CHAPTER 4
RESULTS

4.1 Phytoplankton diversity

4.1.1 Phytoplankton identification and classification

This study found forty-one genera with seventy-nine species of phytoplankton in five localities in four water resources during three seasons in a year which was identified and classified into six divisions following these: Division Cyanophyta consisted of eight genera with eighteen species; Division Cryptophyta consisted of two genera with two species; Division Pyrrhophyta consisted of four genera with five species; Division Chrysophyta consisted of nine genera with nine species; Division Chlorophyta consisted of fifteen genera with thirty-six species and Division Euglenophyta consisted of three genera with nine species. The phytoplankton species number in each division were different at each different waterbody and in different seasons which are presented in Table 3.

Table 3 The phytoplankton species number in six divisions in water collected from five localities in four water resources at six sampling times during three seasons

Site	Season	Cyanophyta	Cryptophyta	Pyrrhophyta	Crysophyta	Chlorophyta	Euglenophyta	total
Fish pond	Rainy 1	8	1	0	0	9	2	20
	Rainy 2	6	1	0	1	4	2	14
	Cool dry 1	1	0	0	0	1	0	2
	Cool dry 2	6	0	0	0	3	2	11
	Summer 1	6	0	0	0	4	2	12
	Summer 2	6	0	0	0	3	1	10
Open water of Houy Yuak Reservoir	Rainy 1	3	1	1	0	3	4	12
	Rainy 2	5	1	2	0	3	2	13
	Cool dry 1	8	1	2	1	3	5	20
	Cool dry 2	6	1	1	2	4	4	18
	Summer 1	9	1	3	1	8	5	27
	Summer 2	9	1	2	2	6	5	25

Table 3 (Continued)

Site	Season	Cyanophyta	Cryptophyta	Pyrrhophyta	Crysophyta	Chlorophyta	Euglenophyta	total
Small pond of Houy Yuak Reservoir	Rainy 1	8	1	1	3	3	5	21
	Rainy 2	7	1	3	1	3	4	19
	Cool dry 1	5	1	0	5	4	5	20
	Cool dry 2	3	1	1	0	2	3	10
	Summer 1	1	0	0	0	1	5	7
	Summer 2				No sampling			
Reservoir of Mae Kuang Udomtara Dam	Rainy 1	7	0	1	1	8	1	18
	Rainy 2	6	1	3	0	10	1	21
	Cool dry 1	2	1	2	0	9	1	15
	Cool dry 2	4	1	2	2	10	2	21
	Summer 1	6	1	2	1	14	1	25
	Summer 2	5	0	1	3	14	2	25
Sakon Nakhon sewage oxidation pond	Rainy 1	5	2	0	2	7	2	18
	Rainy 2	6	2	0	3	6	3	20
	Cool dry 1	6	2	0	3	6	3	20
	Cool dry 2	6	2	1	2	7	2	20
	Summer 1	4	2	0	4	4	4	18
	Summer 2	5	2	0	2	4	1	14

4.1.2 Phytoplanktons distribution and abundance

The largest number of phytoplanktons, in term of species, was chlorophyte (36 species, 46%) followed by cyanophyte (18 species, 23%). The most frequently abundant groups were also both cyanophyte and chlorophyte which were found in all sampling sites. The distribution and the abundance of phytoplanktons were different in each waterbody and in each season and are shown in Table 4.

The fish pond

Massive surface blooms of cyanophyte, *Microcystis aeruginosa* were found during the investigation covering all three seasons of the year, followed by *Planktolyngbya limnetica* and *Euglena* spp. occurring as the secondary principal populations. The lowest biovolume of *M. aeruginosa* was 17,789 mm^3 m^{-3} found at the beginning of the rainy season. The highest biovolume of *M. aeruginosa* was 310,903 mm^3 m^{-3} found at the beginning of the cool dry season (Figure 3 and Figure 4).

The open water of Houy Yuak Reservoir

The filamentous cyanophyte, *Cylindrospermopsis raciborskii* occurred in all seasons with the biovolumes ranging between 9,855 - 64,055 mm^3 m^{-3} and it was the dominant species followed by *Peridiniopsis* sp.1, *Planktolyngbya limnetica* and *Trachelomonas oblonga*, respectively in the rainy season and the cool dry season. Then, *Planktolyngbya limnetica* was the dominant species with the highest biovolumes of 84,460 mm^3 m^{-3} followed by *Cylindrospermopsis raciborskii* and *Trachelomonas oblonga* in the summer (Figure 5 and Figure 6).

The small pond of Houy Yuak Reservoir

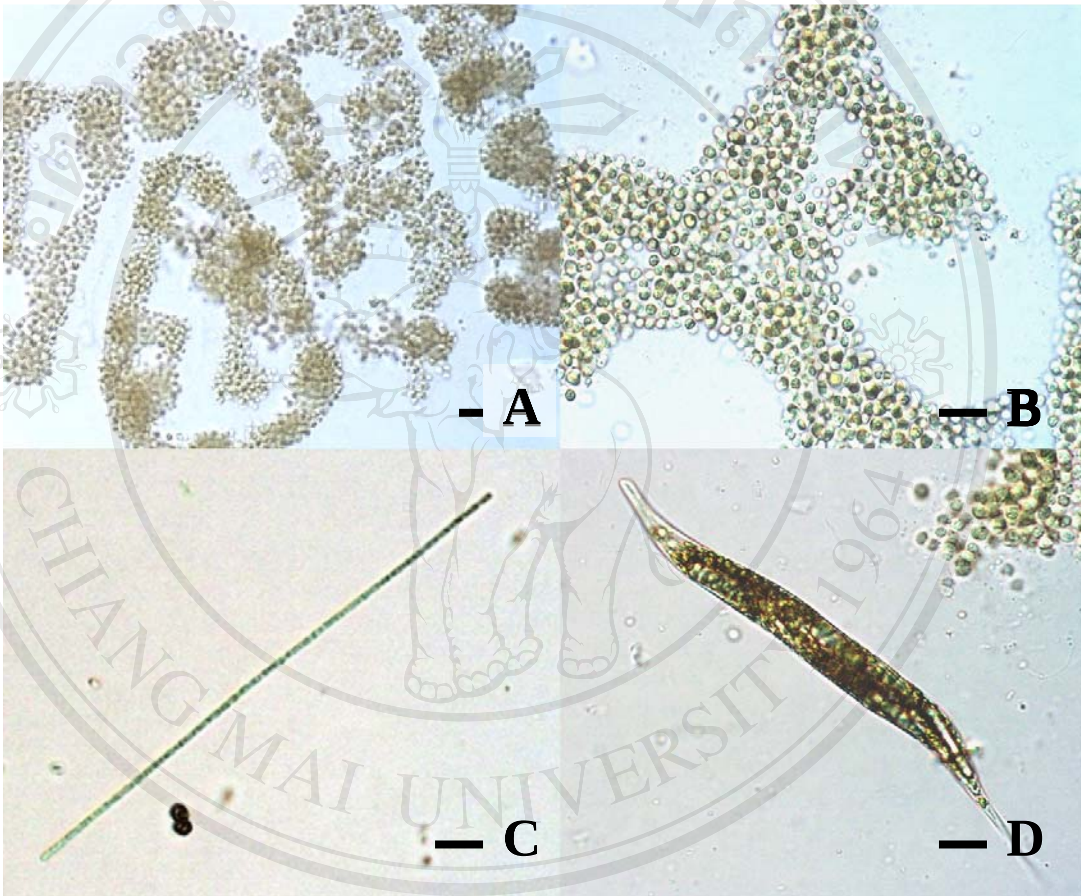
Cylindrospermopsis raciborskii was the dominant species with the highest biovolume of 19,709 mm^3 m^{-3} followed by *Peridiniopsis* sp.1, *Trachelomonas oblonga* and *Oscillatoria* sp. 1 respectively in the rainy season. Then, *Trachelomonas oblonga* was the dominant species with the highest biovolume of 13,767 mm^3 m^{-3} in the cool dry season and the summer instead of *C. raciborskii* in the summer (Figure 7 and Figure 8).

The reservoir of Mae Kuang Udomtara Dam

Cylindrospermopsis philippinensis occurred in the rainy season and it was the dominant species with the biovulume of 161,590 mm^3 m^{-3} at the end of the rainy season followed by *Staurodesmus crassus* then *C. philippinensis* which decreased whilst many desmids species were dominant in the cool dry season and the summer, for example *Staurodesmus crassus*, *Staurastrum gracile*, *Staurastrum smithii*, *Cosmarium* spp. and *Trachelomonas oblonga* (Figure 9 and Figure 10).

Sakon Nakhon sewage oxidation pond

Spirulina platensis always occurred between 5,928 - 16,378 mm^3m^{-3} during three seasons of the year and it was the dominant species followed by *Trachelomonas oblonga* and *Microcystis aeruginosa* in the rainy season then *Trachelomanas oblonga* was the dominant species followed by *Diatomella* sp. 1 and *Spirulina platensis* in the cool dry season. However, *Spirulina platensis* was dominant again with *Microcystis aeruginosa* in the summer followed by *Trachelomonas* and *Diatomella* (Figure 11 and Figure 12).



(scale bar: 10 μm)

Figure 3 Microscopic images of dominant phytoplankton species occurring in the fish pond during the rainy season from August 2003 to the summer in May 2004. (A) *Microcystis aeruginosa* (magnification: 100x), (B) *Microcystis aeruginosa* (magnification: 400x), (C) *Planktolyngbya limnetica* and (D) *Euglena acus*.

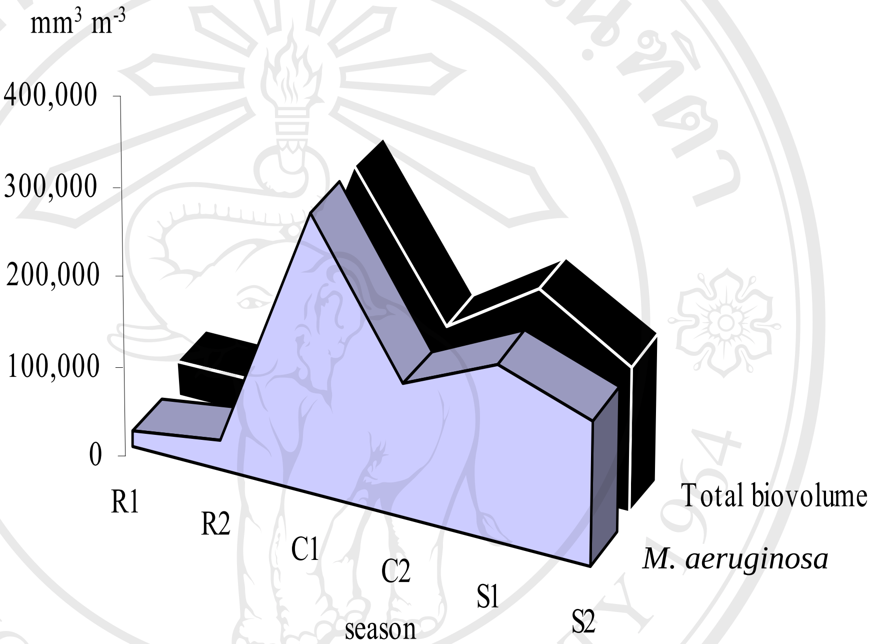
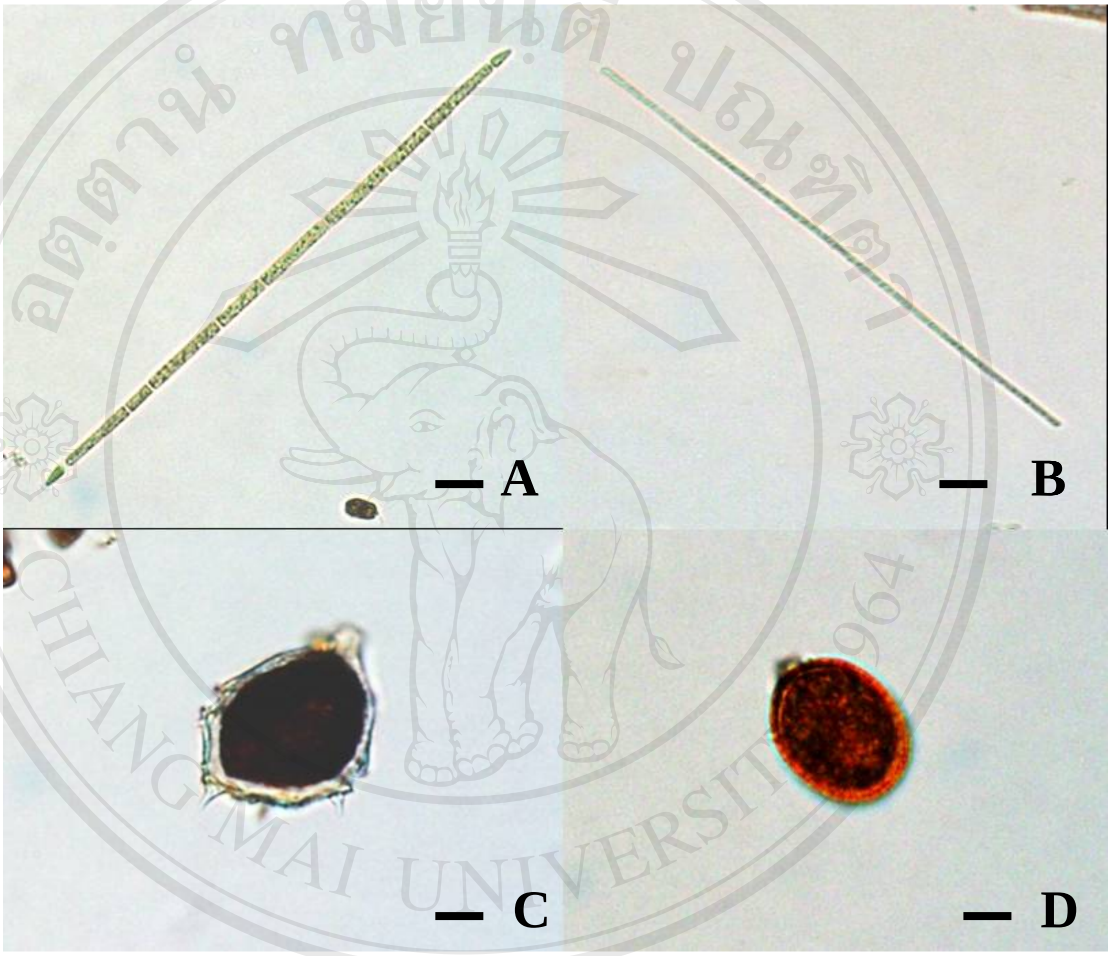


Figure 4 The biovolumes of dominant phytoplankton species occurring in the fish pond during the rainy season from August 2003 to the summer in May 2004. The first sampling in the rainy season (R1), the second sampling in the rainy season (R2), the first sampling in the cool dry season (C1), the second sampling in the cool dry season (C2), the first sampling in the summer (S1) and the second sampling in the summer (S2)



(scale bar: 10 µm)

Figure 5 Microscopic images of dominant phytoplankton species occurring at the open water of Houy Yuak Reservoir during the rainy season from August 2003 to the summer in May 2004. (A) *Cylindrospermopsis raciborskii*, (B) *Planktolyngbya limnetica*, (C) *Peridiniopsis* sp.1 and (D) *Trachelomonas oblonga*.

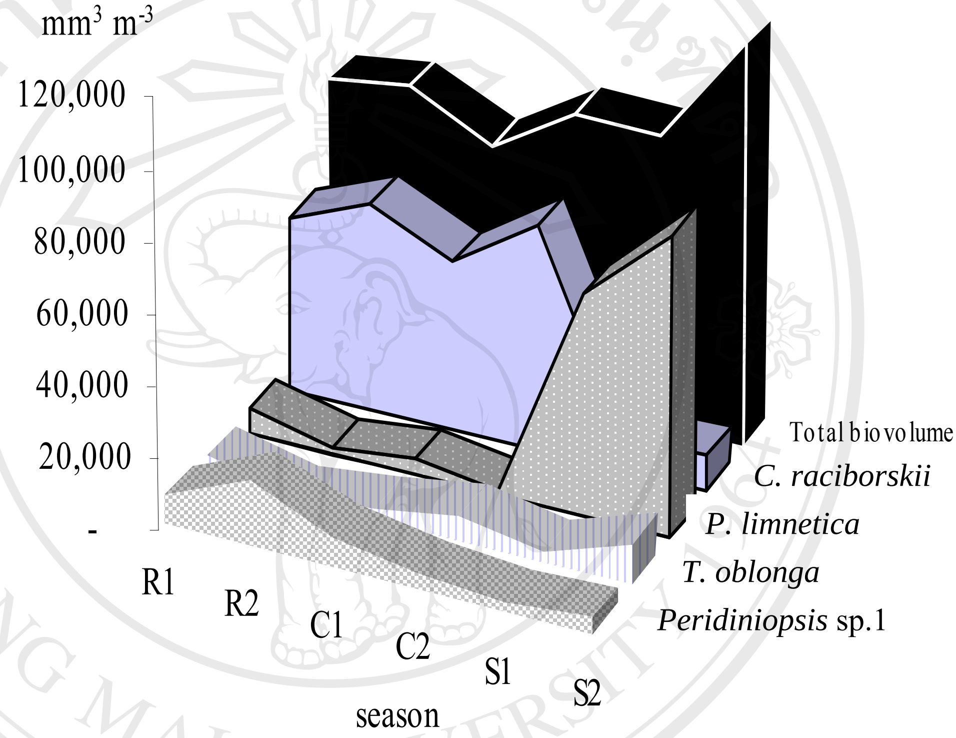
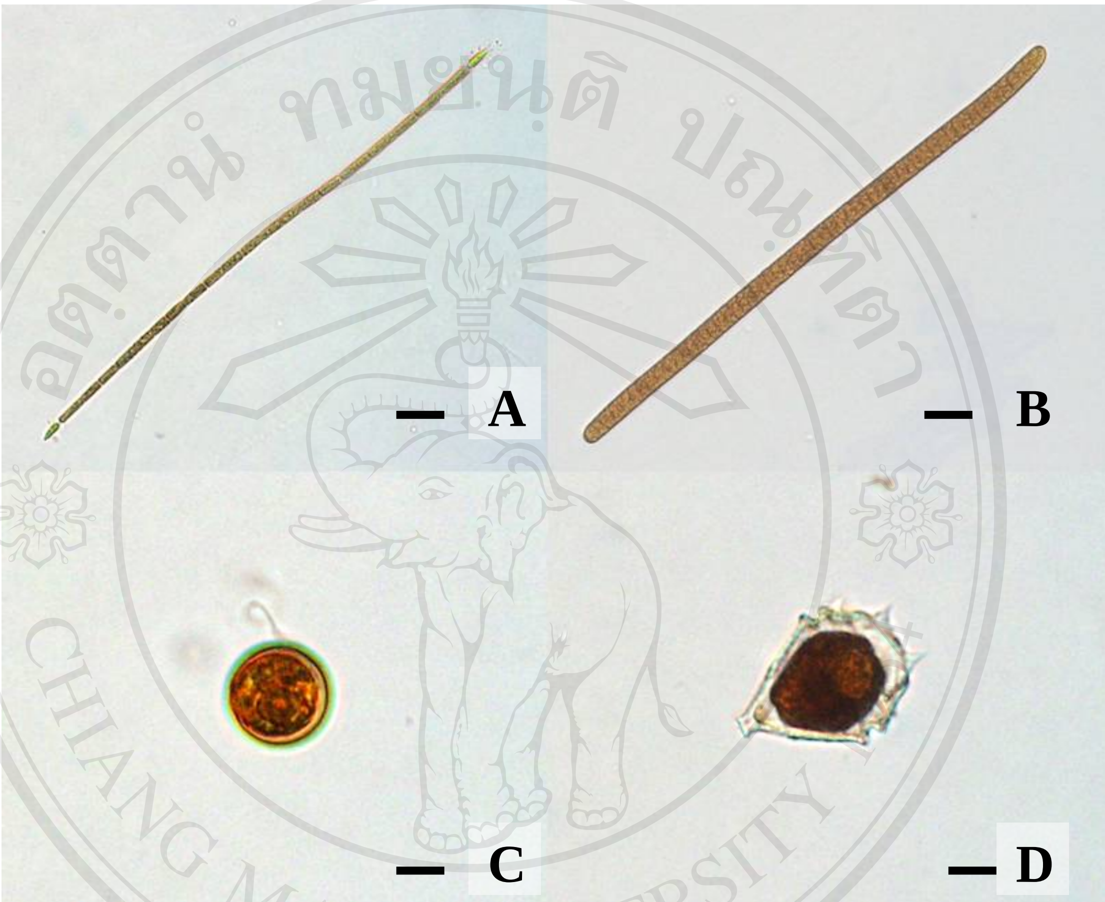


Figure 6 The biovolumes of dominant phytoplankton species occurring at the open water of Houy Yuak Reservoir during the rainy season from August 2003 to the summer in May 2004



(scale bar: 10 µm)

Figure 7 Microscopic images of dominant phytoplankton species occurring at the small pond of Houy Yuak Reservoir during the rainy season from August 2003 to the summer in May 2004. (A) *Cylindrospermopsis raciborskii*, (B) *Ocillatoria* sp.1, (C) *Trachelomonas oblonga* and (D) *Peridiniopsis* sp.1

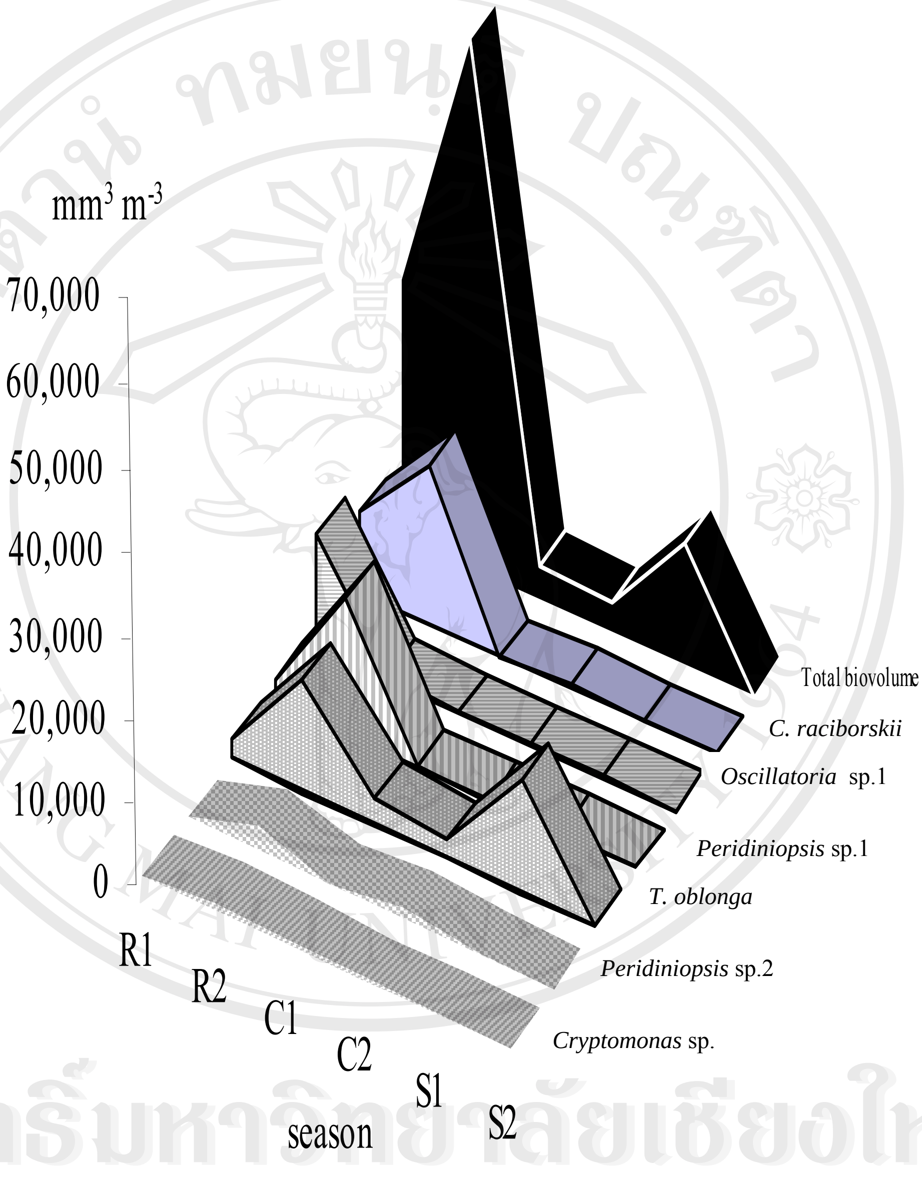
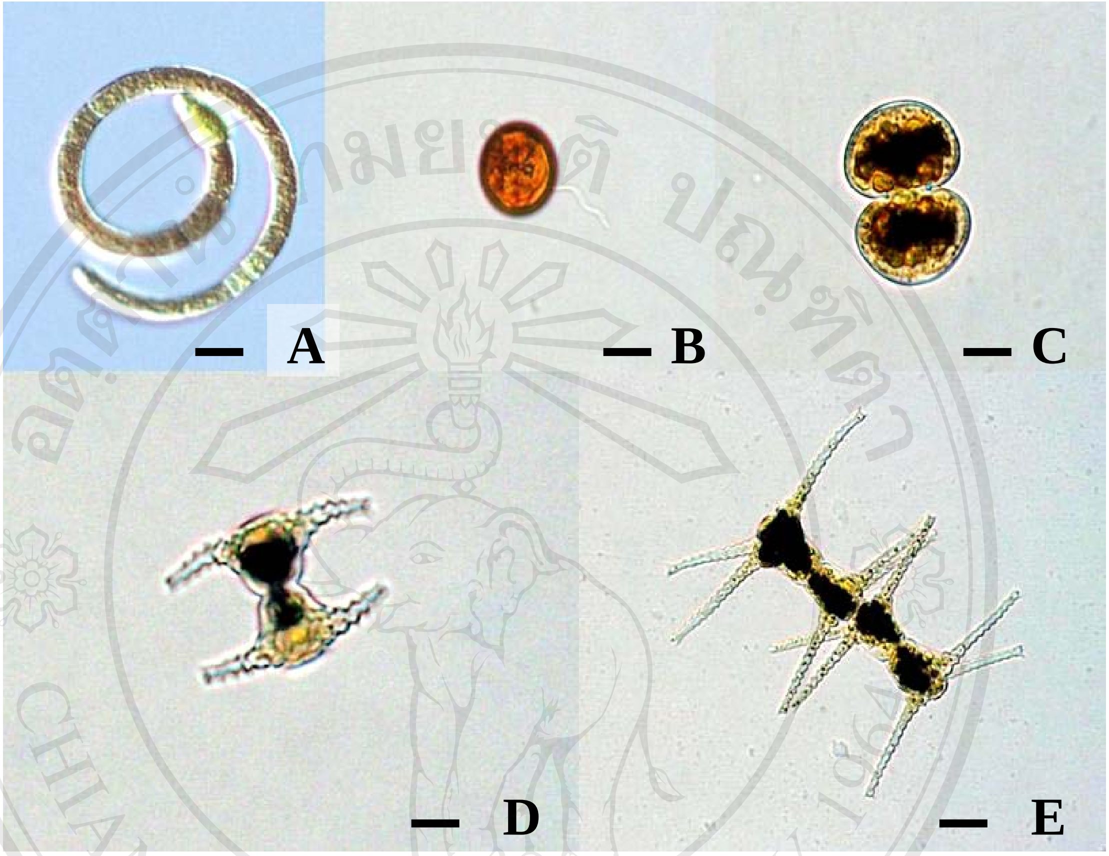


Figure 8 The biovolumes of dominant phytoplankton species occurring at the small pond of Houy Yuak Reservoir during the rainy season from August 2003 to the summer in May 2004.



(scale bar: 10 µm)

Figure 9 Microscopic images of dominant phytoplankton species occurring in the reservoir of Mae Kuang Udomtara Dam during the rainy season from August 2003 to the summer in May 2004. (A) *Cylindrospermopsis philippinensis*, (B) *Trachelomonas oblonga*, (C) *Cosmarium* sp. 1, (D) *Staurastrum gracile* and (E) *Staurastrum smithii*

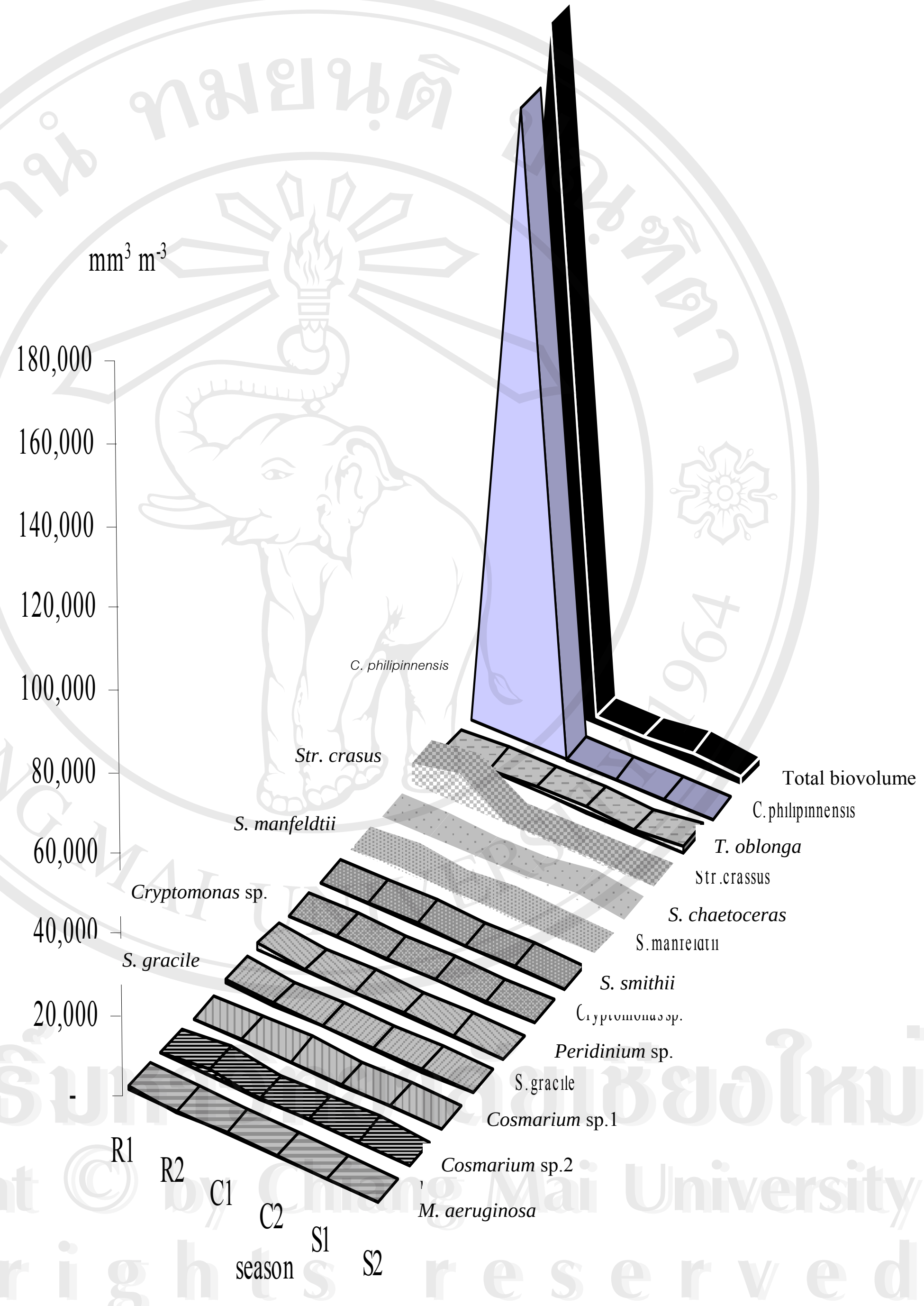
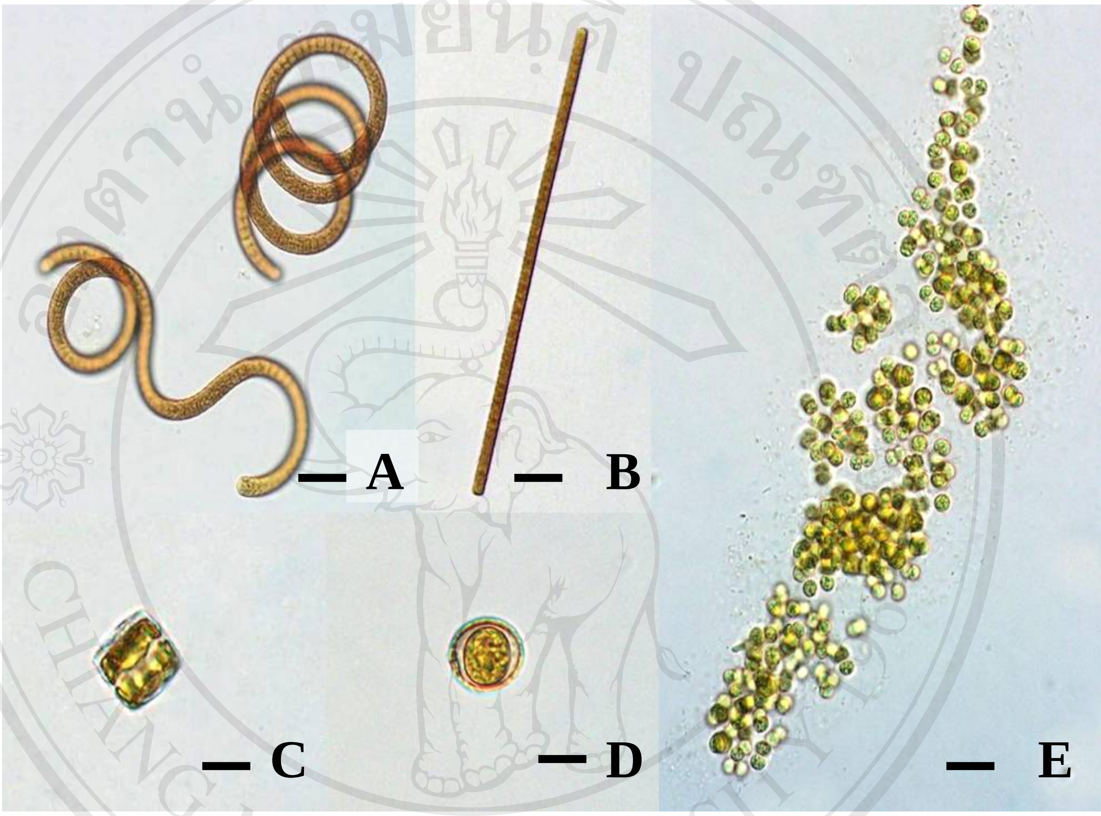


Figure 10 The biovolumes of dominant phytoplankton species occurring in the reservoir of Mae Kuang Udomtara Dam during the rainy season from August 2003 to the summer in May 2004.



(scale bar: 10 μm)

Figure 11 Microscopic images of dominant phytoplankton species occurring in Sakon Nakhon sewage oxidation pond during the rainy season from August 2003 to the summer in May 2004. (A) *Spirulina platensis*, (B) *Oscillatoria* sp. 2, (C) *Diatomella* sp. 1, (D) *Trachelomonas oblonga* and (E) *Microcystis aeruginosa*

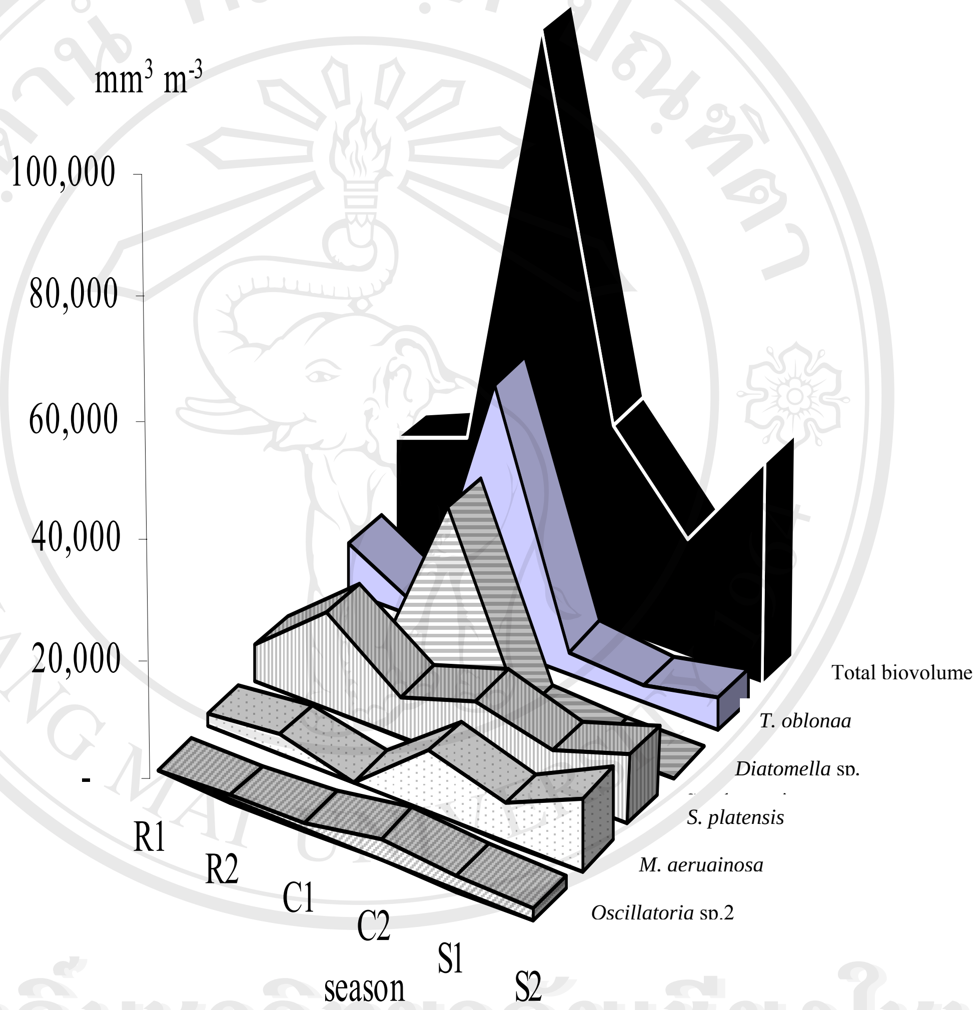


Figure 12 The biovolumes of dominant phytoplankton species occurring in Sakon Nakhon sewage oxidation pond during the rainy season from August 2003 to the summer in May 2004

Table 4 The distribution and the abundance of phytoplanktons are represented using the biovolume (mm^3 m^{-3}) and found in five water resources from the rainy season of 2003 to the summer of 2004 [FP = a fish pond, HYr = Houy Yuak Reservoir (open water), HYs = Houy Yuak Reservoir (small pond), MK = the reservoir of Mae Kuang Udomtara Dam and SK = Sakon Nakhon sewage oxidation pond].

Species	Site																	
	FP						HYr						HYs					
	Rainy		Cool dry		Summer		Rainy		Cool dry		Summer		Rainy		Cool dry		Summer	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Division Cynophyta																		
Anabaena aphnizomenoides Forti											4.71	4.71						
A. catenula (Kg.) Bornet et Flahault																		
Anabaena sp. 1	2,157.25	2,584.21		1,123.57	17,527.65	1,258.40												
Anabaena sp. 2											1.76		0.20					
Cylindrospermopsis philipinnensis (Taylor) Ka									215.72	647.17	431.45	431.45						
C. raciborskii (Woloszyńska) Seenayya & Subba et Raju							49,273.54	59,128.25	48,288.07	64,055.60	9,854.71	9,854.71	9,854.71	19,709.42		147.82		

Table 4 (continued)

Species	Site											
	MK						SK					
	Rainy		Cool dry		Summer		Rainy		Cool dry		Summer	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Division Cynophyta												
Anabaena aphnizomenoides Forti												
A. catenula (Kg.) Bornet et Flahault	62.29	57.84		20.76	167.58	13.35						
Anabaena sp. 1		5.06			0.77	0.11						
Anabaena sp. 2												
Cylindrospermopsis philipinnensis (Taylor) Ka	53.93	161,590.57										
C. raciborskii (Woloszyńska) Seenayya & Subba et Raju	492.74	2,217.31			49.27			344.91	1,576.48	197.09		

Table 4 (continued)

Species	Site																	
	FP						HYr						HYs					
	Rainy		Cool dry		Summer		Rainy		Cool dry		Summer		Rainy		Cool dry		Summer	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Chroococcus sp. 1	266.71	1.39																
Chroococcus sp. 2	11.03																	
Merismopedia punctata Komárek	78.45	522.97		3,347.01	797.53	980.57												
Merismopediia sp. 1	1,129.61	339.93		2,248.77	6,275.64	156.89		31.38	10.46		20.92	83.68		125.51				
Microcystis aeruginosa Kütz.	17,789.4	33,152.8	310,902.8	148,622. 2	197,083.3	161,730.6	140.3	297.8	186.1	180.8	74.3	34.1	178.4	975.33	79.75	266.29	78.83	
Oscillatoria sp. 1								17.42	108.86	391.89	17.42		95.79	165.46	78.38			
Oscillatoria sp. 2																		
Planktolyngbya contorta Lemmermann				0.26		0.03			10.54									
P. limnetica Lemmermann	8,818.25	1,014.07			2,778.28	122.24	7,223.52	1,611.40	4,445.24	1,278.01	62,233.38	84,459.59	2,444.88	5,112.03	11.11	5.56		
Spirulina platensis (Noedst) Geitler Gomont Nach.																		
Spirulina sp. 1									0.03	0.25	0.12	0.06	0.06	0.06	0.61			

Table 4 (continued)

Species	Site											
	MK						SK					
	Rainy		Cool dry		Summer		Rainy		Cool dry		Summer	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Chroococcus sp. 1												
Chroococcus sp. 2						0.01						
Merismopedia punctata Komárek					13.07		13.07					
Merismopediia sp. 1								83.68	41.84	20.92		41.84
Microcystis aeruginosa Kütz.	1,088.39	114.22	89.31	137.01	9.17	81.16	2,080.77	3,510.34	234.42	10,195.17	6,440.81	12,516.78
Oscillatoria sp. 1												
Oscillatoria sp. 2							317.28	971.67	1,440.98	3,430.59	2,511.80	1,890.46
Planktolyngbya contorta Lemmermann												
P. limnetica Lemmermann	16.67			5.56	11.11	5.56	16.67	83.35	555.66	133.36	388.96	689.01
Spirulina platensis (Noedst) Geitler Gomont Nach.							5,928.32	16,378.24	6,933.12	11,052.80	7,335.04	11,454.72
Spirulina sp. 1												

Table 4 (continued)

Species	Site																	
	FP						HYr						HYs					
	Rainy		Cool dry		Summer		Rainy		Cool dry		Summer		Rainy		Cool dry		Summer	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Spirulina sp. 2												0.08						
Division Cryptophyta																		
Cryptomonas sp.	1,312.00	91.11					127.56	91.11	236.89	291.56	36.44	947.56	72.89	947.56	546.67	36.44		
Rhodomonas sp.																		
Division Pyrrhophyta																		
Ceratium furcoides (Levander) Langhans								46.16			46.16	161.56		80.78				
Gymnodinium sp.																		
Peridiniopsis sp. 1							7,814.64	17,760.54	8,169.85	4,262.53	2,841.69	4,262.53	2,841.69	17,050.12				
Peridiniopsis sp. 2									3,552.11		2,841.69			2,841.69		1,065.63		
Peridinium sp.																		

Table 4 (continued)

Species	Site											
	MK						SK					
	Rainy		Cool dry		Summer		Rainy		Cool dry		Summer	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Spirulina sp. 2	0.08	0.16	0.08									
Division Cryptophyta												
Cryptomonas sp.		36.44	54.67	400.89			583.11	72.89	1,968.00	911.11	109.33	801.78
Rhodomonas sp.							5.83	283.55	3,062.31	2,722.06	113.42	4,083.09
Division Pyrrhophyta												
Ceratium furcoides (Levander) Langhans		265.42	11.54	0.35	46.16							
Gymnodinium sp.										998.87		
Peridiniopsis sp. 1		355.21										
Peridiniopsis sp. 2												
Peridinium sp.	1,434.82	5.85	1.17	28.09	5.85	7.02						

Table 4 (continued)

Species	Site																	
	FP						HYr						HYs					
	Rainy		Cool dry		Summer		Rainy		Cool dry		Summer		Rainy		Cool dry		Summer	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	1st	2nd	1st
Division Chrysophyta																		
Aulacoseira glanulata (Ehrenberg) Simonsen										2.07	2.76	4.14			1.38			
Diatomella sp.																		
Gyrosigma sp.		677.20													0.51			
Navicula sp.													1.69					
Nitzschia sp.													1.09					
Fragilaria sp.									2.55	0.27					7.79			
Gomphonema sp.															2.75			
Isthmochloron gracile Chodat													0.02	0.02	0.07			
Pseudostaurastrum gracile chodat												0.02						

Table 4 (continued)

Species	site											
	MK						SK					
	Rainy		Cool dry		Summer		Rainy		Cool dry		Summer	
	1st	2nd	1st	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st
Division Chrysophyta												
Aulacoseira glanulata (Ehrenberg) Simonsen	4.14			13.10		0.69				0.69		1.38
Diatomella sp.							1,541.94	308.39	31,661.23	1,027.96		
Gyrosigma sp.												
Navicula sp.												
Nitzschia sp.								445.75	1,783.00			
Fragilaria sp.				1.07								
Gomphonema sp.												
Isthmochloron gracile Chodat						0.02						
Pseudostaurastrum gracile chodat												

Table 4 (continued)

Species	Site																	
	FP						HYr						HYs					
	Rainy		Cool dry		Summer		Rainy		Cool dry		Summer		Rainy		Cool dry		Summer	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Division Chlorophyta																		
Crucigeniella sp.																	1.96	
Ceolastrum reticulatum (Dangeard) Senn																		
Tetrastrum sp.	15.16	30.32		30.32														
Dictyosphaerium sp.																		
Scenedesmus acuminatus (Lagerheim) Chodat	3,234.16	511.73			13.65		27.29	40.94	27.29		27.29	0.03		0.07				
S. acuminatus var. tetradesmoides Smith	326.04	23.29								62.10								
S. bicaudatus Dedusenko											0.05							
S. calyptratus Comas		9.52			0.09													
Tetraedron incus Smith								32.77			196.60	131.07		262.14	0.08			
T. minimum (A.Br.) Hansg. sensu Skuja	140.96										37.59	75.18	18.79					
Botryococcus braunii Kütz.																		
Chlorella sp.																		

Table 4 (continued)

Species	Site											
	MK						SK					
	Rainy		Cool dry		Summer		Rainy		Cool dry		Summer	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Division Chlorophyta												
Crucigeniella sp.						1.96			7.84			54.90
Ceolastrum reticulatum (Dangeard) Senn				0.35						0.35		
Tetrastrum sp.							151.58	60.63				
Dictyosphaerium sp.				7.84			15.69	5.64				
Scenedesmus acuminatus (Lagerheim) Chodat							62.10	81.88	218.34	81.88	27.29	54.58
S. acuminatus var. tetradesmoides Smith							13.65	139.73	124.21	93.15		
S. bicaudatus Dedusenko												
S. calyptratus Comas					19.04							
Tetraedron incus Smith							32.77	32.77				
T. minimum (A.Br.) Hansg. sensu Skuja						28.19						
Botryococcus braunii Kütz.	16.72	9.12	6.08	3.04	4.56	38.00						
Chlorella sp.							33.18	85.31	170.62	274.89	66.35	

Table 4 (continued)

Species	Site																	
	FP						HYr						HYs					
	Rainy		Cool dry		Summer		Rainy		Cool dry		Summer		Rainy		Cool dry		Summer	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Monoraphidium arcuatum (Korshikov) Hindák	1,507.62		0.25	100.51					0.12		1.48				0.25	5.17		
M. contortum (Thuret) Komárková-Legnerová	102.96						1,715.99	840.84	394.68	4,118.39	686.40	514.80	288.29	617.76	6.86			
M. tortile (West et West) Komárková-Legnerová	1,939.07			1.13	38.42	0.68				0.23	1.36					4.97		
Pediastrum duplex var. *subgranulatum* Racib	0.35				0.35	0.18				0.18								
P. longecornutum (Gutwinski) comas															39.18			
P. simplex Meyen var. *simplex*						0.22					0.87	0.65						
Eudorina sp.							1,534.59					1.25						
Cosmarium contractum Kirchner var. *contractum*																		
C. moniliforme (Turpin) ex Ralfs var. *panduriforme*																		
Cosmarium sp. 1	3,346.19																	
Cosmarium sp. 2																		

Table 4 (continued)

Species	Site											
	MK						SK					
	Rainy		Cool dry		Summer		Rainy		Cool dry		Summer	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Monoraphidium arcuatum (Korshikov) Hindák	0.49	201.02	2.95	21.16	5.41	7.38	0.98		2,814.23	1.72	402.03	
M. contortum (Thuret) Komárková-Legnerová		1.72		3.43		1.72				3.43		
M. tortile (West et West) Komárková-Legnerová												1,108.04
Pediastrum duplex var. *subgranulatum* Racib												
P. longecornutum (Gutwinski) comas				0.24								
P. simplex Meyen var. *simplex*												
Eudorina sp.					5.01				1.25	8.76	2.50	3.76
Cosmarium contractum Kirchner var. *contractum*	7.25		28.98									
C. moniliforme (Turpin) ex Ralfs var. *panduriforme*		309.04		1.51	1.13	2.58						
Cosmarium sp. 1	3.64	1.82	363.63	20.02	20.02	6.37						
Cosmarium sp. 2		1,818.14			363.63							

Species	Site																	
	FP						HYr						HYs					
	Rainy		Cool dry		Summer		Rainy		Cool dry		Summer		Rainy		Cool dry		Summer	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Staurastrum arachne Ralfs ex Ralfs																		
S. cf. longbrachiatum (Borge) gutwinski																		
S. chaetoceras (Schröder) G.M. Smith																		
S. gracile Ralfs																		
S. manfeldtii var. *fluminense* Schumacher																		
S. smithii Teiling																		
Staurastrum sp. 1																		
Staurastrum sp. 2																		
Staurastrum sp. 3																		
Staurastrum sp. 4																		
Staurodesmus convergen var. *Labportei* Teiling																		
Staurodesmus crassus (West et G.S. West) Florin																		

Species	Site											
	MK						SK					
	Rainy		Cool dry		Summer		Rainy		Cool dry		Summer	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Staurastrum arachne Ralfs ex Ralfs						1.26						
S. cf. longbrachiatum (Borge) gutwinski	344.02											
S. chaetoceras (Schröder) G.M. Smith					1,483.93	1.36						
S. gracile Ralfs	1,005.08	335.03	418.78		418.78	251.27						
S. manfeldtii var. *fluminense* Schumacher		1,052.64		701.76	350.88	2.58						
S. smithii Teiling			495.19									
Staurastrum sp. 1	1.44		0.48		196.11	0.48						
Staurastrum sp. 2			0.47									
Staurastrum sp. 3					100.10							
Staurastrum sp. 4						0.47						
Staurodesmus convergen var. *Labportei* Teiling		0.35				0.35						
Staurodesmus crassus (West et G.S. West) Florin	5,433.98	7,607.57			217.36							

Species	Site																	
	FP						HYr						HYs					
	Rainy		Cool dry		Summer		Rainy		Cool dry		Summer		Rainy		Cool dry		Summer	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Xanthidium hastiferum var. jaranicum (Nordstedt) Turner																		
Division Euglenophyta																		
Euglena acus Eherenberg nach Skuja	83.68	296.98		164.08	670.38			4.92	7.38	34.46	9.84	83.68	83.68	85.32	41.02	3.28	759.69	
E. chlamydophora Mainx							107.21											
Phacus longicauda (Ehrenberg) Dujardin									7.84		15.67	15.67	7.84	7.84	39.18	6.06	109.70	
P. pleuronectes (Müller) Dujardin													2.63		13.13		15.75	
Phacus sp. 1									22.72	51.49	21.20	9.09	3.03		57.55		151.44	
Trachelomonas oblonga Lemmermann	706.01			353.00	117.67	235.34	6,118.74	706.01	3,294.71	7,530.76	3,530.04	11,766.82	2,353.36	13,649.51	3,294.71	2,235.70	13,767.17	
T. pulcherrima Playfair									205.92	823.68	205.92	411.84		4,118.39				
Trachelomonas sp. 1		2,024.87					3,037.31											
*T.*rachelomonas sp. 2							214.58											

Species	Site											
	MK						SK					
	Rainy		Cool dry		Summer		Rainy		Cool dry		Summer	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Xanthidium hastiferum var. jaranicum (Nordstedt) Turner			3.87	7.75								
Division Euglenophyta												
Euglena acus Eherenberg nach Skuja								3.28	6.56	3.28	49.23	
E. chlamydophora Mainx												
Phacus longicauda (Ehrenberg) Dujardin				15.67			23.51				23.51	
P. pleuronectes (Müller) Dujardin												
Phacus sp. 1									6.06		18.17	
Trachelomonas oblonga Lemmermann	117.67	353.00	941.35	941.35	353.00	1,882.69	8,472.11	186.31	45,184.57	4,236.05	3,059.37	5,648.07
T. pulcherrima Playfair						102.96						
*Trachelomona*s sp. 1												
*T.*rachelomonas sp. 2												

4.2 Environmental factors

4.2.1 Water properties

4.2.1.1 Physico-chemical and some biological properties of water samples

Physico-chemical and some biological properties of water including the depth of water resource, water volume, Secchi depth, water temperature, electro-conductivity, pH, alkalinity, DO, BOD_5, nitrate-nitrogen, ammonium-nitrogen, soluble reactive phosphorus, chlorophyll-a and total bacterial plate count were measured and have been presented in Figures 13 – 26, respectively.

Depths of water resources

The reservoir of Mae Kuang Udomtara Dam was the deepest study site showing the ranges of depth between 14.00-26.00 m. Sakon Nakhon sewage oxidation pond was the shallowest study site showing the ranges of depth between 1.10-1.50 m. Depths of the fish pond were between 1.10-2.40 m and the depths in Houy Yuak Reservoir at the open water was measured between 1.55-3.60 m while at the small pond the depth was between 0-1.70 m (Figure 13).

Water volume

The reservoir of Mae Kuang Udomtara Dam contained the highest water volume which was between 38,064,000-111,480,000 m^3. The small pond of Houy Yuak Reservoir contained the lowest water volume which was between 0-119 m^3 but the open water contained water volume between 96,875-257,500 m^3. Water volume in the fish pond was between 3,049-6,653 m^3. The water volume in Sakon Nakhon sewage oxidation pond was measured between 44,000-60,000 m^3 (Figure 14).

Secchi depth

The fish pond was always covered with the green scum of predominant cyanobacteria resulting in the Secchi depth being unable to be detected during the study period. Sakon Nakhon sewage oxidation pond showed a regularly low Secchi depth which was between 0.20-0.30 m. The Secchi depths in the open water and the small pond of Houy Yuak Reservoir were between 0.45-0.95 and between 0.20-0.60 m, respectively. The reservoir of Mae Kuang Udomtara Dam showed very high Secchi depth which was between 1.75-4.20 m (Figure 15).

Water temperature

Water temperatures in the fish pond were between 20.2-31.6 °C. Water temperatures in Houy Yuak Reservoir at the open water were between 23.1-31.1 °C and at the small pond, it was between 21.3-30.1 °C. Water temperatures in the reservoir of Mae Kuang Udomtara Dam were between 23.5-32.6 °C. Water temperatures in Sakon Nakhon sewage oxidation pond were between 19.5-29.6 °C. The overall water temperatures in the summer and the rainy season were higher than those in the cool dry season in all study sites. Water temperature changed as seasonal changes occurred so that it was high in the rainy season and it decreased in the cool dry season and increased again in the summer (Figure 16).

Electro-conductivity

Electro-conductivity in the fish pond and Sakon Nakhon sewage oxidation pond was very high and were measured between 295.0-665.0 and between 393.0-707.0 μScm^{-1}, respectively. The lowest conductivity was between 70.7-95.3 μScm^{-1} in the reservoir of Mae Kuang Udomtara Dam. The water conductivities in the open water and the small pond of Houy Yuak Reservoir were between 130.7-211.0 μScm^{-1}, respectively. The conductivity tended to increase from the rainy season to the cool dry season and was continuously higher in the summer (Figure 17).

pH

pH levels in Sakon Nakhon sewage oxidation pond were between 6.00-9.20 and sometimes, the pH level was higher than 9. The fish pond presented pH levels between 6.00-7.94. The pH values in the open water and the small pond of Houy Yuak Reservoir were between 6.50-8.90, and between 6.35-7.33 respectively. The reservoir of Mae Kuang Udomtara Dam presented pH values between 6.20-8.60 (Figure 18).

Alkalinity

The alkalinity in the fish pond ranged between 118.0-173.5 mg l^{-1} as $CaCO_3$ which was clearly higher than other sites. The alkalinity in Sakon Nakhon sewage oxidation pond ranged between 74.0-108.0 mg l^{-1} as $CaCO_3$ was rather high. The alkalinity in the open water and the small pond of Houy Yuak Resevoir ranged between 63.0-82.0 and between 64.5-95.0 mg l^{-1} as $CaCO_3$, respectively. The alkalinity in the reservoir of Mae Kuang Udomtara Dam ranged between 29.5-42.5 mg l^{-1} as $CaCO_3$ was less present than other sites (Figure 19).

Dissolved oxygen (DO)

The DO in the fish pond and Sakon Nakhon sewage oxidation pond were sometimes very low which were between 0.6-3.4 and between 0.9-6.0 mg l^{-1}, respectively. The reservoir of Mae Kuang Udomtara Dam showed the DO between 3.6-7.6 mg l^{-1}. The DO in the open water and the small pond of Houy Yuak Reservoir were between 4.6-7.8 and between 1.5-5.6 mg l^{-1}, respectively. The open water of Houy Yuak Reservoir presented the high DO in the rainy season which then increased in the cool dry season and the summer, respectively (Figure 20).

Biochemical oxygen demand (BOD_5)

The BOD_5 in the fish pond ranged between 26.0-920.0 mg l^{-1} which was obviously higher than other sites. The BOD_5 in Sakon Nakhon sewage oxidation pond and the small pond of Houy Yuak Reservoir ranged between 3.4-44.0 and between 2.2-

34.0 mg l^{-1} respectively, which were considered to be rather high at times. The BOD_5 in the open water of Houy Yuak Resevoir ranged between 1.7-8.0 mg l^{-1}. The BOD_5 in the reservoir of Mae Kuang Udomtara Dam ranged between 0.4-2.0 mg l^{-1} which was considerably lower than other sites (Figure 21).

Nitrate-nitrogen

The nitrate-nitrogen level in the fish pond ranged between being undetectable to 12.10 mg l^{-1} which was very high in the rainy season. The nitrate-nitrogen levels in Sakon Nakhon sewage oxidation pond ranged between being undetectable to 9.6 which was very high in the cool dry season. The nitrate-nitrogen levels in the reservoir of Mae Kuang Udomtara Dam, For both the open water and the small pond of the Houy Yuak Reservoir were not high ranged between 0.54-1.63 mg l^{-1}, 0.10-0.96 mg l^{-1} and between being undetectable and 1.08 mg l^{-1} (Figure 22).

Ammonium-nitrogen

The ammonium-nitrogen levels in the fish pond ranged between 14.37-870.69 mg l^{-1}which was always much higher than other sites. The ammonium-nitrogen in Sakon Nakhon sewage oxidation pond, in the reservoir of Mae Kuang Udomtara Dam and both the open water and the small pond of Houy Yuak Reservoir was also very high at times and ranged between being undetectable and 187.93 mg l^{-1}, between being undetectable and 6.02 mg l^{-1}, between being undetectable and 18.15 mg l^{-1}, and between being undetectable to 4.51 mg l^{-1}, respectively (Figure 23).

Soluble reactive phosphorus

The levels of soluble reactive phosphorus were always very high in the fish pond and Sakon Nakhon sewage oxidation pond which ranged between 2.46-6.39 mg l^{-1} and between 2.24-7.56 mg l^{-1}, respectively. The soluble reactive phosphorus in the reservoir of Mae Kuang Udomtara Dam was also rather high and ranged between1.86-4.78 mg l^{-1}. The levels of soluble reactive phosphorus in both the open water and the small pond of

Houy Yuak Reservoir were not high and ranged between 0.01-0.53 mg l^{-1} and between being undetectable to 0.27 mg l^{-1}, respectively (Figure 24).

Chlorophyll-a

The overall chlorophyll-a level in all sampling sites was high. The chlorophyll-a in the fish pond ranged between 94-4,329 µg l^{-1} which was clearly higher than other sites. The chlorophyll a in the open water of Houy Yuak Resevoir, the small pond of Houy Youk Reservoir, the reservoir of Mae Kuang Udomtara Dam and the Sakon Nakhon sewage oxidation pond ranged between 26-86 µg l^{-1}, between 6-214 µg l^{-1}, between1-71 µg l^{-1} and between 12-166 µg l^{-1}, respectively (Figure 25).

Total bacterial plate count

The total bacterial plate count in water of a fish pond, the open water of Houy Yuak Resevoir, the small pond of Houy Youk Reservoir, the reservoir of the Mae Kuang Udomtara Dam and the Sakon Nakhon sewage oxidation pond ranged between 5.6×10^4 - 1.13×10^7 CFU ml^{-1}, between 3.1×10^4 - 3.8×10^5 CFU ml^{-1}, between 1.8×10^4 - 4.6×10^5 CFU ml^{-1}, between 1.0×10^3 – 2.31×10^6 CFU ml^{-1} and between 1.02×10^4 – 4.4×10^4 CFU ml^{-1}, respectively (Figure 26).

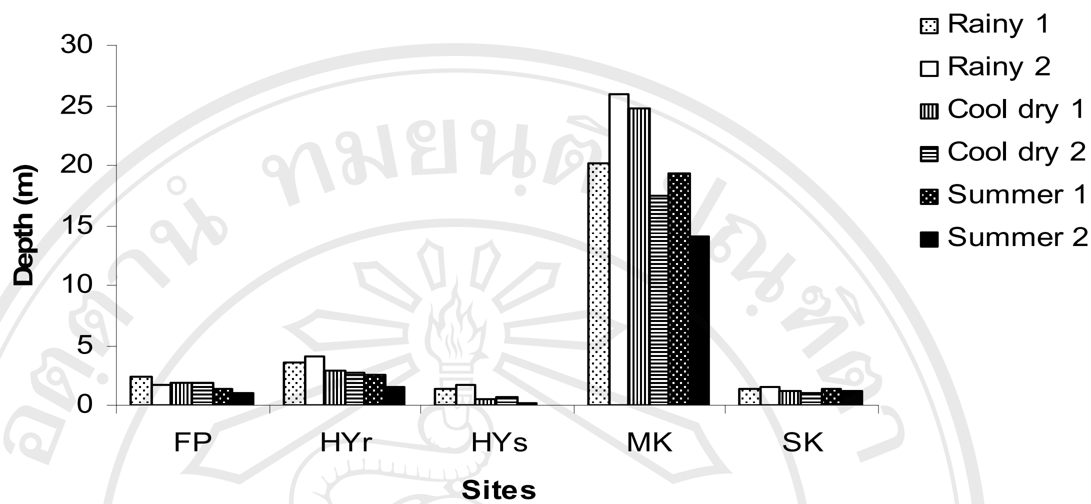


Figure 13 The depths of water resources from the rainy season in August 2003 to the summer in May 2004. the fish pond (FP), the open water of Houy Yuak Reservoir (HYr), the small pond of Houy Yuak Reservoir (HYs), the reservoir of Mae Kuang Udomtara Dam (MK) and Sakon Nakhon sewage oxidation pond (SK).

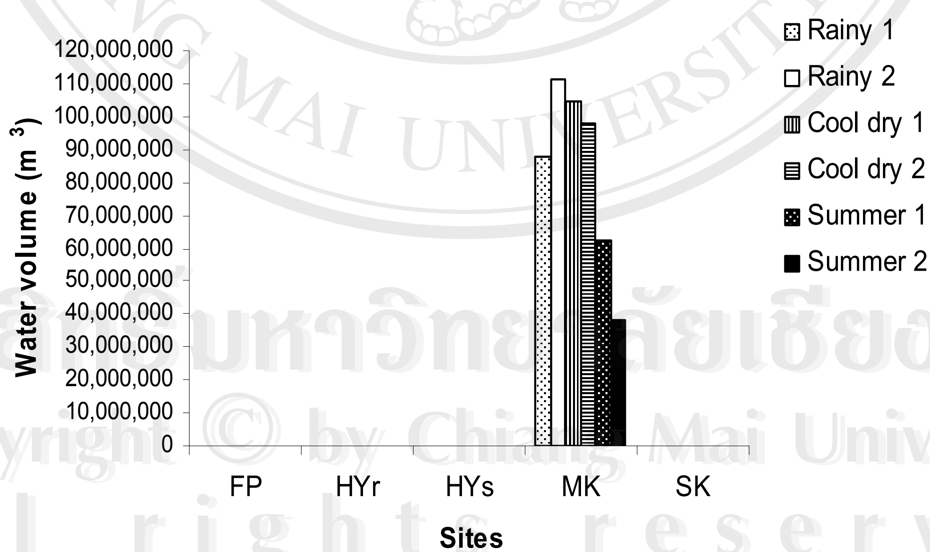


Figure 14 The water volumes of water resources from the rainy season in August 2003 to the summer in May 2004.

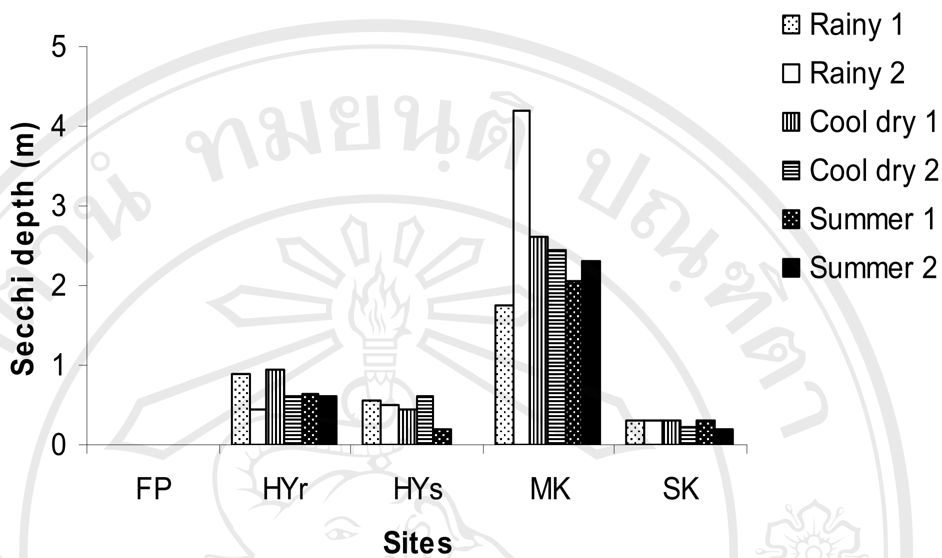


Figure 15 The Secchi depths of water resources from the rainy season in August 2003 to the summer in May 2004.

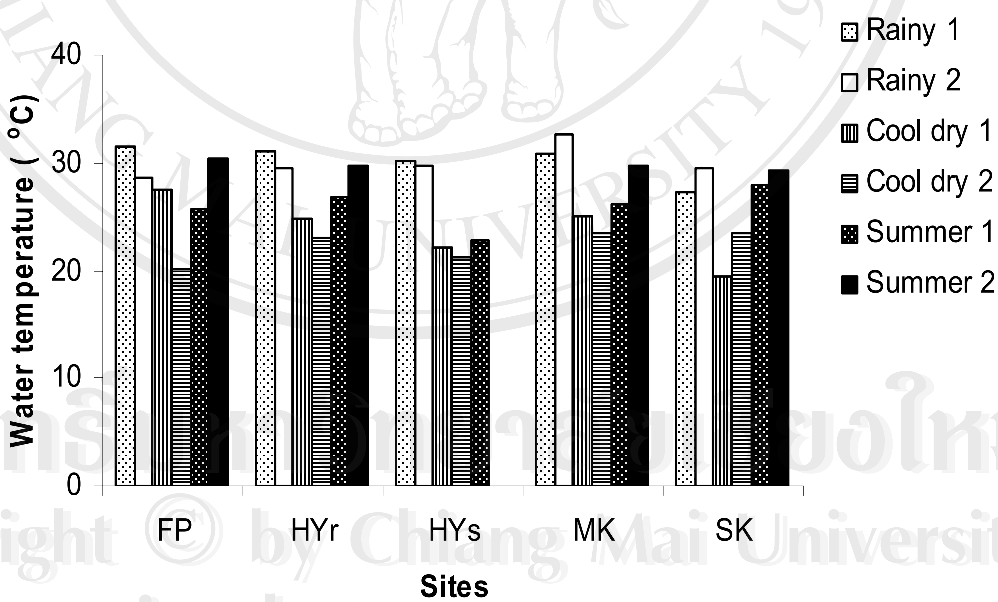


Figure 16 The water temperatures in water resources from the rainy season in August 2003 to the summer in May 2004.

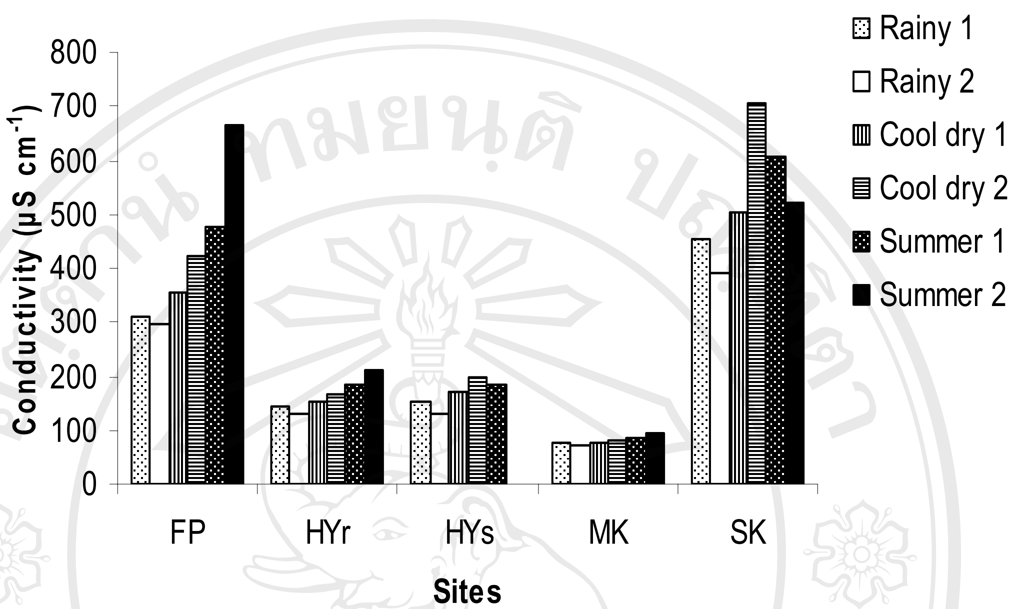


Figure 17 The conductivities levels of water resources from the rainy season in August 2003 to the summer in May 2004

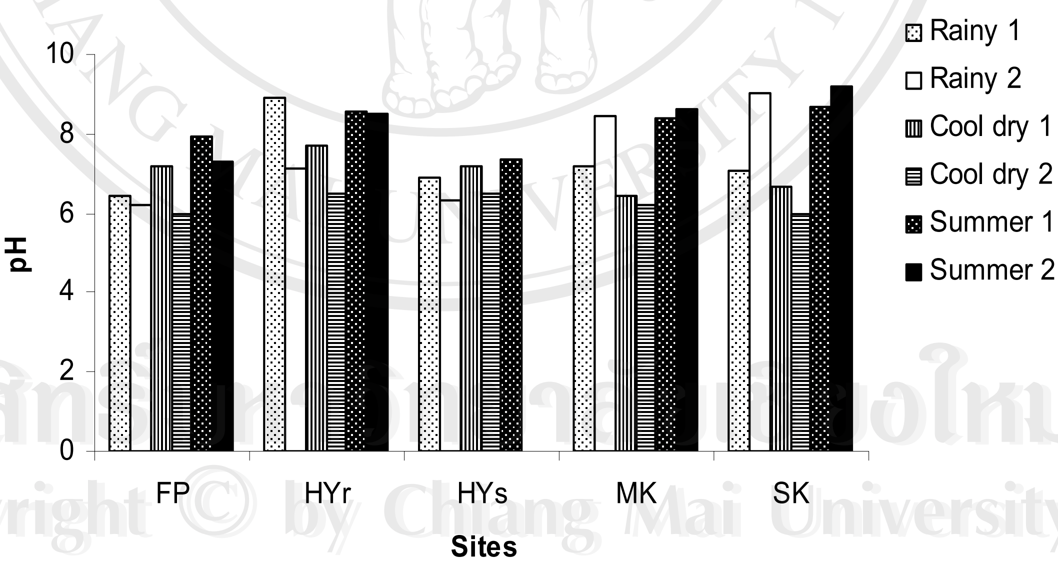


Figure 18 The pH values of water resources from the rainy season in August 2003 to the summer in May 2004

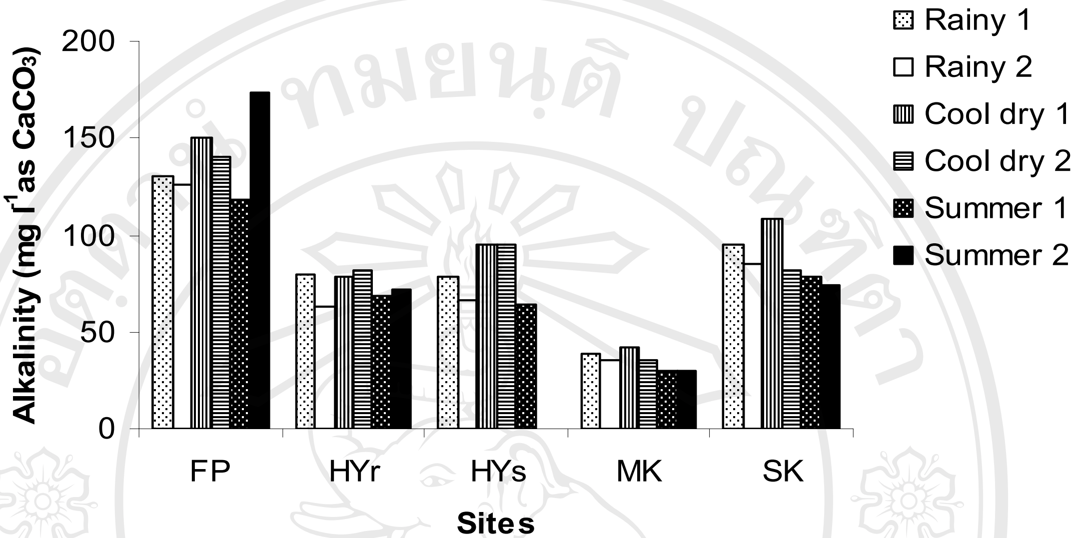


Figure 19 The alkalinity of water resources from the rainy season in August 2003 to the summer in May 2004

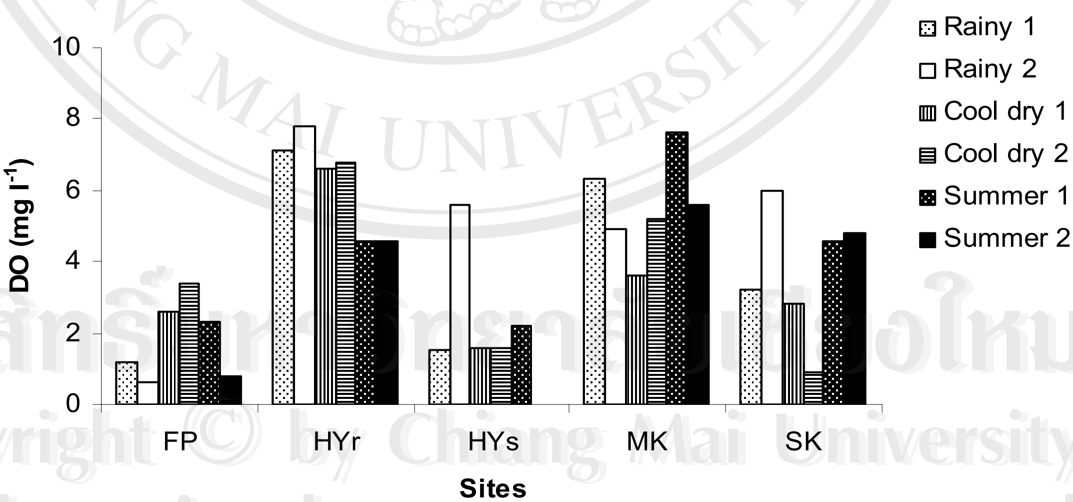


Figure 20 The dissolved oxygen in water resources from the rainy season in August 2003 to the summer in May 2004

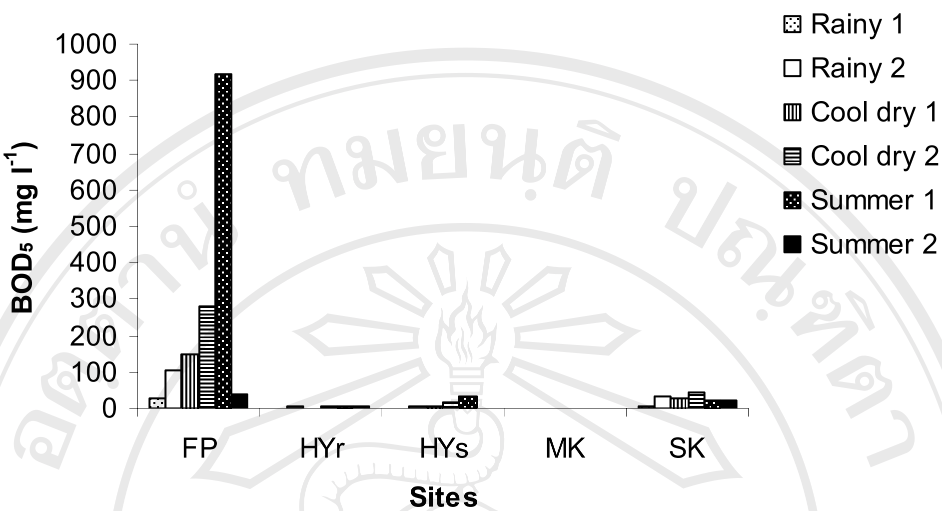


Figure 21 The biochemical oxygen demand (BOD_5) in water resources from the rainy season in August 2003 to the summer in May 2004

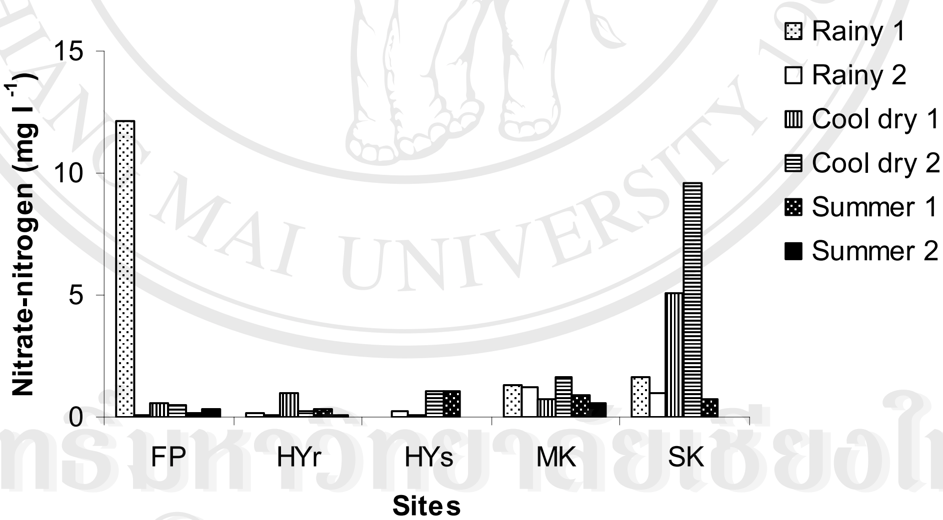


Figure 22 The nitrate-nitrogen levels of water resources from the rainy season in August 2003 to the summer in May 2004

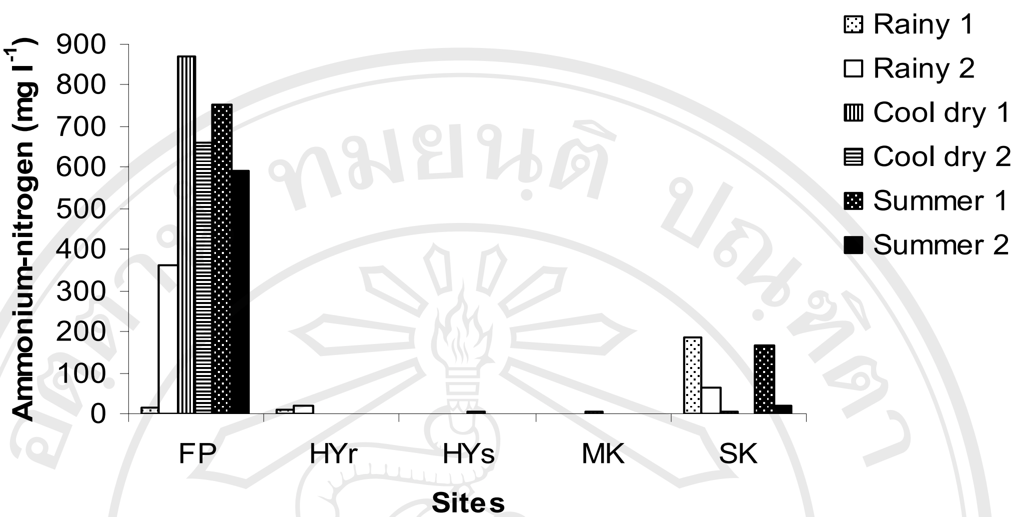


Figure 23 The ammonium-nitrogen levels of water resources from the rainy season in August 2003 to the summer in May 2004

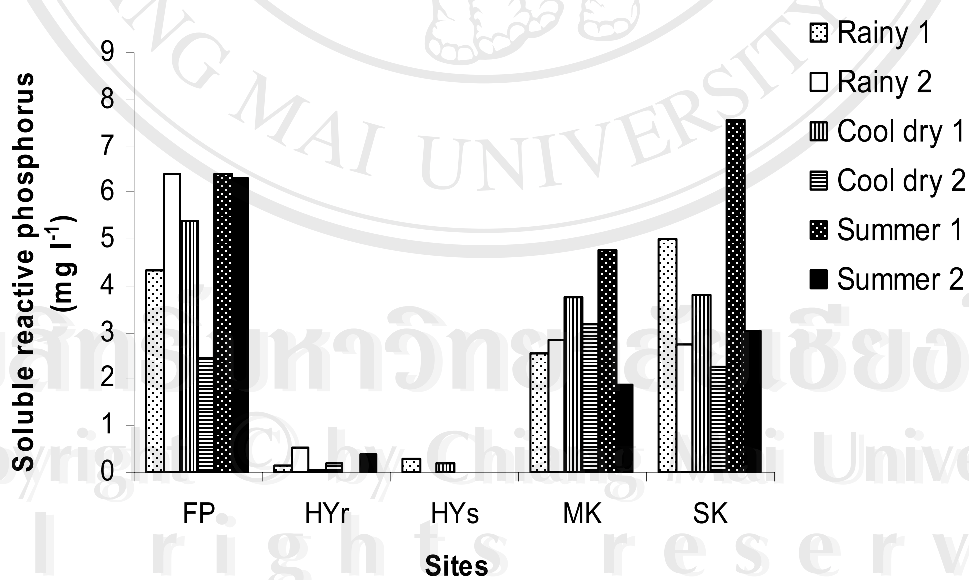


Figure 24 The soluble reactive phosphorus of water resources from the rainy season in August 2003 to the summer in May 2004

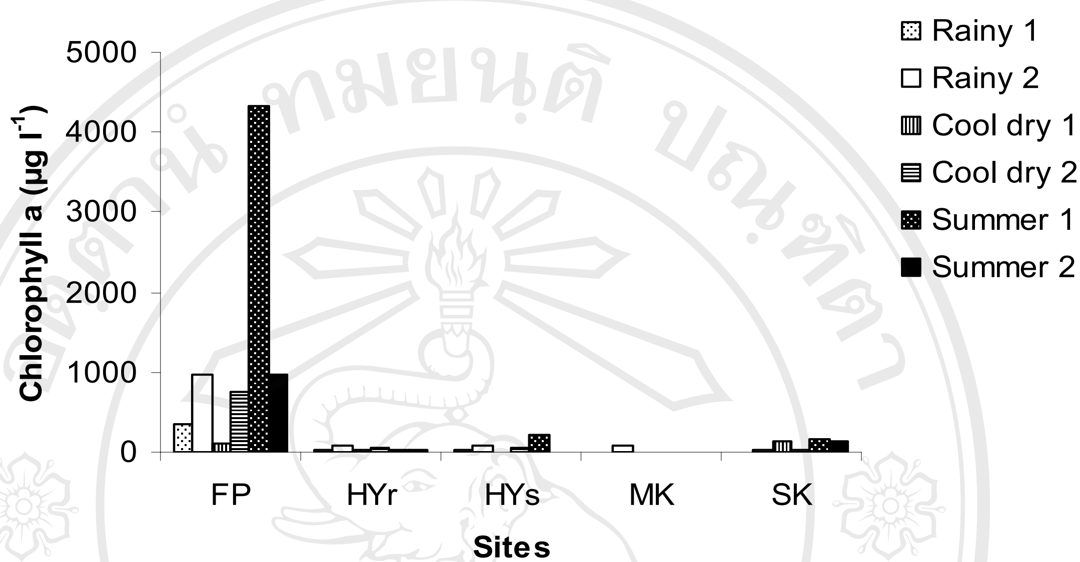


Figure 25 The chlorophyll-a levels of water resources from the rainy season in August 2003 to the summer in May 2004

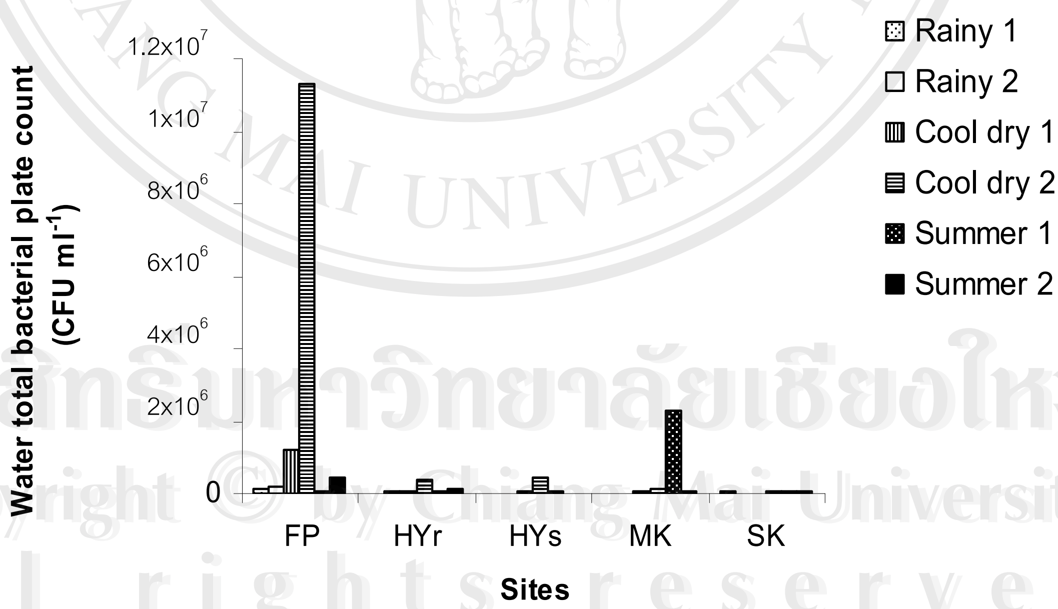


Figure 26 The total bacterial plate count of water resources from the rainy season in August 2003 to the summer in May 2004.

4.2.1.2 Trophic level estimation

Trophic levels of waterbodies were evaluated using the dominant phytoplanktons, some physico-chemical and biological parameters following Wetzel (1983); Lorraine and Vollenweider (1981) and AARL-CMU scores (peerapornpisal, 2006; Peerapornpisal *et al.*, 2004) as described in the APPENDIX A. It was found that the results were at different levels between water resources and seasons (Figures 27 - 32).

The fish pond

According to Wetzel (1983); Lorraine and Vollenweider (1981), the water in the surface bloom fish pond was classified as the hyper-eutrophic level during the entire period of the study (Figures 27 and 30). According to AARL-PP score, the water was classified as eutrophic level during the entire period of the study (Figures 28 and 31). According to AARL-PC score, the water was classified as hyper-eutrophic level in a whole period of the study (Figures 29 and 32).

The open water of Houy Yuak Reservoir

According to Wetzel (1983); Lorraine and Vollenweider (1981), the water in the open water of Houy Yuak Reservoir was classified as the eutrophic level in a whole period of the study (Figures 27 and 30). According to AARL-PP score, the water was classified as meso-eutrophic to eutrophic level (Figures 28 and 31). According to AARL-PC score, the water was classified as meso-trophic to meso-eutrophic level (Figures 29 and 32).

The small pond of Houy Yuak Reservoir

According to Wetzel (1983); Lorraine and Vollenweider (1981), the water in the small pond of Houy Yuak Reservoir was classified as the eutrophic level at the end of the rainy season, at the end of the cool dry season and at the beginning of the summer whilst it was classified as the meso-eutrophic level at the beginning of the rainy season and at the beginning of the cool dry season (Figures 27 and 30). According to AARL-PP score, the water was classified as meso-eutrophic to eutrophic level (Figures 28 and 31). According to AARL-PC score, the water was classified as mesotrophic to eutrophic level (Figures 29 and 32).

The reservoir of Mae Kuang Udomtara Dam

According to Wetzel (1983); Lorraine and Vollenweider (1981), the water in the reservoir of Mae Kuang Udomtara Dam was classified as the oligo-mesotrophic level in all seasons apart from the end of the rainy season when it was classified as the meso-eutrophic level (Figures 27 and 30). According to AARL-PP score, the water was classified as meso- to eutrophic level (Figures 28 and 31). According to AARL-PC score, the water was classified as mesotrophic to meso-eutrophic level (Figures 29 and 32).

Sakon Nakhon sewage oxidation pond

According to Wetzel (1983); Lorraine and Vollenweider (1981), the water in Sakon Nakhon sewage oxidation pond was classified as the hyper-eutrophic level in the cool dry season and in the summer whilst it was classified as the meso-eutrophic level at the beginning of the rainy season and as the eutrophic level at the end of the rainy season (Figures 27 and 30). According to AARL-PP score, the water was classified as eutrophic level in a whole period of the study (Figures 28 and 31). According to AARL-PC score, the water was classified as hyper-eutrophic level in a whole period of the study (Figures 29 and 32).

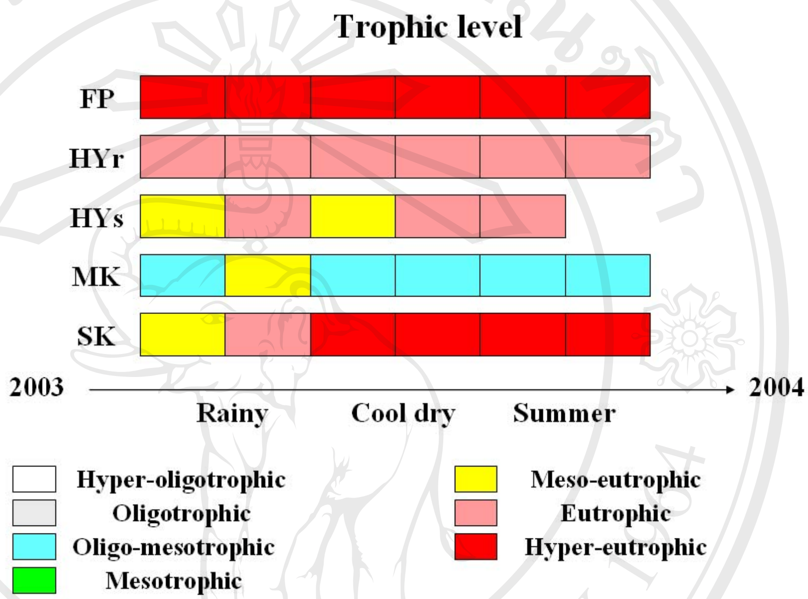


Figure 27 The trophic level of water in all water resources from the rainy season in August 2003 to the summer in May 2004, following Wetzel (1983); Lorraine and Vollenweider (1981). the fish pond (FP), the open water of Houy Yuak Reservoir (HYr), the small pond of Houy Yuak Reservoir (HYs), the reservoir of Mae Kuang Udomtara Dam (MK) and Sakon Nakhon sewage oxidation pond (SK).

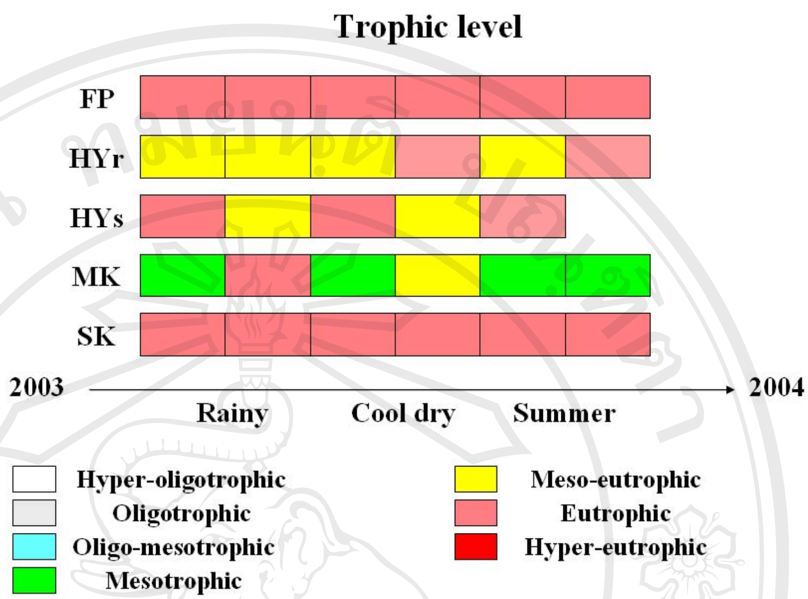


Figure 28 The trophic level of water in all water resources from the rainy season in August 2003 to the summer in May 2004, following AARL-PP score

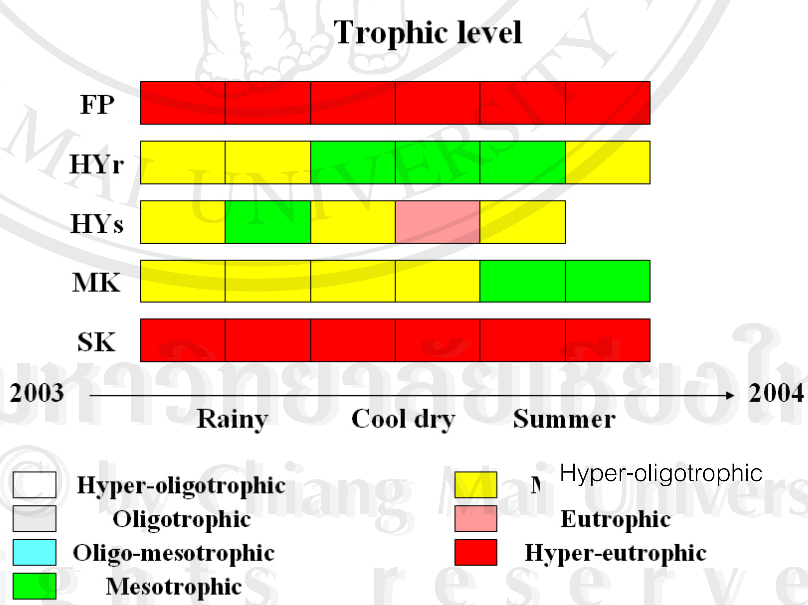


Figure 29 The trophic level of water in all water resources from the rainy season in August 2003 to the summer in May 2004, following AARL-PC score

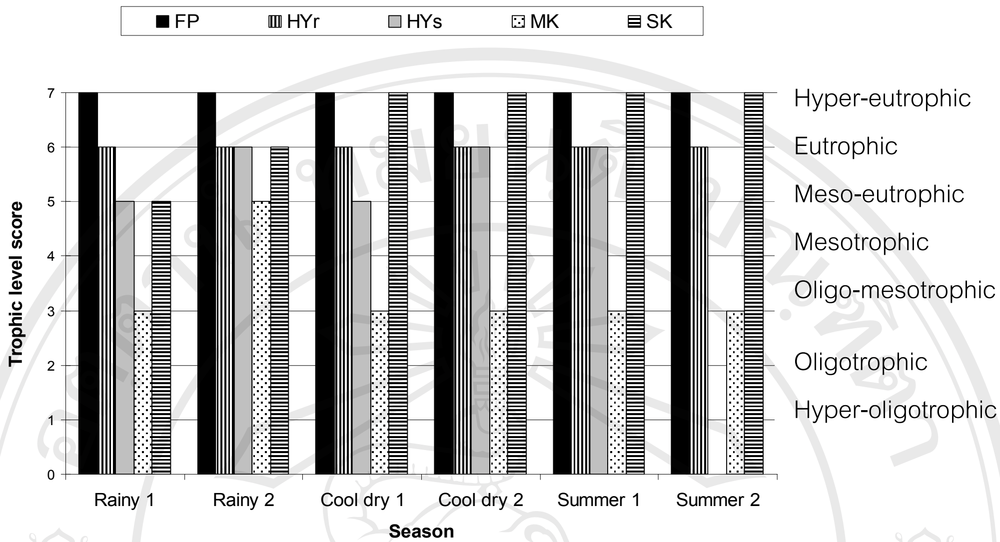


Figure 30 The trophic level score of water in all water resources from the rainy season in August 2003 to the summer in May 2004, following Wetzel (1983); Lorraine and Vollenweider (1981)

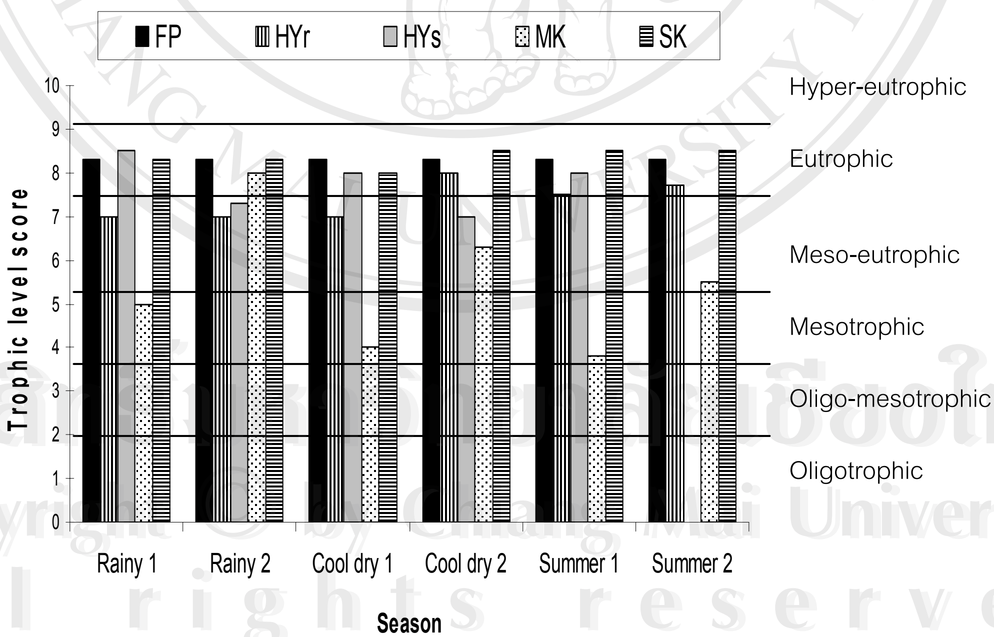


Figure 31 The trophic level score of water in all water resources from the rainy season in August 2003 to the summer in May 2004, following AARL-PP score

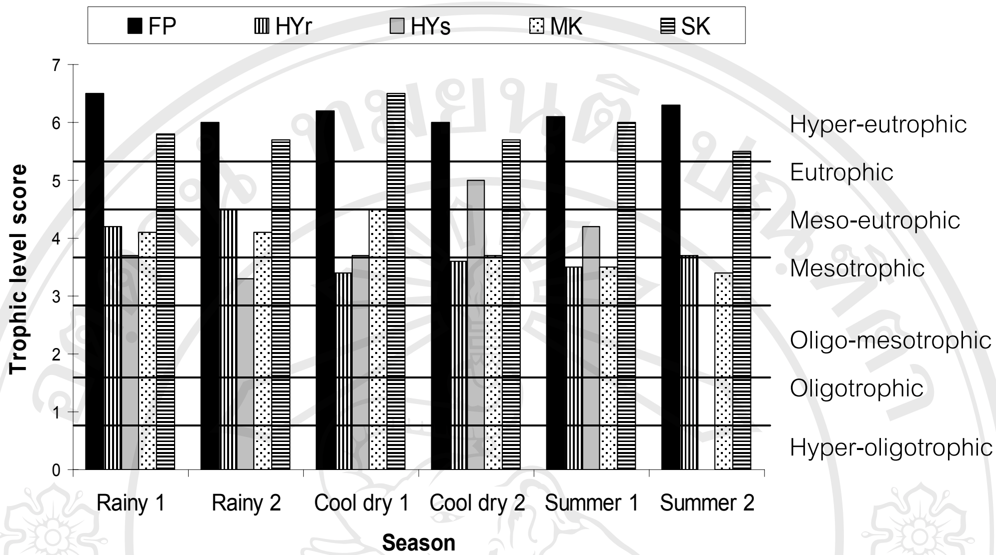


Figure 32 The trophic level score of water in all water resources from the rainy season in August 2003 to the summer in May 2004, following AARL-PC score

4.2.2 Sediment properties

4.2.2.1 Physico-chemical and some biological properties of sediment samples

pH

All sediment samples in the fish pond were rather acidic and ranged between 6.19-6.47 over all seasons apart from the samples collected at the end of the summer which was seriously acidic (pH 5.41). The pH value of the samples from the open water of Houy Yuak Reservoir ranged between 6.21-7.31. The pH level of the samples from the small pond of Houy Yuak Reservoir ranged between 6.03-6.78. The pH in the samples from the reservoir of Mae Kuang Udomtara Dam were seriously acidic and were between 5.22-5.33 ove all seasons. The pH levels in the samples from Sakon Nakhon sewage oxidation pond were between 6.00 - 6.56 (Figure 33).

Total bacterial plate count

The sediment total bacterial plate count in the sediment taken from the fish pond ranged between 9.1×10^4 -1.13×10^7 CFU ml^{-1}. The sediment total bacterial plate count in the sediment taken from the open water and the small pond of Houy Yuak Reservoir ranged between 4.3×10^4 - 6.8×10^5 CFU ml^{-1} and between 6.3×10^4 - 4.0×10^5 CFU ml^{-1}, respectively. The sediment total bacterial plate count in the sediment taken from the reservoir of Mae Kuang Udomtara Dam and Sakon Nakhon sewage oxidation pond ranged between 3.9×10^4 -1.46×10^5 CFU ml^{-1} and between 3.2×10^4 – 9.3×10^4 CFU ml^{-1}, respectively. The highest numbers recorded of sediment total bacterial plate count were obtained from all study sites over the summer (Figure 34).

Organic matter

The percent of organic matter in sediments from the fish pond was very high over all seasons and were measured between 8.23-15.09 %. The percent of organic matter in sediment taken from the open water of Houy Yuak Reservoir was between 1.87-4.70 %, most of these levels were considered to be high. The percent of organic matter in sediment samples taken from the small pond of Houy Yuak Reservoir was between 3.87-5.45% and considered to be high. The percent of organic matter in sediment samples taken from the reservoir of Mae Kuang Udomtara Dam was between 1.31-7.55% and most of these levels considered were very high. The percent of organic matter in sediment samples taken from Sakon Nakhon sewage oxidation pond was lower than those in other sites and these levels were between 1.37-4.49 % (Figure 35).

Nitrate-nitrogen

Most sediment nitrate-nitrogen levels were less than the detection limit in the fish pond apart from at the beginning of the summer when it was 1.18 mg l^{-1}. The sediment nitrate-nitrogen levels were less than the detection limit and ranged up to 2.16 mg l^{-1} and then were found to be between 0.36 - 9.77 mg l^{-1} at the open water and the small pond of

Houy Yuak Reservoir, repectively. The sediment nitrate-nitrogen levels were below the detection limit over all seasons in the reservoir of Mae Kuang Udomtara Dam and the Sakon Nakhon sewage oxidation pond (Figure 36).

Ammonium-nitrogen

Sediment ammonium-nitrogen was very high in all samples collected in every season from all study sites. The sediment ammonium-nitrogen in the fish pond was between 2,832.59 and 5,482.14 mg l^{-1} which were considered to be considerably higher than the other sites, which were the open water site of the Houy Yuak Reservoir, the small pond of Houy Yuak Reservoir, the reservoir of the Mae Kuang Udomtara Dam and the Sakon Nakhon sewage oxidation pond which also contained very high ammonium-nitrogen levels ranging between 455.90 - 1,277.72 mg l^{-1}, 277.96 - 1,952.07 mg l^{-1}, 658.98 - 989.18 mg l^{-1} and 545.23 - 767.71 mg l^{-1}, respectively (Figure 37).

Soluble reactive phosphorus

Sediment samples collected from the fish pond, the open water of Houy Yuak Reservoir, the small pond of Houy Yuak Reservoir, the reservoir of the Mae Kuang Udomtara and the Sakon Nakhon sewage oxidation pond contained very high soluble reactive phosphorus levels ranging between 108.63 - 189.19 mg l^{-1}, 35.60 - 231.03 mg l^{-1}, 55.99 - 785.92 mg l^{-1}, 37.63 - 152.24 mg l^{-1} and 52.18 - 1,217.87 mg l^{-1} respectively (Figure 38).

Sediment texture (percent of sand, silt and clay)

Sediment samples in the fish pond contained sand 31.52 - 53.52 %, silt 25.28 – 41.28 % and clay 19.20 - 29.20 % and they mostly consisted of loam but it was clay loam at the beginning of the rainy season and it was sandy clay loam at the beginning of the cool dry season. Sediment at the open water of Houy Yuak Reservoir contained sand 11.52 - 51.32 %, silt 19.28 - 27.28 % and clay 21.20 - 61.20 % so they were mostly clay but at the end of the cool dry season and at the end of the summer, they were clay loam and sandy clay loam respectively. Sediment in the small pond of Houy Yuak Reservoir contained sand 21.52 - 33.52 %, silt 25.28 - 29.28 % and clay 39.20 - 49.20 % and it was mostly clay apart from at the end of the summer when it was clay loam. Sediment in the reservoir of the Mae Kuang Udomtara was clay and contained sand 23.52 – 31.52 %, silt 7.28 - 9.28 % and 59.20 - 69.20 %. Sediments in Sakon Nakhon sewage oxidation pond contained sand 69.52 - 81.52 %, silt 1.28 - 13.28 %, clay 9.20 - 29.20 % and was mostly sandy loam apart from at the end of the rainy season, it was sandy clay loam (Table 5).

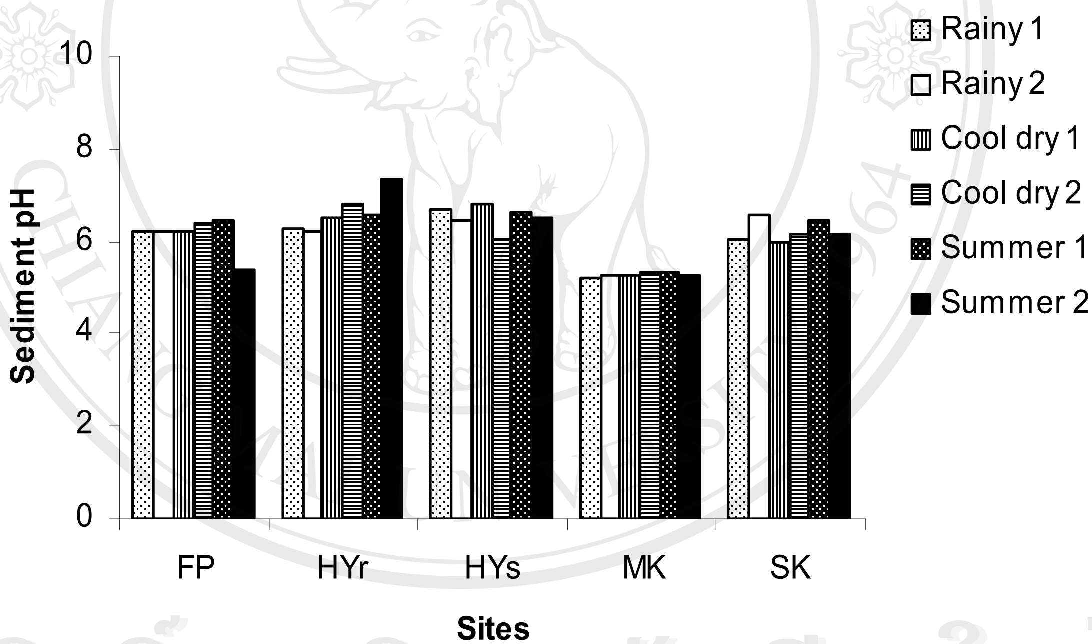


Figure 33 The sediment pH levels of water resources from the rainy season in August 2003 to the summer in May 2004. The fish pond (FP), the open water of Houy Yuak Reservoir (HYr), the small pond of Houy Yuak Reservoir (HYs), the reservoir of Mae Kuang Udomtara Dam (MK) and Sakon Nakhon sewage oxidation pond (SK)

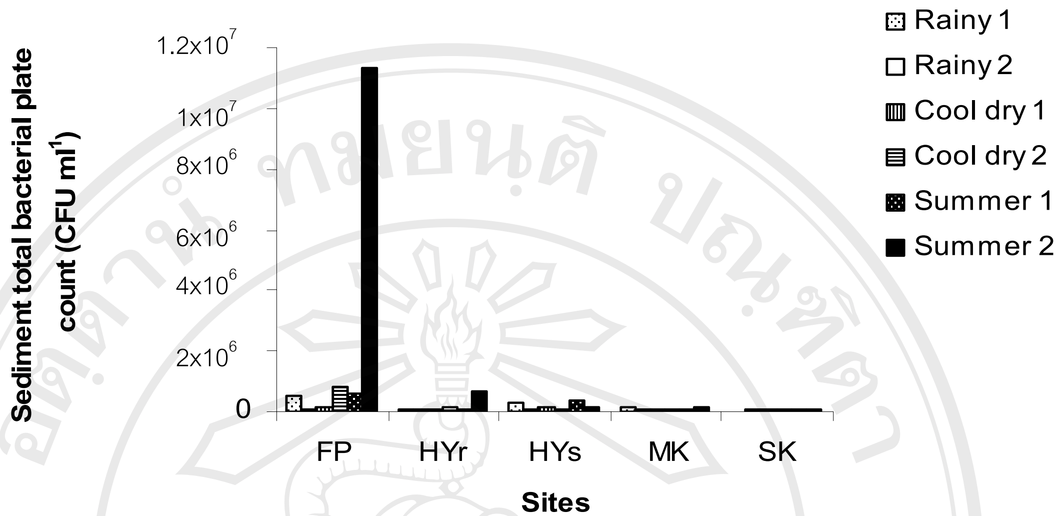


Figure 34 The total bacterial plate count in sediment of water resources from the rainy season in August 2003 to the summer in May 2004

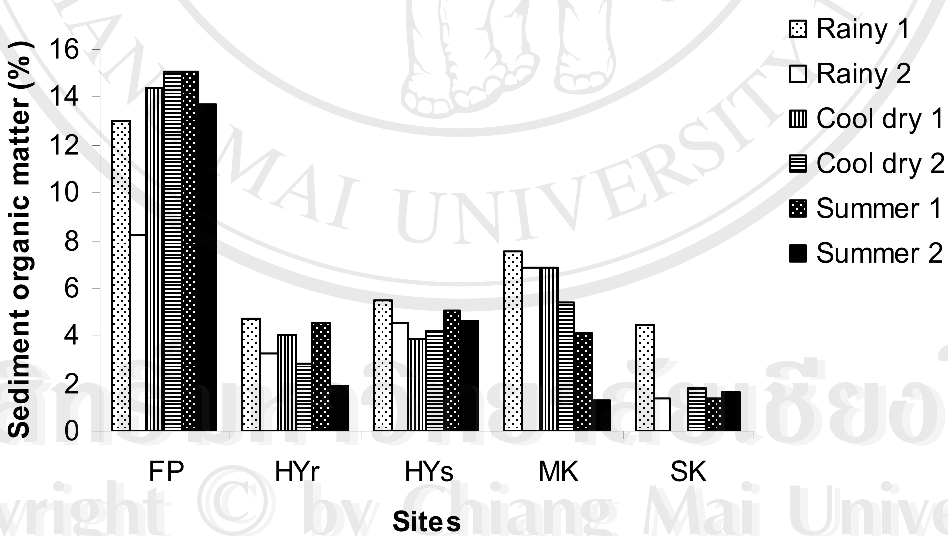


Figure 35 The percent of organic matter of sediment in water resources from the rainy season in August 2003 to the summer in May 2004

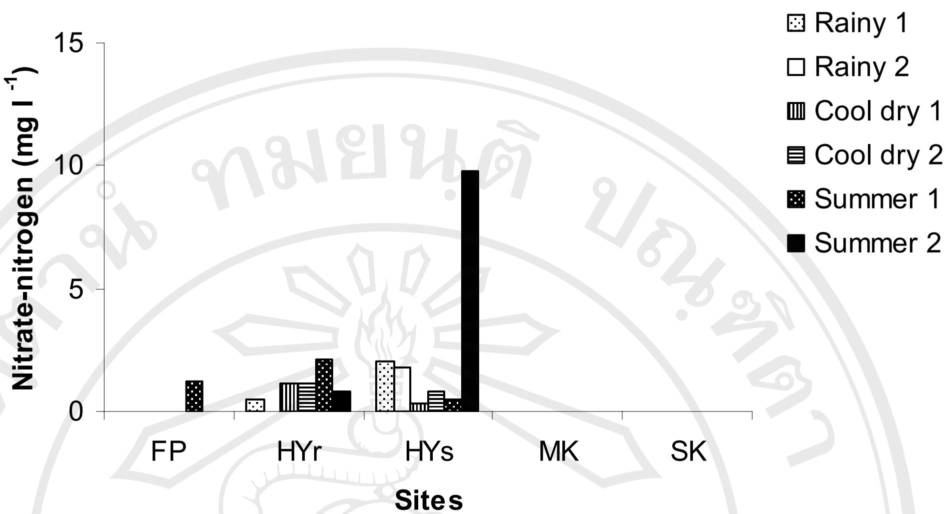


Figure 36 The sediment nitrate-nitrogen levels in water resources from the rainy season in August 2003 to the summer in May 2004

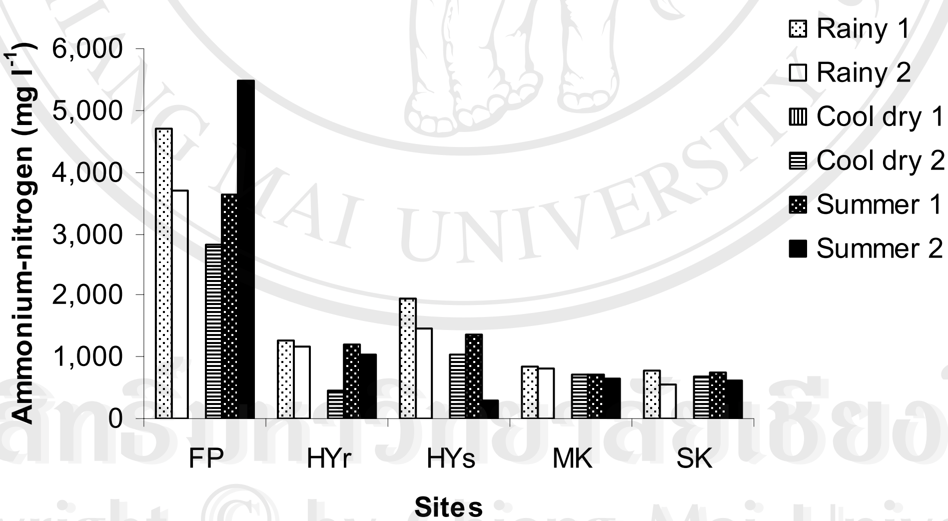


Figure 37 The sediment ammonium-nitrogen levels in water resources from the rainy season in August 2003 to the summer in May 2004

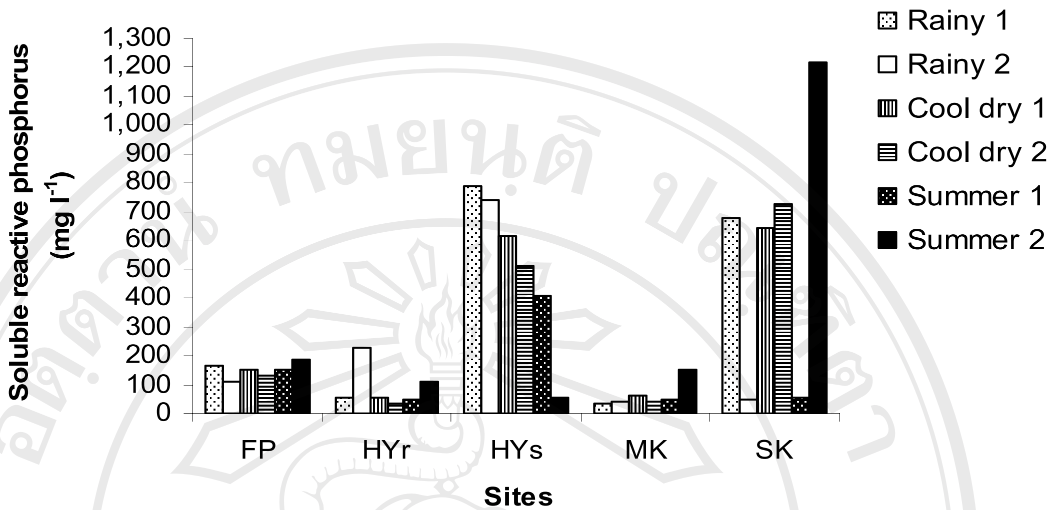


Figure 38 The sediment soluble reactive phosphorus levels in water resources from the rainy season in August 2003 to the summer in May 2004

Table 5 The percent of sediment components and the sediment texture of sediment samples from all water resources during the rainy season in August 2003 to the summer in May 2004.

Site	Season	% sand	% silt	% clay	Texture
Fish pond	Rainy 1	31.52	39.28	29.20	Clay loam
	Rainy 2	35.52	41.28	23.20	loam
	Cool dry 1	53.52	25.28	21.20	Sandy Clay loam
	Cool dry 2	41.52	29.28	19.20	loam
	Summer 1	37.52	37.28	25.20	loam
	Summer 2	47.52	29.28	23.20	loam
Houy Yuak Reservoir (open water)	Rainy 1	11.52	27.28	61.20	Clay
	Rainy 2	23.52	19.28	57.20	Clay
	Cool dry 1	17.52	23.28	59.20	Clay
	Cool dry 2	39.52	21.28	39.20	Clay loam
	Summer 1	37.52	19.28	43.20	Clay
	Summer 2	51.32	27.28	21.20	Sandy Clay loam
Houy Yuak Reservoir (small pond)	Rainy 1	21.52	29.28	49.20	Clay
	Rainy 2	21.52	29.28	49.20	Clay
	Cool dry 1	23.52	29.28	47.20	Clay
	Cool dry 2	33.52	25.28	41.20	Clay
	Summer 1	21.52	29.28	49.20	Clay
	Summer 2	33.52	27.28	39.20	Clay loam

Table 5 (continued)

Site	Season	% sand	% silt	% clay	Texture
Reservoir of Mae Kuang Dam	Rainy 1	29.52	7.28	63.20	Clay
	Rainy 2	29.52	7.28	63.20	Clay
	Cool dry 1	23.52	7.28	69.20	Clay
	Cool dry 2	31.52	9.28	59.20	Clay
	Summer 1	29.52	9.28	61.20	Clay
	Summer 2	27.52	9.28	63.20	Clay
Sakon Nakhon sewage oxidation pond	Rainy 1	77.52	5.28	17.20	Sandy loam
	Rainy 2	69.52	1.28	29.20	Samdy Clay loam
	Cool dry 1	73.52	7.28	19.20	Sandy loam
	Cool dry 2	77.52	13.28	9.20	Sandy loam
	Summer 1	81.52	9.28	9.20	Sandy loam
	Summer 2	79.52	11.28	9.20	Sandy loam

4.3 Microcystin analysis

4.3.1 Microcystins in cyanobacterial scum

Many microcystin variants were determined from predominant cyanobacterial scum collected from five water resources. Twelve microcystins showing typical UV absorption spectra for microcystins were found, which were microcystin-RR, microcystin-LR, and ten unknown variants of microcystin showing typical UV absorption spectra for microcystins. Predominant *Microcystis aeruginasa* scum from the fish pond was found to contain microcystin-RR, microcystin-LR and seven unknown microcystin variants at a total concentration of 1.42 ± 0.04 g kg^{-1} dry weight. The most abundant variant was microcystin-RR at concentration of 0.60 ± 0.04 g kg^{-1} dry weight. Predominant cyanobacterial scum from Houy Yuak Reservoir was found to contain microcystin-RR and microcystin-LR at concentrations of 0.13 ± 0.03 and 0.12 ± 0.002 g kg^{-1} dry weight, respectively. Predominant cyanobacterial scum from the reservoir of Mae Kuang Udomtara was found to contain microcystin-LR, microcystin-RR and two unknown microcystin variants at total concentration of 0.46 ± 0.03 g kg^{-1} dry weight. The most abundant variant was microcystin-LR at concentration of 0.22 ± 0.009 g kg^{-1} dry weight. Simultaneously predominant *Microcystis aeruginosa* and *Spirulina platensis* scum from Sakon Nakhon sewage oxidation pond was found to contain only one microcystin variant which was microcystin-RR at the concentration of 0.07 ± 0.003 g kg^{-1} dry weight. Predominant *Microcystis aeruginosa* scum from the prawn cultivation pond was found to contain microcystin-RR, microcystin-LR and an unknown microcystin at the total concentration of 0.45 ± 0.02 g kg^{-1} dry weight, the most abundant variants were microcytin-RR and microcystin-LR at the concentrations of 0.21 ± 0.02 and 0.20 ± 0.002 g kg^{-1} dry weight respectively (Figure 39).

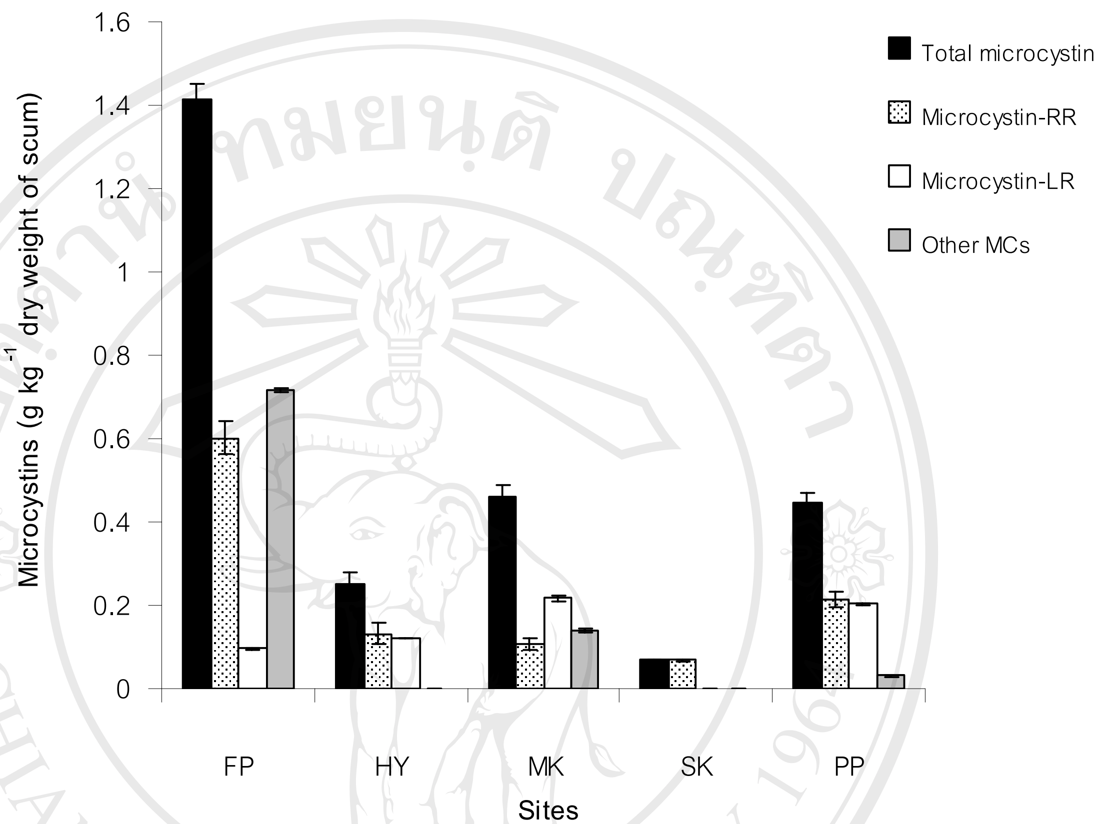


Figure 39 Microcystins in cyanobacterial scum samples collected from the fish pond (FP), the open water of Houy Yuak Reservoir (HYr), the small pond of Houy Yuak Reservoir (HYs), the reservoir of Mae Kuang Udomtara Dam (MK), Sakon Nakhon sewage oxidation pond (SK) and the prawn pond (PP). The error bar represents the standard deviation (n = 3)

4.3.2 Microcystins in water

Water samples collected from five study sites at six sampling times during three seasons were found to contain many microcystin variants with different types and amounts in different seasons which are explained as follows (Figures 40-43).

The fish pond

The fish pond water samples were found to contain microcystin-RR, microcystin-LR and twenty-two unknown microcystin variants at the total concentration between 14.22 ± 1.47 – 23.44 ± 2.08 µg l^{-1} microcystin-LR equivalents. The lowest and the highest concentrations of total microcystin were found at the beginning of the rainy season and at the end of the summer respectively. Microcystin-RR was found at the concentration between 0.02 ± 0.03 – 3.33 ± 0.25 µg l^{-1} microcystin-LR equivalents. The lowest and the highest microcystin-RR concentrations were found at the end of the rainy season and at the beginning of the rainy season, repectively. Microcystin-LR was found at the concentration between 1.00 ± 0.10 – 2.26 ± 0.23 µg l^{-1} microcystin-LR equivalents. The lowest and the highest concentrations of microcystin-LR were found at the end of the summer and the beginning of the summer, respectively. Other microcystin variants were found at the total concentration between 1.57 ± 1.01 – 18.57 ± 0.59 µg l^{-1} microcystin-LR equivalents. The lowest and the highest total concentrations of other microcystin variants were found at the beginning of the summer and at the end of the summer, respectively.

The open water of Houy Yuak Reservoir

Water samples at the open water of Houy Yuak Reservoir were found to contain microcystin-RR and nine unknown microcystin variants at the total concentration between less than the detection limit and 1.15 ± 0.17 µg l^{-1} microcystin-LR equivalents. Total microcystin was less than the detection limit at the beginning of the rainy season. The highest concentration of total microcystins was found at the end of the cool dry season. Microcystin-RR was found at the concentration between less than the detection limit and 0.05 ± 0.02 µg l^{-1} microcystin-LR equivalents. Microcystin-RR was below the detection limit in the rainy season and at the beginning of the summer. The highest concentration of microcystin-RR was found at the beginning of the cool dry season. Other microcystin variants were found at the total concentration levels between less than the detection limit and 1.09 ± 0.15 µg l^{-1} microcystin-LR equivalents. The total concentration of other microcystin variants was below the detection limit at the end of the rainy season. The highest total concentration of other microcystin variants was found to be at the end of the cool dry season.

The small pond of Houy Yuak Reservoir

Water samples at the small pond of Houy Yuak Reservoir were found to contain microcystin-RR and eleven unknown microcystin variants at the total concentration levels between 0.13 ± 0.05 and 1.06 ± 0.26 $\mu g\ l^{-1}$ microcystin-LR equivalents. The lowest and the highest concentrations of total microcystin were found at the beginning of the summer and at the end of the cool dry season respectively. Microcystin-RR was found at the concentration level between below the detection limit and 0.07 ± 0.04 $\mu g\ l^{-1}$ microcystin-LR equivalents. Microcystin-RR was less than the detection limit at the end of the rainy season and in the summer. The highest concentration of microcystin-RR was found at the end of the cool dry season. Other microcystin variants were found at the total concentration level between less than the detection limit and 0.97 ± 0.22 $\mu g\ l^{-1}$ microcystin-LR equivalents. Total concentration of other microcystin variants was below the detection limit at the end of the summer. The highest total concentration of other microcystin variants was found at the end of the cool dry season.

The reservoir of Mae Kuang Udomtara Dam

Water samples from the reservoir of Mae Kuang Udomtara Dam were found to contain microcystin-RR, microcystin-LR and four unknown microcystin variants at the total concentration between below the detection limit and 0.43 ± 0.06 $\mu g\ l^{-1}$ microcystin-LR equivalents. The total microcystins level was below the detection limit at the end of the rainy season. The highest concentration of total microcystin was found at the beginning of the rainy season. Microcystin-RR was found at the concentration between below the detection limit and 0.04 ± 0.01 $\mu g\ l^{-1}$ microcystin-LR equivalents. Microcystin-RR was below the detection limit at the end of the rainy season and in the summer. The highest concentration of microcystin-RR was found at the end of the cool dry season. Microcystin-LR was found at the concentration between below the detection limit and

0.08 ± 0.01 µg l^{-1} microcystin-LR equivalents. Microcystin-LR was below the detection limit at the end of the rainy season. The highest concentration of microcystin-LR was found at the end of the summer. Other microcystin variants were found at the total concentration between below the detection limit and 0.40 ± 0.10 µg l^{-1} microcystin-LR equivalents. Total concentration of other microcystin variants was below the detection limit at the end of the rainy season. The highest concentration of other microcystin variants was found at the beginning of the rainy season.

Sakon Nakhon sewage oxidation pond

Water samples from Sakon Nakhon sewage oxidation pond were found to contain microcystin-RR, microcystin-LR and four unknown microcystin variants at the total concentration between 0.11 ± 0.05 and 1.35 ± 0.28 µg l^{-1} microcystin-LR equivalents. The lowest and the highest concentrations of total microcystin were found at the beginning of the rainy season and at the beginning of the cool dry season respectively. Microcystin-RR and microcystin-LR were found at the concentrations of 0.22 ± 0.01 and 0.24 ± 0.06 µg l^{-1} microcystin-LR equivalents only at the beginning of the cool dry seasson. Other microcystin variants were found at the total concentrations between 0.11 ± 0.05 and 0.88 ± 0.23 µg l^{-1} microcystin-LR equivalents. The lowest and the highest total concentrations of other microcystin variants were found at the beginning of the rainy season and at the beginning of the cool dry season.

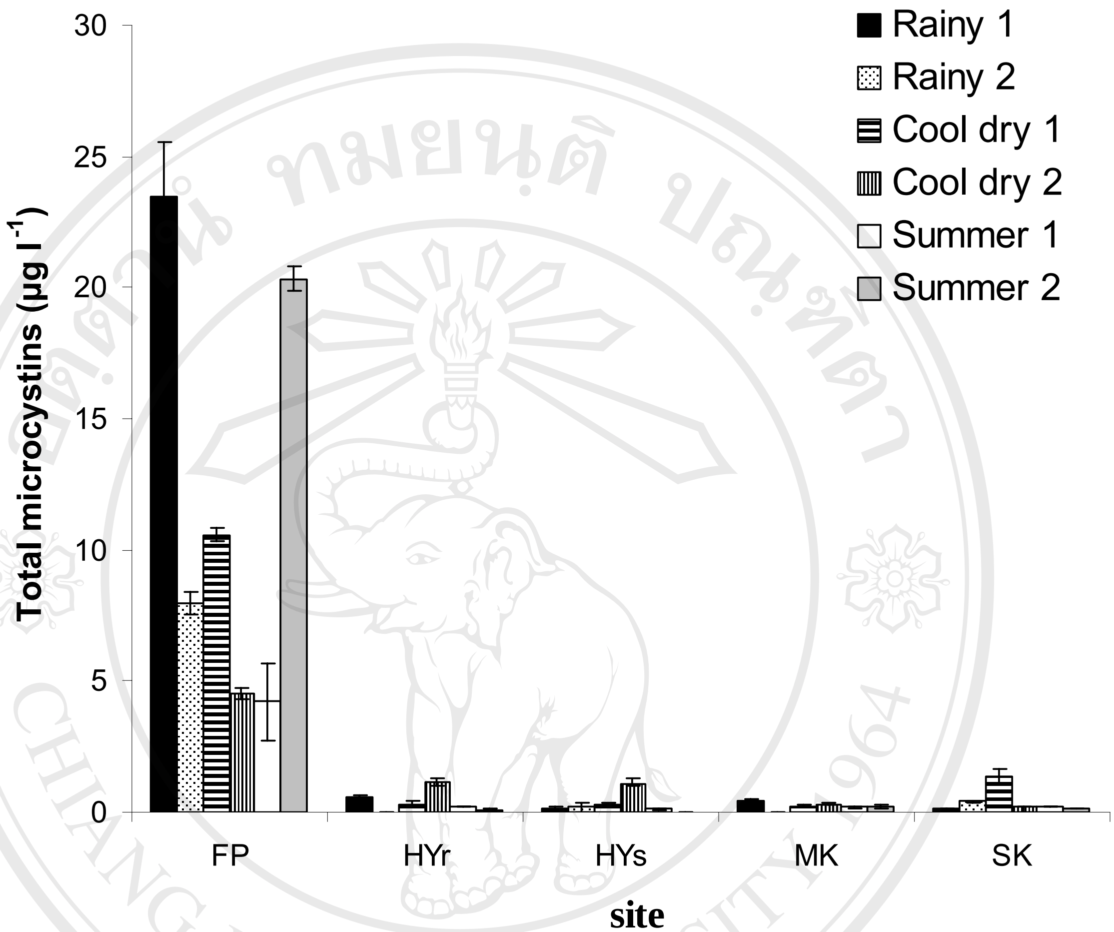


Figure 40 Total microcystins in water samples collected from five water resources from the rainy season in August 2003 to the summer in May 2004. The fish pond (FP), the open water of Houy Yuak Reservoir (HYr), the small pond of Houy Yuak Reservoir (HYs), the reservoir of Mae Kuang Udomtara Dam (MK) and Sakon Nakhon sewage oxidation pond (SK). The error bar represents the standard deviation (n = 2).

Figure 41 Microcystin-RR in water samples collected from five localities in four water resources from the rainy season in August 2003 to the summer in May 2004

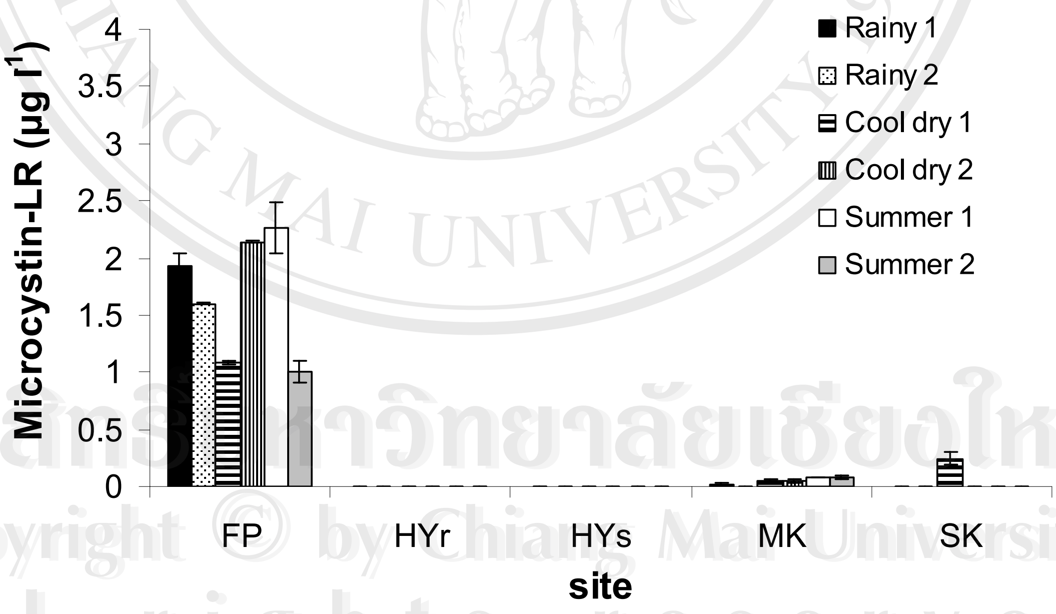


Figure 42 Microcystin-LR in water samples collected from five localities in four water resources from the rainy season in August 2003 to the summer in May 2004

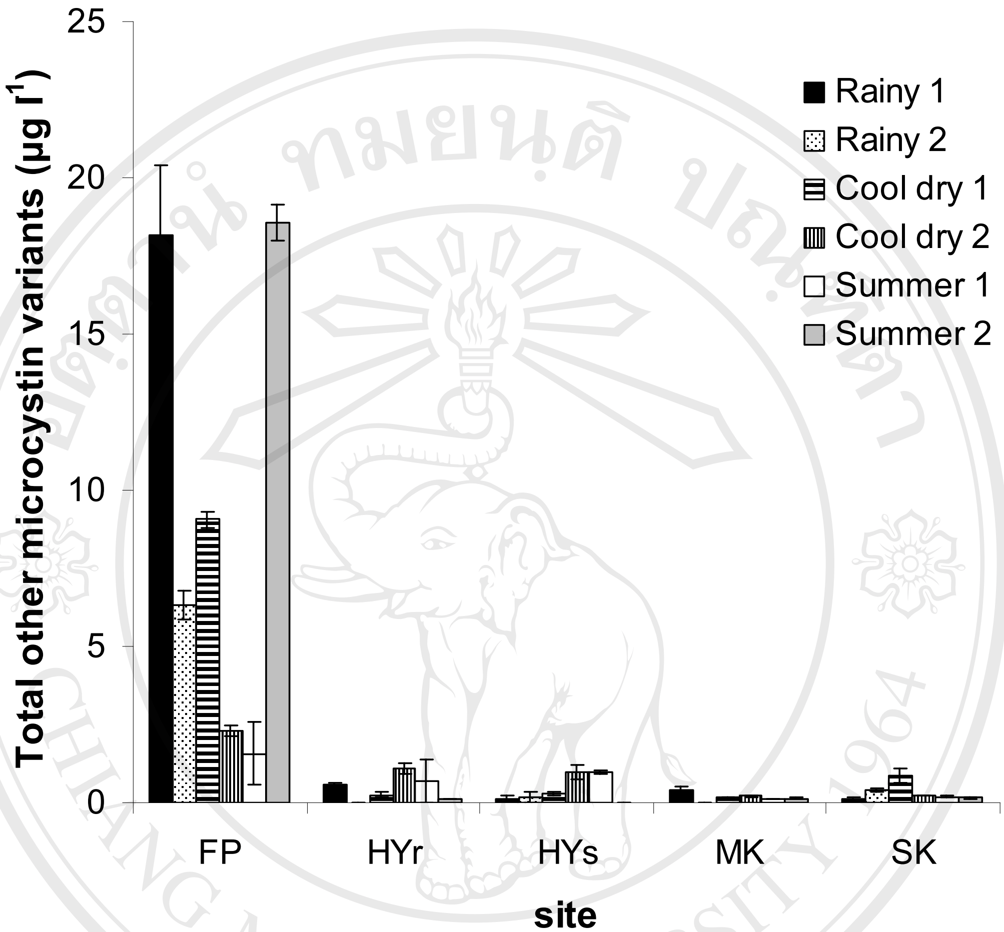


Figure 43 Total concentrations of other microcystin variants (unknown microcystins varints) in water samples collected from five localities in four water resources from the rainy season in August 2003 to the summer in May 2004

4.3.3 Microcystins in sediment

4.3.3.1 Microcystin-LR extractions from Scottish sediment

It was found that microcystin-LR was very difficult to extract from the sediment. Several solvents and applications of microwave plus sonication were used for extraction providing different results as follows, sterilised Milli-Q water showed the highest percent extraction followed by 0.1%TFA in methanol, which were 18.09 ± 1.85 % and 12.76 ± 3.88 %, respectively. Whilst methanol, 5% acitic acid in 0.1% TFA-methanol and microwave plus sonication proved to be very poor solvents and method for microcystin-LR extraction from sediments providied very low percent extraction of 1.88 ± 0.30 %, 2.36 ± 1.58 % and 0.56 ± 0.03 %, respectively (Figure 44).

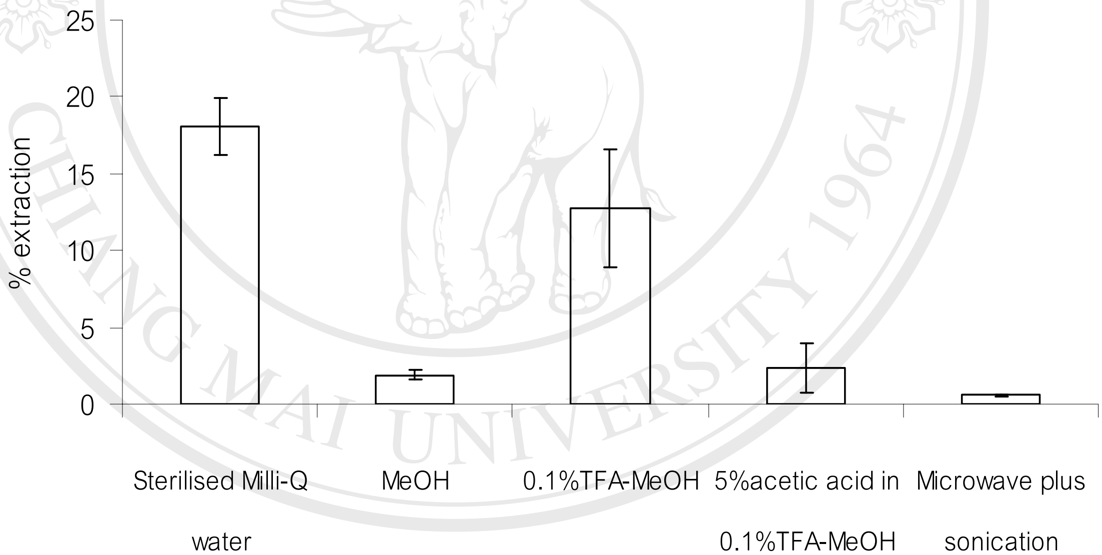
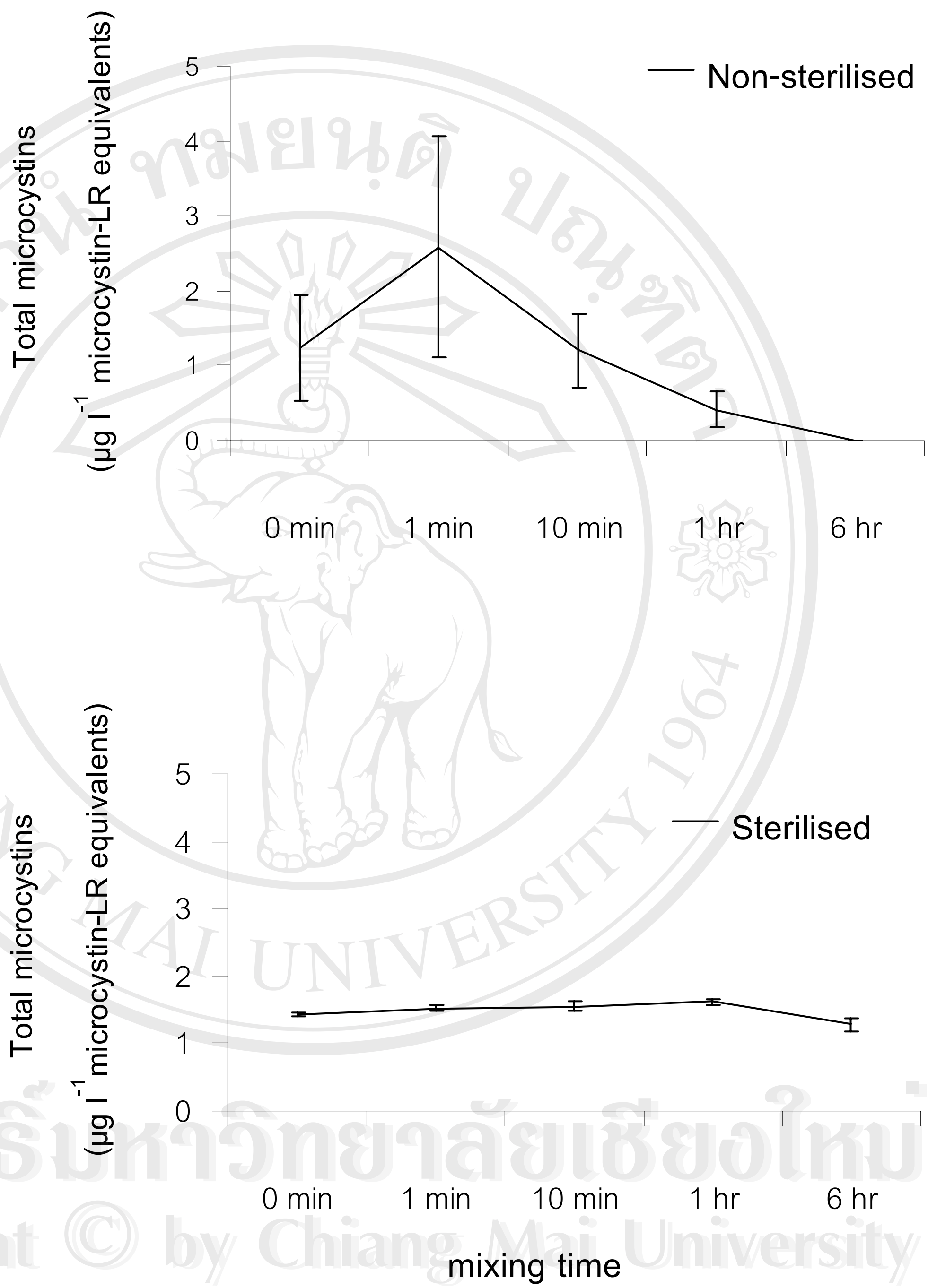


Figure 44 Comparison of percent extraction of microcystin-LR from the sediment using different solvents and microwave plus sonication detected by ELISA. The error bar represents the standard deviation (n = 3)

4.3.3.2 Microcystin-LR sorption onto Scottish sediment

(1) Microcystins in sterilised and non-sterilised environmental sediment

According to determination of remaining total microcystin in supernatants of suspended environmental sediment collected from Loch Rescobie, Scotland, after the magnetic stirring at different mixing times, It was found that the remaining total microcystins level at 0 minute, 1 minute, 10 minutes, 1 hour and 6 hours in non-steriled sediment samples were 1.24 ± 0.71, 2.58 ± 1.48, 1.20 ± 0.50, 0.41 ± 0.24 µg l^{-1} and below the detection limit, respectively. There were not a significant difference between the remaining total microcystins level at 0 minute, 1 minute and 10 minutes but there were a significant diference between the remaining tatal microcystins level at 10 mintes and at 1 hr evaluated using paired sample T-test. Whilst in sterilised sediment, the levels were 1.44 ± 0.03, 1.52 ± 0.04, 1.55 ± 0.07, 1.62 ± 0.04 and 1.28 ± 0.10 µg l^{-1}, respectively. The non-sterilised sediment gave higher variation of remaining total microcystins in supernatant than that in the sterilised sediment. Remaining total microcystins had the trend of decrease after one minute forward to six hours that remaining total microcystins were below the detection limit. Whilst, remaining total microcystins were still not different over six hours with very small variation, remaining total microcystins did not much decrease from one to six hours (Figure 45). This experiment presented that the total microcystins in non-sterilised and sterilised sediments resulted in different concentrations during the different mixing periods. So that, all sediment samples were sterilised for all experiments regarding microcystins in sediment to obtain the stability of microcystin concentration in sediment and the smaller variation of the results.



Figures 45 Comparison of remaining total microcystins in the supernatant of suspended environmental sediment after magnetic stirrer mixing at different times detected by ELISA. The error bar represents the standard deviation (n = 3).

(2) The effect of microcysin-LR concentration on microcystin sorption onto the sediment

The effect of microcystin concentration on microcystin sorption onto sediment was determined using three concentrations of standard microcystin-LR. It found that the standard microcystin-LR concentration of 1, 2 and 3 µg ml^{-1} remained 0, 31.52 ± 0.60 and 45.38 ± 0.82 ng in 25 µl, repectively (Figure 46). Likely, the percent sorption of standard microcystin-LR at the concentration of 1, 2 and 3 µg ml^{-1} were approximately 100%, 34% and 40%, respectively (Figure 47). The standard microcystin-LR concentration of 1 µg ml^{-1} gave a very low concentration of remaining spiked microcystin-LR in supernatant whilst, the higher concentrations which were microcystin-LR concentrations of 2 µg ml^{-1} and 3 µg ml^{-1} gave higher concentration of remaining spiked microcystin-LR in supernatant. These findings mean the percent of microcystin sorption onto sediment would be high at the low concentration level of microcystin in the sediment and the percent of microcystin sorption would be lower at the higher concentration of microcystin in the sediment. So the percent of microcystin sorption would vary negatively with the microcystin concentration in the sediment. However, the percent of microcystin sorption would not increased or would be stable when the concentration of microcystin in the sediment exceeded the binding site onto the sediment.

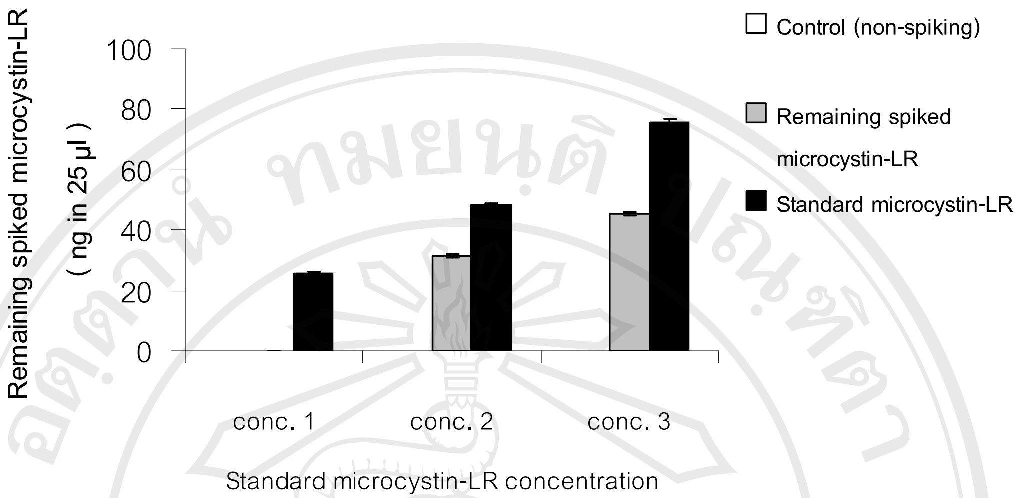


Figure 46 Comparison of the remaining spiked microcystin-LR in the supernatant separated from the sediment detected by HPLC (conc. 1 = standard micocystin-LR concentration of 1 µg ml^{-1}; conc. 2 = standard micocystin-LR concentration of 2 µg ml^{-1}; conc. 3 = standard micocystin-LR concentration of 3 µg ml^{-1}). The error bar represents the standard deviation (n = 3).

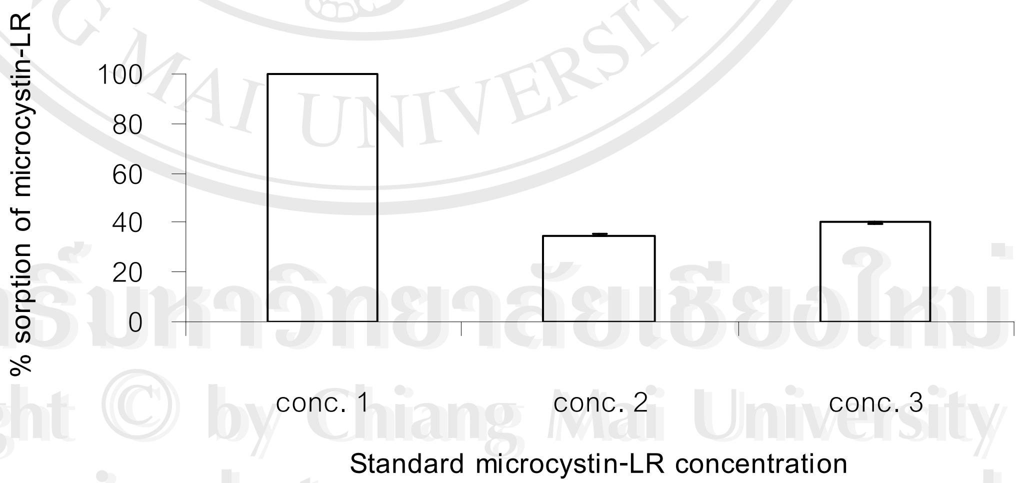


Figure 47 Comparison of the effect of microcystin-LR concentration on microcystin-LR sorption onto the sediment detected by HPLC. The error bar represents the standard deviation (n = 3).

(3) The effect of sediment concentration on microcystin-LR sorption onto sediment

The effect of sediment concentration on microcystin-LR sorption onto sediment was determined using three concentrations of the sediment. It found that the percent sorptions of the standard microccystin-LR onto the sediment concentration of 1.25, 2.5 and 5 g of sediment dry weight in 25 ml of steriled Milli-Q water were 93.00 ± 0.94, 94.99 ± 0.52 and 97.48 ± 0.18 % respectively. The concentration of 1.25 g of sediment dry weight in 25 ml of steriled Milli-Q water gave the lower percentage of microcystin-LR sorption than those at the concentrations of 2.5 and 5 g of sediment dry weight in 25 ml of steriled Milli-Q water whilst the concentration of 5 g of sediment dry weight in 25 ml of steriled Milli-Q water gave the highest percent sorption. These findings mean percent sorption of microcystin-LR varies positively with the concentration of the sediment. However, percent sorption of microcystin-LR was very high (over than 90%) at the lowest concentration of sediment (1.25 g) in this study (Figure 48).

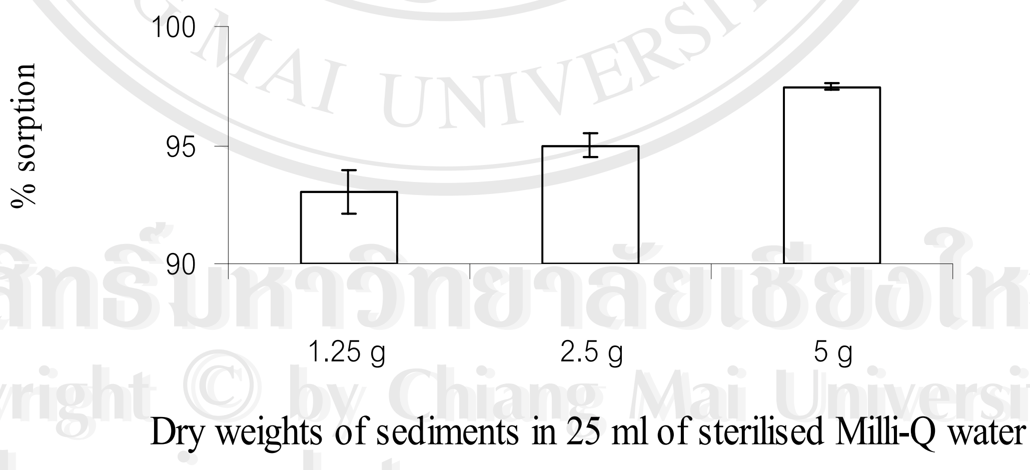


Figure 48 Comparison of the effect of the sediment concentration on microcystin-LR sorption onto the sediment detected by ELISA. The error bar represents the standard deviation (n = 3).

4.3.3.3 Microcystin-LR sorption onto Thai environmental sediment samples

The fish pond sediment samples

The percent sorption of microcystin-LR onto sediment samples collected from the fish pond were very high (97.25 ± 0.30 – 99.13 ± 0.80 %) in all seasons apart from the sample collected at the end of the summer, which showed a significantly lower percent sorption of 33.58 ± 8.78 % (Figure 49).

Houy Yuak Reservoir open water sediment samples

The percent sorption of microcystin-LR onto sediment samples collected from Houy Yuak Reservoir at the open water were very high (96.61 ± 2.95 – 99.78 ± 0.38%) apart from the samples collected at the beginning of the cool dry season and at the beginning of the summer, which were 4.56 ± 4.46 and 32.06 ± 8.71%, respectively (Figure 49).

Houy Yuak Reservoir small pond sediment samples

The percent sorption of microcystin-LR onto sediment samples collected from Houy Yuak Reservoir at the small pond were clearly high in all seasons and were between 96.99 ± 0.59 – 100 ± 0.00% (Figure 49).

The reservoir of Mae Kuang Udomtara Dam sediment samples

The percent sorption of microcystin-LR onto sediment samples collected from the reservoir of Mae Kuang Udomtara Dam were also very high during all seasons and were between 98.25 ± 0.40 – 99.36 ± 0.05% (Figure 49).

Sakon Nakhon sewage oxidation pond sediment samples

The percent sorption of microcystin-LR onto sediment samples collected from Sakon Nakhon sewage oxidation pond presented different results over each season.

Percent sorptions of the rainy season samples were not found whilst percent sorptions of the cool dry season samples were very poor with large variations (24.51 ± 22.46 – 28.22 ± 33.89%), but percent sorptions of the summer samples were very high with small variations (92.51 ± 2.27 – 94.06 ± 1.50%) (Figure 49).

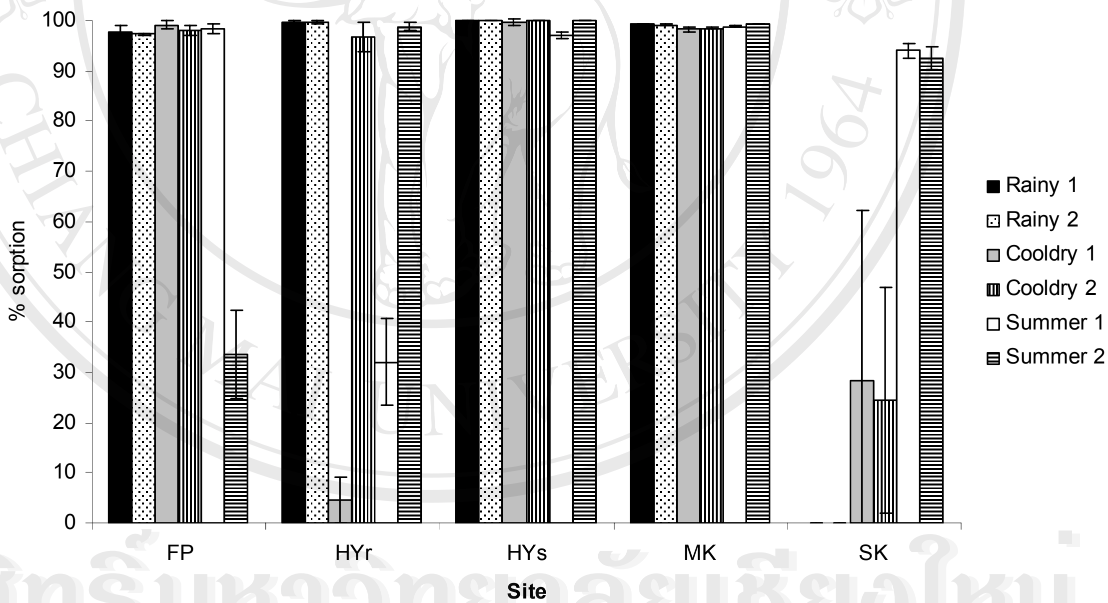


Figure 49 Microcystin-LR sorption onto Thai environmental sediment samples collected from five localities in four water resources from the rainy season in August 2003 to the summer in May 2004. The error bar represents the standard deviation (n = 3).

4.3.3.4 Total microcystins in Thai environmental sediment samples

According to the results of microcystin-LR extractions from Scottish sediment, sterilised Milli-Q water could be used as the solvent for microcystin extraction from the sediment giving the highest percent extraction in comparison with other solvents and microwave plus sonication. So that, total microcystin determination for all Thai environmental sediment samples was done by using sterilised Milli-Q water as the solvent and the results are presented as follows (Figure 50).

The fish pond sediment samples

The total microcystin in fish pond sediment samples were clearly higher than those in other sites. They were between 30.64 ± 1.00 and 162.25 ± 6.13 µg kg^{-1} sediment dry weight. The lowest concentration level was found at the end of the cool dry season sample whilst the highest concentration level was found at the end of the summer and this sample was also the highest concentration level of all samples from all study sites.

Houy Yuak Reservoir open water sediment samples

Total microcystin in Houy Yuak Reservoir at the open water sediment samples were between $5.99 \pm 1.03 – 68.56 \pm 6.37$ µg kg^{-1} sediment dry weight. The lowest and the highest concentrations were found at the beginning of the rainy and at the beginning of the cool dry season, respectively.

Houy Yuak Reservoir small pond sediment samples

Total microcystins concentrations in Houy Yuak Reservoir at the small pond sediment samples presented with large variations. Concentrations were below the detection limit in the samples from the beginning of the rainy season and the beginning of the summer, whilst the other season samples were between 2.30 ± 3.99 and 21.28 ± 5.63 µg kg^{-1} sediment dry weight and the highest concentration was found in the sample taken at the beginning of the rainy season.

The reservoir of Mae Kuang Udomtara Dam sediment samples

The total microcystins concentration in the reservoir of Mae Kuang Udomtara Dam sediment samples was found rather lower than the other sites which were between 2.47 ± 0.33 and 5.97 ± 2.53 μg kg^{-1} sediment dry weight. The lowest and the highest concentrations were found in the beginning and at the end of the rainy season samples, respectively.

Sakon Nakhon sewage oxidation pond sediment samples

The total microcystins concentrations in Sakon Nakhon sewage oxidation pond sediment samples were between 12.33 ± 0.70 and 35.10 ± 1.39 μg kg^{-1} sediment dry weight. The lowest and the highest concentrations were found in the beginning of the rainy season and in the samples taken at the beginning of the cool dry season samples, respectively.

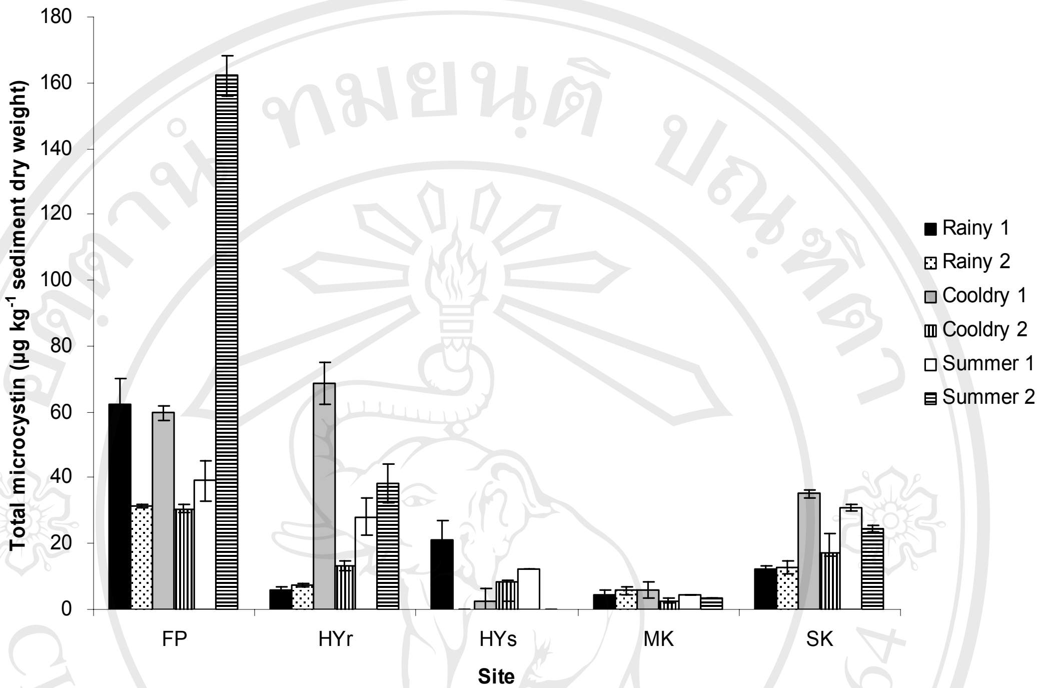


Figure 50 Total microcystins in Thai environmental sediment samples collected from five localities in four water resources from the rainy season in August 2003 to the summer in May 2004. The error bar represents the standard deviation (n = 3).

4.4 Multiple-correlations

4.4.1 Principal Component Analysis (PCA)

4.4.1.1 PCA for environmental factors of water

The results of PCA for environmental factors of water presented that all PCA case score plots could be grouped into two groups based on the environmental factors in the water when one group comprised the fish pond in all seasons, and the other group comprised the other study sites over all seasons. The PCA case score plots of the fish pond clearly were far separated from the reservoir of Mae Kuang Udomtara Dam whilst the PCA case score plots of the open water, the small pond of Houy Yuak Reservoir and Sakon Nakhon sewage oxidation pond were not clearly separated from each other (Figure 51). Therefore, the environmental factors of the water were not much different among the open water and the small pond of Houy Yuak Reservoir and Sakon Nakhon sewage oxidation pond, but there was clearly a difference between the fish pond and the reservoir of Mae Kuang Udomtara Dam. Moreover, the PCA case score plots of each season were close to each other and could be grouped as the same group at each study site indicating that each study site was not much different in terms of seasonal change. The principal factors that made the difference between the fish pond and the reservoir of Mae Kuang Udomtara Dam were the alkalinity, conductivity, soluble reactive phosphorus, ammonium-nitrogen BOD_5, chlorophyll-a, total microcystin, microcystin-RR, microcystin-LR and other microcystins in the water which all had a strong influence in the fish pond, whilst the water volume, depth, the Secchi depth and the dissolved oxygen level had a strong influence in the reservoir of Mae Kuang Udomtara Dam (Figure 52).

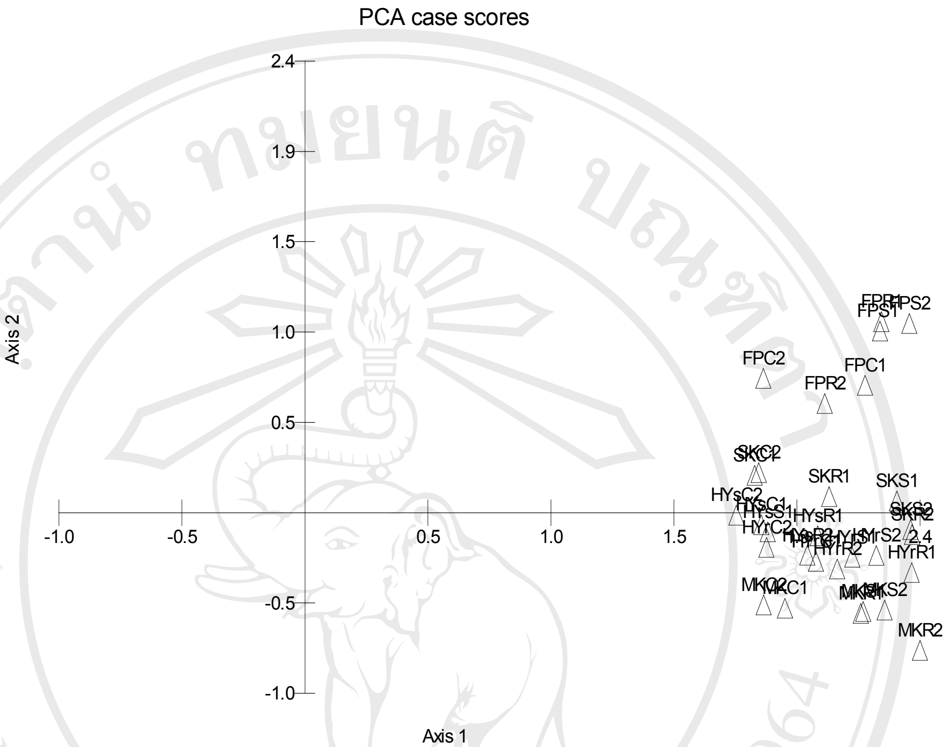


Figure 51 PCA for environmental factors of water in five localities in four water resources from the rainy season in August 2003 to the summer in May 2004

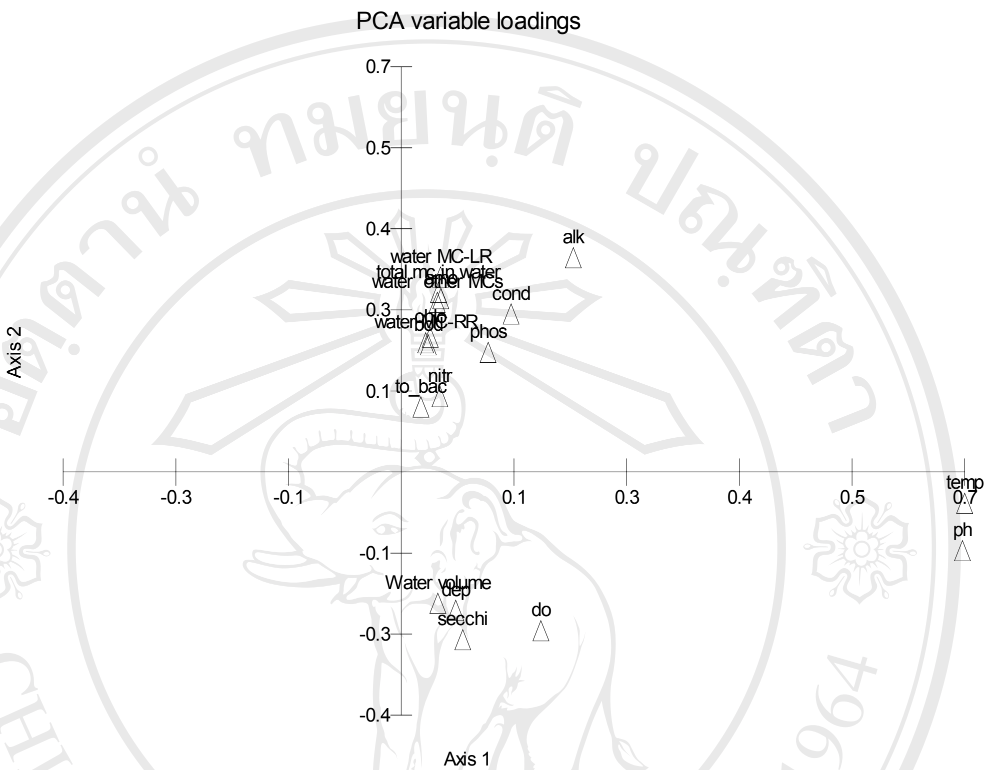


Figure 52 PCA variable loading for environmental factors of water in five localities in four water resources from the rainy season in August 2003 to the summer in May 2004

4.4.1.2 PCA for environmental factors of sediment

The results of PCA for environmental factors of the sediment presented that all PCA case score plots were grouped into three groups based on the environmental factors in the sediment. The first group was the fish pond at the end of the summer. The second group comprised the fish pond in all seasons apart from the end of the summer. The third group comprised the open water, the small pond of Houy Yuak Reservoir, the reservoir of Mae Kuang Udomtar Dam and Sakon Nakhon sewage oxidation pond over all seasons. These three groups of the PCA case score plots were clearly more separated from other groups than those based on the environmental factors in water, whilst the PCA case score plots of each group were closer to each other plot than those based on the environmental factors in water (Figure 53). Therefore, the environmental factors of sediment in the fish pond at the end of the summer was different from other seasons whilst there was no difference in terms of the seasonal change at the open water, the small pond of Houy Yuak Reservoir, the reservoir of Mae Kuang Udomtar Dam and Sakon Nakhon sewage oxidation pond over all seasons based on the environmental factors in the sediment. The principal factors that made the differentiation among the three groups of the study sites were total microcystin in sediment, ammonium-nitrogen in sediment, percent organic matter, total bacterial plate count and percent silt which had the strong influence in the fish pond whilst percent clay had the strong influence in the reservoir of Mae Kuang Udomtara Dam (Figure 54).

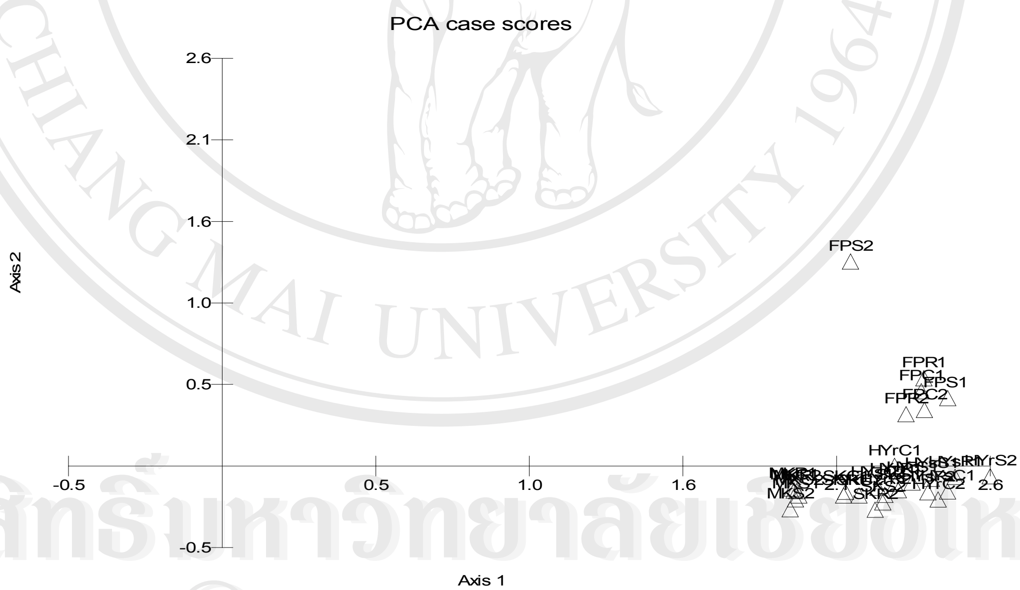


Figure 53 PCA for environmental factors of sediment in five localities in four water resources from the rainy season in August 2003 to the summer in May 2004

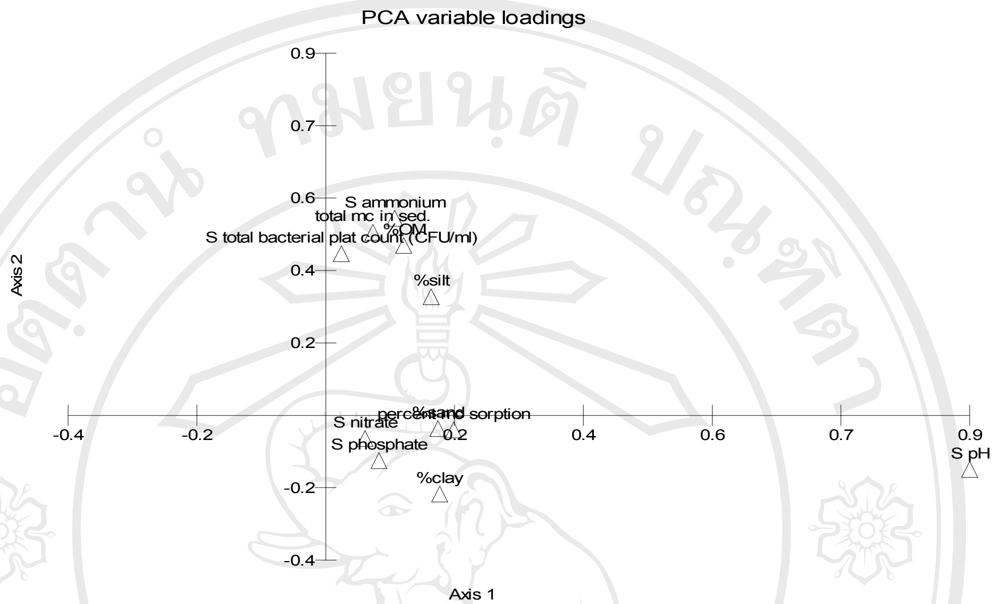


Figure 54 PCA variable loading for environmental factors of sediment in five localities in four water resources from the rainy season in August 2003 to the summer in May 2004

4.4.2 Detrended Correspondence Analysis (DCA) for phytoplankton species composition

The DCA case score plots showed that seasons and study sites can be grouped as many different groups based on phytoplankton species composition. The fish pond at the beginning of the rainy season was different from other seasons. At the open water of Houy Yuak Reservoir, the phytoplankton species composition could be divided into three groups which are Houy Yuak Reservoir at the open water in the rainy season, the beginning of the cool dry season and the beginning of the summer. The second group is Houy Yuak Resevoir at the open water at the end of the summer and the third is Houy Yuak Resevoir at the open water at the end of the cool dry season. At the small pond of Houy Yuak Reservoir and the reservoir of Mae Kuang Udomtara Dam, the phytoplankton species compositions in each sampling time over three seasons were clearly different, whilst at Sakon Nakhon sewage oxidation pond phytoplankton species compositions at each sampling time in the three seasons were not different (Figures 55 and 56).

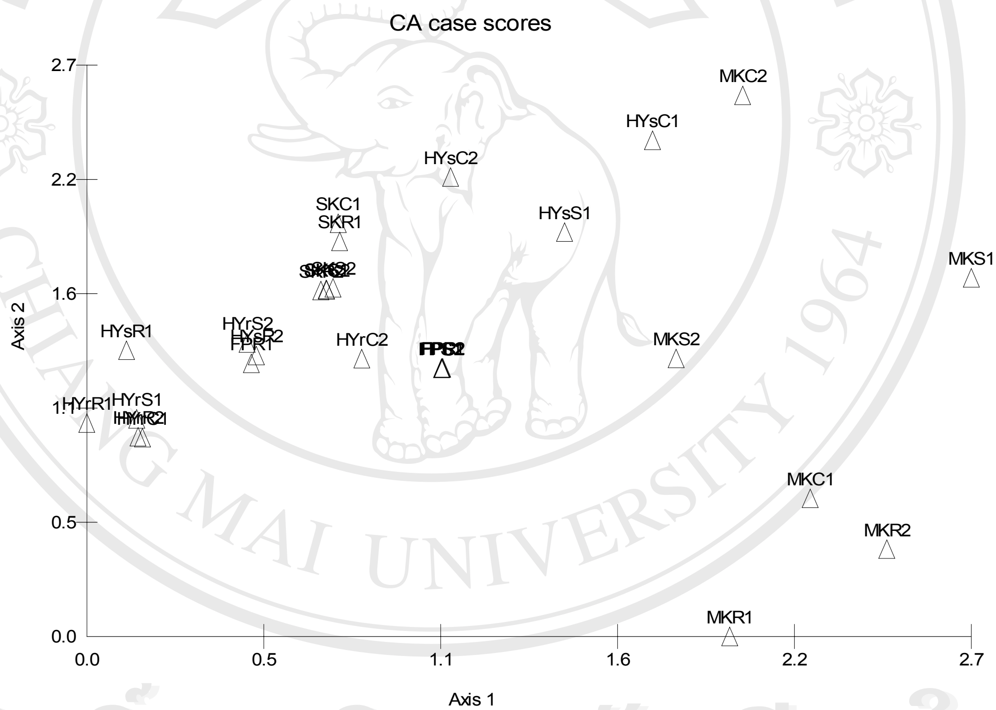


Figure 55 DCA for phytoplankton species composition in five localities in four water resources from the rainy season in August 2003 to the summer in May 2004

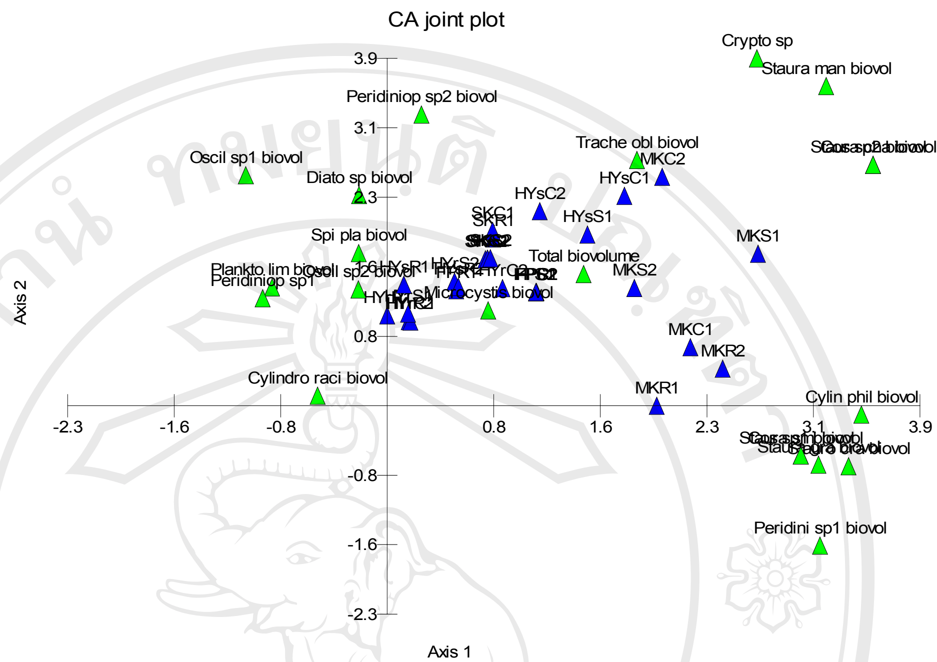


Figure 56 CA joint plot for phytoplankton species composition in five localities in four water resources from the rainy season in August 2003 to the summer in May 2004

4.4.3 Canonical Correspondence Analysis (CCA)

The correlations among environmental factors of water, the sediment, phytoplankton composition and microcystins over all seasons of all water resources were done by Canonical Correspondence Analysis (CCA). This study found that phytoplankton species composition was highly correlated to many environmental factors.

4.4.3.1 CCA for environmental factors of water, phytoplankton species composition and microcystins

Cylindrospermopsis philipinnensis, *Staurodesmus crassus*, *Staurastrum smithii*, *Cosmarium* sp.1, *Staurastrum gracile*, *Peridinium* sp., *Staurastrum manfeldtii*, *Staurastrum chaetoceras* and *Cosmarium* sp.2 were highly positively correlated with Secchi depth, the depth and the water volume in the reservoir of Mae Kuang Udomtara Dam except at the end of the summer. Whereas *Microcystis aeruginosa* was strongly positively correlated with alkalinity, ammonium-nitrogen, BOD_5, chlorophyll-a and microcystins in the fish pond. Nitrate-nitrogen and conductivity were positively correlated with *Oscillatoria* sp.2, *Spirulina platensis* and *Diatomella* sp. in Sakon Nakhon sewage oxidation pond and were positively correlated with *Trachelomonas oblonga* and *Peridiniopsis* sp. 1 at the small pond of Houy Yuak Reservoir in the cool dry season and the summer (Figure 57).

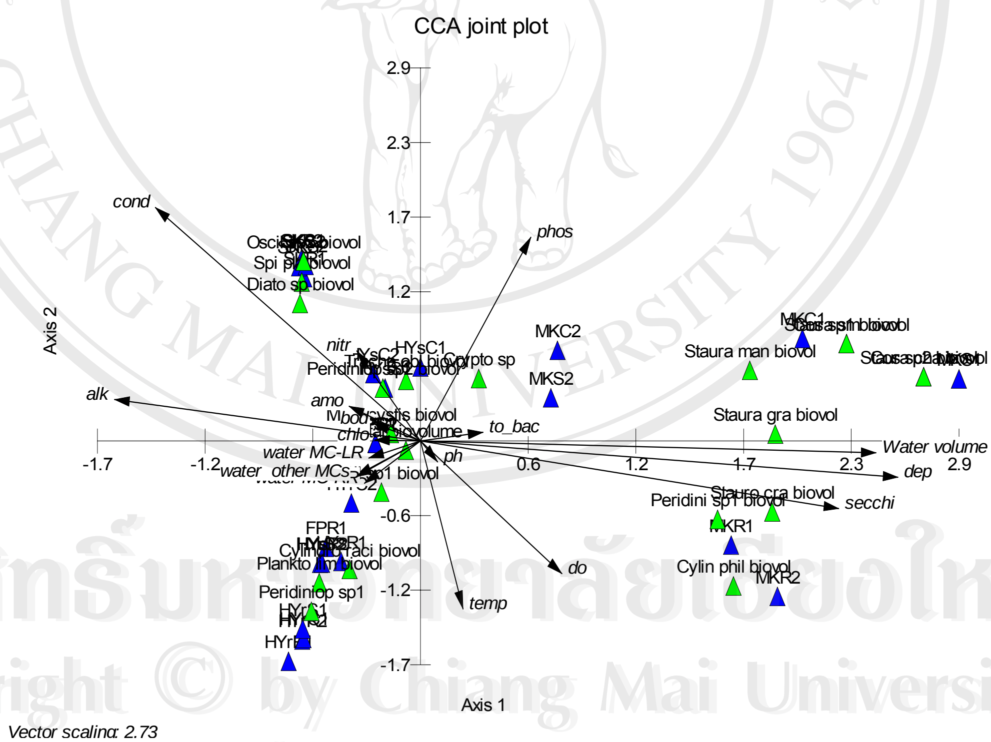


Figure 57 CCA for Environmental factors of water, phytoplankton species

composition and microcystins in five localities in four water resources from the rainy season in August 2003 to the summer in May 2004

4.4.3.2 CCA for Environmental factors of sediment, phytoplankton species composition and microcystins

It was found that the percent sorption of microcystin-LR onto the sediment showed the highly positive correlation with the percent clay and percent organic matter in the sediment. The total microcystin content in the sediment was not clearly correlated with the *Microcystis aeruginosa* biovolume in the water but it showed a positive correlation with the sediment pH value. The nitrate-nitrogen and the ammonium-nitrogen in the sediment strongly positively correlated with the percent silt of sediment and many phytoplankton species, which were *Oscillatoria* sp.1, *Planktolyngbya limnetica*, *Cylindrospermopsis raciborskii* and *Peridiniopsis* sp.1 and were found at both the fish pond and the small pond of Houy Yuak Reservoir in the rainy season and were also found at the open water of Houy Yuak Reservoir during all sampling times. The biovolumes of *Diatomella* sp. *Spirulina platensis* and *Oscillatoria* sp. 2 correlated with percent sand of the sediment at Sakon Nakhon sewage oxidation pond (Figure 58).

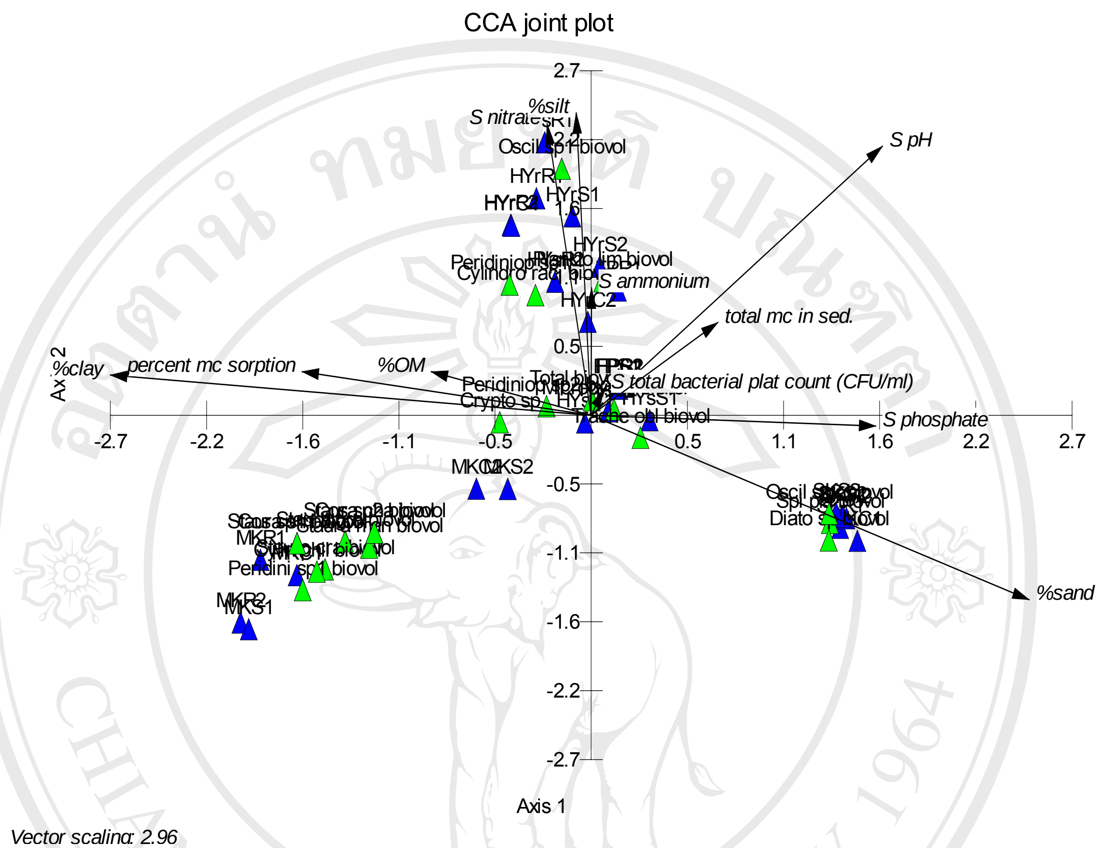


Figure 58 CCA for Environmental factors of sediment, phytoplankton species composition and microcystins in five localities in four water resources from the rainy season in August 2003 to the summer in May 2004

The multiple-correlations between some phytoplankton species and some environmental factors were shown in the Table 6. Also, the multiple-correlations among some environmental factors were shown in the Table 7.

Table 6 The conclusion of multiple-correlations between some phytoplankton species and some environmental factors. (+) represnts the presence of the correlation.

Some environmental factors / Some species	Secchi depth	Depth	Water Volume	Alkalinity	NH_4^+ - N	NO_3^- - N	Conductivity	BOD_5	Chlorophyll-a	% sand	Microcystins
Cylindrospermopsis raciborskii	+	+	+								
Staurodesmus crassus	+	+	+								
Staurastrum smithii	+	+	+								
S. *gracile*	+	+	+								
S. *manfeldtii*	+	+	+								
S. *chaetoceras*	+	+	+								
Cosmarium sp.1	+	+	+								
Cosmarium sp.2	+	+	+								
Peridinium sp.	+	+	+								
Microcystis aeruginosa				+	+			+	+	+	+
Diatomella sp.						+	+			+	
Spirulina platensis						+	+			+	
Oscillatoria sp.2						+	+				
Trachelomonas oblonga						+	+				
Peridiniopsis sp.1						+	+				

Table 7 The conclusion of multiple-correlations among some environmental factors. (+) represnts the presence of the correlation.

Some environmental factors	% clay	% silt	% Organic mater	Sediment pH
% MC-LR sorption	+		+	
Total Microcystins in sediment				+
NO_3^- - N in sediment		+		
NH_4^+- N in sediment		+		