EVALUATION OF WATER QUALITY IN AQUATIC ECOSYSTEMS

Harukuni Tachibana
Hokkaido University, Sapporo, Japan

Toshiro Maruyama
Miyazaki University, Miyazaki, Japan

Yasumoto Magara
Hokkaido University, Sapporo, Japan

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Contents

Summary

To maintain the water environment in a favorable state, a sound and stable ecosystem is essential. In other words, ecosystems are qualitative indicators of the water environment because their formation depends on that environment. In studies on the relationship between water environment and ecosystems, Kolkwitz and Marrson summarized, in 1909, the relation between the aquatic environment and ecology as a saprobity system of water quality. The biological indicator table, created based on the saprobity system, categorizes biological, physical, and chemical characteristics according to a four-group hierarchy of water quality pollution.

Because of the evidence that species structure of the diatom community is affected by the organic pollution level of the river in where located in middle to high latitude regions, the Diatom Assemblage Index of pollution (DAIpo) is applied to give the numerical parameter of the organic pollution level. These general phenomena of conventional water pollution such as oxygen depletion, contamination, acute toxicity, etc., which relate directly to factors responsible for life and death of biota, are assessed by the saprobity system.

While focus of research has shifted from ecological systems to chemical substances, the saprobity system provides an important approach to understand the effect of water pollution. Recent water quality standards reflect a shift of consciousness of the water environment to that focusing on toxicity of specific pollutants such as persistent organic

chemicals (POPs) and inorganic chemicals in the water environment, from that focusing on general phenomena of organic pollution. Therefore, in order to protect aquatic life many countries have developed water quality criteria for specific pollutants such as zinc, cadmium and so on based on the results of biological toxicity tests.

The toxicity of unidentified pollutants can be evaluated by bioassay system to know the general toxicity of them in water. Nori plant (*Porphyra yezoensis*, edible laver seaweed), that is cultivated in estuarine water bodies where is affected by nutrients and pollutants flowed in river water. Therefore, as an example, the bioassay system using Nori plant for the evaluation of municipal sewage effluent was developed. From this test the growth inhibition of. Monochloramine (NH_2Cl) was found to be more toxic to Nori plant than free chlorine, which is the opposite of the sensitivity found in microorganisms.

1. Introduction

In order to maintain the water environment in a favorable state, a sound and stable ecosystem is essential. Indeed, ecosystems are qualitative indicators of the aquatic environment because their formation depends on that environment: Destruction of a healthy ecosystem means destruction of the environment itself. In order to preserve the health of ecosystems, the relationship between ecosystems and water quality, which governs the life of animals, must be clarified. Also, an understanding of the healthy state of aquatic ecosystems requires clarification of their relationships regarding amounts of water, bottom sediment, and the catchment basin environment, as well as the interactions between living communities that constitute ecosystems.

2. Saprobity system

In studies on the relation between the aquatic environment and ecology, the German researchers Kolkwitz and Marrson summarized, in 1909, the relation between the aquatic environment and ecology as a saprobity system of water quality. Their method focuses on the phenomenon whereby the community structure of algae, protozoa, bacteria and fungi living in a riverbed corresponds to water quality. The method is also occasionally applied to organisms attached to gravel in lakes.

In other words, the state of a biological community, or ecosystem, varies with the state of pollution of that water environment. They adopted algae as a biological indicator in their attempt to evaluate the biological community, or aquatic ecosystem, because algae are abundant in terms of species in a biological community and are sensitive to water quality.

This concept was holistically re-examined and refined in 1950-60, and with the reference to this method, a practical biological indicator table based on the saprobity system is shown in Table 1. Although this system was developed to evaluate aqua ecosystem in middle to high latitude regions, such table for aqua-ecosystem in low to middle latitude region can be developed through a field survey.

Class of river water environment	Status of pollution
αps: α–polysaprobic	Polluted
βps: β–polysaprobic	↓
αms: α–mesosaprobic	
βms: β–mesosaprobic	
os: oligosaprobic	Clean

		αps	**βps**	**αms**	**βms**	**os**
Bacteria	*Zoogloea*	x x x x	x x x x			
	Sphaerotilus natans		x x x x	x x x x		
	Beggiatoa	x x x x	x x x x	- -		
	Leptothrix and Crenothrix					
	Iron bacteria				x x x x	x x x x
Fungi	*Leptomitus lacteus*		x x x x	x x x x		
Blue-green algae	*Anabaena flos-aquae*			- -	x x x x	- -
	Anabaena spiroides			- -	x x x x	- -
	Aphanizomenon flos-aquae			x x	x x x x	
	Coelasphaerium				x x x x	
	Gloeotrichia				- - - -	
	Merismopedia				- - - -	
	Microcystis aeruginosa			x x x x	x x x x	- - - -
	Microcystis flos-aquae			- - -	x x x x	
	Nostoc				- - - -	
	Oscillatoria limosa			x x x x	x x x x	
	Oscillatoria princeps				x x x x	
	Oscillatoria tenuis	x x	x x x x	x x x x		
	Phormidium		x x x x	- - - -	- - - -	
	Lyngbya contorta	x x	x x x x	x x x x	- - - -	
	Spirulina	x x	x x x x	x x x x	- - - -	

x x x x: Occurs in large quantities or occurs frequently

- - - -: Occurs in small quantities or occurs sometimes

[Notes: Some species of blue green algae that produce toxic substances such as microsystine are often categorized as cyanobacteria. However, most of blue-green algae do not produce toxic substances, therefore this paper describe as blue-green algae based on classification system of algae].

Table 1: Practical biological indicator table

Taking the different viewpoint that the structure of an ecosystem constantly varies that species structure of the diatom community is affected by the organic pollution level of the river. The Diatom Assemblage Index of pollution (DAIpo), which numerically represents the organic pollution level as follows.

$$DAIpo = 50 + \frac{(C - A)}{2} \quad (1)$$

Where C is total relative abundance of all saproxenous taxa (algae that found in clean water) at the sampling site (%), and A is total relative abundance of all saprophilous taxa (algae that found in polluted water) at the sampling site (%). The above equation was transformed to the following equation

$$DAIpo = 50 + \frac{1}{2} \cdot \left(\sum_{i=1}^{p} X_i - \sum_{j=1}^{q} S_j \right) \quad (2)$$

$\sum_{i=1}^{p} X_i$ = the sum of relative abundance (%) of saproxenous taxa from l to p at the sampling site.

$\sum_{j=1}^{q} S_j$ = the sum of relative abundance (%) of saprophilous taxa from l to q at the sampling site.

DAIpo is very effective in numerically expressing the average water quality level of the water area based on biological indicators, as shown in Table 2. This table shows that the relationship between the water quality pollution hierarchy and a chemical indicator for water quality, BOD, was summarized; this demonstrated a close correlation between these two. In view of the above, the distribution range of BOD was summarized with respect to the saprobity system (Table 2). This table shows that the water quality indicator, BOD, relates closely to composition of ecosystems.

DAIpo	**BOD**	**Saprobic Level**
100 - 70	0 - 1.25	β -oligosaprobic
70 - 50	1.25 - 2.5	α -oligosaprobic
50 - 30	2.5 - 5.0	β -mesosaprobic
30 - 15	5.0 - 10.0	α -mesosaprobic
15 - 0	> 10.0	Polysaprobic

Table 2: Saprobity system and the water quality distribution range of DAIpo

Based on the saprobity system, a practical table, as shown in Table 3, of biological indicators and water quality was summarized as a saprobity system in middle and high latitude region. The table categorizes biological, physical, and chemical characteristics according to a four-group hierarchy of water quality pollution and evaluates them in terms of chemical indicators of water quality: BOD, DO, hydrogen sulfide, and others. These have been applied to assaying the state of pollution of urban streams, tap water resources, and sewage treatment, and their wide application has contributed to an increasing grassroots awareness of ecosystems.

	Polysaprobic water	**α - mesosaprobic water**	**β - mesosaprobic water**	**Oligosaprobic water (α and β)**
Chemical reaction	putrefaction including reduction	oxidation occurs in water and bottom sediment	oxidation occurs intensively	Final stage of oxidation and mineralization
Dissolved oxygen	almost zero	detectable (1-3 mg L^{-1})	high (3-8 mg L^{-1})	Saturate(>8 mg L^{-1})
BOD	High(>10 mg L^{-1})	high(5.0-10 mg L^{-1})	low (2.5-5.0 mg L^{-1})	very low (<2.5 mg L^{-1})
Generation of H_2S	Strong odor of H_2S	slightly odor of H_2S	none	none
Organic substance in water	high molecular organics	Amino acids degraded by high molecular organics	Lower molecular organics	none or slight of organics
Bottom sediments	Blackish by iron sulfide	Brown by oxidation of iron sulfide	–	clean by oxidation of reductants
Bacteria	abundant such as 10^6 mL^{-1}	abundant such as<10^5 mL^{-1}	less abundant such as<10^4 mL^{-1}	less such as 100 mL^{-1}
Ecological properties	bacteria predator that can survive in anoxic condition	still dominant bacteria predator and somecarnivors that sensitive to H_2S	animals that sensitive to oxygen and pH	animals that sensitive to oxygen and pH
Algae	none	algal bloom by blue green algae,chlorophyceas,conjugate and diatoms	dominant by Cosnarium and other species	few algae in water but many epiphytic algae in bottom
Protozoa	Amoebida, Mastigophora and Ciliophora are dominant	Heliozoea and Suctoria	Species pollution vulnerable in Heliozoea and Suctoria , Mastigophora	few of Mastigophora and Ciliophora
Metazoa	few Rotifera, Vermes and insect larvae	shellfish, Crustaceans Conchifera, Crustacea and insect larvae. Cyprinus, Carassius, Parasiluras, Siluriformes	freshwater Porifera, Bryozoa, *Hydra*, Conchifera, small Crustacea and many species of insect larvae. Amphibians and many species of fish	few but many species of insect larvae and animals

Table 3: General properties of water environment by saprobity system

Polysaprobic water environment is typically observed at the immediate down stream of organic discharge. In that condition dissolved oxygen is consumed by the reductants from high molecular organic substances by anaerobic digestion. Hydrogen sulfide and iron sulfide are also produced.

Therefore, strong odor of hydrogen sulfide and blackish color of bottom sediment are aspect of polysaprobic water environment. Because of anaerobic reaction is slower than aerobic reaction, many bacteria can survive and present such as more than 10^6 mL^{-1} in water. A few species such as protozoa and metazoan that are bacteria predator can live in anaerobic condition.

α-mesophiric water environment is the first stage of recovery from polysaprobic water environment. Because the organic substances are oxidized to such as amino acids from protein by anoxic/aerobic organisms, dissolved oxygen is detected such as from 1 to 3 mg L^{-1}. However, hydrogen sulfide that does not completely oxidized in water gives slight odor of it.

The color of bottom changed to brown from black by the oxidation of iron sulfide. The number of bacteria is reduced to such as less than 10^5 mL^{-1}. Because of low dissolved oxygen in water bacteria predator are dominant and some carnivore are observed. Transparency of water increase by the lowering anaerobic reductants, however there still remain nutrients such as nitrogen and phosphorus, algal bloom by blue green algae, chlorophycea and conjugate are observed. And protozoa and it predator such as shell fish and fish such as carp are appeared in water environment.

β-mesophiric water environment is a further stage of recovery where decomposition products approach to mineralization. Lower molecular organics such as lower fatty acids and ammonia compounds become major organics, but the concentration is less than 2.5 mg L^{-1} of BOD in water. Therefore, dissolved oxygen is reach to almost saturated concentration. The number of bacteria decreases whereas the diversity of both flora and fauna increased.

Oligosaprobic water environment is full recovery to the level of upstream condition. Therefore, dissolved oxygen is saturated concentration and organic substances are oxidized or mineralized, up to less than 0.5 mg L^{-1} of BOD. Bottom sediments is turned clean color by oxidation of reductants. And number of bacteria becomes less than 100 mL^{-1} because of deficiency of substrate to them. Animals that sensitive to oxygen and pH become dominant. Many species, but low number, of algae, protozoa and metazoan are observed in water environment.

Water quality evaluation by the biological indicator table based on the saprobity system has the advantage of being able to measure in a single survey, in a short time, the average pollution level of the water area prevailing over a long period,. Since the levels of pollution have been judged conveniently, the development of pollution maps based on the saprobity system is useful tool for environmental education in school as well as community level.

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Biographical Sketches

Harukuni Tachibana is Associate Professor of Engineering at Hokkaido University, where he has been on faculty since 1996. He was admitted to Hokkaido University in 1963 and received the degree of Bachelor of Engineering in Sanitary Engineering in 1967 and Master of Engineering in 1969. Since 1970, he worked in the same department as an instructor, until 1996. He obtained his Doctor of Engineering from Hokkaido University in 1994 and served as associate professor of the newly established Division of Environmental Resource Engineering at Hokkaido University. His principal research field covers aquatic environmental engineering, aquatic chemistry for water pollution control, and environmental biology. He regards the keywords of his research field as: water analysis, preservation of water environment, eutrophication, and preservation of wetland.

Doctor Tachibana has written several books on water analysis and aquatic environments including lakes and rivers. He is a member of the Japanese Society of Civil Engineering, Japan Society on Water Environment, and Japanese Society of Limnology.

Toshiro Maruyama is Professor of Engineering at Miyazaki University, where he has been on faculty since 1993. He was admitted to Hokkaido University in 1960 and received the degree of Bachelor of Engineering in Sanitary Engineering in 1964 and Master of Engineering in 1966. He worked for Hakodate National College of Technology for ten years. He was also assigned as Lecturer of Faculty of Fishery at Hokkaido University from 1973 to 1976. He then moved to Tokyo University of Fishery in 1976. He served as Lecturer, then as Associate Professor until 1993. In the meantime, he performed an overseas research activity with the U.S. Environmental Protection Agency, USA, from 1971 to 1972. He also obtained his Ph.D. in Engineering from Hokkaido University in 1979. His research subjects have been in environmental engineering especially the evaluation of environmental toxicity of wastewater, river water, etc. by bioassay using seaweeds. He chaired the Environmental Conservation Committee of Japan Committee of Fisheries Science from 1997 to 1999. He has been a member of The Liaison Committee of Social Environmental Engineering of Science Council of Japan since 1997.

Professor Maruyama has been the author or co-author of various research articles in the field of marine environmental conservation. He is a member of Japanese Society of Civil Engineering, Japan Society on Water Environment, Japan Water Works Association, and Japan Sewage Works Association.

Yasumoto Magara is Professor of Engineering at Hokkaido University, where he has been on faculty since 1997. He was admitted to Hokkaido University in 1960 and received a degree of Bachelor of Engineering in Sanitary Engineering in 1964 and Master of Engineering in 1966. After working for the same university for four years, he moved to the National Institute of Public Health in 1970. He served as the Director of the Institute. From 1984 he worked for the Department of Sanitary Engineering, then the Department of Water Supply Engineering. He obtained a Ph.D. in Engineering from Hokkaido University in 1979 and was conferred an Honorary Doctoral Degree in Engineering from Chiangmai University in 1994. Since 1964, his research subjects have been in environmental engineering and have included advanced water purification for drinking water, control of hazardous chemicals in drinking water, planning and treatment of domestic waste including human excreta, management of ambient water quality, and mechanisms of biological wastewater treatment system performance. He has also been a member of governmental deliberation councils of several ministries and agencies including Ministry of Health and Welfare, Ministry of Education, Environmental Agency, and National Land Agency. He performs international activities with JICA (Japan International Cooperation Agency) and World Health Organization. As for academic fields, he plays a pivotal role in many associations and societies, and has been Chairman of Japan Society on Water Environment.

Professor Magara has written and edited books on analysis and assessment of drinking water. He has been the author or co-author of more than 100 research articles.