Journal of Applied Phycology **14:** 63–69, 2002.

Applicability of a generic index for diatom assemblages to monitor pollution in the tropical River Tsanwun, Taiwan

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Received 15 March 2001; accepted in revised form 18 July 2001

Key words: Bioindicator, Diatom, Generic index, Taiwan, Tropical river, Water pollution, Water quality

Abstract

A generic index (GI) utilizing epilithic diatom assemblages as a bioindicator of water pollution in subtropical rivers in Taiwan was applied to a study of a tropical river. Seven sites on the River Tsanwun were sampled seasonally from August 1995 to June 1998. Although there is a marked difference in water chemistry between tropical and subtropical rivers in Taiwan, the dominant genera of their diatom assemblages are quite similar. The six genera used for the calculation of GI in the subtropical rivers were also the main components of diatom assemblages in the River Tsanwun. The calculated values displayed a close correlation with water quality, evaluated on the basis of physical and chemical variables. A strong correlation was found between this GI and other diatom-based indices of water quality.

Abbreviations: BOD – biochemical oxygen demand, CEC – Commission for Economic Community index, DAI – diatom assemblage index for organic pollution, GDI – generic diatom index, GI – generic index of diatoms, IBD – indice biologique diatomique, IPS – indice de polluosensibilité, SI – saprobity index, TDI – trophic diatom index, WQI – river water quality index

Introduction

Diatoms have been used in a number of countries as bioindicators of river pollution (Whitton et al. 1991; Whitton and Kelly 1995; Whitton and Rott 1995; Prygiel et al. 1998; Stevenson and Pan 1999) and a variety of indices have been developed for this purpose. These include the Descy index (Descy 1979), indice de polluosensibilité (IPS) (Coste in Cemagref (1982)), saprobity index (SI) (Sládeček 1986), generic diatom index (GDI) (Coste and Ayphassorho 1991), Commission for Economic Community index (CEC) (Coste and Descy 1991), indice biologique diatomique (IBD) (Lenoir and Coste 1996), diatom assemblage index for organic pollution (DAI) (Watanabe et al. 1986) and the trophic diatom index (TDI) (Kelly and Whitton 1995). These indices were derived and applied principally in temperate regions, and there is little information regarding their applicability in the tropics and subtropics. This needs be evaluated before the indices are applied routinely in warmer climates.

Taiwan covers both subtropical and tropical climatic zones. Diatoms have been used to monitor pollution in some Taiwan rivers during the last two decades (Wu and Suen 1985; Wu 1986). Recently, a generic index (GI) of diatom assemblages was proposed on the basis of studies of the subtropical Keelung River, as an alternative to the conventional diatom-based indices (Wu 1999). The GI differs from conventional indices in that only six dominant genera (*Achnanthes, Cocconeis, Cyclotella, Cymbella, Melosira, Nitzschia*) are used for calculation. This index has the advantages of simplicity and user-friendliness, because only identification to the genus is required.

Our previous investigation showed that the river environment in the tropical southern part of Taiwan is somewhat different from that in the subtropical

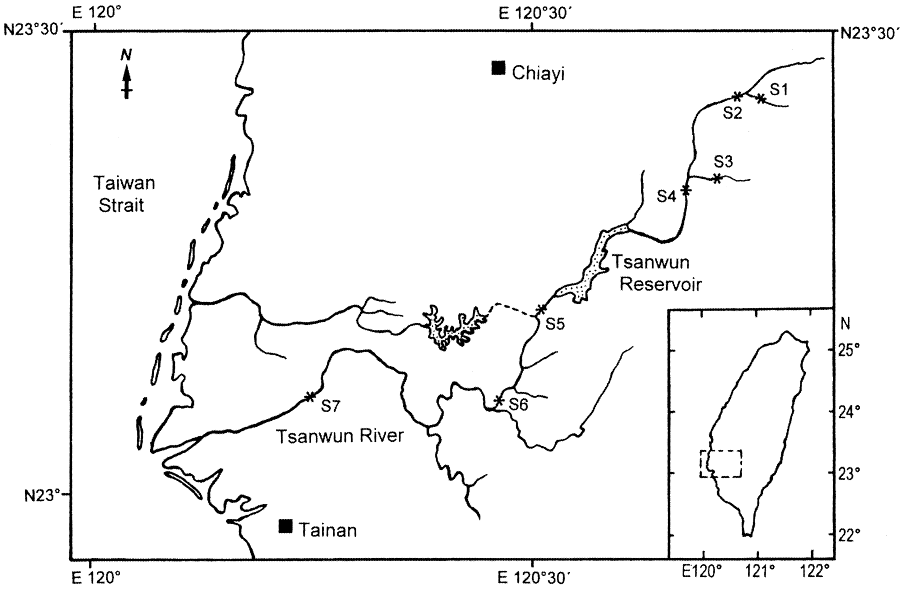

Figure 1. Location of sampling sites on River Tsanwun.

north (Wu and Yang 1996). For instance, the hardness, conductivity, pH and temperature of river water all tend to be considerably higher in the southern rivers. This has given rise to quantitative as well as qualitative differences in the biota. The aim of the study reported here was to test the validity of using the GI for a tropical river. The River Tsanwan was chosen for this purpose, utilizing data from 1995 to 1998.

Materials and methods

Study sites

The River Tsanwun in southern Taiwan (Figure 1) is the major water resource for the Chia-Nan Plain. This river is 138.5 km long and has a basin of 1177 km^2. The watershed has a yearly precipitation of 2594 ± 696 mm (30-year mean) (Wang et al. 1994). A rainy season occurs from May to August, when 87% of the yearly total precipitation occurs. A dry season occurs from October to April. Monthly mean air temperature ranges from 17 to 29 °C, with a yearly average of 24 °C.

Rapid growth of the human population and use of mountain slopes over the past fifty years have given rise to a pronounced change in quality and quantity of the river water, particularly in the lower reaches. In the upper reaches, the watershed has various land uses, serious habitat fragmentation, expanding areas of human disturbance and rapid habitat alteration. It appears to be only slightly polluted by heavy metals (Hung et al. 1996), but organic sewage discharges from households and agriculture are a serious concern.

Site selection and sampling

The study included seven sampling sites (S1–S7) distributed from the upper to lower reaches of the river (Figure 1). Sampling was conducted seasonally from September 1995 to April 1998. Epilithic diatoms were collected from at least five randomly selected cobbles or boulders at each sampling site, in locations where the current was 0.2 to 1.0 m s^{-1}, as recommended by Kelly et al. (1998). A toothbrush was used to remove diatoms from an area of ca. 36 cm^2 stones that were free from filamentous algae. The samples were fixed by Lugol's iodine solution immediately after collection and cleaned with acid (acetic acid: sulfuric acid = 9: 1) in the laboratory. After washing with deionized water, samples were mounted on a slide with Naphrax (Northern Biological Supplies Ltd., Ipswich, UK). Diatoms were observed and identified under a phase contrast microscope.

Samples for water quality analyses were collected at the same time as the diatoms. Environmental factors such as temperature, pH and conductivity of the river water were measured in situ. For analysis of chemical constituents, samples were filtered through

Table 1. Summary of physicand chemical variables of water at sites (S1–S7) along River Tsanwun during 1995–98. (Mean ± standard deviation, n = 12).

Variable	unit	S1	S2	S3	S4	S5	S6	S7
pH	–	7.6 ± 0.8	7.5 ± 1.0	7.5 ± 1.1	7.9 ± 1.1	7.5 ± 0.7	7.6 ± 1.2	7.3 ± 0.9
Dissolved oxygen	mmol L^{-1}	0.24 ± 0.02	0.23 ± 0.05	0.25 ± 0.02	0.25 ± 0.02	0.23 ± 0.02	0.24 ± 0.4	0.20 ± 0.08
Conductivity	$\mu S\ cm^{-1}$	198 ± 39	174 ± 49	201 ± 35	227 ± 33	257 ± 48	521 ± 66	1015 ± 252
Turbidity	NTU	5.0 ± 2.5	9.1 ± 3.6	2.0 ± 1.4	35.4 ± 10.5	16.4 ± 4.3	53.6 ± 25.6	146.0 ± 38.5
NH_4^+-N	meq L^{-1}	0.04 ± 0.02	0.04 ± 0.02	0.04 ± 0.02	0.03 ± 0.03	0.05 ± 0.04	0.56 ± 0.72	2.60 ± 1.90
NO_2^--N	μeq L^{-1}	12 ± 6	24 ± 36	12 ± 6	13 ± 8	14 ± 8	77 ± 87	176 ± 74
NO_3^--N	meq L^{-1}	0.71 ± 0.52	0.61 ± 0.47	0.74 ± 0.60	0.77 ± 0.66	0.94 ± 0.83	1.70 ± 1.08	2.08 ± 1.11
SiO_2	μmol L^{-1}	55 ± 18	52 ± 15	65 ± 23	60 ± 20	47 ± 13	52 ± 20	68 ± 25
Phosphate-P	μmol L^{-1}	0.30 ± 0.15	0.33 ± 0.19	0.34 ± 0.13	0.32 ± 0.19	0.35 ± 0.25	2.27 ± 2.72	5.47 ± 5.33
Total-P	μmol L^{-1}	0.33 ± 0.15	0.44 ± 0.22	0.42 ± 0.23	0.36 ± 0.20	0.70 ± 0.48	3.96 ± 4.57	12.34 ± 6.48
Chlorophyll *a*	μg L^{-1}	0.6 ± 0.3	0.8 ± 0.5	0.5 ± 0.5	1.0 ± 0.6	1.2 ± 0.8	7.9 ± 11.8	48.4 ± 41.7
BOD_5	mmol L^{-1}	0.04 ± 0.05	0.05 ± 0.05	0.03 ± 0.02	0.03 ± 0.03	0.05 ± 0.02	0.21 ± 0.15	0.36 ± 0.18
Total organic N	μmol L^{-1}	20.0 ± 8.6	23.6 ± 11.4	21.4 ± 9.3	22.9 ± 7.1	22.1 ± 12.9	52.9 ± 55.7	240.0 ± 418.5
WQI	–	82 ± 5	80 ± 2	85 ± 4	79 ± 4	77 ± 4	57 ± 4	52 ± 7

0.45 μm membrane filters immediately after collection and stored at 4 °C in the dark for transport to the laboratory. Analyses were performed within 5 h of sampling.

Laboratory procedures

The analysis of ammonium, nitrite, nitrate, phosphate, silicate, total organic nitrogen, total phosphorus, biochemical and chemical oxygen demands, and dissolved oxygen followed American Public Health Associations (APHA), American Water Works Association and Water Pollution Control Federation (1992). Turbidity was measured in the laboratory with an Orbeco-Hellige (Farmingdale, New York) turbidometer. Turbidity, pH, conductivity, ammonium, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), and total phosphorus (TP) were used for the calculation of a water quality index (WQI), calculated on a weighted average of variables, employing the modified model of House and Newsome (1988) by O-Yang (1990): $WQI = 0.1\ [\Sigma\ W_iQ_i]^{1.5}$, where W_i is the weight, and Q_i the quality score of variable *i*.

Diatoms were identified to genus according to Cleve-Euler (1951–1955); Patrick and Reimer (1966); Gerloff and Cholnoky (1970); Rabenhorst (1971); Krammer and Lange-Bertalot (1986–1991). The frequency of occurrence of each genus was calculated by counting at least 400 valves per sample. Values of SI and TDI were calculated after Sládeček (1986); Kelly and Whitton (1995), respectively, employing the equation of Zelinka and Marvan (1961). The values of DAI were calculated according to Watanabe et al. (1986). The GI was calculated for each sample as the ratio of the relative abundance of *Achnanthes, Cocconeis* and *Cymbella* to that of *Cyclotella, Melosira* and *Nitzschia* (Wu 1999). Data were analyzed statistically using Statistica (Microsoft Inc., Oklahoma, USA).

Results

Physical and chemical conditions

The upper reaches of the River Tsanwun occur in mountainous terrain with little human disturbance. The water collected from sampling sites (S1–S3) in this area contained lower concentrations of nutrients with nearly saturated dissolved oxygen levels (Table 1). In the middle and lower reaches, there were progressive increases in conductivity, turbidity, BOD_5, and nutrient variables such as ammonium, nitrite, nitrate and phosphate, indicating an elevated degree of pollution. The degree of pollution was clearly indicated by the integrated water quality index. The characteristics of water quality are consistent with the

Table 2. Number of taxa in each diatom genus in River Tsanwun.

Genus	No. of taxa	Genus	No. of taxa	Genus	No. of taxa
Achnanthes	19	*Cymbella*	21	*Navicula*	26
Amphipleura	2	*Diatoma*	1	*Neidium*	3
Amphora	4	*Diploneis*	1	*Nitzschia*	28
Anomoeneis	2	*Epithemia*	1	*Pinnularia*	2
Aulacoseira	3	*Fragilaria*	11	*Pleurosira*	1
Bacillaria	1	*Frustulia*	1	*Stephanodiscus*	1
Brachysira	1	*Gomphonema*	13	*Surirella*	5
Caloneis	4	*Gyrosigma*	2	*Tabellaria*	2
Cocconeis	1	*Hantzschia*	1		
Cyclotella	3	*Melosira*	1	Total	161

model that the river was polluted mainly by organic sewage discharges from households or agriculture.

Characteristics of the diatom assemblages

A total of 161 taxa, belonging to 30 genera were recorded (Table 2). The composition of the diatom assemblage changed from site to site and season to season, but the majority of species encountered in this river were similar with those found in the River Keelung.

At sites located in the upper reaches (S1–S4), the dominant genera were *Achnanthes, Cocconeis, Cymbella*, and *Gomphonema*. In the middle reach, there was an increase in abundance of *Melosira, Nitzschia Fragilaria*, and *Navicula*, while in the lower reaches (S6–S7), the dominant genera became *Cyclotella* and *Nitzschia*. The genera used as the numerator for GI calculation were more abundant in upper reaches where water was less polluted, whereas those used as the denominator were more abundant in lower reaches where the water was more polluted (Figure 2). As a result, the calculated GI values were higher in less polluted reaches and were lower in more polluted ones (cf. Table 3). Thus, the calculated GI values were a good measure of the degree of pollution at sampling sites. Furthermore the values of GI and WQI were strongly related to one another. Figure 3 shows that they are linearly correlated.

A plot of the abundance of individual diatom genera against WQI at each sampling site indicated that *Achnanthes, Cocconeis*, and *Cymbella* had a similar distribution pattern, with greater abundances at higher WQI values (Figure 4). In contrast, *Cyclotella, Melosira*, and *Nitzschia* were more abundant when WQI values were lower, with an overall negative correlation with WQI.

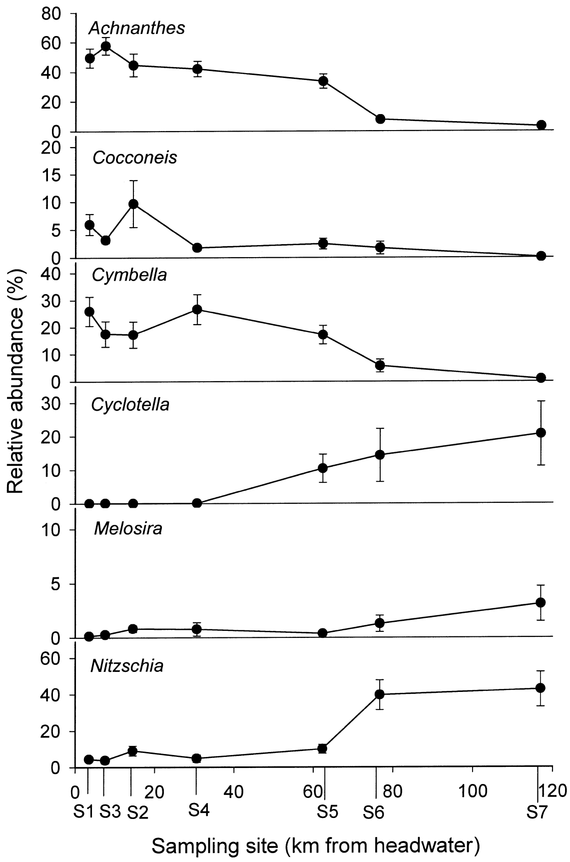

Figure 2. . Changes in relative abundance of six genera of at the seven sites in the during the period of study.

Correlation between various indices of the diatom assemblage

In addition to GI, other indices were calculated, including the DAI, TDI, SI, MI, and species diversity index (H). The values of MI and H did not vary significantly among sites (Table 3), indicating that over-

Table 3. Values of the Magalef species richness index (MI), Shannon diversity index (H), generic index (GI), saprobity index (SI), diatom assemblage index for pollution (DAI), and trophic diatom index (TDI) of the diatom assemblages at each sampling site (S1–S7) in River Tsanwun. Mean ± standard deviation, n=12.

Sampling site	MI	H	GI	SI	DAI	TDI
S1	5.4 ± 1.3	3.7 ± 0.5	26.4 ± 9.1	1.2 ± 0.5	73.3 ± 6.1	1.7 ± 0.4
S2	5.5 ± 1.1	3.8 ± 0.5	16.7 ± 5.3	1.3 ± 0.4	72.4 ± 4.5	2.1 ± 0.6
S3	6.1 ± 1.2	3.8 ± 0.5	44.4 ± 30.6	1.0 ± 0.4	68.9 ± 6.6	1.7 ± 0.4
S4	6.2 ± 1.4	3.9 ± 0.6	25.3 ± 24.3	1.5 ± 0.4	76.1 ± 6.1	1.9 ± 0.5
S5	6.2 ± 1.7	4.0 ± 0.9	20.4 ± 17.5	1.6 ± 0.3	67.5 ± 5.6	2.4 ± 0.6
S6	6.4 ± 1.2	3.9 ± 0.7	0.7 ± 0.6	2.2 ± 0.3	54.8 ± 9.7	3.8 ± 0.4
S7	4.6 ± 1.3	3.5 ± 0.6	0.1 ± 0.1	2.4 ± 0.2	48.3 ± 8.5	4.3 ± 0.1

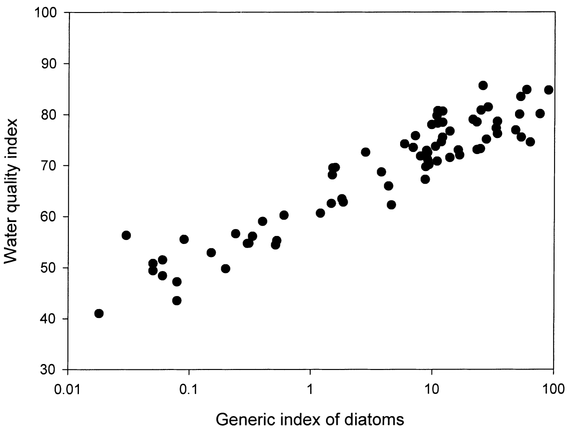

Figure 3. Relationship between values of generic index of the diatom assemblages and water quality index in the River Tsanwun.

all biodiversity was not affected by the water pollution in this river system.

The average values of SI at sampling sites ranged between 1.0 and 2.5, indicating levels between oligo- and meso-saprobity; with increased saprobic levels from upstream to downstream. The values of TDI were lower at sampling sites located in upper reaches and higher in lower reaches, showing a similar tendency of change with the saprobity. The DAI values were higher at upstream sites and lower at downstream. They fluctuated in the same manner as GI and WQI along this river. The results of Canonical analysis of these indices showed that GI was well correlated with SI, TDI, and DAI, with correlation coefficients higher than 0.5, but was not well correlated with MI or H (correlation coefficients <0.3) (Table 4).

Discussion

The diatom flora in the River Tsanwun was somewhat similar to that in River Keelung, on which the derivation of GI was based (Wu 1999). The major difference concerned the relative abundance of certain components of the assemblage. However, the same genera were dominant at both locations. The present study showed that the GI also works effectively to characterize water quality in a tropical river in Taiwan, despite major differences in climate and water chemistry. The GI values at seven sampling sites in the studied river agreed well with the degree of pollution indicated by physical and chemical variables (WQI), as they did in the subtropical river of the north. These results support widespread use of the GI as an indicator of water pollution in Taiwanese rivers and suggest that the method should be tested more widely in tropical and subtropical rivers.

The River Tsanwun is a shallow ecosystem, and we collected only epilithic diatoms. The way of sampling and the conditions at sampling sites may strongly affect the composition of this attached diatom assemblage (Cox 1984; Lay and Ward 1987; Wendker 1992). To avoid the effect of undesirable interferences on the results, the conditions for selecting sampling sites and choice of suitable sampling methods should be strictly taken into account. In this concern, the recommendations for sampling of Kelly et al. (1998) provide a framework that can be adapted to most river types, including tropical ones.

In the present study, a comparison has been made between GI and six conventional diatom indices. The correlation coefficients between GI and SI, TDI and DAI are quite high, suggesting that either GI or other indices tested can be used as the indicator of water pollution in the river studied. However, the use of GI may be preferred because only identification to genus level is required. This makes the use of GI more convenient than other indices. In this concern, GI is suggested as one of first priorities in the selection of indices for monitoring of river pollution.

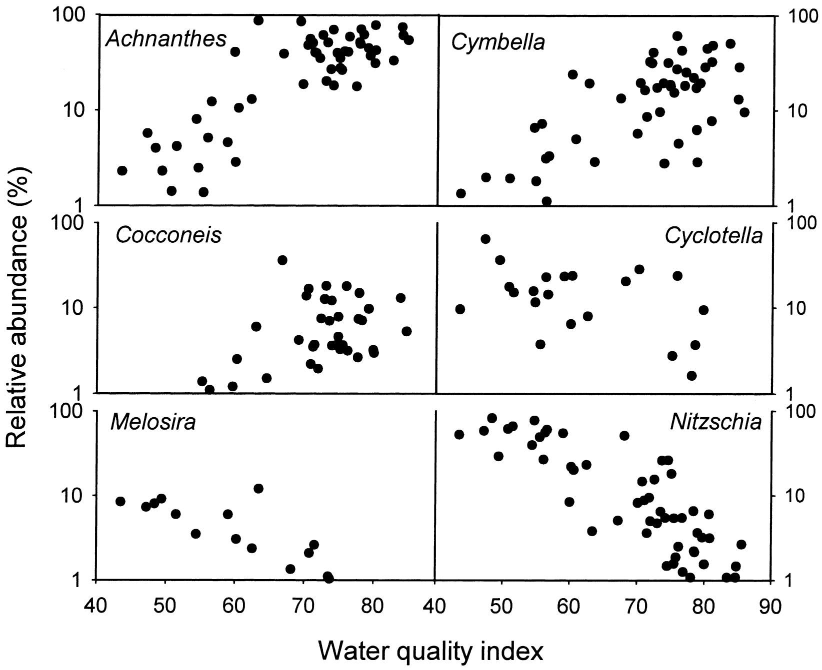

Figure 4. Relationship between relative abundance of the six diatom genera and the water quality index calculated on the basis of physical and chemical variables at sites on River Tsanwun.

Table 4. Correlation coefficients of Cannonical analysis between generic index (GI), saprobity index (SI), species richness index (MI), species diversity index (H), diatom assemblage index for pollution (DAI) and trophic diatom index (TDI) of River Tsanwun.

	GI	SI	MI	H	DAI
SI	−0.73				
MI	0.11	−0.15			
H	−0.06	−0.15	0.69		
DAI	0.52	−0.76	0.25	0.26	
TDI	−0.72	0.88	−0.25	−0.22	−0.81

The GI characterizes water quality according to a ratio of the relative abundance of *Achnanthes, Cocconeis*, and *Cymbella* to that of *Cyclotella, Melosira*, and *Nitzschia* in the diatom assemblage. In the studied river, the occurrences of some other genera such as *Gomphonema, Fragilaria, Aulacoseira*, and *Navicula* also were well correlated with WQI. For the reasons of consistency and simplicity in the use of index model, these four genera are excluded from the calculation of GI. However, this information may be useful in regions where these taxa comprise a more dominant portion of the community. According to the model of GDI (Coste and Ayphassorho 1991), the occurrence of certain diatom genera is related to the extent of water pollution. The present study also shows that the genera used as the numerator for GI calculation were more abundant in upper reaches where water was less polluted, while those used as the denominator were more abundant in the more polluted environment. A similar phenomenon has been observed in the majority of Taiwanese rivers. It is likely that this is related to some underlying physiological characteristics of the genus. In order to ascertain this a further study is necessary.

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