Use of benthic diatom indices for assessing ecological status of the Sai Gon river, Vietnam

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Abstract:

In the present study, the Biological diatom index (BDI) and the Trophic diatom index (TDI) were calculated for the assessment the ecological status and the water quality of the Sai Gon river in comparison with the physico-chemical variables. In addition, a multivariate method was used to elucidate the main environmental variables driving the diatom community. A total of 87 diatom species were identified and used to calculate the diatom indices. The results of the biological data indicate that ecological status of upstream has a fine water quality; however, the downstream of the river was moderately polluted, and in some cases, of poor status. Canonical correspondence analysis (CCA) permutation tests demonstrated that diatom community was divided into two groups that corresponded to rural and urban characteristics. The BDI and TDI indices showed sensitivity to environmental stressors and served as potential application for bio-monitoring and water quality assessment of surface water in tropical region.

***Keywords:* benthic diatoms, bio-indicator, Biological diatom index, Sai Gon river, Trophic diatom index.**

***Classification number:* 3.4**

Introduction

The use of benthic diatoms for assessment of water quality in lentic systems has recently been applied in many countries. Due to their diversity and wide distribution in various habitats, diatoms are among the most common groups that are being used to monitor ecological status of rivers [1, 2]. Many diatom indices have been developed and applied for the classification water quality. As a multi-metric approach, the TDI originally developed by Kelly and Whitton (1995) [3], and the BDI developed by Lenoir and Coste (1996) [4], were commonly used in monitoring aquatic conditions. The TDI and BDI indices have been applied in several countries for assessing water quality. Nevertheless, there was no study for assessing the ecological condition in Vietnam using these indices.

Water quality monitoring programs in Vietnam have been mainly based on water physic-chemical parameters [5]. However, the use of aquatic community composition in water quality assessment has several advantages compared to the physical and chemical variables. For example, aquatic communities can reflect the interactions between abiotic quality and the integrity of biotic factors. Therefore, they can accurately indicate water quality [2]. In addition, each group of aquatic communities can reflect the changes of water environment in different ways [6]. Aquatic communities such as phytoplankton, diatom, macroinvertebrates, zooplankton and fish have been used to assess the effects of pollutants on water quality. Currently, benthic diatom and benthic macroinvertebrates are the most widely used bioindicators in lentic water. The indices of Biological monitoring working party (BMWP^{VIETNAM}) and Average Tolerance Score per Taxa (ATSPT) calculated from benthic macroinvertebrate community have been developed and applied for the classification of the Vietnamese water quality [7, 8]. However, the use of freshwater benthic diatoms, especially in Vietnam, is in its infancy and is limited. Due to living on non-mobile substrates, diatom are more sensitive to pollution than other mobile organisms such as fishes, zooplankton and macroinvertebrates [6].

The Sai Gon river is important to Ho Chi Minh city, as it is the main water supply as well as the host of the Sai Gon port [9]. Over the past years, the industrial cluster and the urban population have grown considerably. This fast development has caused water pollution and *water quality degradation* of the river. In this study, the two diatom-based indices (the TDI and the BDI) were first applied for assessing the ecological status of the Sai Gon river.

Materials and methods

Study area

The Sai Gon river is located in Southern Vietnam, originating from Phum Daung in Southeastern Cambodia. The river flows south and southeast downstream along the western boundary of Binh Duong before entering the territory of Ho

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Chi Minh city and empties into the Dong Nai river at Nha Be, which, in turn, empties into the East Sea after flowing some 20 kilometres. The total length, catchment area and average flow rate of the Sai Gon river are 280 km, 4,750 km^2 and 85 m^3/s, respectively [10].

Fig. 1. Map of the Sai Gon river showing the seven study sites.

Environmental variables

The water samples were collected in dry and wet seasons at seven sampling stations coded SG1to SG7, including rural upstream sites (SG1 to SG3; SG1: near Dau Tieng dam, SG2: Dau Tieng town, and SG3: Ben Suc bridge) and urban downstream sites (SG4 to SG7; SG4: close to the confluence of the Sai Gon and Thi Tinh rivers, SG5: Phu Long bridge, SG6: Binh Phuoc bridge, and SG7: Sai Gon bridge) of the Sai Gon river (Fig. 1). Water temperature, electrical conductivity, turbidity (TB), pH and dissolved oxygen concentration (DO) were measured on sites by using the Portable multi-meter (Hach 156, USA). The following variables total suspended solid (TSS), biochemical oxygen demand after 5 days (BOD_5), chemical oxygen demand (COD), total organic nitrogen (TN) and total phosphorus (TP) were measured according to APHA (2005) [11].

To measure the Total suspended solids (TSS), about 300-500 mL of water samples were filtered into a pre-weighed glass-fibre filter (Whatman GF/C, England) and dried completely at 95±5°C. Then, the TSS concentration was estimated gravimetrically. The total dissolved solid (TDS) was calculated from the conductivity concentration by multiplying with a factor of 0.6.

Diatom collection identification

Benthic diatoms were collected on hard substrates according to the method described by Chen, et al. (2016) [6], by brushing five substrates (stone, brick, wood, bamboo or five areas on the hard surfaces in urban area) over a surface area of 10 cm^2. Diatom samples were kept in 100 mL plastic vials and fixed with Lugol solution. In the laboratory, the diatom valves were cleaned with concentrated nitric acid, and then washed several times with distilled water according to the method described by Gray and Vis (2013) [12]. An aliquot of 1 mL sample was settled and counted on the Sedgewick rafter counting chamber. Diatom valves were examined under an inverted microscope (Olympus CK40-F200, Olympus, Tokyo, Japan) at 400× magnification. At least 500 diatom valves were counted for each sample; rare species were counted several times on some slides. Taxonomic identification and classification were based on the systems of Krammer and Lange-Bertalot (1986, 1988, 1991a, 1991b) [13-16]; Metzeltin and Lange-Bertalot (1998, 2002) [17, 18]; Krammer (2000) [19]; Rumrich, et al. (2000) [20]; and Wehr, et al. (2003) [21].

Calculating diatom metrics

Diatoms composition and abundance were used to calculate the BDI and TDI indices. The TDI index was first developed by Kelly and Whitton (1995) [3] and later revised by Kelly, et al. (2001) [22]. This index was calculated by using species composition and abundance of each diatom species. Each diatom species was given a sensitivity value from 1 to 5, where 1 indicates species that favour very low nutrients and 5 very high nutrients, and an indicator value from 1 to 3, where 3 means a species is a good indicator of nutrient sensitivity and 1 means that it is a poor indicator [3, 22]. Values were originally determined for each diatom species/genus based on the orthophosphate concentrations, where taxa are most abundant. The TDI is calculated as:

$$TDI = (WMS \times 25) - 25$$

where, the Weighted mean sensitivity (WMS) value is calculated as:

$$WMS = \frac{\sum_{j=1}^{n} a_j v_j i_j}{\sum_{j=1}^{n} a_j v_j}$$

where: a_j is abundance or density of valves of species j, v_j is indicator value (ranging from 1-3) and i_j is pollution sensitivity (ranging from 1-5) of species j. The generated TDI values vary from 0 (indicating very low nutrient concentrations) to 100 (indicating very high nutrient concentrations) [22].

The BDI index was calculated by using the Calculate BDI with Excel program. The ecological status and the water quality were classified based on the BDI values according to the method described by Lenoir and Coste (1996) [4], as shown in Table 1.

Table 1. Trophic status and water quality class based on BDI index.

BDI value	Quality class	Trophic status
>17	High quality	Oligotrophic
15-17	Fine quality	Oligo - mesotrophic
12-15	Moderate quality	Mesotrophic
9-12	Low quality	Meso - eutrophic
<9	Poor quality	Eutrophic

In addition, diatom indices, including species richness (S), Shannon-Weiner index (H), species evenness (J) and Simpson's diversity index (D), which are commonly used in water quality bioassessment [23], were used to characterise the diatom community structure and the environmental status at each site. These metrics were calculated by using the PRIMER V.5 analytical software.

Statistical analysis

One-way analysis of variance (ANOVA) was applied to examine the significance of the differences between the upstream and downstream sites. The analysis was completed by using Tukey's HSD test significant difference. The Pearson correlation analysis was used to determine the correlation between the diatom metrics and the environmental variables. All statistical analysis was done by using SPSS v.16.0 (IBM Corp., Armonk, NY, USA). Canonical Correspondence Analysis (CCA) was analysed by using the program CANOCO 4.5 for Windows to elucidate the main environmental variables' driving force in the diatom community and diatom metrics. All variables were log-transformed to normalise their distributions before analysis.

Results

Environmental variables

The physico-chemical variables measured in the field at each site were summarised in Table 2. The water of the Sai Gon river is slightly acidic. The pH value decreased at downstream and ranged from 5.5 to 6.3. DO values were low (less than 5 mg/L) and decreased at downstream sites. TDS, TSS, BOD_5 and COD increased gradually while moving towards the downstream of the river. Electrical conductivity is one of the environmental variable that changed significantly from 110 to 1,496 µS/cm between upstream and downstream sites. Additionally, nutrient pollutants increased at downstream with TN values ranging from 1.3 to 2.1 mg/L and TP values ranging from 0.1 to 0.5 mg/L. Based on the TN and TP values, the water quality of the Sai Gon river is now considered eutrophic to hypertrophic, according to the classification described by Forsberg and Ryding (1980) [24] (hypertrophic: total phosphate > 100 µg/L, total nitrogen > 1,500 µg/L; eutrophic: total phosphate, 25-100 µg/L; total nitrogen, 600-1,500 µg/L). Moreover, it was noted that the maximum values of nutrient pollutants were reported to three sites at urban downstream (SG5 to SG7). ANOVA results showed that there was no significant change in the water temperature, TB, pH, DO, BOD_5 and COD (ANOVA, $p<0.05$), while significant differences in TSS, TN and TP between dry and wet seasons (data not show) were observed.

Diatom composition and abundance

In total, 83 species of benthic diatom, corresponding to 19 genera, were identified in the Sai Gon river. The most abundant genera were *Navicula*, *Nitzschia*, *Eunotia* and *Coscinodiscus* with 13, 11, 6 and 6 species, respectively (Fig. 2A). The diatom composition and distribution were different between in rural and urbanised regions. On the spatial scale, the species named *Achnanthidium minutissimum*, *Cymbella affinis* and *Eunotia robusta* were the consistently dominant species at rural sites (SG1 to SG3). However, tolerant species belonging to *Navicula* and *Nitzschia* were predominated at urban sites (SG4 to SG7).

Table 2. The mean ± SD (n=6) of physico-chemical variables measured at each site during the study period.

Site	SG1	SG2	SG3	SG4	SG5	SG6	SG7
pH	6.5±0.2	6.7±0.2	6.4±0.2	6.2±0.1	6.0±0.2	6.3±0.3	6.2±0.4
DO (mg/L)	4.7±0.3	4.6±0.4	4.4±0.5	3.3±0.7	3.5±0.8	3.2±0.3	3.3±0.4
Temperature (°C)	29.3±1.0	29.1±0.7	29.5±0.6	29.4±0.2	29.0±0.5	29.4±0.6	29.7±0.3
TDS (mg/L)	59.2±33.0	70.6±30.7	64.2±29.3	80.0±33.5	171.9±16.3	162.7±11.6	195.0±8.7
TSS (mg/L)	40.4±20.3	59.8±7.5	66.8±3.1	71.9±6.5	114.0±31.4	99.3±19.7	87.7±7.1
TB	38.2±3.9	49.5±5.3	52.8±0.8	85.5±19.9	70.6±4.1	79.0±18.9	71.3±4.0
Conductivity (mS/cm)	110±27	366±61	524±48	831±64	1200±99	1496±97	1438±155
BOD_5 (mg/L)	4.1±1.0	4.3±0.3	5.1±0.6	5.0±0.2	6.1±0.2	5.7±0.9	5.6±0.2
COD (mg/L)	5.4±0.7	5.7±0.7	6.0±0.5	5.7±0.4	6.9±0.5	6.8±0.9	6.8±0.8
TN (mg/L)	1.3±0.4	1.4±0.1	1.4±0.1	1.8±0.1	2.0±0.2	1.8±0.3	2.1±0.1
TP (mg/L)	0.1±0.03	0.3±0.06	0.2±0.02	0.3±0.05	0.4±0.03	0.5±0.08	0.4±0.05

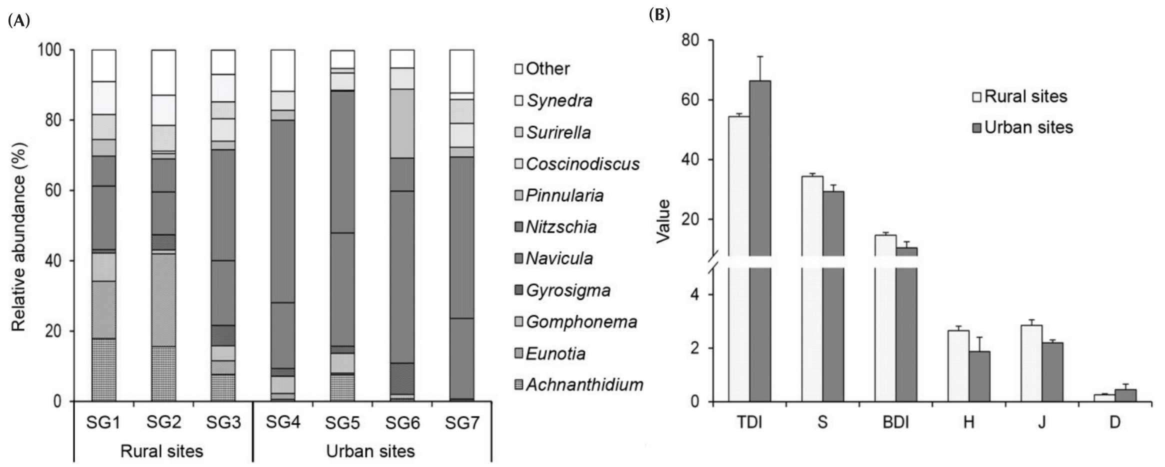

Fig. 2. (A) Composition of the 10 most dominant genera and (B) the diatom metrics of the Sai Gon river.

Table 3. Results of TDI and BDI indices with correspondent judgment and class of quality.

Site	BDI	TDI	Trophic status*		Quality class	Water quality
			A	*B*		
SG1	16.0	53.9	Oligo-mesotrophic	Eutrophic	Fine quality	A_1
SG2	14.2	57.4	Mesotrophic	Eutrophic	Moderate quality	A_1
SG3	13.5	51.8	Mesotrophic	Eutrophic	Moderate quality	A_1
SG4	12.7	58.6	Mesotrophic	Hypertrophic	Moderate quality	A_1
SG5	11.8	59.8	Meso–eutrophic	Hypertrophic	Low quality	A_1
SG6	8.5	73.2	Eutrophic	Hypertrophic	Poor quality	A_1
SG7	8.7	73.6	Eutrophic	Hypertrophic	Poor quality	A_1

*Trophic status (A) based on the classification systems of Lenoir and Coste (1996) [4] and (B) based on the eutrophic classification systems of Forsberg and Ryding (1980) [24].

Diatom indices and ecological status assessment

The BDI and TDI indices were clearly different between urban sites and rural sites ($p<0.05$), and they ranged from 10.4 to 14.6, and from 53.4 to 66.3, respectively (Fig. 2B). These diatom-based indices indicated a similar pattern of seasonal variation. The BDI decreased while the TDI values increased at downstream. Other diatom indices including species richness index (S), Shannon diversity (H), species evenness (J) and Simpson diversity (D) also showed that there were significant differences between urban sites and rural sites ($p<0.05$). The lower course sites registered the lowest score of all indices, but had the highest value of relative abundance of dominant taxa and tolerance TDI score (Fig. 2B). The high TDI but lower BDI score in the urban sites indicated a higher impact from urbanisation downstream of the river.

The values of the TDI and BDI indices calculated for each site, with correspondent judgement and class of quality, is presented in Table 3. The water quality in the Sai Gon river varied between moderate to poor status, corresponding from Oligo-mesotrophic to Hypertrophic (strongly polluted at downstream urban sites), based on the classification systems of Lenoir and Coste (1996) [4], Kelly, et al. (2001) [22] and Forsberg and Ryding (1980) [24]. However, based on BOD_5, COD and total nitrogen according to QCVN 08:2008 (the Vietnamese national technical regulations for surface water quality), water quality was classified into A_1 class, which could be used for drinking.

Canonical correspondence analysis

The environmental variables, diatom indices of abundance, species richness, TDI, BDI and H indices were used in the CCA analysis. The results for CCA exhibited 94.4% variability of the total axis with 91% for Axis-1 and 3.4% for Axis-2 of the total variance. The diatom abundance and TDI had a significant correlation with TP, TN, EC, TB, TDS, TSS, COD and BOD_5. Whereas species richness, BDI and H indices showed negative correlation with the above parameters, but correlative with DO (Fig. 3).

Of the 83 diatom taxa identified in this investigation, 31 taxa, with relative abundance ≥10%, were included in data analysis using CCA. In total, 97.8% of the variation between selected species and environmental variables were explained by the first two axes of CCA. The CCA was divided into two groups with difference species indicators. Group 1 was those species who were preferred in rural areas with higher DO and oligo-mesotrophic conditions. The other group included species tolerant to high urbanisation. Those species had positive correlation with TP, TN, TB, EC, TDS, TSS, COD and BOD_5 (Fig. 3).

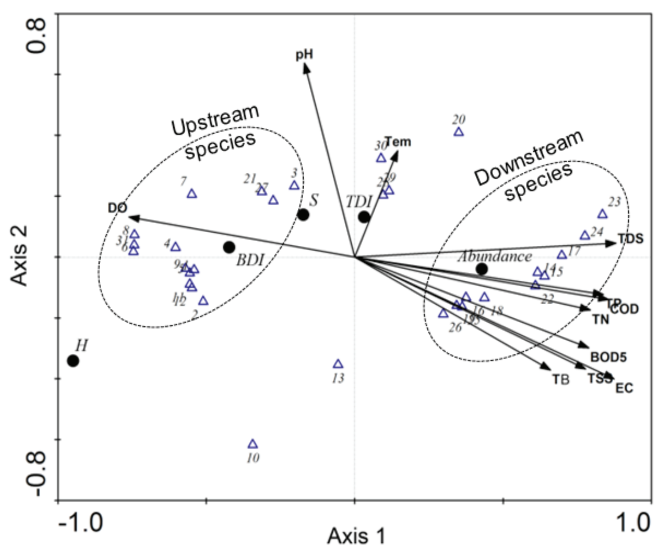

Fig. 3. Canonical correspondence analysis for environmental variables with biological indices and diatom community. Taxa codes correspond to those in Appendix 1.

Discussion

The Sai Gon river water quality was slightly acidic. This can be explained by surface run-off, which brought acidity from acid sulphate soils in the downstream area of the river basin. DO values were low in the Sai Gon river and rapidly decreased at downstream sites. The results were in agreement with Le, et al. (2016) [25], that the DO concentrations decreasing at downstream may be due to the consumption by heterotrophic bacteria and nitrifiers for the degradation of biodegradable organic matter. Water pollution from the Sai Gon river's tributaries adversely affected the raw water quality of the Sai Gon river, which resulted in increasing BOD_5, COD, TSS and TDS at downstream sites. EC is a parameter related to salinity or chloride content [25]. The result of increasing EC at downstream of the river may be due to the seawater intrusion. According to previous studies, water quality of the Sai Gon river polluted mainly organic matter, heavy metal, e-EDCs and microorganisms [25, 26]. Particularly, bacteria, heavy metal of Fe, Cd, Mn and e-EDCs had higher potential risk and may have an effect on human health as well as on safe water supply [9, 10, 26]. Results of this study showed that water quality of the Sai Gon river was also contaminated with nutrient concentration, particularly, nitrogen and phosphorus. This may be associated with stormwater runoff, increase in urban development and discharge of waste water due to human activities.

The Sai Gon river is affected simultaneously by multiple anthropogenic pressures, including heavy metal, organic pollution resulting on eutrophication and degradation of water quality [25]. Additionally, aquatic life is unique and reflects on these impacts. In this study, the use of more integrative diatom metrics together with the physico-chemical variables gain more reliable tools for water quality classification. Diatom indices are shown to be one of the most effective tools for monitoring the trophic status of the river [27]. In case of the Sai Gon river, the water quality varied between fine to poor status. According to these results, it was possible to conclude that only the upper part of this river currently supports conditions for the drinking water supplies. Generally, the downstream sites of the Sai Gon river had lower water quality than the upper stream sites. This common trend may be caused by an increase in human pressure and pollutants on the surrounding lands as water flows down [10].

Compared to water quality assessment solely based on physico-chemical variables, the diatom indices clearly added more information. Decrease in environmental quality on the Sai Gon river was indicated by the BDI and TDI indices, more so than by the physico-chemical variables. Diatom indices are potential tool to elucidate the possible impact of human activity differences on the river ecosystem with the degree of pollution. The BDI and TDI indices, developed in temperate region, is the most widely used diatom-based index for water quality monitoring tools [2]. However, they have never been applied in Vietnam waters. The TDI could reflect nutrient enrichment, mainly phosphorus. It permits rapid assessment of the overall condition of the complicated ecology of streams and rivers and be easily understood by non-technical managers [28]. The BDI is an index routinely used in France for ecological status assessment. It uses a list of key species that show different pollution sensitivities. Therefore, the BDI reflected the pollution sensitivity, or 'ecological profile' of each diatom species in the river [29]. This study suggested that the BDI and TDI indices would be able to distinguish sites of various degrees of pollution and therefore, they may be adequately applied in Vietnam and other regions for surface water monitoring purpose. These results well agree with the previous study that benthic diatom assemblages could be used to assess human impacts on streams across a rural to urban gradient [30].

Appendix 1. List of 31 most abundant diatom species from the Sai Gon river, Vietnam. The code number of diatom species was used in CCA analysis.

Code	Species	Upstream sites	Downstream sites
1	*Achnanthes brevipes*	+	
2	*Achnanthidium minutissimum*	+	
3	*Cyclotella striata*	+	+
4	*Cymbella affinis*	+	+
5	*Cymbella lanceolata*	+	+
6	*Cymbella sgracilis*	+	+
7	*Cymbella turgida*	+	
8	*Eunotia gracilis*	+	+
9	*Eunotia intermedia*		+
10	*Eunotia pectinalis*	+	
11	*Eunotia robusta*	+	+
12	*Fragilaria sp.*	+	+
13	*Gomphonema gracile*	+	+
14	*Melosira granulata*		+
15	*Melosira varians*		+
16	*Nacicula placentula*	+	+
17	*Nacicula salinarum*	+	+
18	*Navicula antonii*		+
19	*Navicula cryptocephala*	+	+
20	*Navicula cryptotenella*		+
21	*Navicula elegans*	+	
22	*Nitzschia angustatula*	+	+
23	*Nitzschia fonticola*	+	+
24	*Nitzschia palea*		+
25	*Nitzschia recta*	+	+
26	*Nitzschia umbonata*	+	
27	*Pinnularia major*	+	+
28	*Surirella capronii*	+	+
29	*Surirella elegans*	+	
30	*Surirella linearis*	+	+
31	*Synedra acus*	+	

Conclusions

In this study, the diatom metrics of BDI and TDI were applied to assess the water quality and the ecological status of the Sai Gon river. Results indicated that the benthic diatom community reflected the water quality and ecological status more accurately than the routine investigation of physico-chemical variables. Additionally, it differentiated the water quality and the ecological conditions in the Sai Gon river, Vietnam. Therefore, it is necessary to use diatoms together with the physico-chemical variables in the water quality monitoring program.

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