Ecological co-inhabitance index (ECI) as a management tool for ecosystem preservation in rivers

C. Yoshimura, Y. Kumagai, K. Fukushi and T. Omura
Department of Civil Engineering, Graduate School of Engineering, Tohoku University, Aoba-yama 06, Sendai 980–8579, JAPAN

Abstract The number of novel man-made hazardous substances produced by industries is increasing year after year, resulting in conventional discharge standards ineffective to preserve the natural ecological environment. A novel index, ecological co-inhabitance index (ECI), was proposed in order to evaluate the river ecosystem sensitively. The river benthic community with a high value of ECI is formed in the healthy ecosystem where benthic animals can share resources in the river environment efficiently, keep the ecosystem functioning, and give the least adverse effect to lower reaches of the river. In order to clarify the characteristic of ECI, the relationship between ECI and water quality in the river was investigated using the data on benthic animals obtained from 17 various rivers. Results of this investigation indicated that ECI could synthetically evaluate the river environment without a bias toward a specific water quality. Moreover, ECI had the significant correlation coefficients with diversity index, biotic index and pollution index at significance level 0.05, respectively. Therefore, ECI is a promising index for managing the river ecosystem.
Keywords Benthic community; ecological co-inhabitance index (ECI); management; river ecosystem; river water quality

Introduction

In the past several years, there has been increasing interest in the environmental pollution due to chemical substances that were created by industries. For example, effects of endocrine disrupting chemicals (Colborne *et al.*, 1996), dioxins (Tanaka, 1997), and by-products of disinfection (Aizawa, 1993; Blatchley *et al.*, 1997) on the river ecosystem were reported. According to the diversification of man-made hazardous substances, the Environment Agency in Japan are increasing the number of water quality items on the effluent discharge standard. However, this standard cannot control effects of hazardous substances on river ecosystems, though it can control the concentration of each hazardous substance in the river. Furthermore, the destruction or the fragmentation of the river ecosystem caused by the exposure of various hazardous substances to the river environment should be avoided so that human society can keep the good relationship with the river ecosystem (Cairns and Niederlehner, 1995). Therefore, it is important that the river environment is evaluated from the viewpoint of composition, structure and function of the river ecosystem (Cummins, 1974; Noss, 1990; Kerans and Karr, 1994; Kelly, 1998).

Authors have developed a novel monitoring index with ecological co-inhabitance index (ECI) (Yoshimura *et al.*, 1999) to detect unknown pollutants sensitively. The river benthic community with a high value of ECI is formed in the healthy ecosystem where benthic animals can share resources in the river environment efficiently, keep the ecosystem functioning, and give the least adverse effect to lower reaches of the river (Morishita and Rossano, 1997). Therefore, ECI has the possibility to be a better management tool for making a decision to improve the river ecosystem than other biological indices when a river ecosystem would be regarded as an unhealthy ecosystem. In this research, in order to clarify this possibility, the relationship between ECI and water quality in the river was investigated using the data on benthic animals obtained from 17 various rivers. Moreover,

Water Science and Technology **Vol 43 No2 pp 161–170**

advantages for evaluating river ecosystems with ECI were exhibited by the comparison between ECI and biological indices.

Ecological Co-inhabitance Index (ECI)

Ecological co-inhabitance index (Yoshimura *et al.*, 1999) was developed in order to detect effects of hazardous substances on river ecosystems. Benthic animals living on the riverbed were selected as test organisms because they were known to be sensitive for environmental change (Hatakeyama, 1988; Kerans and Karr, 1994). The benthic community that has steadily succeeded to a climax without the exposure of hazardous substances will have the high value of ECI. Conversely, the evaluation of river ecosystems with ECI can indicate community changes due to hazardous substances in the river water. Ecological co-inhabitance index comprises four parameters of the diversity index of Simpson (1949) (D), the ecosystem function (F), the stability of the ecosystem (S), and the adverse effect on the outside of the system (E). Odum (1985) also pointed out some trends of ecosystem changes when ecosystems suffered from the exposure of hazardous substances. These trends were related to changes in energy, nutrient cycling, and community structure and function. That is, taking into account these trends between hazardous substances and ecosystems, ECI would be considered as a management tool for the ecosystem preservation in the river.

The diversity index of Simpson (D) indicates the most important aspect because the species diversity can exhibit the efficiency of resource use and the intensity of co-inhabitance and competitions among species. The diversity index of Simpson is calculated by the number of species and the total number of individuals as:

$$D = 1 - \sum_{i=1}^{M} \left(\frac{n_i}{N} \right)^2 \tag{1}$$

where M is the total number of species, n_i is the number of the species i, and N is the total number of individuals. A high value of D means a high diversity and a high efficiency use of resources in the community.

The ecosystem function (F) involves the number of stages of a food chain because this aspect of ecosystem is deeply related to preserving a nutrient cycle system and species. When the river benthic community is investigated, this parameter can be achieved by the rate of carnivores (e.g., Plecoptera, Odonata, etc.) in the benthic community as:

$$F = \frac{3x}{N} \tag{2}$$

where x is the number of carnivores in the benthic community, and N is the total individual number of benthic community. As the rate of carnivores in this parameter of the ecosystem function (F) used to be within one third, the coefficient was decided to be three so that the value of F should be dropped between zero to unity. The high value of F indicates that the environment ensures ecosystem function such as the nutrient cycle system.

When the water quality in the river is kept at the normal quality for the benthic community, the river ecosystem would be stable and succeed to the climax (the last stage of the succession) where *K*-strategy species dominate the river benthic community. The rate of *K*-strategy individuals in the benthic community indicates how close to the climax the benthic community is. In case of the river benthic community, *K*-strategists belonging to net-spinner species consist of six families of Hydropsychidae, Stenopsychidae, Philopotamidae, Polycentropidae, Psychomyiidae and Kitagamiidae (Takekado *et al.*, 1995; Mizuno and Gose, 1972). Thus, the third parameter of the stability of the ecosystem (S) can be achieved by the rate of these species in the benthic community as:

$$S = \frac{y}{N} \tag{3}$$

where y is the individual number of net spinner species, and N is the total number of individuals.

The adverse effect on the outside of the system means how the benthic community gives a harmful influence to the lower reach community. There are a lot of factors harmful influences such as the oxygen consumption and metabolites. In this parameter, the oxygen consumption is considered as a typical factor. Generally, a heavy benthic animal consumes less volume of oxygen per unit weight than a light one (Mizuno and Gose, 1972). And it's known that the weight is roughly proportional to the body length. These relationships indicate that the oxygen consumption per unit weight can be decided by the body length. Therefore, the mean body length of all individuals was defined as the factor showing the adverse effect to outside of the system (*E*). In order to simplify the calculation of this parameter, body lengths of all species are referred to in identification manuals (Koda *et al.*, 1984). The equation (4) which is expressed in terms of the mean body length is used for calculating the adverse effect on the outside of the system (*E*) where *z* is the mean body length, and *L* is the body length of the typical benthic animal.

$$E = \frac{1}{1 + \exp[-0.5(z - L)]} \tag{4}$$

In this research, L was given the value 10 mm because the body length of the typical benthic animal in Japan was about 10 mm. Therefore, a high value of *E* indicates that the adverse effect on the outside is little. The coefficient 0.5 in the equation (4) was decided because the sensitivities of these four parameter (*D*, *F*, *S*, and *E*) were almost even.

The proposed index, *ECI*, consists of these four parameters (ranging 0 to 1) based on the information of the benthic community composition as shown in Table 1. If parameters should be high, the river ecosystem would be considered to be healthy. When four parameters are plotted on the radar graph with four axes, the area of the quadrilateral surrounded by four points is defined as *ECI* in evaluating the state of the ecosystem. The equation for *ECI* is

$$ECI = \frac{1}{2}(D \cdot S + S \cdot F + F \cdot E + E \cdot D) \tag{5}$$

where *D*, *S*, *F*, and *E* are four parameters. Since *F* is significantly related to the species diversity, *D* and *F* were placed in opposite directions in order to give the effect of species diversity to all four triangles on the radar graph. An example for calculating *ECI* was illustrated in Figure 1. When no benthic animal was sampled, *ECI* and four parameters were decided as zero.

The criteria for the ECI evaluation was established by the investigation on the benthic communities in the Taru river in Japan as shown in Table 2. The Taru river is a typical natural river and could be considered as a standard river which had the ordinarily healthy ecosystem. The river ecosystem with the higher value of ECI than the maximum value of ECI (0.15) in the Taru river is categorized as level 3. The river environment with level 3 will be looked upon as a better one. Conversely, the river ecosystem with the lower value of

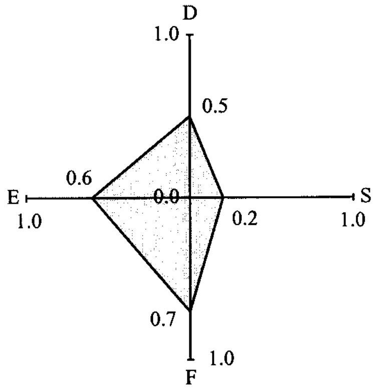

Figure 1 An example of the evaluation from the viewpoint of ecological co-inhabitance

ECI than the minimum value of ECI (0.025) in the Taru river is categorized as level 1. The river environment with level 1 will be looked upon a worse one. And the middle value of ECI between the maximum and the minimum is categorized as level 2. The river environment with level 2 will be looked upon as a normal one. Furthermore, four parameters (D, F, S, and E) will be additionally utilized when the river ecosystem is evaluated by ECI. Values of these parameters obtained from the Taru river are shown as a standard in Table 1.

Material and methods

The sampling protocol of benthic animals

As the condition of the riverbed decided the benthic community composition (Tanaka 1958; Nakajima *et al*., 1984), the sampling point for evaluating with ECI was fixed at the rapids in a river. The velocity of the river flow at the sampling point was about 0.5 m/sec. And the sampling of benthic animals was conducted in the area over 0.25 m^2 of a riverbed with a surber net. Thus, the value of ECI can evaluate the effect of the water quality on the

Table 1 Meanings of four parameters

Parameter	Diversity index of Simpson	Ecosystem function	Stability of the ecosystem	Adverse effect to outside of the system
Score	D	F	S	E
Sense	Intensity of co-inhabitance and competition Efficiency of resource use	Preservation of the system of a nutrient cycle Preservation of species	Normal range of water quality	Formation and adjustment of the environment as a habitat
Value of parameter	Diversity of species	Number of stages of a food chain	Degree to climax	Volume of breath in a community
Standard value*	0.62	0.0048	0.16	0.094
ECI	ECI = (D S + S F + F E + E D)/2			

*These values are based on the evaluation of the Taru river in Japan

Table 2 The criteria of the evaluation with ECI

Level	ECI	River ecosystem	River environment
1 ★	<0.025	not healthy	polluted
2 ★★	0.025 < ECI < 0.15	ordinarily healthy	normal
3 ★★★	>0.15	healthy	better

benthic community, exclusive of any other physical factors. Benthic animals except chironomidae were identified with a taxa of species. As it was very difficult to classify chironomidae into a taxa of species, it was regarded as one species.

Rivers selected for the evaluation with ECI

Total 241 points in 17 rivers shown in Table 3 were selected for the evaluation with ECI in Japan. The sampling of benthic animals in these rivers was conducted according to the above protocols. The data of benthic communities and water qualities obtained from investigations in these rivers were used for the analysis of relationships between ECI and other water qualities. Eight of these rivers did not received any kind of discharges, while other rivers received the discharge from sewage, agriculture, or mine. The data of benthic communities and water qualities from 13 rivers except the Kitakami river, the Oh river, the Tsunaki river and the Mirumae river were based on references as shown in Table 3.

Analysis between ECI and water quality

34 water qualities (organic matter, nutrient, metal, bacteria, etc.) and 3 biological indices were used for analysis as shown in Table 5. Investigations of water qualities in the Kitakami river, the Oh river, the Tsunaki river and the Mirumae river were conducted with Standard Methods (1993). The diversity index of Simpson, biotic index and pollution index (Tsuda and Morishita, 1974) were considered as biological indices. Population size (the total number of individuals), the total number of species and the standing crop in 1.0 m^2 were also considered as biological parameters. Relationships between ECI and these parameters were studied by means of correlation analysis and principal component analysis. In the correlation analysis, the null hypothesis that population correlation coefficient between ECI and these parameters was equal to zero was tested at a significance level 0.05 or 0.01.

Results and discussion

Relationship between ECI and the composition of the benthic community

The result of the correlation analysis between ECI and the composition of the benthic community was shown in Table 4. Ecological co-inhabitance index had the positive correlation coefficient (0.24) with the total number of species and the negative correlation coefficient (-0.18) with population size at significance level 0.01, respectively. As the total number of species in the benthic community increases in the case that the benthic community is healthy, the positive correlation coefficient between ECI and the total number of species means that ECI can evaluate whether the benthic community is healthy or not. However, the river environment where a few species of benthic animals are predominant used to be unfavorable from the viewpoint of the river ecosystem. In this case, the population size is quite large because of the supplement of nutrient and organic matter from various discharges. Therefore, it is natural that there should be the negative correlation between ECI and the population size. These facts indicate that ECI can reflect the actual population dynamics created in the river environment. There was no significant correlation between ECI and standing crop because the weight of a benthic animal was varied with species, instar, etc. Therefore, standing crop does not play an important role in evaluating the river ecosystem with ECI.

Moreover, parameters D and S had significant correlation coefficients with the composition of the benthic community, though parameters F and E did not have. Thus, the species diversity that is the most important aspect of the ecosystem is reflected by parameters D and S. As *K*-strategy species could inhabit only the benthic community with high species diversity, the parameter S was related to the total number of species. Parameters E and F are essential factors in ECI, but these parameter did not have any correlation with the composi-

Table 3 Rivers selected for the evaluation with ECI

River	Prefecture	Types of main discharges	Point of investigation	Number of sampling points	Period of investigation	Reference
The Taru river	Nagano	None	middle stream	1	Mar. 1968–Mar. 1974	(Komatsu, 1975)
The Hiki river	Wakayama	None	from upper to lower stream	6	Mar. 1973–Dec. 1973	(Maki, 1980)
the Se river	Nagasaki	None	from upper to lower stream	7	Feb. 1975	(Machida and Ishizaki, 1975)
			from upper to lower stream		Jul. 1975	(Ishizaki and Machida, 1980)
The Yoshino river	Nara	None	middle stream	1	Mar. 1960–Jun. 1960	(Tsuda and Gose, 1964)
			middle stream		Aug. 1967	(Shinobu, 1968)
the Nyu river	Nara	None	middle stream	1	Aug. 1960	(Tsuda and Gose, 1964)
the Akino river	Nara	None	middle stream	1	Aug. 1961	(Tsuda and Gose, 1964)
the U river	Kyoto	None	from upper to lower stream	5	Aug. 1958	(Tezuka and Kamegai, 1960)
the Satsuki river	Nara	None	from upper to lower stream	3	Aug. 1956	(Tsuda and Watanabe, 1958)
the Kitakami river	Iwate, Miyagi	Agriculture	middle stream	1	Oct. 1995–Oct. 1996	
the Oh river	Iwate	Agriculture	from upper to middle stream	5	Jun. 1992–Aug. 1993	
the Hirose river	Miyagi	Agriculture, Sewage	from upper to lower stream	8	Sep. 1983–Oct. 1984	(Kanno *et al*. 1984)
the Murasaki river	Fukioka	Agriculture, Sewage	from upper to lower stream	9	Sep. 1984	(Ueda and Ogata, 1987)
the Tsunaki river	Miyagi	Sewage	discharge point	3	May 1997–Mar. 1998	
the Mirumae river	Iwate	Sewage	discharge point	3	Oct. 1995–Oct. 1996	
the Sasu river	Nagasaki	Mine	from upper to lower stream	12	Feb. 1975	(Machida and Ishizaki, 1975)
					Jul. 1975	(Ishizaki and Machida, 1980)
the Watarase river	Gumma	Mine	from upper to lower stream	19	Jul. 1964	(Ide *et al*., 1966)
					May and Sep. 1970	(Ide, 1971)
					Jul. 1973	(Ide and Arai, 1978)
the Aka river	Iwate	Mine	from upper to middle stream	6	Jun. 1997–Mar. 1998	(Kikuchi *et al*., 1988)

Table 4 Relationship between ECI and the composition of the benthic community

	ECI	D	F	S	E
Population size ($1/m^2$)	– –	– –		–	
Total number of species ($1/m^2$)	++	++		++	
Standing crop (mg/m^2)		+			

("++" and "+" stand for positive correlation coefficients at significant level 0.05 and 0.01, respectively.
"– –" and "–" stand for negative correlation coefficients at significant level 0.05 and 0.01, respectively.)

tion of the benthic community. This result means that ECI can evaluate the river ecosystem from another aspect except the composition of the benthic community. Therefore, ECI is a promising index for evaluating the river ecosystem from the aspect of the composition of the benthic community.

Relationship between ECI and water quality

As shown in Table 5, ECI did not have any significant relationship with specific water quality. Nevertheless, parameters D, F and E that were the main factors making ECI had significant correlations with various types of water qualities at significance level 0.05. This fact shows that water qualities in the river indirectly influence ECI through parameters D, F and E, and that the parameter S introduces the effects except for water quality into ECI. The parameter D was significantly related to organic matter and nitrogen components because the number of species decreased in the river where concentrations of organic matter and nutrient were high. And parameters F and E were significantly related to metals (Ca, Fe, Cr, etc.). These results indicate that organic matter, nutrient and metal give harmful effects to the river ecosystem. Therefore, it is difficult to evaluate with water qualities in Table 5 whether the river ecosystem is healthy or not. Because ECI is not related to water qualities in the river water in Table 5. Since four parameters D, F, S and E influence ECI, this ECI enables us to evaluate the river ecosystem synthetically without a bias toward a specific water quality.

Table 5 Relationship between ECI and water quality

	ECI	D	F	S	E		ECI	D	F	S	E
Water temperature		++	+			Ca			–		–
DO						Fe			–		–
DOS*						As		–			–
SS						Cd					
Alkalinity						Cr			–		–
Hardness		+				Cu					–
pH						Pb					
TOC		– –				Mn			–		
BOD		– –	–			Ni			–		
COD			–			Zn					–
NO_3-N		– –				Cl-					
NO_2-N		– –				Residual chlorine		– –			
NH_4-N		– –				SO_4^{2-}		+			
T-N		– –				SiO_2		–	–		
PO_4-P		–	–			Total bacteria					
T-P						Coliform group					
Al						Enterococcus group		+	++		

*Degree of oxygen saturation
("++" and "+" stand for positive correlation coefficients at significant level 0.05 and 0.01, respectively.
"– –" and "–" stand for negative correlation coefficients at significant level 0.05 and 0.01, respectively.)

On the other hand, Figure 2 shows the result of the principal component analysis concerning ECI and ten kinds of water qualities. These water qualities were pH, SS, organic matter and nutrients. From this result, nitrogen components, organic matter and pH significantly contributed to the first principal component. These water qualities can be evaluated by the diversity index (the parameter D) as shown in Table 5. They also can be evaluated by Saprobien system (e.g., biotic index, pollution index, etc.) (Tsuda and Morishita, 1974). However, in the second principal component, ECI and phosphorus components had a larger factor loading than organic matter and nitrogen components. And the third principal component is regarded as the aspect represented by the physical water qualities. Thus, the second principal component related to ECI was almost independent of most of water qualities. This result will be supported by the previous outcome that there was no correlation between ECI and water qualities.

Relationships between ECI and other biological indices

Biotic index (BI) and pollution index (PI) were taken up for contrasting with ECI. As shown in Table 6, there was the negative correlation coefficient (-0.50) between ECI and pollution index at significance level 0.01. And ECI had the positive correlation (0.44) with biotic index. These results indicate that ECI can sufficiently reflect the aspect of the river ecosystem evaluated with Saprobien system. Regression formulas obtained from Table 6 were BI = 29ECI + 10 and PI = -3.6ECI + 2.7. Based on these regression formulas, Figure 3 was prepared. In this figure, 0.025 of ECI (the standard value) corresponds to 11 of biotic index and 2.6 of pollution index. On the other hand, 0.15 of ECI corresponds to 14 of biotic index and 2.2 of pollution index. That is, two standard values of ECI (0.025 and 0.15) are regarded as beta and alpha mesosaprobic of Saprobien system, respectively. Results obtained from benthic communities in the Mirumae river at the sewage discharge point (not healthy), the Kitakami river (ordinarily healthy) and the Hirose river at the uppermost stream (healthy) were also represented in Figure 3. The Mirumae river was polluted by the sewage effluent. The Kitakami river was slightly polluted by the discharge from agriculture. And the Hirose river at the uppermost stream was out of pollution. So, characteristics of these river ecosystems were properly evaluated with ECI though biotic index and pollution index did not show proper values of these river ecosystems. Therefore, ECI is regarded as a more inclusive index than these biological indices.

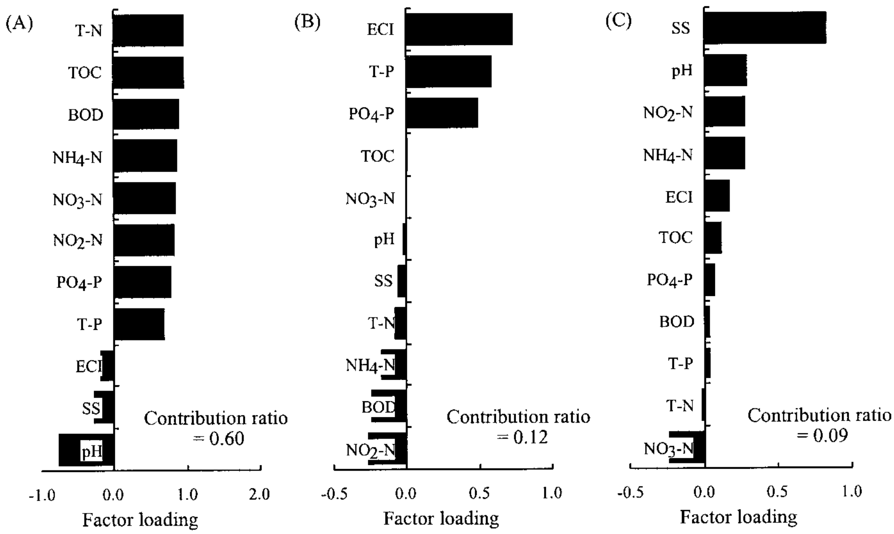

Figure 2 Factor loadings of (A) first, (B) second, (C) third principal component

Table 6 Relationships between ECI and biological indices

	ECI	D	F	S	E
Biotic index	++	++		++	++
Pollution Index	−−	−−	−−	−−	

("++" and "−−" stand for positive and negative correlation coefficients at significant level 0.01, respectively.)

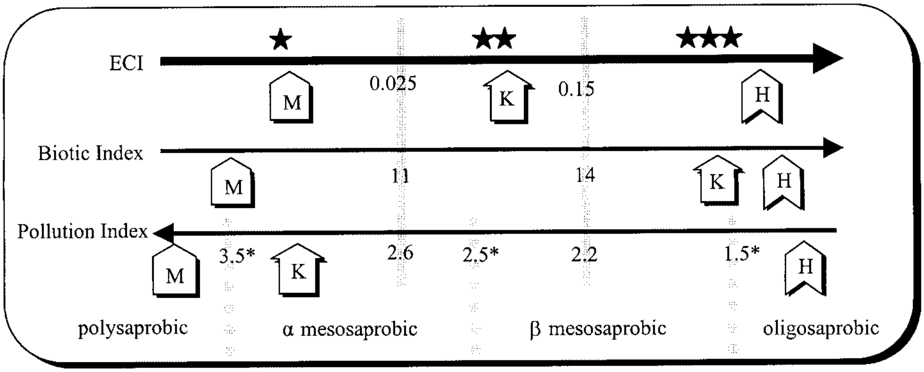

Figure 3 Relationships among ECI, biotic index (BI) and pollution index (PI) based on regression formulas (BI = 29ECI + 10 and PI = -3.6ECI + 2.7). Letters M, K and H stand for results obtained from benthic communities in the Mirumae river at the sewage discharge point, the Kitakami river and the Hirose river at the uppermost stream, respectively. * These numbers were based on the reference Tsuda and Morishita (1974)

Conclusions

Conclusions obtained in this study were as follows:

(1) Ecological co-inhabitance index is promising for managing the river ecosystem.
(2) Using ECI, the river ecosystem could be synthetically evaluated without a bias toward a specific water quality.
(3) Ecological co-inhabitance index had significant correlations with diversity index and biotic index and pollution index at significance level 0.01 (0.50, 0.44 and -0.50, respectively).
(4) Ecological co-inhabitance index is regarded as a more inclusive index for evaluating the river ecosystem than biotic index and pollution index.

Reference

Aizawa, T. (1993) Characterization of chlorination by-products. *Japan Journal of Water Pollution Research*, **16**(12), 830–835 (in Japanese).

Blatchley III, E. R., Hunt, B. A., Dugirala, R., Thompson, J. E., Zhao, J., Halaby, T., Cowger, R. L., Straub, C. M., and Alleman J. E. (1997). Effects of disinfectants on wastewater effluent toxicity. *Wat. Res.*, **31**(7), 1581–1588.

Cairns, John Jr. and Niederlehner, B. R. (1995). Ecosystem health concepts as a management tool. *Journal of Aquatic Ecosystem health*, **4**, 91–95.

Colborne, T., Dumanoski, D. and Myers, J. P. (1996). *Our Stolen Future*. Dutton, New York, USA.

Cummins, K. W. (1974). Structure and functin of stream ecosystems. *BioScience*, **24**(11), 631–641.

Hatakeyama, N. (1988). Methods for estimating the toxicity of chemicals to zooplankton and benthic organisms. *Japan Journal of Water Pollution Research*, **11**(11), 676–680 (in Japanese).

Ide, Y. (1971). Aquatic insects in the Watarase river. *Journal of Water and Weste*, **13**(12), 1488–1498 (in Japanese).

Ide, Y. and Arai, T. (1978). Annual change of the benthic community in the Watarase river. *Journal of Water and Waste*, **20**(3), 301–314 (in Japanese).

Ide, Y., Fukushima, H. and Morita, Y. (1966). Limnological study in the Watarase river. *Journal of Water and Waste*, **8**(12), 842–856 (in Japanese).

Ishizaki, S. and Machida, Y. (1980). On the benthic fauna of some river systems in the Nagasaki district (4) the Sasu and the Se rivers of Tsushima in winter. *Japanese Journal of Limnology*, **41**(1), 19–23 (in Japanese).

Kanno, T., Taguchi, S., Satake, T. and Seki, T. (1984). Biological investigation of water in the Hirose river (the third report). *Report of the Sendai Municipal Institute of Public Health*, **14**, 381-389 (in Japanese).

Kelly, M. G. (1998). Use of the trophic diatom index to monitor eutrophication in rivers. *Wat. Res.*, **32**(1), 236–242.

Kerans, B. L. and Karr, James R. (1994). A benthic index of biotic integrity (B-IBI) for rivers of the Tennessee valley. *Ecological Applications*, **4**(4), 768–785.

Kikuchi, K., Ito A., Kitada, K., Aizawa, J. and Umita, T. (1998). Water environment in the river Akagawa receiving the effluent from a mine drainage treatment wastewater. *Environmental Engineering Research*, **35**, 273–284 (in Japanese).

Koda, K. *et al.* (1984). *Illustrated Insect Larvae of Japan*. Hokuryu-kan, Tokyo, Japan (in Japanese).

Komatsu, T. (1975). The seasonal and the annual changes of benthic communities of the climax in rapids of the stream. Japanese *Journal of Ecology*, **25**(3), 160–172 (in Japanese).

Machida, Y. and Ishizaki, S. (1975). On the benthic fauna of some river systems in the Nagasaki district (1) the Sasu and the Se rivers of Tsushima in winter. *Japanese Journal of Limnology*, **36**(4), 122–130 (in Japanese).

Maki, I. (1980). On macro-benthic communities in the middle and down stream of the river Kikigawa, Wakayama prefecture – 1, comparisons of the community structure between different riverbed types, sampling sites and seasons. *Japanese Journal of Limnology*, **41**(1), 24–40 (in Japanese).

Mizuno, N. and Gose, K. (1972). *Ecology in River*. Tsukijisyokan, Tokyo, Japan (in Japanese).

Morishita, I. and Rossano E. M. (1997). *Stream Organisms in Japan*. Sankaido, Tokyo, Japan.

Nakajima, S., Oda, T. and Matsunami, Y. (1984). Interrelationship between some environmental factors of riverbed gravels and pollution index of bottom fauna in the river. *Japanese Journal of Limnology*, **45**(3), 220–230 (in Japanese).

Noss, F. R. (1990). Indicators for monitoring biodiversity: A hierarchical approach. *Consevation Biology*, **4**(4), 355–364.

Odum, E. P. (1985). Trends expected in stressed ecosystems. *BioScience*, **35**(7), 419-422.

Shinobu, T. (1968). Minimum area in the quantitative sampling of aquatic insects. *Biology of Inland Waters*, **1**, 13–15 (in Japanese).

Simpson, E. H. (1949). Measurement of diversity. *Nature*, **163**(4148), 688.

Standard Methods for the Examination of Water (1993). Japan water works association, Tokyo, Japan (in Japanese).

Takekado, Y., Takeda, K., Tamaki, A., Murai, H. and Kawabata, Z. (1995). *Ecology of Habitat*. Heibonsya, Tokyo, Japan (in Japanese).

Tanaka, M. (1958). On the standing crops of benthic insects in different bottom types of a river. *Journal of Fresh Water*, **8**(1), 15–26 (in Japanese).

Tanaka, S. (1997). Environmental pollution due to chemicals created accidentally. *Journal of Water and Waste*, **39**(5), 381 (in Japanese).

Tezuka, Y. and Kamegai, K. (1960). On the benthic algae and aquatic insects of the Ukawa river in 1958. *Japanese Journal of Ecology*, **10**(5), 201–207 (in Japanese).

Tsuda, M. and Gose, K. (1964). On the succession of aquatic insect communities in rapids of the river. *Physiology and Ecology*, **2**(1), 243–251 (in Japanese).

Tsuda, M. and Morishita, I. (1974). Biotic index and pollution index. *Water Purification and Liquid Wastes Treatment*, **15**(5), 457–462 (in Japanese).

Tsuda, M. and Watanabe, T. (1958). Ecological study on the algae and the aquatic insects of Satsuki-gawa, Tsukigase-mura, Nara prefecture. *Japanese Journal of Ecology*, **8**(1), 43–49 (in Japanese).

Ueda, N. and Ogata, S. (1987). Evaluation of water in a municipal river by benthic community and algae. *Journal of Water and Waste*, **29**(6), 537–542 (in Japanese).

Yoshimura, C., Kumagai, Y., Fukushi, K. and Omura, T. (1999). Evaluation of water environment in rivers by the ecologicalco-inhabitance index (ECI) based on the information on benthic communities composition. *Proceedings of 7th IAWQ Asia-Pacific Regional Conference*, 1381–1386.