Mj. Int. J. Sci. Tech. **2008**, *2*(01), 24-36

Maejo International

Journal of Science and Technology

ISSN 1905-7873

Available online at www.mijst.mju.ac.th

Full Paper

Biological indices for classification of water quality around Mae Moh power plant, Thailand

Pongsarun Junshum [1]*, Somporn Choonluchanon[2], and Siripen Traichaiyaporn [1]*

[1] Department of Biology, Faculty of Science, Chiang Mai University, Chiang Mai, 50200, Thailand

[2] Department of Soil Science and Conservation, Faculty of Agriculture, Chiang Mai University, Chiang Mai, 50200, Thailand

* Corresponding author, e-mail: pjunshum@hotmail.com and siripen_t@yahoo.com

Received: 10 October 2007 / Accepted: 1 November 2007 / Published: 29 December 2007

Abstract: The algal communities and water quality were monitored at eight sampling sites around Mae Moh power plant during January-December 2003. Three biological indices, viz. algal genus pollution index, saprobic index, and Shannon-Weaver index, were adopted to classify the water quality around the power plant in comparison with the measured physico-chemical water quality. The result shows that the Shannon-Weaver diversity index appears to be much more applicable and interpretable for the classification of water quality around the Mae Moh power plant than the algal genus pollution index and the saprobic index.

Keywords: algae, algal genus pollution index, biological indices, Mae Moh power plant, saprobic index, Shannon-Weaver index, water quality

Introduction

Biological methods of assessing aquatic ecosystem have long been used in many countries. Algae as a component of aquatic ecosystem are an indicator of water quality which is determined by their species composition and diversity. Algae have been pointed out as a useful tool for estimation of the environmental impact on the aquatic ecosystem due to its quick response to changes in the environmental condition thus enabling a quick assessment of water quality [1-4]. A reduction in the number of species and an increase in the number of individuals that characterise polluted areas result in significant decrease in the value of diversity [5-6]. In contrast, high diversity (few individuals but many species) and low biomass indicate a healthy area [5]. The biological indices have been used to

monitor the impact of disturbance and pollution on aquatic ecosystems and discussed by many researchers [6-9].

Mae Moh power plant is a thermal electricity unit, operated by the Electricity Generating Authority of Thailand (EGAT). It consists of 13 units, which can be operated continually to produce about 2,625 megawatts at full capacity. All the power plant units employ lignite fuel to heat water in boilers producing hot steam for operating the generators. The drainage water and effluent from the activities of the power plant are treated by both physical and biological processes in the wastewater treatment system. This research was undertaken to determine the species composition of algae and to test the utility and suitability of some biological indices as indicator of water quality around the power plant.

Materials and Methods

Studied area

The Mae Moh power plant is located in Mae Moh district, Lampang province, approximately 650 kilometers north of Bangkok (99º 46' E, 18º 18'N). The power plant requires about 46,000,000 m^3 of water per year for its cooling system and other activities. This amount of water comes from the Mae Kham and Mae Chang reservoirs which are the main natural water supplies. About 25,640 m^3 of industrial wastewater and 200 m^3 of domestic wastewater pass through the physical and biological wastewater treatment system of the power plant. The wastewater treatment system is composed of 4 ponds in series: settleable solid and oxidation pond, bio-treatment pond, diversion pond and south wetland pond. Eight sites selected for water sampling around the power plant are as follows (Figure 1): site 1 - Mae Kham reservoir (capacity 36,979,000 m^3), site 2 - Mae Chang reservoir (capacity 105,780,000 m^3), site 3 - main drain 1, site 4 - main drain 2, site 5 - settleable solid and oxidation pond (capacity 20,000 m^3), site 6 - bio-treatment pond (capacity 100,000 m^3), site 7 - diversion pond (capacity 100,000 m^3), and site 8 - south wetland pond (capacity 192,600 m^3).

Physico-chemical water quality analysis

Water samples were collected monthly from the eight sampling sites during January-December 2003. Some variables including temperature, pH and conductivity were measured in situ by using portable electronic measuring instruments (pH meter: Horibra, model D21, and conductivity meter: Jenway, model 4200). Water samples were collected near the outlet points and from water surface (0.3 m), middle depth and bottom for sites 1 and 2. However, water samples of sites 3–8 were collected only at the depth of 0.3 m and preserved in an ice-box until further processing. Analysis of dissolved oxygen (DO) and biochemical oxygen demand (BOD) was carried out using azide modification method whereas chemical oxygen demand (COD) was determined by closed reflux method [10-11]. Suspended solids (SS) and hardness were determined by hot air oven (105 ºC) and EDTA titrimetric method, respectively. Silica (SiO_2), ammonia nitrogen (NH_3-N) and orthophosphate phosphorus (PO_4-P) were analysed by heteropoly blue methods, nesslerisation method and stannous chloride method, respectively. Chlorophyll-a was determined by cold acetone method [10-11].

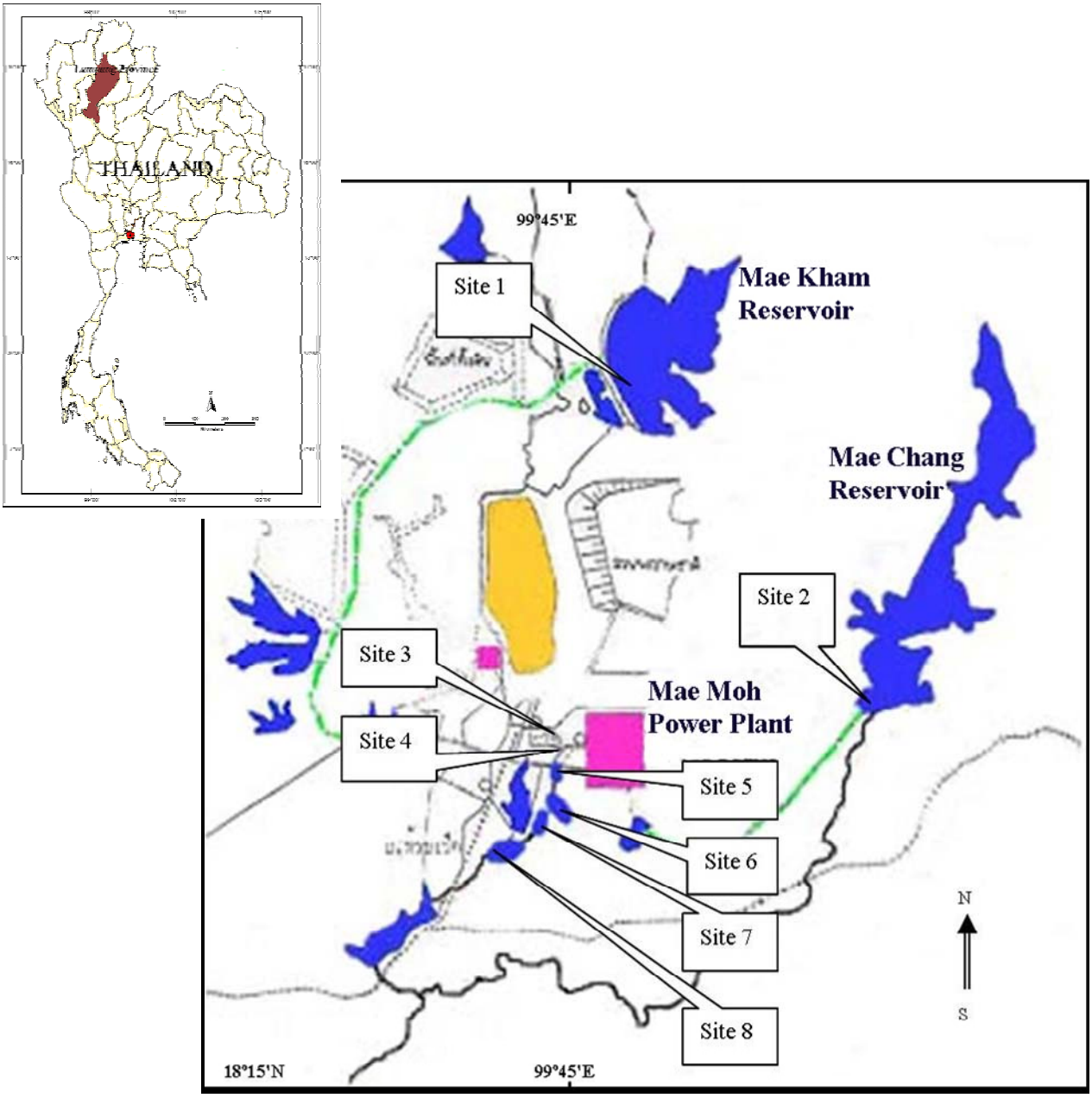

Figure 1. Map of Thailand and location of sampling sites around the Mae Moh power plant:
sites 1, 2 - natural water supplies for power plant activities
sites 3, 4 - effluents from power plant activities
sites 5-8 - wastewater treatment system

Algal analysis

Water sample for algal counting was transfered to a 500 ml cylinder and fixed with Lugol's iodine solution (5 ml). The preserved sample was left to stand in the dark for 10 days to allow concentration by decantation. Then the lower layer (20-25 ml) containing the sedimented algae was transfered to a 50 ml cylinder. The second decantation was conducted after 7 days, and the lower layer (10 ml) containing sedimented algae was put in a plastic vial and stored in a dark box. The concentrated

sample containing the sedimented algae was used for identification and counting of algae under a compound light microscope [11].

Three biological indices were calculated as follows:

1) Algal genus pollution index [12], as shown in Table 1. In making a microscopic analysis of a sample, all of the 20 algae observed were recorded (providing 5 or more individuals per slide of a particular kind were present). The index factors of the algae present were then totalled.

2) Saprobic index (*S*) [9],

$$S = \sum (rh) / \sum (h)$$

where *r* is the taxon saprobic rating (1 = oligosaprobic organism, 2 = β-mesosaprobic organism, and 3 = α-mesosaprobic organism), and *h* is the taxon occurrence rating (1 = occurring incidentally with < 100 cells ml^{-1}, 2 = occurring frequently with 100-200 cells ml^{-1}, and 3 = occurring abundantly with > 200 cells ml^{-1}).

3) Shannon-Weaver diversity index (*H'*) [6],

$$H' = -\sum^{n}_{I=1} Pi \ \ln Pi$$

where *Pi* is proportion of species i in the community and n is number of species.

Table 1. Algal genus pollution index [12]

Genus	Pollution index	Genus	Pollution index
Anacystis	1	*Micractinium*	1
Ankistrodesmus	2	*Navicula*	3
Chlamydomonas	4	*Nitzschia*	3
Chlorella	3	*Oscillatoria*	5
Closterium	1	*Pandorina*	1
Cyclotella	1	*Phacus*	2
Euglena	5	*Phormidium*	1
Gomphonema	1	*Scenedesmus*	4
Lepocinclis	1	*Stigeoclonium*	2
Melosira	1	*Synedra*	2

Note: Larger number indicates more pollution.

Results and Discussion

Assessment of water quality from eight sampling sites around Mae Moh power plant was conducted during January-December 2003. The water quality based on measurements of physico-chemical and biological parameters from all sampling sites (Table 2) was investigated**.**

Classification of Algae

The algae from 8 sampling sites of Mae Moh power plant consisted of 107 species distributed in 6 divisions. The species belong to 42 Chlorophyta, 25 Cyanophyta, 23 Chrysophyta, 11 Euglenophyta, 3 Cryptophyta, and 3 Pyrrophyta (Table 3). The higher numbers of algal taxa in each site were found in Cyanophyta, Chlorophyta and Chrysophyta. A total of 7 dominant species was reported, viz. *Cylindrospermopsis raciborskii*, *Oscillatoria* sp.3, *Raphidiopsis curvata, Synechococcus* sp., *Gomphosphaeria* sp., *Chlamydomonas* sp., and *Platymonas* sp. The common algae of all sampling sites were *Coelomoron* sp., *Cylindrospermopsis raciborskii*, *Dactylococcopsis* sp., *Merismopedia* sp.2, *Oscillatoria* spp., *Raphidiopsis curvata*, *Spirilina laxiscina, Crucigenia* sp., *Scenedesmus* sp.1, *Cyclotella* sp., *Gomphonema* sp., *Mallomonas* sp., *Nitzschia palea*, and *Cryptomonas* sp.

Table 2. Means and standard deviations of selected physico-chemical and biological characteristics of water around Mae Moh power plant

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Temperature (^oC)	29.32± 2.26	26.82± 2.95	28.73± 2.54	34.29± 3.75	32.11±3.30	32.01± 3.45	31.49±2.68	30.12± 3.60
SS (mg L^{-1})	7.58± 7.39	8.58±9.70	15.75±8.80	573.42±358.63	246.08±257.33	19.92±19.56	14.17±8.84	15.33±20.37
pH	7.88±0.39	7.77±0.49	7.23±0.47	9.01±0.53	8.69±0.50	7.62±0.50	7.66±0.68	7.09±0.48
Conductivity ($\mu S\ cm^{-1}$)	268±44.14	218±37.24	330±70.20	683±114.14	846±137.23	997±366.93	1072±410.89	1198±354.70
Hardness (mg L^{-1}as $CaCO_3$)	145±22.10	123±22.60	120±26.89	343±103.30	464±116.90	555±111.50	596±163.03	702±185.68
DO (mg L^{-1})	3.83±1.24	4.84±1.40	4.12±1.57	4.02±2.13	4.68±1.90	4.07±1.03	6.48±3.33	3.17±1.55
BOD (mg L^{-1})	1.98±0.87	1.50±0.81	7.70±3.79	5.03±3.01	3.68±2.53	2.38±1.57	3.10±2.04	2.49±1.32
COD (mg L^{-1})	2.07±0.81	1.85±1.04	12.30±7.50	6.32±11.16	7.10±2.98	3.51±1.43	3.07±1.46	3.56±1.85
NH_3-N (mg L^{-1})	0.188±0.21	0.124±0.12	2.649±1.80	0.246±0.22	0.225±0.21	0.134±0.13	0.208±0.23	0.268±0.36
PO_4-P (mg L^{-1})	0.008±0.01	0.006±0.01	0.417±0.36	0.050±0.05	0.030±0.03	0.039±0.04	0.034±0.03	0.044±0.05
SiO_2 (mg L^{-1})	14.07±2.13	11.88±3.43	10.38±2.50	23.36±3.80	20.96±4.70	21.36±4.84	22.00±4.63	21.66±4.46
Chlorophyll-a (mg m^{-3})	7.52±4.13	3.66±1.44	4.21±2.28	1.63±1.17	2.83±1.61	2.96±1.91	10.27±10.01	3.73±2.22

Table 3. Diversity and classification of algae around Mae Moh power plant

Algae	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
DIVISION CYANOPHYTA								
Anabaena sp.	+	+	-	+	+	-	+	+
Chroococcus sp.	+	+	-	+	+	+	+	+
Coelomoron sp.	+	+	+	+	+	+	+	+
Cylindrospermopsis raciborskii	+++	+	+	++	++	+	+	+
C. curvispora	+	-	-	-	+	-	+	-
Dactylococcopsis sp.	++	+	+	+	++	+	+	+
Gomphosphaeria sp.	+	+++	-	+	+	+	+	+
Lemmermanniella sp.	+	++	-	-	+	+	-	-
Lyngbya sp.	-	-	-	+	-	-	-	-
Merismopedia sp.1	-	+	+	+	+	++	+	+
Merismopedia sp. 2	+	++	+	+	+	+	+	+
Merismopedia sp. 3	+	+	-	-	-	+	-	-
Microcystis sp.	+	-	-	-	-	+	-	-
Oscillatoria sp.1	+	+	+	+	+	+	+	+
Oscillatoria sp.2	+	+	+	+	+	+	+	+
Oscillatoria sp.3	+++	+	++	++	++	++	++	++
Oscillatoria sp.4	++	+	+++	++	+	+	+	+
Romeria sp.	+	-	-	-	-	+	-	-
Plectonema sp.	-	-	+++	-	+	+	+	-
Pseudanabaena sp.	+	+	+	+	+	+	+	+
Raphidiopsis curvata	+++	+++	++	++	++	++	+	+
Spirulina laxissima	+	+	+	+	+	+	+	+
S. subsalsa	-	-	-	-	-	-	+	-
Synechocystis sp.	+	+	+	+	+	+	+	+
Synechococcus sp.	+++	-	+++	++	++	++	++	+
DIVISION CHLOROPHYTA								
Actinastrum sp.	+	+	-	-	+	+	+	+
Ankyra sp.	-	+	-	-	-	+	+	+
Ankistrodesmus braunii	+	+	-	+	+	+	+	+
Ankistrodesmus falcatus	+	+	+	+	+	+	+	+
Ankistrodesmus sp.	+	+	-	-	-	-	-	-
Acanthosphaera sp.	+	-	-	-	-	-	-	-
Chlamydomonas sp.	+	+	+	-	+	++	+++	+
Chlorella sp.	+	+	-	-	-	+	+	+
Chlorogonium sp.	-	+	-	-	-	+	+	+
Closterium sp.	+	+	-	-	-	-	+	-
Coelastrum sp.	+	+	-	+	+	-	+	+

Notes: - (not found), + (1-100 unit ml^{-1}), ++ (101-1000 unit ml^{-1}), +++ (> 1000 unit ml^{-1})

Table 3 (continued). Diversity and classification of algae around Mae Moh power plant

Algae	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Cosmarium sp.	+	+	-	-	+	-	-	-
Crucigenia sp.	+	+	+	+	+	+	+	+
Chodatella sp.	+	+	-	-	-	+	+	-
Dictyosphaerium sp.	+	+	-	+	-	+	+	-
Dimorphococcus sp.	-	+	-	-	-	-	+	-
Gloeocystis sp.	+	-	-	-	+	-	-	-
Golenkinia sp.	+	+	-	-	-	-	+	-
Gonium sp.	-	-	-	-	-	-	-	-
Halosphaera sp.	+	-	-	-	-	-	+	+
Interfilum paradoxum	+	+	-	-	+	-	-	-
Micractinium sp.	-	-	-	-	+	-	+	-
Oocystis sp.	+	-	-	-	-	+	+	+
Pandorina sp.	-	+	-	-	-	-	+	+
Pediastrum sp.	+	-	-	+	-	+	-	-
Platymonas sp.	-	++	-	-	+	+	+++	++
Pteromonas sp.	-	-	-	-	-	-	-	-
Scenedesmus sp. 1	+	+	+	+	+	+	+	+
Scenedesmus sp. 2	+	-	-	+	-	-	+	+
Scenedesmus sp. 3	+	-	-	+	+	+	+	+
Scenedesmus sp. 4	+	-	-	-	-	+	+	+
Scenedesmus sp. 5	+	+	-	-	-	+	+	+
Scenedesmus sp. 6	-	-	-	+	-	-	+	-
Spermatozopsis erultans	+	+	-	-	-	+	+	+
Staurastrum longbrachiatum	+	+	-	-	+	-	-	-
Staurastrum gracile	-	+	-	-	-	-	-	-
Staurodesmus sp.	+	+	-	-	-	+	-	-
Tetraedon caudatum	+	+	-	-	-	+	+	-
T. gracile	-	+	-	-	+	-	-	-
T. trigonum	+	-	-	-	-	-	-	-
T. minimum	+	-	+	+	-	+	+	+
Treubaria sp.	-	-	-	-	-	-	-	-
DIVISION CRYSOPHYTA								
Achnanthes sp.	+	+	+	+	+	+	-	+
Cyclotella sp.	++	++	+	+	+	+	++	+
Cymbella sp.	+	+	-	-	+	+	+	+
Centritractus sp.	-	+	-	-	-	-	+	+
Cocconeis sp.	-	+	-	+	+	-	+	+
Dinobryon sp. 1	+	+	-	+	+	+	-	-

Notes: - (not found), + (1-100 unit ml^{-1}), ++ (101-1000 unit ml^{-1}), +++ (> 1000 unit ml^{-1})

Table 3 (continued). Diversity and classification of algae around the Mae Moh power plant

Algae	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Dinobryon sp. 2	+	+	+	+	-	-	-	-
Fragilaria sp.	+	-	-	+	+	+	+	+
Gomphonema sp.	+	+	+	+	+	+	+	+
Gyrosigma sp.	-	-	-	-	+	+	+	-
Mallomonas sp.	+	+	+	+	+	+	+	+
Merosila sp.	+	+	-	-	-	-	-	-
Navicula sp. 1	+	+	+	+	+	+	-	+
Navicula sp. 2	++	+	-	+	+	+	+	+
Nitzschia sp. 1	+	+	-	-	+	+	+	+
Nitzschia sp. 2	+	+	-	+	+	+	+	+
N.reversa	-	-	-	-	+	+	+	+
N. palea	+	+	+	+	+	+	+	+
N. sigma	-	-	+	+	+	+	-	+
Pinnularia sp.	-	-	+	+	+	+	+	+
Surirella sp.	-	-	-	-	-	-	-	+
Stauroneis sp.	-	-	-	-	-	-	-	+
Synedra sp.	-	-	-	+	-	+	-	+
DIVISION EUGLENOPHYTA								
Euglena acus	-	-	-	-	+	-	+	+
E. fusca	-	-	-	-	-	-	+	+
E. caudate	-	-	-	+	+	+	+	+
Euglena ehrenbergii	+	+	-	-	+	-	+	+
Phacus curvicauda	+	+	+	-	+	+	+	+
P. longicauda	+	+	-	-	-	-	+	+
P. helikoides	+	-	-	-	-	-	+	+
Trachelomonas sp. 1	+	-	+	-	+	+	+	+
Trachelomonas sp. 2	+	+	-	-	-	-	+	-
Strombomonas sp.	-	-	-	-	-	-	+	-
Lepocinclis sp.	+	+	-	-	-	+	+	+
DIVISION CRYPTOPHYTA								
Cryptomonas sp.	+	+	+	+	+	+	++	++
Chroomonas sp.	+	+	+	+	-	+	+	+
Hemiselmis sp.	-	+	-	-	-	-	+	+
DIVISION PYRROPHYTA								
Peridinium sp. 1[1]	+	+	+	+	-	+	+	+
Peridinium sp. 2[1]	+	+	-	+	+	-	+	+
Ceratium sp.	-	+	-	+	-	-	-	-

Notes: - (not found), + (1-100 unit ml^{-1}), ++ (101-1000 unit ml^{-1}), +++ (> 1000 unit ml^{-1})

Classification of water quality based on physico-chemical and biological indices

The water quality around the Mae Moh power plant is classified as shown in Table 4.

Table 4. Classification of water quality around Mae Moh power plant using both biological indices and surface water quality

Sampling site	Surface water quality index	Algal genus pollution index	Saprobic index	Shannon-Weaver index
Site 1	2-4	9-16	2.25-2.50	1.44-2.21
Site 2	2-4	12-16	2.25-2.75	1.61-2.46
Site 3	5	1-14	2.45-2.86	0.13-1.59
Site 4	5	0-18	2.40-3.00	0.06-2.37
Site 5	5	3-22	2.42-2.75	1.32-2.18
Site 6	3-5	1-21	2.00-2.60	0.96-2.67
Site 7	3-5	12-24	2.10-2.67	0.48-2.74
Site 8	3-5	8-27	2.13-2.55	1.14-3.13

Notes: (1) Surface water quality index was derived from comparing the measured physico-chemical water quality with the surface water quality standards set by the Pollution Control Department of Thailand [13].

(2) Larger value of surface water quality index, algal genus pollution index, and saprobic index indicates more pollution, while larger value of Shannon-Weaver index indicates less pollution.

Algal genus pollution index: According to the three quality classes (Table 5) defined for algal genus pollution index by Palmer and Adams [12], the water quality around the Mae Moh power plant is classified as clean water and moderately polluted water. The minimum value was recorded in site 3 (Table 4, Figure 2a), partially due to the reduction in the number of algal species. As can be seen, this index is apparently unapplicable and uninterpretable for the classification of water quality around the Mae Moh power plant, since it contradicts with the physico-chemical water quality or surface water quality index, especially for sites 3 and 4 (Table 4). Thus the algal genus pollution index is unsuitable for prediction of water quality around the Mae Moh power plant.

Table 5. Water quality classes according to algal genus pollution index [12]

Algal genus pollution index	Condition
≤14	low organic pollution
15 – 19	moderate organic pollution
≥20	high organic pollution

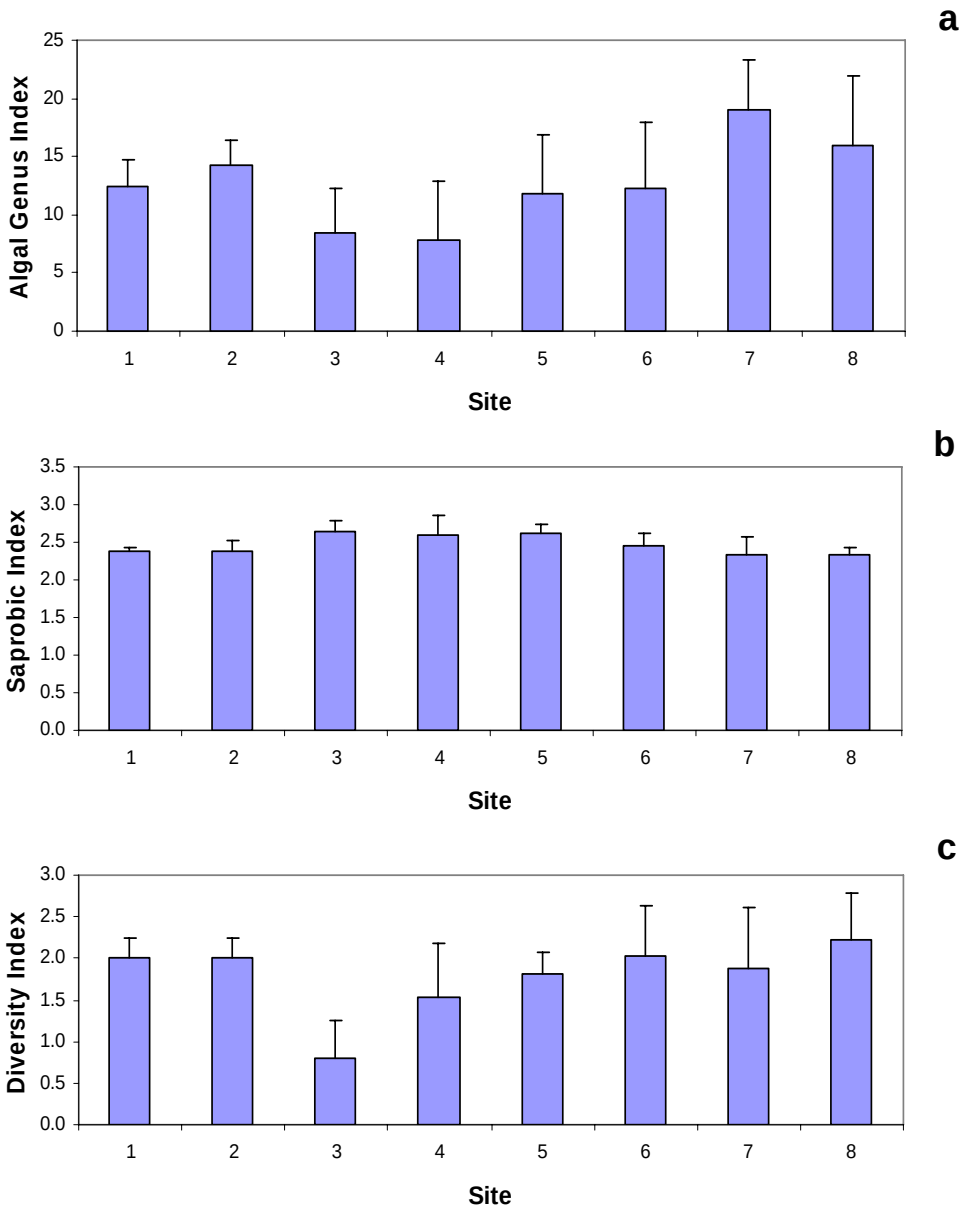

Figure 2. Changes in biological indices: (a) algal genus pollution index, (b) saprobic index, and (c) Shannon-Weaver index

Saprobic index: Four water quality classes are defined for saprobic condition index by Yap [9] as shown in Table 6. By this index, the water quality around the Mae Moh power plant ranged between 2.00-3.00, which is classified into class II and class III (moderate and high organic pollution). However, they were hardly different for all sampling sites (Figure 2b). This index is therefore not applicable to the differentiation of the water quality around the Mae Moh power plant.

Table 6. Water quality classes according to saprobic index [9]

Saprobic index	Class	Condition
1.0-1.5	I	very slight contamination
1.5-2.5	II	moderate contamination
2.5-3.5	III	heavy contamination
3.5-4.0	IV	very heavy contamination

The Shannon-Weaver index: Three water quality classes are defined for Shannon-Weaver diversity index by Wilhm [6] as shown in Table 7, which implies that the high *H'* value suggests the more healthy ecosystem (less pollution) while the low *H'* value suggests poor diversity in a community and a less healthy ecosystem (more pollution). The *H'* value of water around the Mae Moh power plant ranges between 0.06-3.13 (Table 4 and Figure 2c), 1.44-2.46 and 0.06-2.37 being for the reservoirs (sites 1 and 2) and the effluent from the power plant (sites 3 and 4), respectively. These two sources of water can only be classified into class II and class III (moderately and heavily polluted). However, as apparent from Table 4, the Shannon-Weaver index (*H'* value), compared with other indices, seems to be the best indicator of the water quality around the power plant. This is partly substantiated by the fact that the change in the *H'* value, which shows a trend declining sharply from site 1 to site 3 and increasing gradually from site 3 to site 8 (Figure 2c), can be positively correlated with water hardness and negatively correlated with BOD and NH_3-N, as shown in Figure 3.

Table 7. Water quality classes for Shannon-Weaver index [6]

Shannon-Weaver index	Class	Condition
> 3	I	clean water
1 – 3	II	moderately polluted
<1	III	heavily polluted

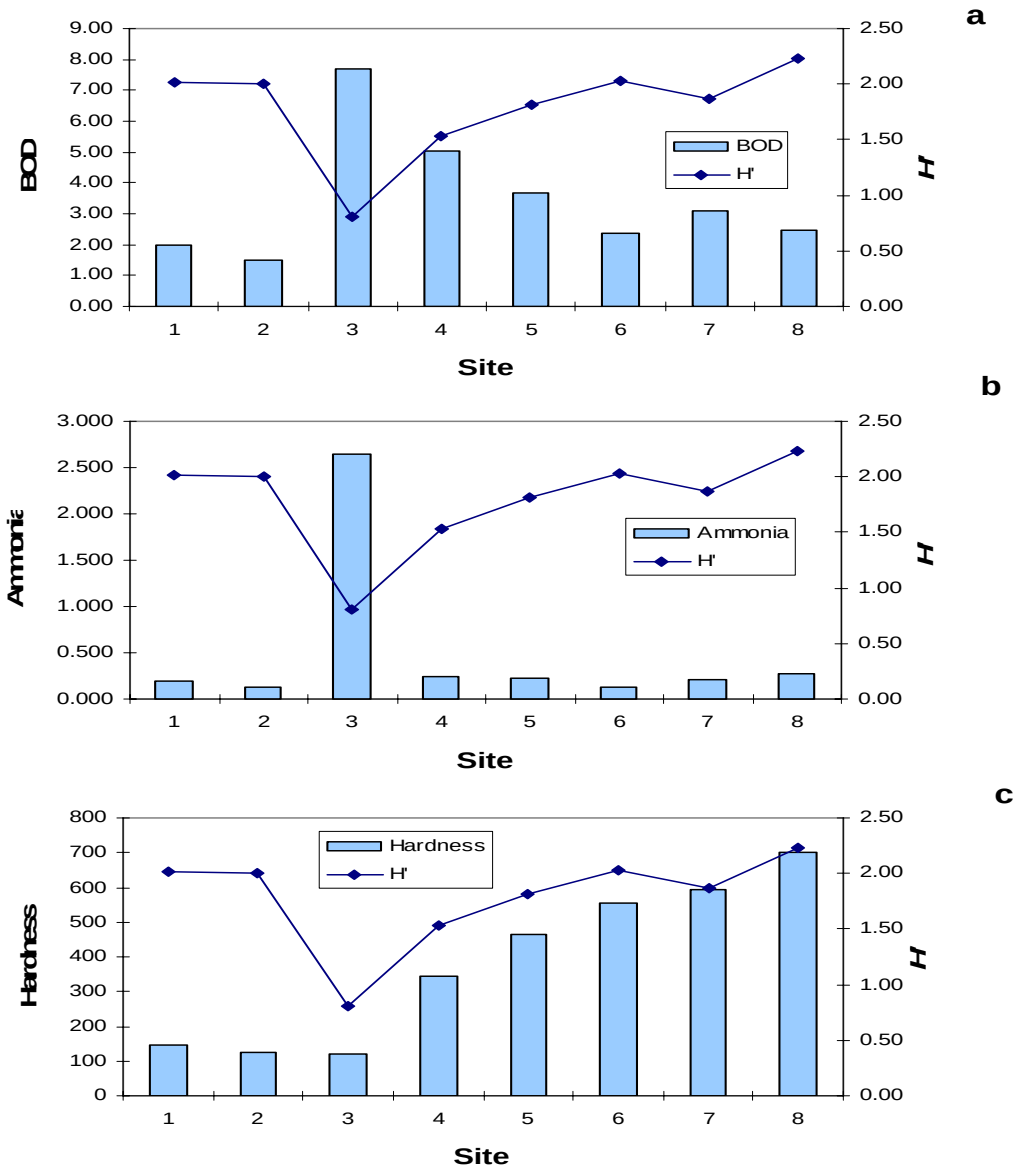

Figure 3. Changes in Shannon-Weaver index (*H'*) with (a) BOD (mg L^{-1}), (b) ammonia nitrogen (mg L^{-1}), and (c) hardness (mg L^{-1} as $CaCO_3$)

Conclusion

Diversity change of algal communities (*H'* value of the Shannon-Weaver index) can be used to compare and classify the water quality around Mae Moh power plant. This biological classification scheme depicts a difference in water quality between the clean upstream water, the polluted water (drainage from the power plant), and the remediated water. It is also in general agreement with the classification based on the traditional chemical water quality assessment. However, this preliminary attempt on biological classification is still in a developmental stage which can be recommended to serve as a guide for more intensive testing and application. This index may become a useful tool in assessing water quality around the Mae Moh power plant.

Acknowledgements

This research was financially supported by the Graduate School of Chiang Mai University. Mr.Yasothorn Budhchan at the Mae Moh power plant is thanked for providing boat facility for collecting water samples, and the Geology Department (Chiang Mai University) is thanked for heavy metal analytical service.

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