Korean J. Ecol., 21(6):759~770, 1998

Biotic Indices as Assessment Tools of Water Quality in the Han River System, Korea

Chung, Pyung-Rim[1], Sung-Joon Aw[2], Younghun Jung[1], Jae-Jin Kim[3] and Sun-Keun Choi[4]
Department of Parasitology, College of Medicine, Inha University, Inchon, Korea[1]
Pai-Chai High School, Seoul, Korea[2]
Department of Biology, College of Natural Sciences, Pai-Chai University, Daejon, Korea[3]
Kang Nung Military Field Hospital, Kang Nung, Korea[4]

생물지수를 이용한 북한강 수계에서의 생물학적 수질 평가

정평림[1] · 어성준[2] · 정영헌[1] · 김재진[3] · 최선근[4]
인하대학교 의과대학 기생충학교실[1], 배재고등학교[2]
배재대학교 자연과학대학 생물학과[3], 국군강릉야전병원[4]

ABSTRACT

Biotic indices scoring with the benthic macroinvertebrates were assessed as pollution monitoring tools in the north branch of the Han River system, Korea. We investigated the temporal variability of water quality at unpolluted, moderately polluted and heavily polluted sites using several biotic indices and assessed appropriate biological monitoring indices for lotic systems in Korea.

The following biotic and chemical indices were employed in order to compare their applicability to the lotic systems: Trent Biotic Index (TBI), Chandler's Biotic Index-Average Score Per Taxon (CBI-ASPT), Modified Biological Monitoring Working Party Score System-Average Score Per Taxon (BMWP-ASPT), Hilsenhoff's Biotic Index (BI) and Family-level Biotic Index (FBI) models for biotic analyses; and National Sanitation Foundation's Water Quality Index (NSFWQI) and Comprehensive Chemical Pollution Index (Pb/n) for chemical analyses of water quality. Index and score values were compared with each other and with 24 water chemistry parameters.

All biotic indices were significantly auto-correlated ($p<0.001$); and BI and FBI/ROK among them were highly correlated ($r=0.84$). BI and BMWP-ASPT models were also highly correlated with NSFWQI, while TBI values showed high correlation with the Pb/n. The BI and BMWP-ASPT were highly correlated with the most water chemistry parameters.

We conclude that the BI model, which includes indicator species and abundance of taxa, is best suited for the bioassessment of lotic systems in Korea. For rapid field-based assessments, FBI/ROK and BMWP-ASPT models are also appropriate.

Key words: Biotic indices, Macroinvertebrates, Water quality, Han River system, Republic of Korea.

INTRODUCTION

Organic pollution from municipal sewage, agricultural wastes, and industrial effluents is common in Korean river systems (Environmental Office/ROK 1986, 1991). Biological monitoring of river systems is common in North America, Europe and Australia as an assessment tool for water quality, because water pollution affects the diversity and composition of aquatic communities (Metcalfe 1989). The structure of stream assemblages is a result of both long-term environmental factors, and critical conditions of short duration. In contrast, water quality conditions rely on physical and chemical determinations, and measure only those characteristics existing at the time of sampling and not necessarily past short-term and long-term pollution stresses.

Macroinvertebrates have long been used to evaluate the water quality of streams (Hilsenhoff 1977). Since Kolkowitz and Marsson (1967) first used arthropods to evaluate water quality, much has been written concerning their potential and the methods for collecting and evaluating them (Cairns and Dickson 1973). Few studies on pollution in freshwater systems have been carried out in Korea and these have concentrated on water quality and biological fauna in the Han River system (Yoon 1978, Kim *et al.* 1980, Yoon and Byon 1981, Yoon *et al.* 1986, Ra and Cho 1986, Yoon *et al.* 1987, Chung *et al.* 1992).

There are three principal approaches to biological assessment which use taxonomic and pollution tolerance data, these being the saprobic, diversity and biotic approaches. Recently, emphasis has been placed on developing potential biotic indices for more comprehensive assessment of pollution status in an aquatic ecosystem (Metcalfe 1989).

The biotic approach to freshwater assessment in developing countries such as Korea has the following advantages: 1) Chemical monitoring says little of the effects of pollution, especially as pollution is essentially a biological phenomenon. Moreover, biomonitoring allows spatial evaluation of the effect of a discharge point, and is sensitive to synergistic or antagonistic effects of mixes of chemicals that can not be predicted from chemical analysis alone. 2) Biomonitoring is a low-cost technology and not dependent on advanced environmental chemistry; it uses much less laboratory equipment, so that it may be of particular relevance to the developing countries.

The specific objectives of this study were: 1) to determine the nature, intensity and seasonality of polluting sources of a selected portion of the Han River; 2) to evaluate water quality of the river by studying the temporal variability of unpolluted, moderately polluted and heavily polluted sites of the river; 3) to recommend preferred biological methods to governmental authorities which are responsible for water quality monitoring.

SITES STUDIED

The Han River system originates in the mountainous areas of Kangwon province, and drains the mid-west area of the Korean peninsula. It drains an area of about 26,018 km^2 and 481.7 km long (Environmental Office/ROK 1986). The north branch of the Han River is 317.5 km in length, and has five man-made reservoirs; namely, the Hwachon, Chunchon, Soyang, Euiam and Chongpyong dams. Our sampling sites were located on three tributaries of the north branch.

The Sagimak-Chon (Chon means stream) (station 1) was regarded as the cleanest tributary, while Masok-Chon (station 3) was selected as a severely stressed stream. The Chochong-Chon (station 2) has been assessed as moderately polluted stream (Environmental Office/ROK 1991, Fig. 1). The sampling stations in all the tributaries were similar in size and substrate.

MATERIALS AND METHODS

Macroinvertebrate sampling

Four macroinvertebrate samples were collected with

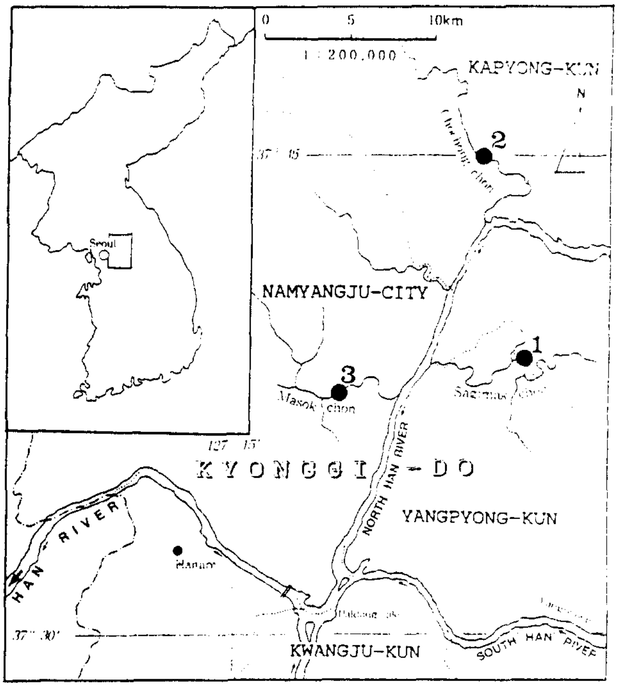

Fig. 1. A map of the north branch of the Han River, showing 3 stations for the biological evaluation of water quality with macroinvertebrates collected. Station 1=Sagimak-Chon; Station 2=Chochong-Chon; Station 3=Masok-Chon.

a Surber sampler (Wildco Instruments Co., MI, U.S.A.; 30 × 30cm; mesh size, 750μm) on each sampling occasion. In some cases, qualitative samples were taken with a hand net (90 × 60 cm; mesh size, 1 mm), scoop (25 cm/diameter; mesh size, 1 mm), and a D-frame net (mesh size, 750 μm). Samples were preserved in the field in Kahle's solution. Organisms were picked, counted and identified to the lowest taxonomic level (Tsuda 1962, Kawata 1962, Hilsenhoff 1975, Cummins 1978, Pennak 1978, Wiggins 1978, Kawai 1985, Yoon 1988, Kwon 1990, Yoon and Kim 1992, Lee 1992). Oligochaetes, chironomids and amphipods were subsampled, while animals from all other groups were identified individually.

Physical and chemical measurements

Stream temperatures, current velocity (m/sec), stream width (m) and discharge (m^3/sec) were recorded at each sampling occasion. Water samples were refrigerated and returned immediately to the laboratory of NIER/ROK for analysis of pH, BOD_5, COD_{cr}, COD_{Mn}, turbidity, Eh (ORP), TOC, TN, TP, S.S., coliform, Cl^-, NH_4-N, NO_2-N, NO_3-N, PO_4-P, alkalinity and hardness. Dissolved oxygen (DO) and conductivity were recorded at each visit with portable meters. A total of 24 physical and chemical parameters were evaluated at each site.

Biotic indices

The biotic approach to bioassessment is one which combines diversity on the basis of certain taxonomic groups, with the pollutional indication of individual species or higher taxa into a single index or score (Tolkamp 1985). The biotic indices applied in this study were: 1) the Trent Biotic Index, which rates a site on a 1～10 scale, 10 being unpolluted (TBI, Sladecek 1973), 2) Chandler's Biotic-Average Score Per Taxon assessing an average tolerance score per taxon, which rates a site on a 1～100 scale, 100 being unpolluted (CBI-ASPT, Sladecek 1973), 3) Modified Biological Monitoring Working Party Score System-Average Score Per Taxon, also uses a 1～10 score (BMWP-ASPT, Armitage *et al.* 1983), 4) Hilsenhoff's Biotic Index, allocates tolerance values per taxon (BI, Hilsenhoff 1977) and 5) Family-level Biotic Index (FBI, Hilsenhoff 1988a).

The biotic indices or scores were calculated on the basis of the macrobenthic taxa collected from each sampling station. Each macrobenthic taxon for calculating the biotic index values has its own pollutional indication or tolerance value according to each index or score system. The usefulness of FBI values was investigated by comparing FBI and BI values, using Student's t-test. Tolerance values of each taxon in species- or family-level (Yoon *et al.* 1992a, 1992b) in this study were modified by authors.

Chemical indices

Two water chemistry indices were also evaluated: 1) National Sanitation Foundation's Water Quality Index (NSFWQI, Ott 1978) and 2) Comprehensive Chemical Pollution Index (Pb/n, Shen 1993). NSFWQI values were calculated with nine water chemistry parameters: temperature, pH, DO, BOD, NO_3-N, PO_4-P, turbidity, suspended solid and coliforms. The parameters employed to calculate Pb/n were DO, BOD, COD, TN, TP, SS, coliforms, and Grade Ⅱ values of Environmental Quality Standard for Rivers in Korea were used.

Statistical analyses

The biotic index values of the sampling stations and 24 water chemistry parameters; the biotic index values and water quality index values in the stations; or biotic index values themselves, were mutually compared by the Spearmam's rank correlation coefficient analysis (Spearman 1904), in order to elucidate the mutual correlations of the parameters employed in this study. The one-way ANOVA test and Duncan's multiple range test were also applied for the comparison of statistical differences among means of biological index values obtained from 3 sampling stations.

RESULTS

Biotic indices with macroinvertebrates

A total of 150 macroinvertebrate taxa in 62 families, 16 orders, 6 classes in 4 phyla were collected during the course of this study. Of 150 macroinvertebrate taxa detected during the period of survey, the numbers of taxa in the stations 1, 2 and 3 were 107 (71.3%), 94 (62.7%) and 31 (20.7%), respectively (Table 1). Six biotic indices or scores were employed in this study, and seasonal variations of biotic index/score values are tabulated in Table 2.

The values of all the biotic indices or scores employed for the water quality at 3 stations, except those of FBI/USA, showed significant variation in each season as well as in all the year round. In general, station 1 was classified as clean water, station 2

Table 1. Numbers of taxa collected monthly in the stations of the Han River system during survey period (1993)*

Phylum	Class	Order	No. of taxa (species)		
			St. 1	St. 2	St. 3
Arthropoda	Insecta	Ephemeroptera	39	38	5
		Odonata	7	5	–
		Plecoptera	10	4	–
		Hemiptera	2	2	–
		Megaloptera	2	2	1
		Trichoptera	18	15	6
		Coleoptera	6	5	1
		Diptera	16	16	7
	Crustacea	Decapoda	1	–	–
		Amphipoda	1	–	1
		Isopoda	–	–	1
Annelida	Oligochaeta	Haplotaxida	1	1	1
	Hirudina	Pharyngobdellida	2	–	2
		Rhynchobdellida	–	–	1
Mollusca	Gastropoda	Mesogastropoda	2	5	4
Platyhelminthes	Turbellaria	Tricladida	–	1	1
Total taxa (%)			107 (71.3%)	94 (62.7%)	31 (20.7%)

* A total of 150 macroinvertebrate taxa in 62 families were collected during the course of this study.

Table 2. Biological index values (mean±S.D.) of the sampling stations during the period of four seasons

Index	Season	Station			P value
		1	2	3	
TBI	Spring	7.67±1.50	7.42±1.93	3.83±2.48	0.0008
	Summer	7.33±0.98	6.50±1.09	2.50±0.84	0.0001
	Fall	8.25±1.22	7.58±0.67	5.50±0.55	0.0001
	Winter	8.08±1.31	7.33±1.92	3.83±1.94	0.0001
	Mean	7.83±1.28	7.21±1.52	3.92±1.89	0.0001
CBI-ASPT	Spring	69.57±22.18	72.55±20.61	34.00±20.12	0.0001
	Summer	70.84±18.69	69.94±20.46	35.60±12.28	0.0001
	Fall	71.35±19.52	70.26±21.31	34.96±18.71	0.0001
	Winter	71.80±19.16	70.11±23.48	33.50±20.45	0.0001
	Mean	70.92±19.71	71.02±21.55	34.62±17.76	0.0001
BMWP-ASPT	Spring	7.75±3.05	7.35±3.19	4.35±3.64	0.0001
	Summer	7.69±3.04	7.83±3.01	4.04±3.41	0.0001
	Fall	7.90±2.86	6.95±3.28	3.70±2.54	0.0001
	Winter	7.44±3.05	7.21±3.26	2.80±2.17	0.0001
	Mean	7.70±2.99	7.31±3.20	3.76±2.98	0.0001
BI	Spring	1.62±1.88	1.62±1.99	2.59±3.14	0.0212
	Summer	1.65±2.16	1.72±2.39	2.94±4.83	0.0004
	Fall	1.51±1.36	1.74±1.68	3.39±6.25	0.0084
	Winter	1.50±2.16	1.68±2.37	4.43±4.94	0.0001
	Mean	1.57±1.93	1.68±2.17	3.18±4.75	0.0001
FBI/ROK	Spring	2.01±2.79	1.47±2.02	3.73±4.66	0.0059
	Summer	1.38±1.31	1.51±1.57	3.26±4.65	0.0027
	Fall	1.38±1.28	1.39±1.54	2.94±3.58	0.0003
	Winter	1.45±1.55	1.40±1.90	3.79±4.58	0.0001
	Mean	1.56±1.86	1.44±1.78	3.35±4.24	0.0001
FBI/USA	Spring	3.55±6.84	3.57±6.64	7.26±9.05	0.1818
	Summer	2.93±2.52	3.29±3.68	4.77±5.28	0.1596
	Fall	2.63±3.77	3.01±3.85	4.58±4.64	0.1656
	Winter	2.69±4.10	3.06±4.16	3.57±3.68	0.0879
	Mean	2.96±4.67	3.24±4.82	5.46±6.91	0.0018

was slightly polluted and station 3 showed a heavily polluted condition. Especially in Duncan's multiple range test, stations 1 and 2 were closely grouped, separately from station 3.

Every species was assigned a tolerance value (=index value) on the basis of collections made previously in Korea, in order to calculate BI values suitable for Korean aquatic fauna. The tolerance values for every species of macrobenthos were scaled from 1 through 5, meaning that the lower value the species has, the more sensitive to clean streams. The lower BI values indicate higher quality of water. The tolerance values applied in this study were workable for the application of BI and FBI/ROK indices.

In addition to applying the FBI model using Korean-based tolerance values, tolerance values used in Wisconsin, USA was also applied in this study. The tolerance values in this part ranged from 0 to 10, values of 0 being assigned to species collected only in unaltered streams of very high water quality and values of 10 assigned to species known to occur in severely polluted or disturbed streams. However, FBI/USA values showing at 3 stations were not significantly variable in all the four seasons.

Chemical index values

The NSFWQI values at station 1 ranged from 80.4 in October to 91.8 in April, 76.8 in August to 91.8 in April at station 2, and 58.8 in July to 81.1 in December at station 3. The overall mean values of NSFWQI were: 86.0 in station 1, 83.6 in station 2, and 72.9 in station 3 (Table 3).

The comprehensive chemical index values (P_b/n) in the stations are shown in Table 3. The index values at stations 1 and 2 ranged from 0.5 through 2.1 throughout the survey period. The overall mean values in stations 1 and 2 were 1.1 and 1.3, respectively, suggesting that these two stations are categorized as a slightly polluted status. Station 3 showed the highest mean value of 3.1 categorizing it as "heavily polluted". The stream conditions were well grouped as slightly and heavily polluted in the mean values of P_b/n, as compared with those calculated by the formula of NSFWQI.

Correlations of the values of biotic and chemical indices

A correlation matrix of the biotic indices or scores applied in this study are shown in Table 4. All of the pairings of biotic indices were significantly correlated with each other ($p<0.001$). The value between BI and FBI/ROK was highly correlated ($r=0.84$), while the coefficients between FBI/USA and the other biotic indices were lower ($r<0.69$). In addition to high correlation between BI and FBI/ROK, the pairings showing high coefficient values of more than 0.80 were TBI and FBI/ROK ($r=-0.821$), BI and BMWP ($r=-0.830$).

All the biological index or score values employed in this study were significantly correlated with the values of two standard water quality indices (NSFWQI and P_b/n) as shown in Table 5. Biological indices showing correlation coefficient values of more than 0.60 compared to NSFWQI, were BI, BMWP

Table 3. National Sanitation Foundation's Water Quality Index (NSFWQI) and Comprehensive Chemical Pollution Index (P_b/n) values in the water specimens sampled from the stations of the north branch of the Han River

Month/1993	St. 1		St. 2		St. 3	
	NSFWQI	P_b/n	NSFWQI	P_b/n	NSFWQI	P_b/n
Jan.	89.5	1.6	91.1	2.1	72.7	3.4
Feb.	84.5	0.9	82.8	1.1	77.4	2.3
Mar.	88.2	0.6	84.3	0.8	77.2	2.0
Apr.	91.8	0.6	91.8	0.2	77.9	1.8
May	84.3	0.5	82.5	0.6	67.1	2.0
Jun.	83.6	1.4	78.7	1.5	66.1	2.7
Jul.	87.0	1.3	78.3	1.7	58.8	6.7
Aug.	80.8	1.0	76.8	2.7	69.7	3.5
Sep.	89.1	0.7	83.9	0.7	80.4	2.2
Oct.	80.4	1.9	85.0	1.8	71.5	5.3
Nov.	81.4	1.4	77.4	1.8	74.4	3.3
Dec.	91.1	0.9	90.3	1.5	81.1	2.1
Mean	86.0	1.1	83.6	1.3	72.9	3.1

Table 4. Spearman's correlation coefficients (r) among the biotic indices applied in the stations of Han River system*

	TBI	CBI-ASPT	BMWP-ASPT	BI	FBI/ROK	FBI/USA
TBI	1.000					
CBI-ASPT	0.756	1.000				
BMWP-ASPT	0.720	0.665	1.000			
BI	−0.767	−0.667	−0.830	1.000		
FBI/ROK	−0.821	−0.791	−0.764	0.843	1.000	
FBI/USA	−0.694	−0.571	−0.653	0.565	0.677	1.000

* All of the pairs of biotic indices were significantly correlated each other ($P<0.001$).
The coefficient values of more than 0.80 are underlined in this Table.

Table 5. Spearman's correlation coefficient (r) and probability values (P) of six biotic index values on two standard water quality indices*

Biotic index	NSFWQI		Comprehensive chemical pollution index (Pb/n)	
	r	P	r	P
TBI	0.678	0.0001	−0.717	0.0001
CBI-ASPT	0.530	0.0009	−0.545	0.0006
BMWP-ASPT	0.694	0.0001	−0.654	0.0001
BI	−0.715	0.0001	0.633	0.0001
FBI/ROK†	−0.628	0.0001	0.468	0.0040
FBI/USA‡	−0.558	0.0004	0.450	0.0059

FBI/ROK† : FBI with Korean standard
FBI/USA‡ : FBI with USA standard
* All the biotic indices employed in this study were significantly correlated with two standard water quality indices (NSFWQI and Pb/n).
The coefficient values of more than 0.60 are underlined in this Table.

-ASPT, TBI, and FBI/ROK in the decreasing orders. The highest correlation coefficient value of −0.715 was recorded in the BI. In cases compared with P_b/n values, TBI, BMWP-ASPT and BI values showed high correlations of more than the coefficient value of 0.60. Among biotic indices applied, the TBI matched well with P_b/n with the highest coefficient value of −0.717.

The values of TBI, CBI-ASPT, BMWP-ASPT, BI and FBI/ROK were compared with 24 physical and chemical parameters by Spearman's rank correlation analysis. The TBI correlated with 15 of 24 water chemistry parameters. Similarly, CBI-ASPT and FBI values correlated with 13 water chemistry parameters. The values of BMWP-ASPT and BI were correlated with 16 parameters, showing the highest percentage of 66.7% (Table 6).

Summarizing the results of Tables 4, 5 and 6, the values of BI and BMWP-ASPT were highly correlated with the most water chemistry parameters. BI and BMWP-ASPT models were also highly correlated with NSFWQI, while TBI values showed high correlation once with the P_b/n. Although all of the pairings of biotic indices were significantly correlated with each other, the value between BI and FBI/ROK was most highly correlated.

DISCUSSION

Biotic indices

Diversity indices are mathematical expressions which use three components of community structure, namely, richness (number of species present), evenness (uniformity in the distribution of individuals among the species) and abundance (total number of organisms present), to describe the response of a community to the quality of its environment (Metcalfe 1989). Diversity indices are strictly quantitative, dimensionless, and lend themselves to statistical analy-

Table 6. Spearman's correlation of the biotic indices of the sampling stations with 24 water chemistry parameters at the significance level of 0.05

	TBI	CBI-ASPT	BMWP-ASPT	BI	FBI / ROK
Temperature					
pH					
Conductivity	+		+	+	+
D.O.					
BOD_5	+	+	+	+	+
COD_{Cr}	+	+	+	+	
COD_{Mn}					
Turbidity	+	+	+	+	+
Eh					
TOC	+	+	+	+	
TN	+	+	+	+	+
TP					
S.S.	+	+	+	+	+
Coliform	+		+	+	+
Cl^-	+	+	+	+	+
NH_4^+-N	+	+	+	+	+
NO_2-N	+	+	+	+	+
NO_3-N					
PO_4-P	+		+	+	
Alkalinity	+	+	+	+	+
Hardness	+	+	+	+	+
Width	+	+	+	+	+
Current velocity					
Discharge		+	+	+	+
Sum	15	13	16	16	13
%	62.5	54.2	66.7	66.7	54.2

sis (Cook 1976). However, unlike the saprobic indices, no assumptions are made as to the relative tolerances of individual species, which may be very subjective (Pinder *et al.* 1987).

It is apparent that the "ideal" index should be one which combines a quantitative measure of species diversity (diversity approach) with qualitative information on the ecological sensitivities of individual species (saprobic approach) into a single numerical expression which can be statistically analyzed. This is, in essence, the biotic approach (Metcalfe 1989).

Three indices are widely used in England for classification of streams according to benthic invertebrates: the Trent River Board Biotic Index (Woodiwiss 1964), the Lothians River Purification Board Index (Graham 1970) and the Score System (Chandler 1970). Among these, Trent biotic index (TBI) has been adapted for use in many other countries and appears to form the basis for most modern biotic indices and scores (Persoone and De Pauw 1979).

In this study, the mean TBI values of stations 1, 2 and 3 were 7.83, 7.21 and 3.92, respectively, and the lowest TBI values of all the stations were recorded in the summer season as shown in Table 2. Pinder *et al.* (1987), in their comparison of macroinvertebrate monitoring methods for assessing the water quality of an English stream, suggested that the TBI would not be sensitive enough to detect major differences in water quality among streams because of its restricted range in values. In fact, one major drawback of this index is that abundance is ignored. Chung *et al.* (1992) have applied the TBI model to assess water quality of three largest Korean rivers and obtained good results, which were highly correlated with chemical parameters.

Chandler's system showed very similar trends to the TBI, though the scores ranged from 0.00 to 100. The mean scores of station 1 and 2 were 70.92 and 71.02, respectively, and the lowest mean score of 34.62 was recorded in station 3. However, the highest score of 35.60 was calculated unexpectedly in the summer season in station 3. Washington (1984) compared 19 biotic indices and reported that Chandler's index gave favourable. But, this system is necessarily limited to the geographical area in which the tolerance lists were compiled. Originally designed specifically for upland rivers in Scotland (Cook 1976), the system is theoretically an improvement over the TBI because it includes an abundance factor and incorporates a more detailed list of macroinvertebrates.

The Biological Monitoring Working Party index (BMWP) with the average score per taxon (ASPT) is also in widespread use for family-level identifications in U.K. (Wright *et al.* 1988). Armitage *et al.* (1983) examined the performance of the BMWP-ASPT over a wide range of unpolluted running water sites. They found considerable variability in achievable score and ASPT between sites with different environmental features. ASPT was shown to be less sensitive to seasonal change than BMWP score. Oh and Chon

(1991) compared the biotic indices for the bioassessment of a clean stream in different seasons. They found that there was no seasonal score change at all when calculated with BMWP, while the other indices such as TBI and Chandler's biotic score had a minor change showing the lowest values in the summer season.

In this study, all the stations also showed minor variations in the seasons. The results obtained by the BMWP-ASPT in this study are generally agreed with the above-mentioned former reports.

Hilsenhoff (1977) introduced a biotic index (BI) for evaluating organic pollution in Wisconsin streams based on riffle-dwelling arthropod fauna. To determine the index value for a given site, each taxon should be assigned a "tolerance value" ranging from 0 (most sensitive) to 5 (most tolerant) based on information from 53 streams. Tolerance values assigned to species level in this study were revised for Korean taxa on the basis of Pantle and Buck's saprobic indices (1955), and modified from tolerance values of Yoon *et al.* (1992a, 1992b). The influence of current, temperature and seasonal factors on BI values have also been evaluated (Hilsenhoff 1988b). BI values were found to be erroneously high in summer, when many sensitive species are in diapause.

Hilsenhoff (1988a) also adapted his index for a rapid assessment by providing tolerance values for families. The family-level biotic index (FBI) values were higher than the BI values at unpolluted sites and lower at polluted sites. However, Hilsenhoff (1988a) recommended using the FBI only for rapid assessment of the general status of organic pollution in streams. There are some controversial points of view on application of BI or FBI models. It is clear that different physical and chemical regimes of fast-flowing mountain streams and slow-flowing lowland rivers will support totally different faunal communities (Armitage *et al.* 1990). Secondly, a primary weakness of biotic indices is the subjective approach which is often used to classify organism tolerance. Herricks and Cairns (1982) recommended replacing "subjective tolerance estimates" with "quantitative tolerance determinations", which require extensive correlations between species presence and water quality.

The BI and FBI models were applied in this study, using the subjective tolerance values for every taxon. Pollution tolerances of individual species have been determined by observations on their relative occurrence under specifically defined conditions of water quality. The FBI values in this study were calculated with new tolerance values assigned for Korean taxa.

The FBI results with tolerance values assigned by Korean standard (FBI/ROK) showed similar trends as those calculated with the other indices. The FBI/ROK values of less than 2.0 were detected throughout the year in stations 1 and 2 (1.44~1.56 in range), but the values in station 3 were always in the highest values over 3.0, ranging from 2.94 to 3.79. However, there were some exceptions in the FBI values calculated with the tolerance values of Wisconsin, U.S.A. (FBI/USA). The mean values of FBI/USA at 3 stations were significantly variable; but, there were no regional differences during all the four seasons. In general, the results of FBI/USA had more unexpected exceptions throughout the study as compared with those of FBI/ROK.

Chemical indices

Two stations 1 and 2 were categorized by our chemical indices as slightly polluted sites, and station 3 as a heavily polluted site. The stream conditions were well grouped as slightly and heavily polluted in the mean values of P_b/n, as compared with those calculated by the formula of NSFWQI. Actually it might be the first time for the chemical indices to be used in the water pollution studies in Korea.

Correlation of biotic and chemical indices

For rapid field-based assessments, our results indicate that FBI/ROK and BMWP-ASPT models are more appropriate in the running water systems in Korea. Armitage *et al.* (1983) also recommended the use of a score system that uses a low taxonomical level (i.e. family) to overcome the biogeographical differences among the macroinvertebrate communities. Comparison of the FBI and BI from the samples of Wisconsin streams was made by Hilsenhoff (1988a). Although some accuracy was lost by using the FBI, he recommended the FBI model for a rapid, but less critical evaluation of streams in the field by biologists who can recognize arthropod families by sight. Student's t-test was once applied for the comparison of statistical differences between means of BI and FBI/ROK values obtained from 3 sampling stations. Most of the statistical sets between BI and FBI/ROK arranged according to each station (data not shown) showed no significant differences, though only two sets showed statistically significant differences with unknown reasons. It means that correlation between BI and FBI/ROK models was relatively high.

ACKNOWLEGEMENTS

This study was financially supported by the International Development Research Centre/Canada (Centre file : 91-0176-01, 1992-1994). Authors would like to thank Prof. John Cairns, Jr., Virginia Polytechnic Institute and State University, Virginia, U.S. A. for his encouragement in carrying out this study and for sending his original papers. Thanks are also extended to Dr. E. D. Ongley, National Water Research Institute, Canada Centre for Inland Waters, Ontario, Canada for his proof readings of manuscript and critical suggestions.

적 요

본 연구는 북한강 수계의 3개 지점 (비오염, 중등도 오염, 오염 지점)에서 저서 대형 무척추동물을 1년간 (1993년 1월～12월) 채집, 분류하고 수 개 생물지수를 이용하여 계절별로 수질을 평가하였고, 수질의 이화학적 분석치를 이용한 화학지수 산출 결과와 비교하여 보았다. 사용된 생물지수로는 Trent Biotic Index (TBI), Chandler's Biotic Index-Average Score Per Taxon (CBI-ASPT), Modified Biological Monitoring Working Party Score System-Average Score Per Taxon (BMWP-ASPT), Hilsenhoff's Biotic Index (BI) 및 Family-level Biotic Index (FBI), 화학지수로는 National Sanitation Foundation's Water Quality Index (NSFWQI) 및 Comprehensive Chemical Pollution Index (P_b/n)가 응용되었다. 각 지수치 간의 상관관계와 24가지 이화학적 분석치 및 화학지수치와의 비교는 Spearman's rank correlation coefficient analysis로 분석되었다. 각 계절별 3개 지점간 지수치의 통계적 차이는 one-way ANOVA test로, 지점간의 유사성의 차이는 Duncan's multiple range test로 비교하였다.

BI와 BMWP-ASPT는 16가지 이화학적 수질 분석치와 유의한 상관성을 보였고, 모든 생물지수치들 간에는 각각 유의수준 $P<0.001$에서 상관성을 보였으며, 특히 BI와 FBI/ROK는 가장 높은 상관성을 보였다 ($r=0.84$). 생물지수 BI와 BMWP-ASPT는 화학지수 NSFWQI치와, TBI 지수치는 P_b/n와 높은 상관성을 보였다.

이상의 결과로 보아 BI 지수 모델이 우리나라 하천수계의 생물학적 수질평가에 가장 적당하다고 사료되었으며 단기간의 판정을 위하여서는 FBI/ROK 및 BMWP-ASPT 지수 모델도 추천할 만 하였다.

LITERATURE CITED

Armitage, P.D., D. Moss, J.F. Wright and D.M.T. Furse. 1983. The performance of a new biological water quality score system based on macroinvertebrates over a wide range of unpolluted running-water sites. Water Res. 17: 333-347.

Armitage, P.D., I. Pardo and M.T. Furse. 1990. Assessment and prediction of biological quality. A demonstration of a British macroinvertebrate -based method in two Spanish rivers. Limnetica 6: 147-156.

Cairns, J., Jr. and K.L. Dickson. 1973. Biological methods for the assessment of water quality. Am. Soc. for Testing and Materials Special Tech. Pub. 528: 1-256.

Chandler, J.R. 1970. A biological approach to water quality management. Wat. Pollut. Control 4: 415-422.

Chung, P.R., C.T. Soh, Y.K. Ahn, B.L. Choi and J.K.

Chang. 1992. Biological assessment of water quality in Korean river systems. Yonsei Rep. Trop. Med. 23: 51-79.

Cook, S.E.K. 1976. Quest for an index of community structure sensitive to water pollution. Envir. Poll. 11: 269-288.

Cummins, K.W. 1978. Aquatic insect of North America. Kendal/ Hunt Publishing Co., Iowa, U. S.A.

Environmental Office/ROK. 1986. Environmental conservation. Sam-sin Publishing Co., Seoul.

Environmental Office/ROK. 1991. Environmental conservation. Sam-sin Publishing Co., Seoul.

Graham, T.R. 1970. Ann. Rept Lothians River Purification Board for 1965, cited according to Chandler.

Herricks E.E. and J.Jr. Cairns. 1982. Biological monitoring part Ⅲ-receiving system methodology based on community structure. Water Res. 16: 141-153.

Hilsenhoff, W.L. 1975. Aquatic insects of Wisconsin, with generic keys and notes on biology, ecology and distribution. Technical Bulletin No. 89, Department of Natural Resourses, Madison, U.S.A.

Hilsenhoff, W.L. 1977. Use of arthropods to evaluate water quality of streams. Technical Bulletin No. 100, Dept. of Natural Resources, Madison, Wisconsin.

Hilsenhoff, W.L. 1988a. Rapid field assessment of organic pollution with a family-level biotic index. J. Nor. Amer. Benthol. Soc. 7: 65-68.

Hilsenhoff, W.L. 1988b. Seasonal correction factors for the biotic index. The Great Lakes Entomol. 21: 9-13.

Kawai, T. 1985. An illustrated book of aquatic insects of Japan. Tokai University Press.

Kawata, T. 1962. Illustrated insect larvae of Japan. Hokuryo-kan Publishing Co., Tokyo.

Kim, C.H., I.B. Yoon and C.W. Lee. 1980. Biological assessment of the Han River system. Bull. Korean Assoc. Conser. Nature, Ser. II: 147-156.

Kolkowitz, R. and M. Marsson. 1967. Ecology of animal saprobia (1909). *In*: Biology of water pollution, U.S.D.I., Fed. Water Pollut. Control Admin., Cincinnati.

Kwon, O.K. 1990. Illustrated encyclopedia of fauna and flora of Korea. Vol. 32, Mollusca (1). Ministry of Education. 442p.

Lee, S.H. 1992. Systematics and ecology of the Glossiphoniidae (Hirudinea: Rhynchobdellida) in Korea. Korea Univ. Master Thesis, 43p.

Metcalfe, J.L. 1989. Biological water quality assessment of running waters based on macroinvertebrate communities: history and present status in Europe. Envir. Poll. 60: 101-139.

Oh, Y.N. and T.S. Chon. 1991. A study on the benthic macroinvertebrates in the middle reaches of Paenae stream, a tributary of the Naktong River, Korea. II. Comparison of communities and environments at the upper and lower sites of levees. Korean J. Ecol. 14: 399-413.

Ott, W.R. 1978. Environmental indices, Ann Arbor Science, Michigan, pp. 202-211.

Pantle, R. and H. Buck. 1955. Die biologische Uberwachung der Gewasser und die Darstellung der Ergebnisse. Gas und Wasserfach. 96: 604.

Pennak, R.W. 1978. Fresh-water invertebrates of the United States, 2nd Ed., John Wiley & Sons, New York.

Persoone, G. and N. De Pauw. 1979. Systems of biological indicators for water quality assessment. *In* O. Ravera (ed.), Biological aspects of freshwater pollution. Pergamon Press, Oxford. pp. 39-75.

Pinder, L.C.V., M. Ladle, T. Gledhill, J.A.B. Bass and A.M. Mathews. 1987. Biological surveillance of water quality. 1. A comparison of macroinvertebrate surveillance methods in relation to assessment of water quality in a chalk stream. Arch. Hydrobiol. 109: 207-226.

Ra, C.H. and Y.G. Cho. 1986. Ecological study on the aquatic insects in the Kwangyang stream. Korean J. Limnol. 19: 29-49.

Shen, Y. 1993. Evaluation of water pollution by using PFU method microbial communities in Hanjiang River, China. IDRC Report, Centre File: 91-0176-02.

Sladecek, V. 1973. The reality of three British biotic indices. Water Res. 7: 995-1002.

Spearman, C. 1904. The proof and measurement of association between two things. Am. J. Psychol. 15: 72-101.

Tolkamp, H.H. 1985. Using several indices for biological assessment of water quality in running water. Verh. Internat. Verein. Limnol. 22: 2281-2286.

Tsuda, M. 1962. Aquatic entomology. Hokuryo-kan Publishing Co., Tokyo.

Washington, H.G. 1984. Diversity, biotic and similarity indices - A review with special relevance to aquatic ecosystems. Water Res. 18: 653-694.

Wiggins, G.B. 1978. Larvae of the North American caddisfly genera (Trichoptera). University of Toronto Press, Toronto, Canada.

Woodiwiss, F.S. 1964. The biological system of stream classification used by the Trent River Board. Chem. Ind. 443-447.

Wright, J.F., P.D. Armitage, M.T. Furse and D. Moss. 1988. A new approach to the biological surveillance of river quality using macroinvertebrates. Verh. Internat. Verein. Limnol. 23: 1548-1552.

Yoon, I.B., K.S. Bae and D.S. Kong. 1987. A study on the physicochemical factors and macrozoobenthos community structure in Naktong estuary. Korean J. Limnol. 20: 73-99.

Yoon, I.B., S.J. Aw and K.H. Kim. 1986. A study on the benthic macroinvetebrate community structure of Tongchang stream in Chongdo-gun. Korean J. Limnol. 19: 97-107.

Yoon, I.B. 1978. Aquatic insects in the Han River system. Korean J. Envir. Prot. 13: 163-171.

Yoon, I.B. 1988. Illustrated encyclopedia of fauna & flora of Korea. Vol. 30, Aquatic Insects. Ministry of Education. 840p.

Yoon, I.B. and J.U. Byon. 1981. Biological and chemical analyses of the Han River system. Bull. Korean Assoc. Conser. Nature Ⅲ: 391-411.

Yoon, I.B., D.S. Kong and J.K. Ryu. 1992a. Studies on the biological evaluation of water quality by benthic macroinvertebrates (Ⅰ). Korean J. Envir. Biol. 10: 24-39.

Yoon, I.B., D.S. Kong and J.K. Ryu. 1992b. Studies on the biological evaluation of water quality by benthic macroinvertebrates (Ⅲ). Korean J. Envir. Biol. 10: 77-84.

Yoon, I.B. and J.I. Kim. 1992. Systematics on the larvae of crane flies (Tipulidae: Diptera) in Korea. Entomol. Res. Bull. (Korea) 18: 39-53.

(*Received September 25, 1998*)