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INDEX OF BIOLOGICAL INTEGRITY FOR WATER ENVIRONMENTAL ASSESSMENT OF NATURE-FRIENDLY RIVER WORK

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Abstract : Nature-friendly river project has become a common practice in Japan. In order to make it available for the conservation and rehabilitation of desirable water environment, water criteria for water environmental assessment must be established. Especially, the criteria estimating the effects on the ecosystem in and around river should be set up. In this paper, classification method for water quality has been developed using biological indices and applied to observed data in the Honmyo River, Nagasaki, Japan. Modified PI method (BI') has been suggested and those of three most abundant species resulted in effective estimate for an overall water quality with comparatively simple procedure. Extensive database management code was prepared for the comprehensive ecological monitoring of river basin, which includes various biota. That system offers easy access of all the ecological data for a dissemination of a sound and sustainable water environment. The result of this study could improve knowledge base, serve making consensus for citizens, and help river management plans. In Japan, citizen's realization and action are the most critical factor for nature-friendly river restoration project.

Key Words : The Homyo River, Nature-friendly river work, Modified PI Method

INTRODUCTION

Japan has been suffering from heavy rainfall due to Monsoon effect. Thus, flood control has been a major issue for river management from an ancient era. Japanese River Act was recently revised in 1997. Since its establishment 1896, this is the second revision, following to that in 1964.[1~2] Environmental management is one of the main themes emphasized in that River Act. About twenty years ago, river works were popular to introduce *amenity* to local citizens, such as a construction of park on a water front or river front space.[3] Construction works of habitat for fishes, fireflies, and other biota were also started.

Nowadays, nature-friendly river work has gradually become well known by Japanese. Its main purpose is to create sound and sustainable water environment based on ecosystem. For attaining this final goal, river should be managed through an appropriate manner, considering local history and natural feature. In this regard, many river restoration works have been introduced and/or under construction. However, in practice, there is very little qualitative information available for river restoration work. Thus, it becomes important to discuss that how we can appropriately estimate the impacts on water environment of the river restoration works, and how we should effectively disseminate knowledge of desirable water environment, strategies for a final goal, and so on.

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In order to carry out the above-mentioned matters, extensive field survey has been carried out in the Honmyo river which is classified A-class river in Japan. As this river flows into the Isahaya Bay with sea-dyke and reclamation pond, unsuitable river management could induce the deterioration of water quality such as eutrophication. Indices of water quality have been examined using the Index of Biological Integrity (IBI) for this study. Water environment has been diagnosed using biological indices. Water quality management could be effectively implemented by installing a comprehensive database system.

DIAGNOSIS OF WATER QUALITY USING THE BIOLOGICAL INDICES

Species in aquatic system changes in accordance to the quality of environment. Namely, intolerant flora and fauna to pollution appear in clear water, and vice versa. In this regard, the saprobic theory has been established based on aquatic benthos, which categorizes water into four major ranks; (1) oligosaprobic (os; unpolluted), (2) β-mesosaprobic (β-m; slightly polluted), (3) α-mesosaprobic (α-m; polluted), and (4) polysaprobic (ps; heavily polluted). Here, dominant species method, Biotic Index method (BI method, or Beck-Tsuda method), and Pollution Index method (PI method, or Pantle-Buck method) are well known as the classification of water quality.[4~5] These methods have relatively simple procedures. However, because of their simple structures, results of classification are sometimes not accurate. The first method classifies water quality using one species only, the second one sorts water quality degree by accounting the Biotic Index (BI) based on number of species. On the other hand, the third one carries out classification procedure based on both the numbers of species and individuals. In order to estimate overall water environment in river, PI method seems to be better than the others. Only this parameter is for pollution of water, so it has been defined as a modified parameter of BI' using the following equation.

$$BI' = \frac{\sum(S' \cdot h)}{\sum h} \qquad (1)$$

Where h is the number of individuals and S'is the degree of purity for species. Index, S' is ranked as 4 for os, 3 for β-m, 2 for α-m, and 1 for ps. Calculated BI' can be estimated using Table 1.

In general, a taxa richness or a degree of biological diversity increases in unpolluted water, so appropriate indices should be defined for its evaluation such as Shannon-Weaver function and Index of Biological Integrity (IBI). The former (H') is determined by the following equations.

There are many ways in which the data from biological surveys can be processed to assess the effects of pollution, the aim in general being to express the results in a concise yet meaningful form. One of the more widely used methods applied to benthic invertebrate samples is Shannon's species diversity index. This index takes into account the numbers of organisms of each species present in a given sample, the value being calculated from the equations :

$$H' = -\sum_{i=1}^{S}\left(\frac{q_i}{Q}\right)\ln\left(\frac{q_i}{Q}\right) \qquad (2)$$

Where H' is the species diversity index, S

Table 1. Relation between BI, BI' and water environmental condition

BI	BI'	Rank of saprobic condition	Water environmental condition
20 and over	4.0 - 3.25	Os(Oligosaprobic)	Unpolluted
11 - 19	3.25 - 2.5	β-m(β-mesosaprobic)	Slightly polluted
6 - 10	2.5 - 1.75	α-m(α-mesosaprobic)	Polluted
0 - 5	1.75 - 1.0	Ps(Polysaprobic)	Heavily polluted

number of species, q_i the number of organisms of species i^{th}, and $Q=\sum_{i=1}^{S} q_i$ i.e., the total number of organisms in the sample.

From Eq. (2),

$$H' = -\frac{1}{Q}\sum_{i=1}^{S} q_i \ln\frac{q_i}{Q} \tag{3}$$

$$H' = -\frac{1}{Q}\sum_{i=1}^{S} q_i\left[\ln(q_i) - \ln(Q)\right] \tag{4}$$

$$H' = -\frac{1}{Q}\sum_{i=1}^{S} \left[q_i \ln(q_i)\right] + \frac{\ln(Q)}{Q}\sum_{i=1}^{S}\left[q_i\right] \tag{5}$$

Because, $\sum_{i=1}^{S}[q_i] = Q$

$$H' = \ln(Q) - \frac{1}{Q}\sum_{i=1}^{S}\left[q_i \ln(q_i)\right] \tag{6}$$

After all, we used above Eq. (6) to calculate diversity index. The value has been known to be greatest in unpolluted rivers, decreasing with pollution to a value approaching zero. The data used for this paper were collected after river restoration from upstream started early 1994 to 2001. Then it may be too fast to estimate effect of river restoration. Though, there are many factors which could influence the value of this index as seasonal changes, the use of Shannon's diversity index is to become more widespread.

On the other hand, the concept of IBI was introduced in the latter part of 1980's in U.S.A.[6] This index shows a degree of integrity in streams using many biological indices as metrics. If we consider that water has been polluted mainly by artificial influence, species that are either tolerant or intolerant to pollution conditions can be analyzed using this metrics. In order to make the IBI available for the judgement of water quality, Morishita carried out the detailed investigation, and derived the criteria of judgement for water environment as scoring index for each metric (Table 2).

OUTLINE OF THE HONMYO RIVER AND ITS RIVERSIDE MANAGEMENT

Field observation of aquatic ecosystem has been carried out in the Honmyo River since 1990. This river is small sized urban river in A-class water quality with 21 km length and river basin of about 87 km^2. Because the project of sea-dyke and reclamation in Isahaya Bay is now under construction at the downstream of Honmyo River, the importance of river management should be emphasized. In this project, a regulation pond is also planned, aiming to the disaster prevention as well as creation of new land for agriculture. Because of the possible degradation of water quality in the regulation

Table 2. Scoring criteria of each metric(according to Morishita, 1996)

Metric	Score		
	1	3	5
1. Total taxa richness	0 - 13	14 - 26	> 27
2. Mayfly taxa richness	0 - 4	5 - 8	> 9
3. Caddisfly taxa richness	0 - 3	4 - 6	> 7
4. Clinger taxa richness	0 - 8	9 - 16	> 17
5. Intolerant taxa richness	0 - 9	10 - 17	> 18
6. Tolerant organisms (%)	> 16	16>X> 4	< 4
7. Legless organisms (%)	> 40	40>X> 4	< 4
8. Mud burrowers (%)	> 38	38>X>19	< 19
9. Oligochaeta (%)	> 20	20>X> 6	< 6
10. 3 most abundant taxa (%)	> 82	82>X>42	< 42

pond, the other studies are also being carried out to investigate the effects on water environment by construction of sea dyke.[7~10] Elaborate strategy for prevention of water pollution in the pond should be provided.

For accomplishment of desirable water environment including that of Honmyo river, lots of efforts should be devoted for the integrated management of the river and its basin, for example, suppression of runoff of untreated pollutants into the water, execution of river restoration work, and so on. Following to the prescribed history of river management, river restoration work has been carried out mainly from the end of 1980's. Situation is almost the same in the Honmyo River also. In Japan, existence of traditional river works called the willow tree work, wooden frame work, and others, is well known.[11] As described in the above section, similar river works have been constructed over the numerous Japanese rivers. At the same time, their influences on the water environment were discussed in the various points of view.

In the case of many river restoration works, it was started as a means of integrated flood control considering water quantity and quality. In practice, many facilities in watershed exist for flood control and purifying the pollutants flushed away from the watershed. In upstream of water-

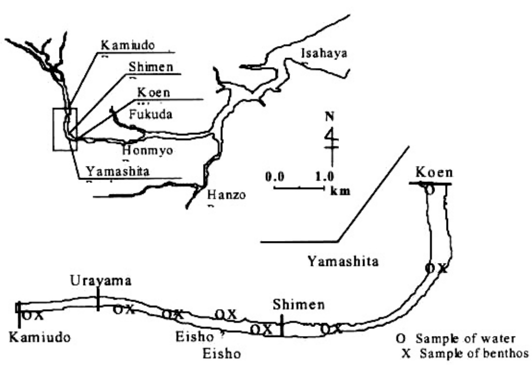

Figure 1. Schematic view of study area.

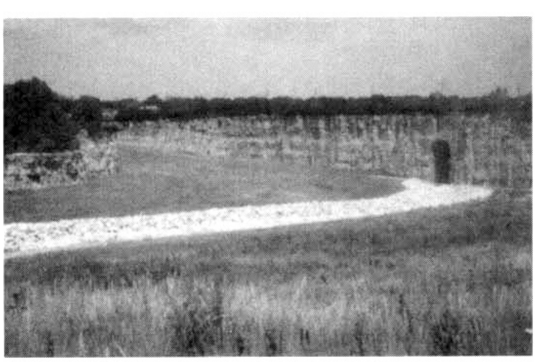

Figure 2. Regulation pond for flood control using wasted quarry.

Figure 3. Biotop for flood control and eco-system.

Figure 4. Purification pond (inflow).

Figure 5. Purification pond (outflow).

shed, regulation ponds(Fig. 2, Fig. 3) were build up to prevent flood damage in Honmyo river side and purification facility(Fig. 4) has been constructed for removing non-point source pollutants using a principle of deposition, filtering, biological change, and so on. These kinds of facilities will serve not only for the reduction of flooding damage, but also for the removal of pollutants from watershed.

ESTIMATION OF WATER ENVIRONMENT IN THE HONMYO RIVER

Extensive field observation has been carried out to estimate water environment in the Honmyo River. Biological indices have been compared with one another for the overall estimation of water environment. In Figure 6 and 7, spatial variations of water environment in a longitudinal direction are shown. For biological estimation, modified PI method (BI' method) has been compared with H' and IBI methods. In these figures, results are shown separately both on the left and right sides of stream. It becomes clear that water quality of the Honmyo River can be judged as slightly polluted, that is β-m or α-m. Difference between each result is not so large for categorizing the rank of water quality, but result derived by the dominant species method sometimes differs from the others. This is due to the fact that water quality is judged based upon only one species. Thus, the method of three most abundant species by counting individuals was ignored in this research.

In Figure 6, the longitudinal distribution of biological diversity was calculated by the Shannon-Weaver function and has been compared with those derived by BI' method. Both results are similar to one another for almost all cases. On the other hand, score of diagnosis in each observatory station has been counted in this reach using the Index of Biological Integrity, which is IBI (Table 3). Comparative result of BI' and IBI has been illustrated as shown in Figure 7, which shows a remarkable discrepancy

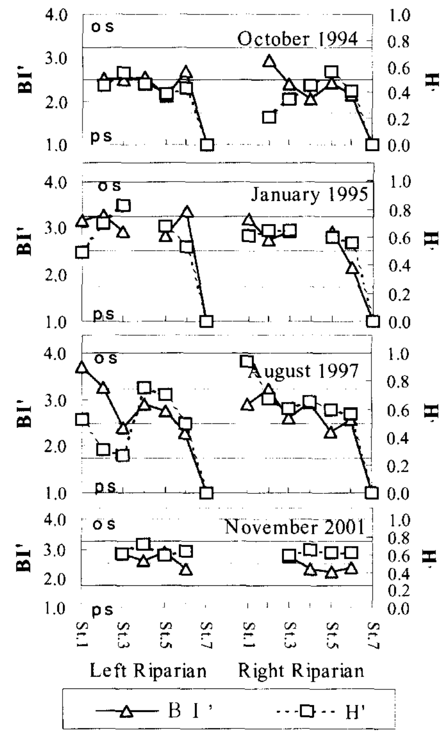

Figure 6. Water environmental classification in BI' and S-W function.

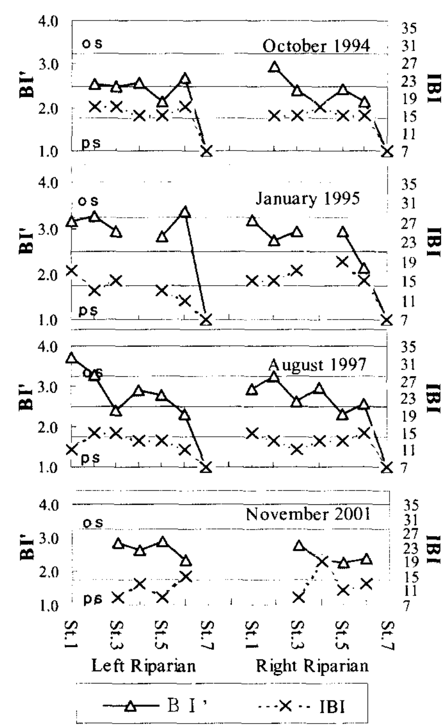

Figure 7. Water environmental classification in BI' and IBI.

Table 3. Score of diagnosis using IBI-J

Oct.-94	Left-Riparian							Right-Riparian						
	St.1	St.2	St.3	St.4	St.5	St.6	St.7	St.1	St.2	St.3	St.4	St.5	St.6	St.7
Total taxa richness		1	1	1	1	1	1		1	1	1	1	1	1
Intolerant taxa richness		1	1	1	1	1	1		1	1	1	1	1	1
Percentage of tolerant organisms(%)		1	1	1	1	1	1		1	1	1	1	1	1
Percentage of legless richness(%)		3	3	1	1	3	1		1	1	3	1	1	1
Percentage of mud burrowers(%)		5	5	5	5	5	1		5	5	5	5	5	1
Percentage of oligochaeta (%)		5	5	5	5	5	1		5	5	5	5	5	1
Percentage of 3 most abundant taxa(%)		1	1	1	1	1	1		1	1	1	1	1	1
Total score		17	17	15	15	17	7		15	15	17	15	15	7
Jan.-95	Left-Riparian							Right-Riparian						
	St.1	St.2	St.3	St.4	St.5	St.6	St.7	St.1	St.2	St.3	St.4	St.5	St.6	St.7
Total taxa richness	1	1	1		1	1	1	1	1	1		1	1	1
Intolerant taxa richness	1	1	1		1	1	1	1	1	1		1	1	1
Percentage of tolerant organisms(%)	1	1	1		1	1	1	1	1	1		1	1	1
Percentage of legless richness(%)	3	1	1		1	1	1	3	1	1		3	1	1
Percentage of mud burrowers(%)	5	1	3		1	1	1	3	5	5		5	5	1
Percentage of oligochaeta (%)	5	5	5		5	5	1	5	5	5		5	5	1
Percentage of 3 most abundant taxa(%)	1	3	3		3	1	1	1	1	3		3	1	1
Total score	17	13	15		13	11	7	15	15	17		19	15	7
Aug.-97	Left-Riparian							Right-Riparian						
	St.1	St.2	St.3	St.4	St.5	St.6	St.7	St.1	St.2	St.3	St.4	St.5	St.6	St.7
Total taxa richness	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Intolerant taxa richness	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Percentage of tolerant organisms(%)	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Percentage of legless richness(%)	1	3	1	1	1	1	1	1	1	1	1	1	3	1
Percentage of mud burrowers(%)	1	3	5	1	1	1	1	5	1	5	1	3	3	1
Percentage of oligochaeta (%)	5	5	5	5	5	5	1	3	5	1	5	5	5	1
Percentage of 3 most abundant taxa(%)	1	1	1	3	3	1	1	3	3	1	3	1	1	1
Total score	11	15	15	13	13	11	7	15	13	11	13	13	15	7
Nov.-01	Left-Riparian							Right-Riparian						
	St.1	St.2	St.3	St.4	St.5	St.6	St.7	St.1	St.2	St.3	St.4	St.5	St.6	St.7
Total taxa richness			1	1	1	1				1	1	1	1	
Intolerant taxa richness			1	1	1	1				1	1	1	1	
Percentage of tolerant organisms(%)			1	1	1	1				1	1	1	1	
Percentage of legless richness(%)			1	1	1	1				1	3	1	1	
Percentage of mud burrowers(%)			1	3	1	3				1	5	1	3	
Percentage of oligochaeta (%)			1	3	1	5				1	5	3	3	
Percentage of 3 most abundant taxa(%)			3	3	3	3				3	3	3	3	
Total score			9	13	9	15				9	19	11	13	

between both results. In spite of this result, water quality in Honmyo River seems to be slightly polluted as described before. Further investigation of an appropriate number of metrics and name of species in IBI needs to be carried out.

CONCLUSIONS

Effective biological classification method has been suggested to evaluate overall water environment and applied to river restoration work of Honmyo River. Some comments are with respect to the sound and sustainable water environment in and around river. The importance of effective monitoring is stressed, including appropriate dissemination strategy for the creation of desirable water environment. This study can be summarized as follows:

1) Diagnosis using Biological Index is useful to estimate water environment, and to monitor water quality for river restoration work.
2) It will be cost-effective and further effects can be expected if associated with chemical

ones.

3) River management utilizing these informations would improve the knowledge base, serves making consensus for citizens, and helps to refine the management plans.
4) It should be emphasized that river environment be managed based upon local history, long term planning, and integral conservation of river and its watershed.

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