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PHYTOPLANKTON AS BIOINDICATOR FOR WATER QUALITY IN TAIPEI[1]

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Abstract

Algal samples from 13 stations including ponds, swamp, lakes and rivers were collected and the phytoplankton community in each station was studied. The diversity index of community and the saprobic index of each station were evaluated. The saprobic class was determined based on the indicative phytoplanktons and their frequency of presence. An association of five algal species as well as genera was used as the indication of water quality.

The physical-chemical properties of each water sample were studied in addition to the study of phytoplankton. The species diversity of community was found to correlate with the N/P ratio in waters.

Key words: Phytoplankton; algal association; bioindicator; water quality; saprobity.

Introduction

It is generally accepted that the communities of aquatic organisms can serve as indices of pollution. Kolkwitz and Marrson (1908) already formulated the relation of aquatic organisms to the degree of water pollution. They first introduced the concept of bioindicator of pollution in their saprobic system, which was based on different zones of saprobity and was characterized by plant and animal species. Although there are several methods, other than saprobic system, for evaluation of water quality, the saprobic system is generally used in many countries. Since the establishment of saprobic system, several methods have been proposed to quantify the indicative organisms found (Knöpp, 1954; Zelinka and Marvan, 1961; Sládeček, 1973). In Taiwan, the use of macroinvertebrates, fishes and microorganisms for monitoring water quality of some streams was also made (Hau *et al.*, 1976; Hong,

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1979; Lee *et al.*, 1967). However, it is still difficult to make use of the biocenoses of a variety of organisms as indication of water quality, because that the basic studies such as floristic and faunistic records of lower plants and animals in local area are insufficient to provide necessary informations for that. An attempt of using phytoplantkon, especially association of some species, as practical method for the evaluation of water quality in Taipei was hence made.

Materials and Methods

Algal samples from 13 stations including ponds, lakes, swamp and rivers (Fig. 1) were collected by plankton net. The collected samples were fixed with Lugol's solution containing 10% acetic acid. Algae were microscopied and identified. The abundance of each species was calculated according to the occurring frequency encountered in at least 500 cell counts. The saprobic index (SI) of community was evaluated based on the formula proposed by Pantle and Buck (1955): $SI=\sum s\cdot h/\sum h$, where s is the indicating value of each species according to Liebmann's list of indicator organisms (Sládeček, 1973) and h is the frequency of the presence of each

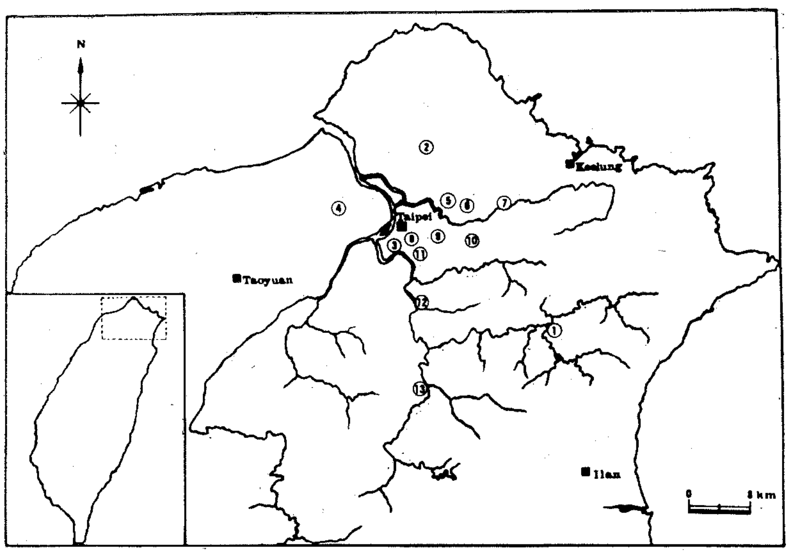

Fig. 1. A map of northern Taiwan showing sampling stations.

1: 0328 Pinlin
2: 0324 Yangmingshan
3: 0332 Tamshui River at Yonho
4: 0331 Wuku
5: 0325 Neihu
6: 0326 Tahu
7: 0327 Keelung River at Hsitzu
8: 0323 K.S. Chiang's Memmorial Hall
9: 0321 Dr. Y.S. Sun's Memmorial Hall
10: 0320 Academia Sinica
11: 0322 National Taiwan University
12: 0329 Hsintien
13: 0330 Wulei

indicator species found. SI ranks from 0 to 4: $SI < 0.5$ for xenosaprobity, $SI=1$ for oligosaprobity, $SI=2$ for beta-mesosaprobity, $SI=3$ for alpha-mesosaprobity, and $SI=4$ for polysaprobity.

The diversity index of community was calculated by the following formula adopted from Shannon and Weaver (1949):

$$DI = -\sum_{i=1}^{s} P_i \log_2 P_i, \quad \text{where } P_i = N_i / N \text{ and } \sum_{i=1}^{s} P_i = 1.$$

N_i is the number of individuals of species i, N is the total number of individuals in the sample and s is the number of species.

The state of water environment was qualified by measuring the contents of ions such as nitrate, nitrite, ammonium, phosphate and some physicochemical properties such as pH-value, dissolved oxygen, colour, turbidity and conductivity of water samples collected from each station. The concentration of above ions was colorimetrically quantified after reacting with the test reagents prepared by Macherey-Nagel GmbH & Co. All the measurements were performed immediately after the collection of water samples.

Results

The characteristics of phytoplankton communities and the dominant algal groups found in each studied station were summarized in Table 1. An association of five genera and their species was given to denote the nature of phytoplankton community at each station. The saprobity of water was also evaluated.

A comparison of the relative abundance of main four groups of algae, namely Bacillariophyceae, Euglenaceae, Chlorophyceae and Oscillatoriaceae, also serves as an important implication of saprobic state of waters. In general, the abundance of Euglenaceae was found at those stations whose saprobic index (Table 4) were greater than 2.0. In the waters of oligosaprobity, diatoms were the dominant group. The dominance of green algae (Table 2) is however an indication of beta-mesosaprobity or between beta- and alpha-mesosaprobity.

Based on the results noted above the important indicative algal associations for each saprobic class is listed in Table 3. The saprobic classes of oligo-, beta-meso- and alpha-mesosaprobity were characterized by the dominance of diatoms, green algae and Euglenaceae respectively. The saprobic level between two classes was then characterized by the quantitative and qualitative combination of indicative species of each saprobic class.

The saprobic index, shown in Table 4, of each studied station did not show any correlation with the diversity index of community. The relationship between them, nevertheless, should be a rather complicated one.

In addition to the study of phytoplankton the chemical composition and some

Table 1. *Summary of the characteristics of phytoplankton communities, algal associations and saprobic class at each studied station*

Station no.	Characteristics of phytoplankton community	Algal association	Saprobic class
0320	pond community; abundant in *Euglena* (47.4%) and *Oscillatoria* (18.6%), *Phacus* (4.9%) and *Trachelomonas* (5.0%).	*Euglena* div. sp. *Oscillatoria* div. sp. *Phacus* div. sp. *Trachelomonas* div. sp. *Crucigenia* sp.	alpha-mesosaprobity
0321	pond community; abundant in blue-green aglae such as *Synchocystis crassa* (24.4%), *Oscillatoria* (28.5%), *Microcystis* (8.6%) and *Lyngbya limnetica* (7.0%).	*Synchocystis crassa* *Microcystis* div. sp. *Lyngbya limnetica* *Romeria leopoliensis* *Chroococcus lineticus* v. *subsalsus*	between oligo- and beta-mesosaprobity
0322	pond community; abundant in blue-green algae such as *Microcystis* (18.5%), *Romeria leopoliensis* (23.1%) and *Anabaena* (13.2%)	*Microcystis* div. sp. *Romeria leopoliensis* *Anabaena* sp. *Pediastrum* div. sp. *Actinastrum hantzschii*	between oligo- and beta-mesosaprobity
0323	pond community; abundant in green algae such as *Staurastrum* (27.3%), *Makinoella* (11.1%), *Oocystis* (9.8%) and some blue-green algae (*Microcystis*, 13.0%)	*Staurastrum manfeldtii* v. *manfeldtii* *Microcystis* div. sp. *Oocystis parva* *Cosmarium subtumidum* f. *minor* *Makinoella tosaensis*	beta-mesosaprobity
0324	pond community; diatoms of predominance (77.5%), no significantly dominant single species.	*Fragilaria* div. sp. *Cyclotella glomerata* *Gomphonema olivaceum* *Synedra* sp. *Hydrosera triquetra*	oligo-saprobity
0325	lake community; abundant in green algae such as *Pediastrum* (21.5%), *Scenedesmus* (17.7%), rich in species of both genera.	*Pediastrum* div. sp. *Scenedesmus* div. sp. *Dictyosphaerium pulchellum* *Merismopedia* sp. *Tetraedron* div. sp.	beta-mesosaprobity
0326	lake community; abundant in blue-green algae such as *Spirulina* (24.1%), *Oscillatoria* (23.8%) and some green algae (*Scenedesmus*, 11.1%).	*Spirulina* sp. *Oscillatoria* div. sp. *Pediastrum duplex* v. *duplex* *Scenedesmus* div. sp. *Anabaena* sp.	beta-mesosaprobity
0327	stream community; abundant in green algae such as *Scenedesmus* (15.1%), *Pediastrum* (6.5%) and some alpha-mesosaprobic indicator species such as *Nitzschia palea* (6.2%) and *Oscillatoria tenuis* var. *tenuis* (3.5%).	*Scenedesmus* div. sp. *Pediastrum* div. sp. *Pandorina morum* *Nitzschia palea* *Oscillatoria tenuis* v. *tenuis*	between beta- and alpha-mesosaprobity
0328	stream community; abundant in diatoms (53.2%) and *Oscillatoria* (33.3%), no significantly dominant single species.	*Fragilaria* div. sp. *Oscillatoria limnetica* *Gomphonema* div. sp. *Cymbella* div. sp. *Synedra ulna*	between oligo- and beta-mesosaprobity
0329	stream community; abundant in diatoms (61.6%) and *Oscillatoria* (18.9%) and *Pediastrum* (18. 6%).	*Melosira italica* *Pediastrum* div. sp. *Fragilaria capucina* *Synedra ulna* *Oscillatoria* div. sp.	beta-mesosaprobity

Station no.	Characteristics of phytoplankton community	Algal association	Saprobic class
0330	stream community; diatoms of predominance (71.6%), highly diverse in diatom species.	*Fragilaria* div. sp. *Melosira italica* *Cymbella ventricosa* *Gomphonema* div. sp. *Rhopalodia gibba*	oligo-saprobity
0331	swamp community; abundant in green algae (46.2%) and Euglenaceae (21.9%), highly diverse in *Scenedesmus* (10 species) and Euglenaceae (12 species).	*Scenedesmus* div. sp. *Euglena* div. sp. *Phacus* div. sp. *Oscillatoria princeps* v. *princeps* *Crucigenia* div. sp.	between beta- and alpha-mesosaprobity
0332	stream community; abundant in diatoms (47.1%), *Oscillatoria* (17.8%) and Euglenaceae (13.2%).	*Nitzschia palea* *Euglena* div. sp. *Phacus* div. sp. *Oscillatoria princeps* v. *princeps* *Pediastrum* div. sp.	alpha-mesosaprobity

Table 2. *Percentages of abundance of Oscillatoriaceae, Bacillariophyceae, Euglenaceae and Chlorophyceae at each studied station*

Station no.	Oscillatoria.	Bacillario.	Euglena.	Chlorophy.
0320	17.1	6.2	54.6	8.6
0321	28.5	2.1	0.0	6.7
0322	11.1	3.1	0.9	20.9
0323	1.2	3.2	0.0	74.6
0324	8.0	77.5	0.0	3.6
0325	3.1	4.6	0.7	76.1
0326	23.8	10.5	6.7	33.3
0327	8.2	15.8	6.6	53.0
0328	33.3	53.2	1.1	6.9
0329	18.9	61.6	0.7	18.6
0330	3.3	71.6	0.9	6.9
0331	5.6	3.3	21.9	46.2
0332	17.8	47.1	13.2	9.0

physical characters of waters were investigated. The results, summarized in Table 5, represented the short-term state of waters. The nutrients in waters might be so rapidly recycled that a short-term composition could not be regarded as indicative of nutrient supply in water. In this case, the N/P ratio is generally used as a better indication of nutrient supply. The low N/P ratio indicates that the state of water in studied station is either of eutrophic or hypereutrophic one.

Table 3. *Indicative algal associations for each saprobic class of waters*

Saprobic class	Indicative association
oligo-saprobity	1. *Fragilaria* div. sp.
	2. *Gomphonema* div. sp.
	3. *Melosira italica* or *Synedra ulna*
	4. *Cymbella ventricosa* or *Cyclotella* sp.
	5. *Rhopalodia gibba* or *Hydrosera triquetra*
beta-mesosaprobity	1. *Microcystis* div. sp.
	2. *Pediastrum* div. sp.
	3. *Scenedesmus* div. sp.
	4. *Coelastrum* sp. or *Tetraedron* sp. or *Oocystis parva*
	5. *Dictyosphaerium pulchellum* or *Staurastrum manfeldtii* v. *manfeldtii*
alpha-mesosaprobity	1. *Euglena* div. sp.
	2. *Phacus* div. sp.
	3. *Nitzschia palea*
	4. *Trachelomonas* div. sp. or *Crucigenia* div. sp.
	5. *Oscillatoria* div. sp.

Table 4. *Saprobic index (SI) of waters and diversity index (DI) of community at each studied station*

Station No.	SI	DI
0320	2.7	3.42
0321	1.6	3.86
0322	1.7	3.75
0323	1.9	3.95
0324	1.5	4.23
0325	1.9	4.59
0326	2.0	4.42
0327	2.2	5.18
0328	1.5	4.80
0329	1.9	4.54
0330	1.3	4.72
0331	2.2	5.01
0332	2.7	3.51

Table 5. *Summary of the physicochemical properties of waters at each sampling station*

All the data were given in unit of mg/l, except conductivity (in μS/cm) and turbidity (in TE/F).

Station No.	NH_4^+	NO_2^-	NO_3^-	PO_4^{3-}	N/P*	DO	pH	Conduct.	Color	Turb.	COD
0320	0.12	0.17	0.45	0.32	2.31	6.51	6.68	177	55	16	58
0321	0.15	0.01	0.13	0.56	0.46	10.15	9.63	183	30	32	133
0322	0.04	0.62	0.20	0.85	1.01	22.63	10.51	223	30	47	43
0323	0.02	0.01	0.18	0.58	0.36	14.06	9.57	196	50	20	22
0324	0.02	0.00	0.29	0.88	0.35	10.99	7.95	202	18	37	57
0325	0.11	0.20	0.46	1.40	0.55	10.21	8.64	199	140	37	93
0326	0.01	0.05	0.15	0.64	0.33	16.99	9.44	260	225	55	80
0327	0.98	0.23	0.58	0.74	2.42	9.66	8.16	290	85	28	47
0328	0.23	0.02	0.67	0.45	2.04	9.02	7.27	84	25	7	25
0329	0.01	0.03	0.78	0.58	1.41	9.02	7.46	89	78	22	15
0330	0.01	0.03	1.43	0.74	1.99	9.88	7.28	118	43	10	55
0331	0.48	0.19	0.49	0.32	3.63	14.40	8.50	340	370	85	125
0332	1.84	0.06	1.75	1.27	2.87	6.00	7.11	171	185	48	42

* N/P ratio was obtained by dividing the sum of the amount of ammonium, nitrite and nitrate by the amount of phosphate.

Abbreviation: DO: dissolved oxygen; Conduct.: conductivity; Turb.: turbidity; COD: chemical oxygen demand.

A plot of the diversity index of community versus N/P ratio (Fig. 2) showed that both were closely correlated, although the relationship between them was not linear. Principally, higher diversity index of community is accompanied with lower N/P ratio. The exception to this principle is the case by which diversity index of community is very low.

Discussion

The bioindicator system mentioned by a number of authors (Liebmann, 1962; Elster, 1966; Kolkwitz and Marrson, 1908) is usually laid on the biocenoses of various organisms such as producers, decomposers and consumers. Phytoplankton, for example, has been used with success in estimation of water pollution (Fjerdingstad, 1964; Williams, 1964; Sze and Kingsbury, 1972; Staker *et al.*, 1974). Nygaard (1949) mentioned that phytoplankton association could be used as an index of pollution. He classified the phytoplankton association based on the ratio of one algal group to the others. The use of phytoplankton association as an index of water quality in this paper is however somewhat different from that mentioned by

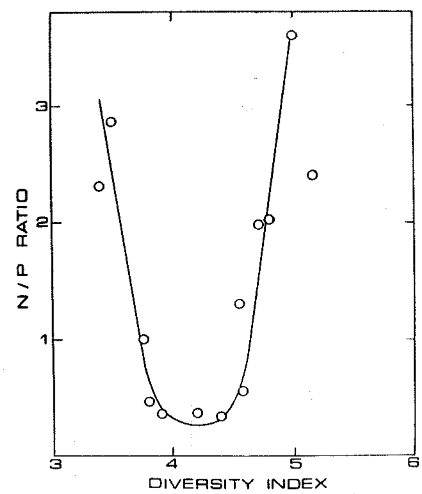

Fig. 2. Relation of diversity index of phytoplankton communities to N/P ratio in waters of studied stations.

Nygaard. An association of five genera or species, rather than the use of the ratio of algal groups, is submitted in this paper.

The species determination is one of the difficulties for the application of bioindicator system. The identification of organisms to species level is particularly difficult in Taiwan. Although there are some papers concerning with the study of local algae (Shen, 1961; Chang, 1968; Li, 1976; Jang, 1976; Tseng *et al.*, 1982), it still can not provide enough informations for species determination. The use of algal associations in this case is an available method for evaluation of water pollution, because it is not necessary to identify phytoplankton exactly to species level.

It is well known that the pattern of algal community is to some extent correlated with the temperature and light conditions. The dominance of blue green algae, green algae or diatoms is dependent on the season and nutrient state of waters. For establishing a useful indicator system for local water quality a further study of seasonal succession of phytoplankton is therefore necessary.

The pattern of phytoplankton community and water quality are interdependent (Venneaux, 1976). A pollution syndrome is observed with fairly rapid and fairly marked reduction of certain species and possibly a proliferation of another species. The dominance of certain species and frequency of the presence of these species are hence the characteristics of polluted waters. In other words, the diversity index of community is correlated in some cases with the degree of pollution. In general, the value of diversity index of community in less polluted waters will be higher. However, the diversity index of community is not linearly correlated with the purity of water. Among studied samples, those with highest diversity index of community were found to be either of beta-mesosaprobity or between beta- and alpha-mesosaprobity in water quality.

The system of water saprobity is correlated with the vital activity of organisms conditioned by physical, chemical and biological environments. The community of phytoplankton is characterized principally by the supply of nutrients in dissolved form, rather than by the concentration at any one time. For phytoplankton, N and P are two of the most important nutrients. The re-cycling of these nutrients in freshwater is so rapidly that a measured short-term concentration is by no means the indication of their supply. For indicating the state of nutrient supply, N/P ratio was found to be a better parameter (Welch *et al.*, 1975). The N/P ratio decreases with increased eutrophication and hence decreased species diversity of community. The results demonstrated above show that the state of waters in the studied area is predominantly of either eutrophic or hypereutrophic one. The xenosaprobity, a pure water level with rare pollution, is fully absent in the area studied.

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以浮游藻作為臺北地區水質之生物指標

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從十三處分由水池、湖泊、沼澤及河川中採得之浮游藻樣本，經分析其藻種組成特性，算出藻羣落之種歧異度，並從指標種出現之頻率，算出各採集地之水污染指數。從結果中，吾人各歸列五個藻種及屬的組合，作爲各級水質之指標。

對各採集地之水質，亦作物理及化學特性之測定分析，結果顯示藻種歧異度與水中氮磷含量比有較密切之關聯。