Epilithic diatom as a biological indicator for the assessment of water quality in the East River

K.W. Fan*, L. Fok**, J.H.W. Lee** and F. Chen*

*Department of Botany, The University of Hong Kong, Pokfulam Road, Hong Kong, China
(E-mail: keithfan@hkucc.hku.hk; sfchen@hkusua.hku.hk)

**Department of Civil Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong, China
(E-mail: lfok02@hkucc.hku.hk; hreclhw@hkucc.hku.hk)

Abstract A group research project has been initiated to develop an integrated river management strategy and assessment criteria for the East River in Guangdong province. Four field surveys were conducted in 2004 to study the geomorphologic, hydrologic and environmental features of the basin. Epilithic diatom and water samples were collected from four sites in the upper and lower reaches of the river. A total of 23 diatom genera were identified from the study sites during the two sampling periods. The diatom genus Nitzschia represented the most pollutant dependent epilithic diatoms, comprising over 38% of the overall diatom population in the polluted sites. The correlation between water quality and the Shannon diversity index (H), generic index (GI), trophic diatom index (TDI) and diatom assemblage index to organic pollution (DAIpo) was investigated in this study. The results suggested that epilithic diatom might be used as a biological indicator for the environmental health assessment of the East River.

Keywords Biological indicator; East River; epilithic diatom; Nitzschia; water quality

Introduction

A group research project entitled “Integrated physical and ecological management of rivers – with particular reference to the East river (Dongjiang)” has been recently initiated to develop integrated river management strategies and assessment criteria that incorporate flood risk; watershed vegetation and erosion; river morphology; sediment load; water supply, navigation and power generation; water quality; ecology; human-induced stresses and river restoration. This paper represents part of the research in relation to the assessment of river health monitoring by means of benthic algae.

The East river, a tributary of the Pearl river located in southern China, has played a vital role in supporting the economic development in nearby cities including the Hong Kong, SAR. It has served as a source of water supply for Hong Kong since 1965 because of the periodic chronic water shortage problem in the region (Peart, 2004). Today the East river is still crucial and provides around 80% of the potable water supply to Hong Kong. In recent years, rapid population growth and the associated anthropogenic activities in the Guangdong province has exerted a great impact on the water quality in both the main stream and the tributaries of East river (Chui, 2000). In the lower reaches of the East river, the river water pollution is mainly associated with an increase in industrial and domestic sewage discharges (Hills et al., 1998). Similarly, the water quality in the upper reaches is also a serious concern, owing largely to the enormous discharge of organic sewage from household and agricultural lands. According to statistics from Guangdong Environmental Protection Bureau, less than 50% of the water resources in the Guangdong province is classified as Classes I and II according to State Water Environmental Quality Standards which indicates the water is “suitable for potable supply after adequate treatment” (Chui, 2000). Therefore, it is urgent to have a long-term
assessment plan to safeguard the water resource in the East river as it is of foremost importance to the development of Hong Kong and the rapidly developing Pearl River Delta region.

Biological assessment has been incorporated into the current investigation of river health assessment and essentially is the use of indicator organisms to reveal the effects of water quality on the changes of the number and abundance of the biota. Despite the importance of the East river’s influence on the function of the ecosystem in the Pearl river region, the number of studies on the biodiversity of the region is meager. The use of benthic algae, in particular, epilithic diatoms as indicator for water quality monitoring has been reported in a number of countries (Round, 1991; Hill et al., 2000). Diatoms are microscopic algae that belong to the division Bacillariophyta. Diatoms (epilithic diatoms) possess a number of notable characteristics, which make them excellent indicator organisms in water quality assessment (Patrick, 1973). They are readily attached to the substrate, and their growth correlated well to their immediate physical, chemical and biological environments during the time of assemblage development. Moreover, diatoms are ubiquitous in the environment and form diverse communities in most aquatic habitats, which enable cross-geographical comparisons. Thirdly, diatoms are characterized by a siliceous cell wall (frustules), which allows their long-term preservation on permanent slides. The sampling of diatom is straightforward and can be adapted to most geographical regions (Kelly and Whitton, 1995). These characteristics make diatoms a better indicator group for evaluating the effect of environmental quality on aquatic habitats than macrophytes or fauna (Kelly et al., 1995; Lowe et al., 1996).

The objective of the present research is to investigate the suitability of using diatom derived indices such as Shannon diversity index (H), generic index (GI) (Wu, 1999), trophic diatom index (TDI) (Kelly and Whitton, 1995), diatom assemblage index of organic pollution (DAIpo) (Watanabe et al., 1986) for river health assessment in both upper and lower reaches of the East river. To the best of our knowledge, this was the first study using epilithic diatoms for water quality assessment in the basin. Results obtained from this study would be used as baseline data for the development of an integrated river management strategy and as assessment criteria for the basin.

Materials and methods

Sampling sites

The East River Basin is located in the subtropical monsoonal climatic zone with wet-hot summers and dry-cool winters. The mean temperature is around 21 °C and the annual precipitation is around 1,800 mm in the watershed. The rainy season is from April to September which accounts for nearly 80% of the annual precipitation. Four sampling sites in the upper and lower reaches of the East river were selected for water and diatom sampling (Figure 1). These sites included Xinfengjiang (XFJ) and Baipuhe (BPH) near Heyuan; as well as Simeizhou (SMZ) and Xizhijiang (XZJ) near Huizhou.

Water quality measurement and diatom sampling

Water quality measurements and diatom sampling were carried out in 2004. Two water samples were retrieved in BPH and SMZ in July 2004 while four further samples were collected in XFJ, BPH, SMZ and XZJ in November 2004. During sampling, conductivity, dissolved oxygen, pH and temperature of the water were measured in situ using a conductivity meter (YSI Model 30), dissolved oxygen meter (YSI Model 55) and pH meter (Smartest Series-Model pHScan 2), respectively. For the analysis of other water parameters, water samples were collected at each site, stored at 4°C in amber bottles and transported back to the laboratory for analysis. Nutrients (NH3−N, NO3−N, total organic
nitrogen, total phosphorus) and the total suspended solid of the water samples were analyzed according to *Standard Methods (20th edition, 1999)* techniques.

Diatom sampling followed the method of Wu and Kow (2002). In brief, epilithic diatoms were collected from five randomly selected cobbles in each sampling site. A toothbrush was used for the removal of diatoms attached on stones and placed into a 250-ml glass sample bottle containing 100ml of sterile distilled water. The samples were fixed with 4 ml of 4% formaldehyde and 5 ml of Lugol’s solution immediately after collection. Upon delivering the samples to the laboratory, each fixed sample was immediately cleaned with 5 ml of concentrated acids (nitric acid: sulfuric acid = 1:1) and boiled in a water bath at 90°C for 3 min (Kelly and Whitton, 1995; Wu and Kow, 2002). After washing with deionized water, diatoms were dried onto coverslips and mounted onto glass slides using Naphrax (Cepar Grove NJ.07009, USA). Diatoms were observed under a 100X oil immersion phase contrast microscope (Leica DM RXA).

The taxonomy and nomenclature of Lange-Bertalot (2000) were used for the identifications of diatom genera. The genera *Achnanthes* had recently been separated into *Achnanthidium*, *Planothidium*, and *Psammothidium*. In such a case, the taxonomic revision supplemented by John and Robert (2003) was adopted. The frequency of occurrence of each genus was calculated by counting 1,000 valves per sample. The percentage of

Figure 1 Location of sampling sites and major cities in the East River Basin
occurrence of epilithic diatoms was used subsequently for the calculation of the H, GI, TDI and DAIpo.

Indices

The water quality index (WQI) is a composite index calculated on the basis of the weighted average of water quality parameters (Tyson and House, 1989) according to the modified model of Štambuk-Giljanović (2003) and Liou et al. (2004). Parameters including conductivity, pH, temperature, the concentrations of ammonium, dissolved oxygen, and total phosphorus were used for the calculation of the WQI. A WQI score of 100 indicated excellent water quality whereas a score of 0 indicated very poor water quality.

Various biological indices had been employed to assess the ecosystem health of the East river. The Shannon diversity index (H) is a measurement of community diversity calculated by using the number of taxa and the number of individuals in each taxa. Generic index (GI) is based on the ratio of abundance of genera that occurs more often in unpolluted environments (Achnanthes, Cocconeis and Cymbella) to those common in polluted environments (Cyclotella, Melosira and Nitzschia) (Wu, 1999). This ratio is found to correlate with water pollution. The higher the GI, the better the water quality would be. GI was modified in this study by adding the genus Achnanthidium to the numerator to accommodate the change of nomenclature. Moreover, the genus Navicula was used instead of Melosira in the denominator because of the abundance of Navicula found associating with the polluted water in the East river. Similar to the GI, the trophic diatom index (TDI) was developed as a practical index from the Urban Wastewater Treatment Directive of the USA to handle the increasing problems of eutrophication occurring in rivers. The index was based on a total of 86 taxa that were selected for their indicator value and ease of identification (Kelly and Whitton, 1995). In general, the value of TDI increased with an increase in the number of polluted species. Calculation of the index used the weighted average equation of Zelinka and Marvan (1961). Diatom assemblage index of organic pollution (DAIpo) (Kelly and Whitton, 1995) was a numerical index calculated on the basis of the amount of organic pollution flowing in water. Calculation of the index was based on the relative abundance of saprophilous and eury saprobic taxa that were present in the diatom communities (Watanabe et al., 1986). A high value of DAIpo indicated an unpolluted water body.

Results and discussion

Water quality

The WQI was applied to the present study in order to provide a basis with which diatom-based indices could be compared among the various sampling sites. Table 1 summarizes

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>July</th>
<th>November</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPH</td>
<td>SMZ</td>
<td>XFJ</td>
<td>BPH</td>
</tr>
<tr>
<td>Temperature</td>
<td>°C</td>
<td>27.5</td>
<td>25.4</td>
</tr>
<tr>
<td>Conductivity</td>
<td>μS/cm</td>
<td>60.4</td>
<td>91.7</td>
</tr>
<tr>
<td>pH</td>
<td>–</td>
<td>7.2</td>
<td>7.67</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>mg/L</td>
<td>7.65</td>
<td>6.29</td>
</tr>
<tr>
<td>Total suspended solid</td>
<td>mg/L</td>
<td>18.4</td>
<td>74.1</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>mg/L</td>
<td>0.78</td>
<td>1.3</td>
</tr>
<tr>
<td>Total phosphorous</td>
<td>mg/L</td>
<td>0.09</td>
<td>0.15</td>
</tr>
<tr>
<td>WQI</td>
<td>–</td>
<td>51.2</td>
<td>34.7</td>
</tr>
</tbody>
</table>
the chemical parameters of water at the sampling sites located in both the upper and middle reaches during the two sampling periods. The water collected in BPH showed a similar nutritional level during the two sampling periods in July and November 2004. Low nutrient concentrations (N, P) and high dissolved oxygen levels were detected in this site and attained a similar score for the WQI. The water collected from XFJ had the lowest amount of total suspended solid, total nitrogen and total phosphorus. Since the sampling site at XFJ is situated immediately under a dam, where the daily fluctuations in water level due to dam operations may have effect on the water quality. In the lower reaches, the water quality conditions at SMZ and XZJ deteriorated. A decrease in dissolved oxygen, accompanied by an increase in conductivity, total suspended solids, total nitrogen and total phosphate was observed at these sites regardless of season. The result of water quality index calculated in our study was in the following order: XFJ (84.6) > BPH (51.2–62.0) > SMZ (34.7 – 45.1) > XZJ (30.9). XFJ was a relatively unpolluted site as indicated by a high WQI of 84.6 while XZJ was the most polluted site with a low WQI of 30.9.

Algal biodiversity

Table 2 summarizes the percentage abundance of the genus in the sampling sites along the East river. A total of 48 taxa, belonging to 23 genera were recorded in this study. The highest numbers of species were observed at BPH (July 2004) with 29 epilithic diatom taxa while the lowest number of taxa (10) was found at XFJ (November 2004), a clean upstream site with a good rating for water quality. At the remaining sites, the number of species found was similar ranging from 18 to 22. The observed results indicated that species richness was favored in environments with slight pollution while the number of

<table>
<thead>
<tr>
<th>Genus</th>
<th>No. of taxa</th>
<th>% abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>July</td>
<td>November</td>
</tr>
<tr>
<td></td>
<td>BPH SMZ XFI</td>
<td>BPH SMZ XZJ</td>
</tr>
<tr>
<td>Achnanthes</td>
<td>2 2 – 1 1 1 1 11.9 8.3 – 2.7 1.2 1.3</td>
<td></td>
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<tr>
<td>Achnanthidium</td>
<td>1 1 – 1 1 1 1 1.3 23 – 1.0 4.5 –</td>
<td></td>
</tr>
<tr>
<td>Amphora</td>
<td>1 – – 1 – – 3.8 – – 1.8 – –</td>
<td></td>
</tr>
<tr>
<td>Caloneis</td>
<td>2 – – – – – 7.2 – – – –</td>
<td></td>
</tr>
<tr>
<td>Cavinula</td>
<td>– 1 – – – – – 1.4 – – – –</td>
<td></td>
</tr>
<tr>
<td>Cocconeis</td>
<td>2 2 1 2 1 1 7.8 11.3 1.5 5.0 2.4 4.9</td>
<td></td>
</tr>
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<td>Cyclotella</td>
<td>– – 1 – – – – – 7.1 – – – –</td>
<td></td>
</tr>
<tr>
<td>Cymbella</td>
<td>2 1 1 1 1 1 6.1 1.1 65.8 34.6 0.9 6.6</td>
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<tr>
<td>Diatoma</td>
<td>1 – – – – – 1 2.6 – – – –</td>
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<tr>
<td>Eunotia</td>
<td>1 – 1 – 1 1 2.4 – 3.8 – 1.7 –</td>
<td></td>
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<tr>
<td>Fragilaria</td>
<td>2 2 – – – 2 8.9 4.1 – – – 7.3</td>
<td></td>
</tr>
<tr>
<td>Gonghnomena</td>
<td>4 1 1 2 3 3 7.9 1.7 1.7 16.9 9.3 20.8</td>
<td></td>
</tr>
<tr>
<td>Lemnicola</td>
<td>1 1 1 1 1 1 6.4 1.7 2.3 3.5 3.3 –</td>
<td></td>
</tr>
<tr>
<td>Luticola</td>
<td>– 1 – – – – – 1.9 – – – –</td>
<td></td>
</tr>
<tr>
<td>Navicula</td>
<td>3 2 3 3 1 2 8.4 2.3 16.7 11.9 4.3 2.3</td>
<td></td>
</tr>
<tr>
<td>Neidium</td>
<td>1 – – 1 1 – 2.4 – – 3.3 1.7 –</td>
<td></td>
</tr>
<tr>
<td>Nitschia</td>
<td>1 2 – 2 5 4 2.2 37.8 – 1.6 57.7 42.2</td>
<td></td>
</tr>
<tr>
<td>Nupela</td>
<td>– – – – – 1 – – – – 1 – – –</td>
<td></td>
</tr>
<tr>
<td>Pinnularia</td>
<td>4 2 1 1 1 2 15.1 6.6 1.1 1.1 2.7 5.0</td>
<td></td>
</tr>
<tr>
<td>Placoneis</td>
<td>1 – – – – – 1 5.6 0.5 – – – 2.2</td>
<td></td>
</tr>
<tr>
<td>Planothidium</td>
<td>– 1 – 2 – – – 3.6 – 1.7 – –</td>
<td></td>
</tr>
<tr>
<td>Psammothidium</td>
<td>– 1 – 1 1 1 12.3 – 14.9 10.3 2.2</td>
<td></td>
</tr>
<tr>
<td>Rossithidium</td>
<td>– 1 – – – – 3.1 – – – –</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>29 22 10 19 18 20</td>
<td></td>
</tr>
</tbody>
</table>
species was hindered in extreme environments. The composition of the diatom assemblages varied among the sampling sites. In general, *Cyclotella*, *Cymbella* and *Navicula* were the dominant genera found at XFJ at 7.1%, 65.8% and 16.7%, respectively. The genera *Achnanthes*, *Cocconeis*, *Cymbella*, *Gomphonema*, *Navivula*, *Pinnularia* and *Psammothidium* were the dominant genera found at BPH. *Cymbella* was the most abundant species present in the upper reach sampling sites at XFJ and BPH. Indeed, *Cymbella* is a freshwater genus common in urban streams and is found across a broad temperature range despite the fact that some species are restricted to cool-water environments. In addition, the occurrence of *Cymbella* is often associated with streams that have low nutrient concentrations (Kelly and Whitton, 1995).

At SMZ and XZJ sites, the dominant genus was represented by *Nitzschia* which accounted from 38% to 58% of the diatoms at the lower reach sites. *Nitzschia* is represented by freshwater species that can withstand pollution, and are recognized as indicators of organic pollution of water (Lowe et al., 1996). The group is often described as “pollution dependent” rather than “pollution tolerant” (Lowe et al., 1996). *Cymbella* and *Gomphonema* represented 6.6% and 20.8% of the diatoms in XZJ but only a small percentage of diatom abundance was observed in SMZ. Thus, the availability of different species pool between SMZ and XZJ for colonization could be responsible for differences in community dynamic and diversity.

Figure 2 shows the correlation between WQI and the values of the H, GI, TDI, and DAIpo indices from all the sampling sites. In this study, the correlation coefficient between WQI and H was 0.34, and a poor relationship existed between WQI and H (Figure 2a). The highest value of H was obtained at BPH (3.24), a mildly polluted site as indicated by the value of WQI. Whereas the value of H was low at XFJ (1.25), a relatively clean site, and at SMZ (2.07) and XZJ (2.40), the relatively polluted sites.

![Figure 2 Scatter plots of (a) Shannon-diversity index; (b) generic index of diatom; (c) trophic diatom index; (d) diatom assemblage index for pollution, with water quality index in the East River](https://iwaponline.com/ws/article-pdf/7/2/147/418491/147.pdf)
The values of H did not vary much between SMZ and XZJ and indicated that the overall biodiversity was not severely affected by water pollution. A high biodiversity in the sample population was maintained when sufficient number of sensitive species occurred together with increasing numbers of tolerant species. Some bio-assessment programs had reported that an increase in biodiversity was observed at locations with moderate stresses (Archibald, 1972; Patrick, 1973; Stevenson, 1984; Hill et al., 2000). A high H value can be achieved by a moderate increase in nutrient concentrations and in slow flowing water (Biggs and Close, 1989). The conditions at the sampling sites favored the co-occurrence of sensitive and tolerance species, resulting in high values of H. The relationship between diversity and water quality has been regarded as a complex process (Podani, 1992). In order to apply the biodiversity index for river health assessment, it is necessary to compare community diversity with similar species (Stevenson, 1984). Archibald (1972) stated that it is necessary to define precisely the species that comprises the community, and the detailed information on the autecology of the individual would be required, before the application of species diversity to assess water quality becomes valid.

The use of diatom-based indices may be hindered, especially in regions where data on diatoms are unavailable. Recently, Prygiel and Coste (1993) suggested a generic level based approach. A generic index (GI) based on the genus level had been proposed by Wu (1999). The GI characterizes water quality according to a ratio of the relative abundance of Achnanthidium, Cocconeis, and Cymbella to that of Cyclotella, Navicula and Nitzschia in the diatom assemblage. In this study, the use of diatoms at the genus level had been shown to be sufficient for water quality assessment without the need for species level identification in the majority of conventional indices. The results showed that the calculated GI values were high at sites located in the upper reaches (XFJ and BPH at 4.02 and 2.56 – 3.20, respectively) while the values were much low at sites located in the lower reaches (SMZ and XZJ at 0.29 and 0.14 – 0.58 respectively). A positive relationship between the WQI and the GI was indicated by a high correlation coefficient (0.83) (Figure 2b). The findings indicated the potential of using GI for river health assessment as it correlates well with the degree of pollution. This agreed with the findings of Wu (1999) and Gurbuz and Kivrak (2002), indicating GI could be employed effectively to assess river pollution.

For TDI, low values were obtained from the sampling sites located in the upper reaches (XFJ: 2.20 and BPH: 2.61 – 3.07) while a high value of TDI was observed at the lower reaches (SMZ: 3.07 – 3.47 and XZJ: 3.32). The results indicated that the TDI value increased with elevated nutrient levels along the East river. WQI and TDI were negatively correlated with a moderate coefficient of 0.56 (Figure 2c). The data suggested that the calculated TDI values were a good supplementary measurement to assess the degree of pollution at the sampling sites.

The values of DAIpo increased from the upstream to the downstream. The results showed that the highest value occurred in the upstream site, XFJ, with a DAIpo value of 87.58. The DAIpo values decreased at other sites along the East river and had the lowest value (40.51) at the most polluted site, XZJ. DAIpo were moderately correlated with WQI giving a positive correlation coefficient of 0.65 (Figure 2d).

Conclusions
The present study represents a survey of epilithic diatoms in the East river. This was the first study using diatoms as a biological indicator to assess water quality in the East river. Based on the comparison of the WQI among the sampling sites, XFJ and BPH at the upper reaches had better water quality than SMZ and XZJ in the lower reaches. A total of 23 diatom genera were identified from the study sites during the two sampling periods.
The diatom genus *Nitzschia* represented the most pollutant dependent epilithic diatom, comprising from 38% to 58% of the overall diatom population at the polluted sites in SMZ and XZJ. The results suggested that the use of benthic diatom community and its derived index synergistically could be applied to monitor river health in the East river. Nevertheless, knowledge of local characteristics of the river and types of substratum is important to the application of diatoms as a biological indicator to assess a river's health. In future studies, more locations along the East river system will need to be sampled in order to fully assess and verify the efficiency and reliability of using epilithic diatom for water quality assessment on a long-term basis.

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**References**


