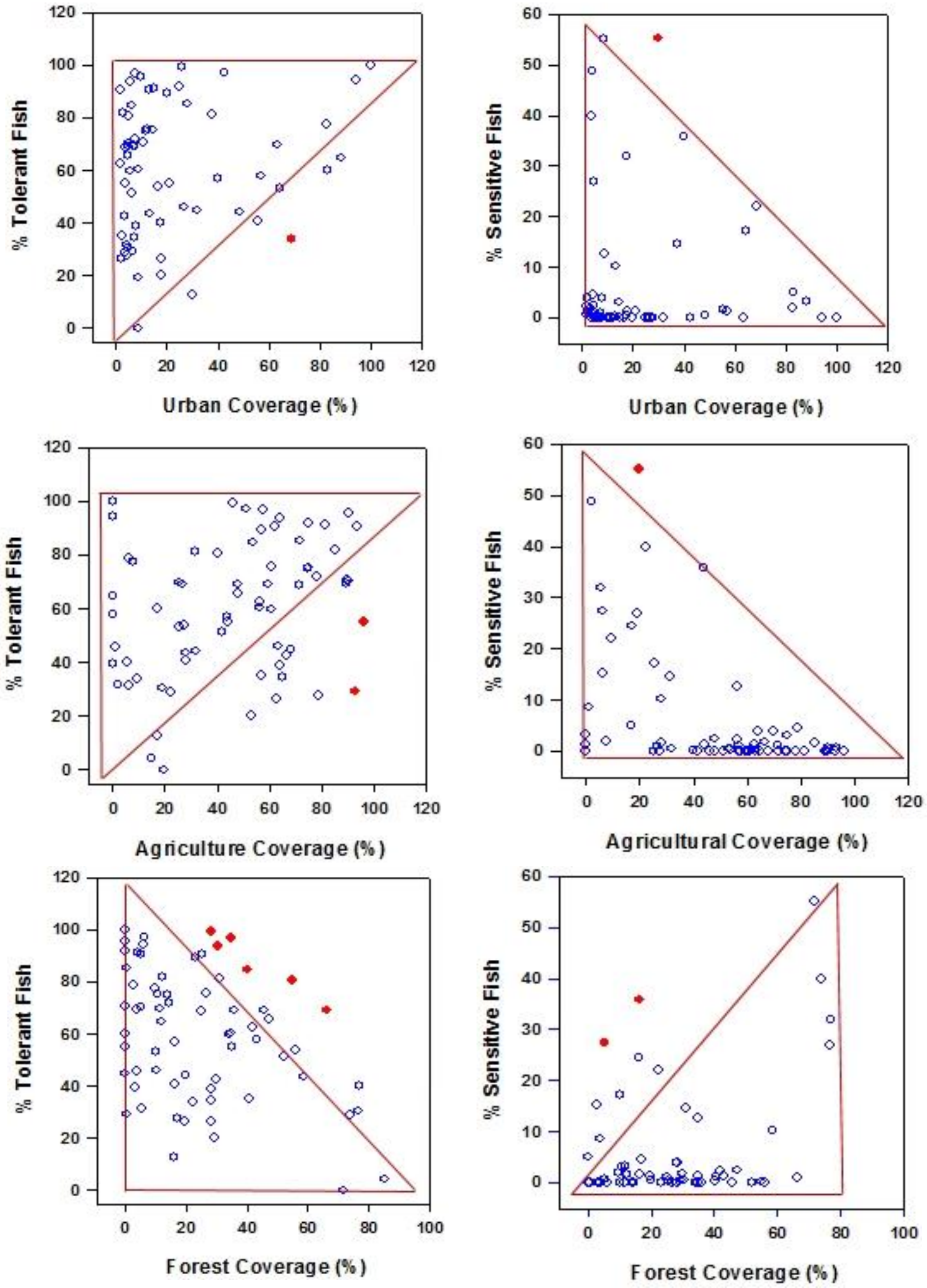

Figure 2. Percentage of tolerant and sensitive fish based on land-use pattern. The red dots denote outliers.

whereas sensitive species prefer cleaner areas (Mamun, Choi, Lee, & An, 2017).

Chemical Tolerance in Three Species

Fish abundance depends on water quality. Biological oxygen demand (BOD) and total phosphorus (TP) were the factors most responsible for organic matter and eutrophication, respectively, in the water. The relationships of biological oxygen demand (BOD) and total phosphorus (TP) were the converse of fish abundance (Figure 3). Total phosphorus (TP) was the limiting factor for primary production in the water, and when the concentration of TP increased, the water became turbid. Nutrient and organic matter polluted the water. Our findings strongly support the view that fish prefer to live in clear water than turbid water (Choi, Kumar, Han, & An, 2011).

Nutrient Contents, Organic Matter, and Sestonic Chlorophyll

Nutrient contents (TP and TN), organic matter (BOD and COD), suspended solids (SS), and sestonic chlorophyll (CHL) were influenced by stream elevation (Figure 4). Concentrations of TP and SS

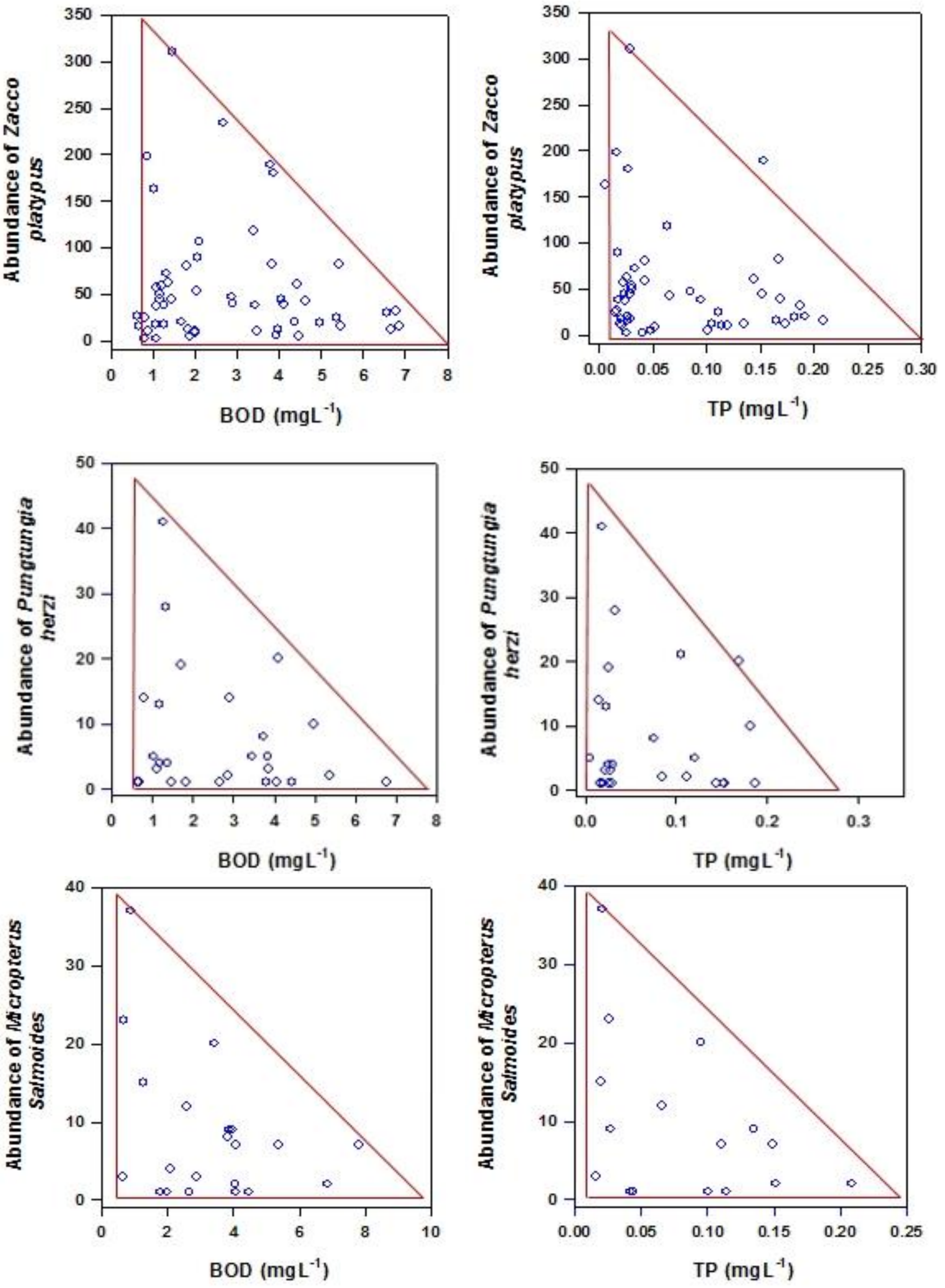

Figure 3. Influence of BOD (mgL^{-1}) and TP (mgL^{-1}) on the abundance of *Zacco platypus, Pungtungia herzi* and *Micropterus salmoides.*

decreased as the stream elevation increased. The R^2 value was highest (R^2 = 0.44) for the relationship among SS, COD, and elevation. With rising elevation, concentrations of BOD, CHL, and TN decreased gradually, with R^2 values of 0.42, 0.16, and 0.14, respectively. When elevation increased, the current velocity also increased. Current flow washed nutrients, organic matter, suspended solids, and chlorophyll from the upper regions to downstream regions. This strongly influenced the concentrations of nutrients, organic matter, suspended solids, and chlorophyll in downstream areas (Table 1; Choi *et al*., 2011).

An Empirical Regression Model of Chlorophyll and Nutrients

An empirical model was used to determine whether the system was phosphorus limited or nitrogen limited. Empirical model of CHL-TP showed

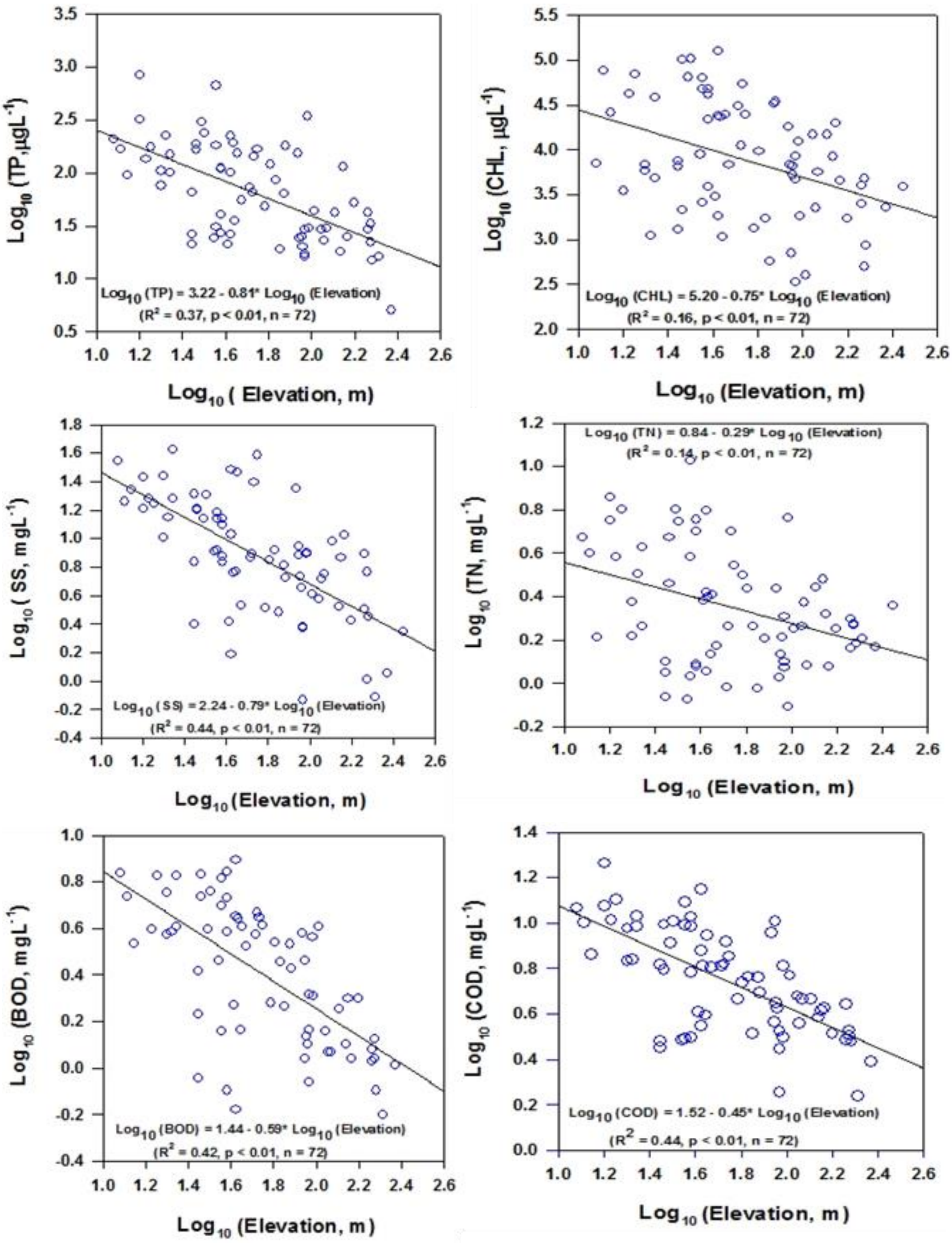

Figure 4. Variations of stream nutrients and chlorophyll with elevation among 72 streams.

a strong relationship, with an R^2 value of 0.16, whereas the empirical models of CHL-TN and CHL-TP showed weak relationships, with R^2 values of 0.11 and 0.09, respectively (Figure 5). In the CHL-TP model, algal growth was influenced by TP, which indicates a phosphorus-limited system. The R^2 value of 0.11 for the CHL-TN model indicated that phytoplankton growth was less affected by the concentration of TN in the water. The relationships reported here support the view that phytoplankton in ecosystems respond to P enrichment and that annual mean TP may provide a reliable basis for predicting average primary productivity (Prepas & Trew, 1983).

Principal Component Analysis Based on Land-Use Patterns, Nutrients and Organic Matter and Trophic and Tolerance Guilds

Principal component analyses assessed how land-use patterns affected physiochemical water quality parameters and trophic and tolerance guilds at the study sites (Legendre & Legendre, 1998; Figure

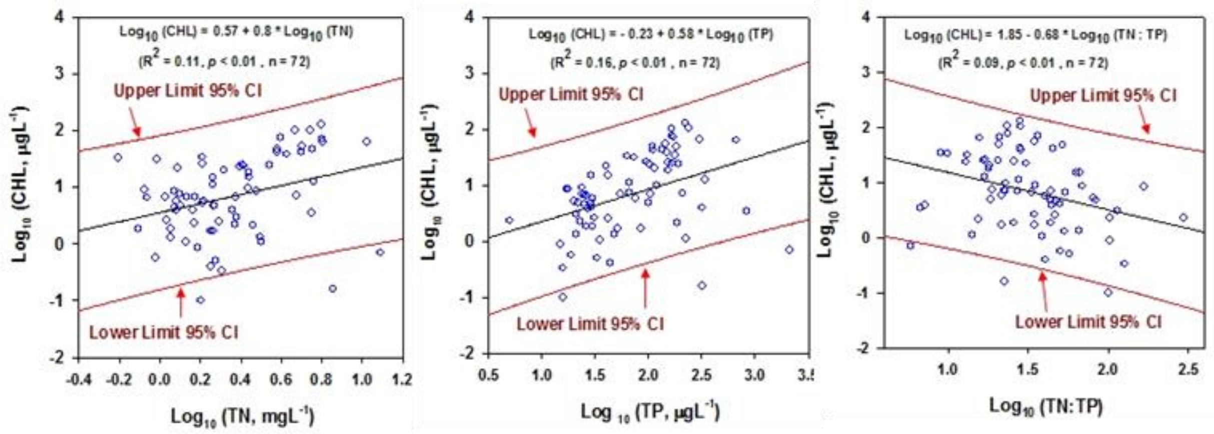

Figure 5. Empirical regression model of Log-transformed CHL (μgL^{-1}), TN (mgL^{-1}), TP (μgL^{-1}) and TN:TP ratio.

6). Streams were divided into agriculture, forestry, and urban zones by PCA analysis. In the PCA ordination, axes 1 and 2 together accounted for 36% of the variance in individual abundances under the trophic and tolerance guild analysis and land-use patterns. In the forestry zone, sensitive, intermediate, and insectivorous species were dominant because the water had greater clarity than in the agricultural and urban zones. In agriculture regions, the abundance of tolerant and carnivorous species were prominent due to high concentration of nutrients, organic matter, and suspended solids which makes the water more turbid. This supports the view that carnivorous and tolerant species prefer polluted areas to clear zones (Lee & An, 2014). The proportion of omnivorous species was highest in an urban area. The stream health conditions and IBI values showed good conditions in the forestry zone.

Ecosystem Health Assessments

To determine the health of streams in South Korea, we used the IBI_{KW} model, which was divided into an eight-metric system including various criteria that were categorized into three groups for regional assessment (An *et al*., 2006, 2010): species richness and composition (group I: M_1–M_4), trophic composition (group II: M_5 and M_6), and fish abundance and condition (group III: M_7 and M_8; Table 2).

The IBI score was calculated using the Karr methodology (Karr, 1981). A score of 5, 3, or 1 was assigned to each metric (Barbour *et al*., 1999) according to whether its value approximated, deviated from, or greatly deviated from, respectively, the expected value in the eight-metric rating. IBI scores were divided into five categories-excellent (46-50), good (36-40), fair (26-30), poor (16-20), and very poor (<10)-using a modified EPA (1994) approach. IBI values varied from stream to stream and depending on location and year. Of the 72 streams surveyed, only one stream was in ecologically good condition, and nine streams were in fair condition. Most of the streams (61) were classified as poor. One stream was classified as being in very poor condition. This strongly implies that the ecological health of these streams remains severely impaired (Choi *et al*., 2011).

IBI values (Figure 7) revealed that the number of riffle benthic species (M_2) and sensitive species (M_3) increased with increasing IBI value and had a positive linear relationship, with r values of 0.63 and 0.54, respectively. Number of native fish species (M_1) and individuals (M_7) were in their highest position when the IBI score was at midlevel. Tolerant (M_4) and omnivorous (M_5) species had inverse relationships with IBI values, which suggests that omnivorous and tolerant species prefer polluted regions. The relationship between native insectivorous species (M_6) and IBI value was not clear. When the IBI value was lowest, the proportion of individuals with anomalies (M_8) was at its peak, which suggests that stream health was poor.

Conclusions

Ecosystem health assessments provide baseline information about stream health. The IBI has been widely used worldwide to evaluate the condition of watersheds, as it is a cost-effective method. Stream health based on the IBI depends on water quality parameters, fish composition, and land-use patterns. This analysis indicated that for most of the streams assessed, health conditions were not good. The Korean government should attend to stream conservation, and additional research is also important in some basic areas such as sampling effort, assemblage responsiveness, and indicator sensitivity.

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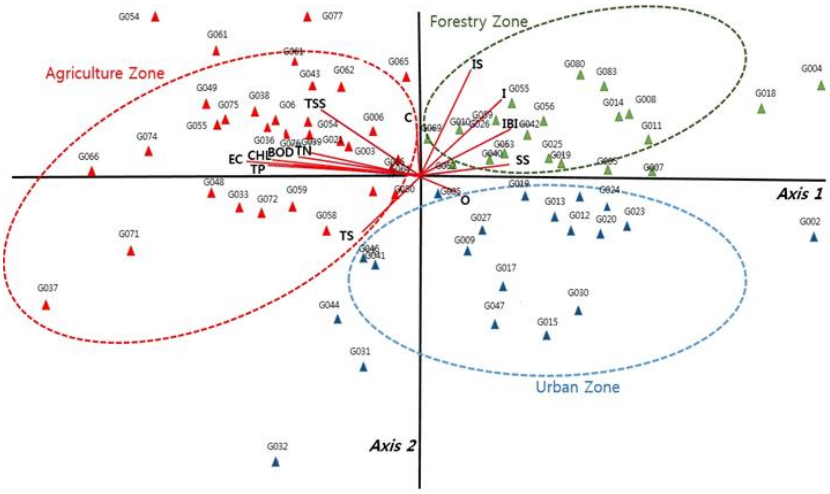

Figure 6. Principal component analysis (PCA) of 72 sampling streams based on biological, chemical and physical variables.

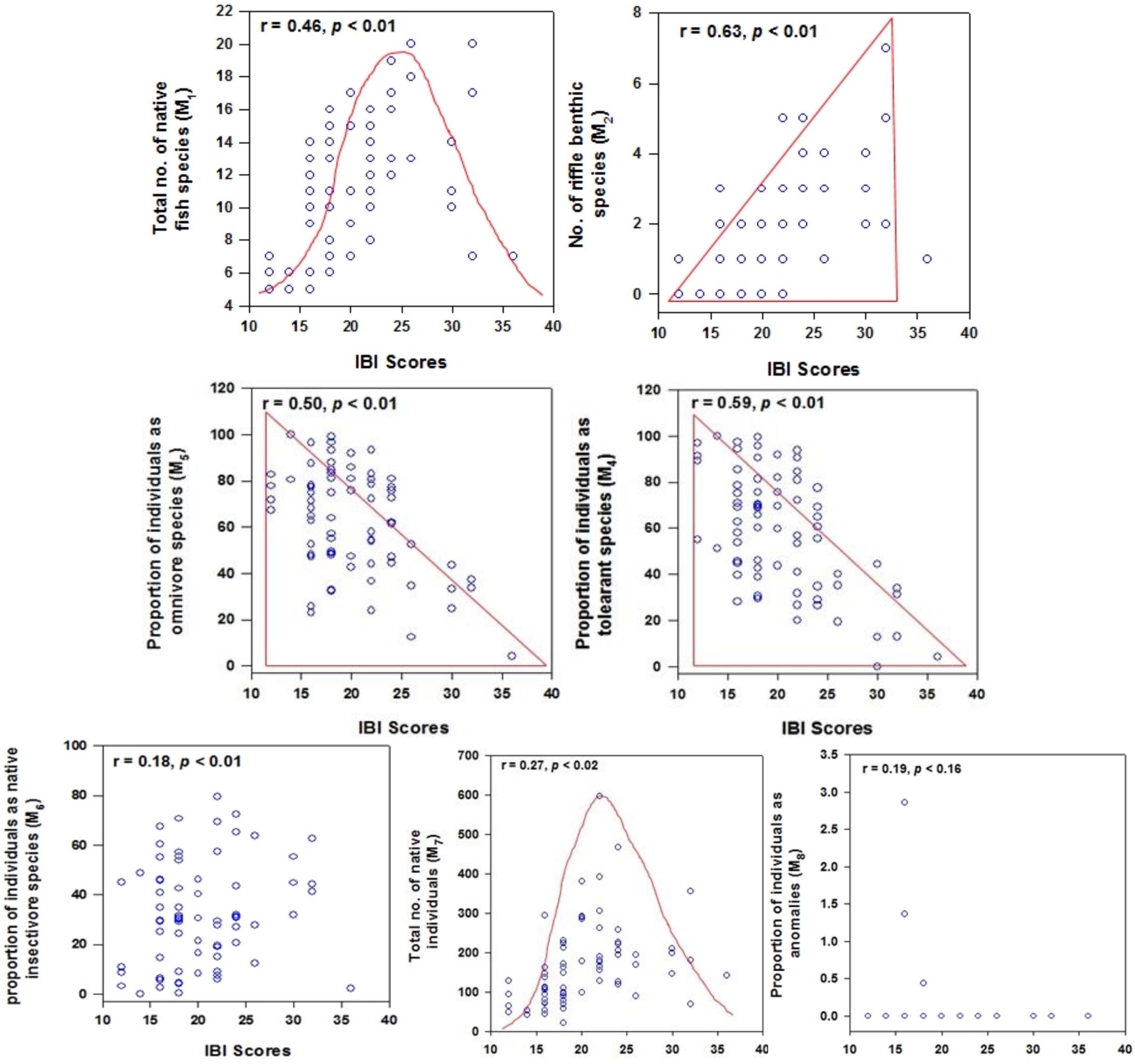

Figure 7. The relationship between the index of biotic integrity (IBI) values of Korean Geum river watershed and all the IBI metrics.

Table 2. Evaluation of the ecological health based on an index of biotic integrity model (IBI_{KW}) of the Geum river watersheds and for each metric value used round figure to describe the IBI scores

Model category	Model metrics	Scoring criteria			Geum river watershed		
		5	3	1	Agriculture zone	Urban zone	Forestry zone
Species richness and composition	M_1: total number of native fish species	Expectations of M_1-M_3 vary with stream size and region			11(5)	11(5)	13(5)
	M_2: number of riffle benthic species				1(1)	2(1)	2(3)
	M_3: number of sensitive species				1(1)	2(1)	3(1)
	M_4: proportion of individuals as tolerant species	<5	5-20	>20	67(1)	62(1)	46(1)
Trophic composition	M_5: proportion of individual as omnivore species	<20	20-45	>45	65(1)	63(1)	58(1)
	M_6: proportion of individuals as native insectivore species	>45	45-20	<20	26(3)	31(3)	34(3)
Fish abundance and condition	M_7: total number of native individuals	Expectations of M_7 vary with stream size and region			170(3)	157(3)	218(3)
	M_8: proportion of individuals with anomalies	0	0-1	>1	<1(3)	<1(3)	0(5)
Overall IBI scores					18	18	22
Health status of the stream					Poor	Poor	Fair-Poor

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