CHAPTER 3

RESULTS

3.1 General characteristics of water quality in the study area

Total arsenic (As)

The total arsenic values in water samples from the six sampling locations were shown in Figure 5. Among the water samples measured, total arsenic values ranged from 0.30±0.01 to 167.85±0.96 μg/L (Appendix B). The highest concentration of total arsenic occurred in April at location 5 and the lowest in October at location 4 (Figure 6). The highest mean value was 84.41±13.95 μg/L for location 5, followed by location 1 (69.31±5.66 μg/L), and the lowest values of 0.92±0.35 μg/L were for location 4. The mean value of total arsenic was the highest in June (62.06±21.03 μg/L), followed by April (50.35±25.79 μg/L) and May (46.17±24.53 μg/L), whilst the lowest mean value was in November (23.39±6.43 μg/L) (Appendix CI). For all sampling locations, it may be observed that locations 1, 3 and 5 had high fluctuation during the sampling periods and obviously showed the highest values during the dry period. The highest value during the dry period was recorded in April at location 5 (167.85±0.96 μg/L), followed by February at location 1 (98.96±0.96 μg/L). The mean values for total arsenic in High Arsenic Contaminated Ponds (HACP) – location 1 (69.31±5.66 μg/L), location 3 (39.06±3.31 μg/L) and location 5 (84.41±13.95 μg/L) were higher than that of the Low Arsenic Contaminated Ponds (LACP) – location 2 (13.64±0.54 μg/L), location 4 (0.92±0.35 μg/L) and location 6 (7.24±0.48 μg/L). In addition, total arsenic values showed high variation in HACP and less in LACP. The HACP values ranged from 19.00±0.03 to 167.85±0.96 μg/L, whilst the LACP values ranged from 0.30±0.01 to 16.08±0.20 μg/L.

Water temperature

Temperature generally showed little variability during the time of sampling. The maximum-minimum values were in the range of 28.3±0.3 to 33.6±0.7 ^{o}C (Appendix B). Of the mean values the highest were in April (33.6±0.7 ^{o}C) and the lowest in December (28.3±0.3 ^{o}C) (Appendix CII). As for observations on seasonal variations the highest values were determined during the dry period, and the lowest in the heavy rainy period (Figure 7).

Light intensity

Light intensity ranged from 466.9±84.2 to 2,002.7±345.6 lux (Appendix B). The mean values of light intensity were also calculated and the sample mean indicated that light intensity was significantly different depending on the season. The light intensity records show discreet seasonal difference, with minimum values during in December (466.9±84.2 lux) and maximum values during in September (2,002.7±345.6 lux) and March (1,747.1±344.9 lux) (Figure 8; Appendix CIII).

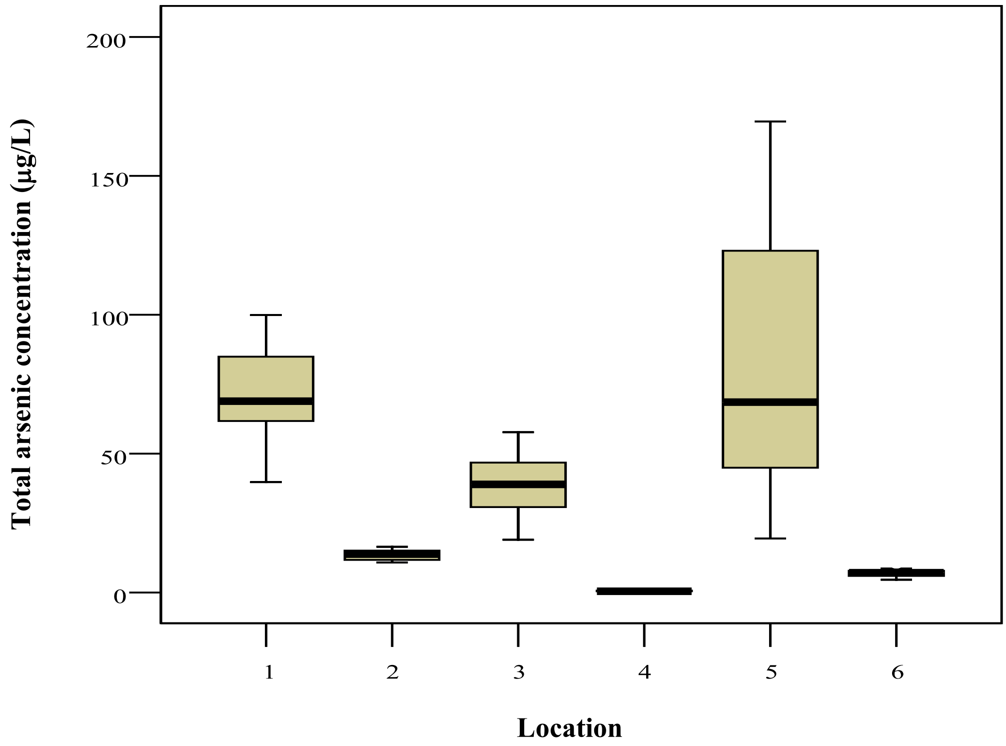


Figure 5. **Boxplot of arsenic concentration presented in sampling locations in the Ron Phibun district of Nakhon Si Thammarat province.**

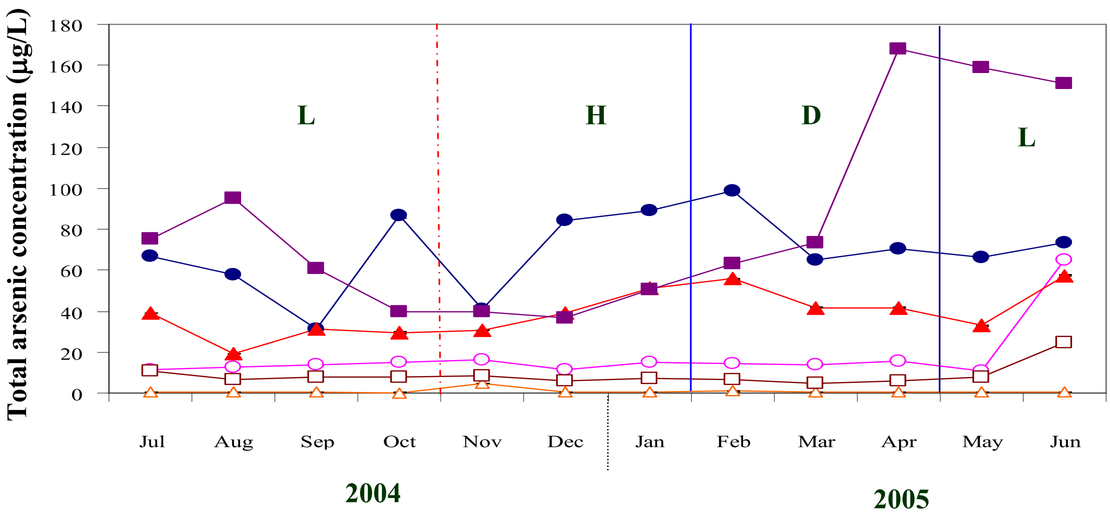


Figure 6. **Temporal patterns of total arsenic (mean ± SE; n=3) from July 2004 to June 2005.**

location 1, location 2, location 3, location 4,

location 5, location 6,

L = light rainy period, H = heavy rainy period, D = dry period.

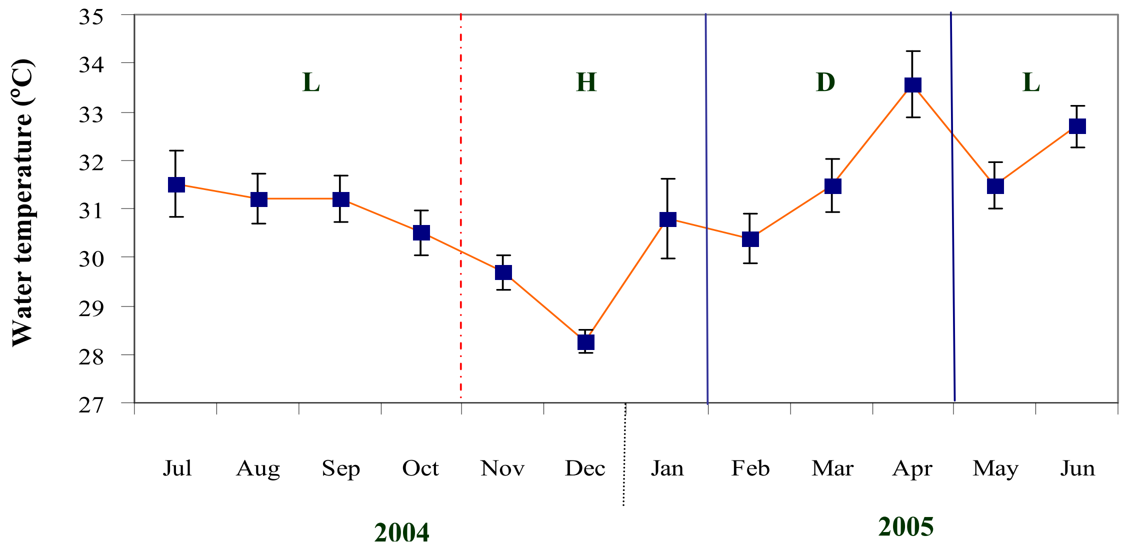


Figure 7. Temporal patterns of water temperature (mean ± SE; n=6) from July 2004 to June 2005.

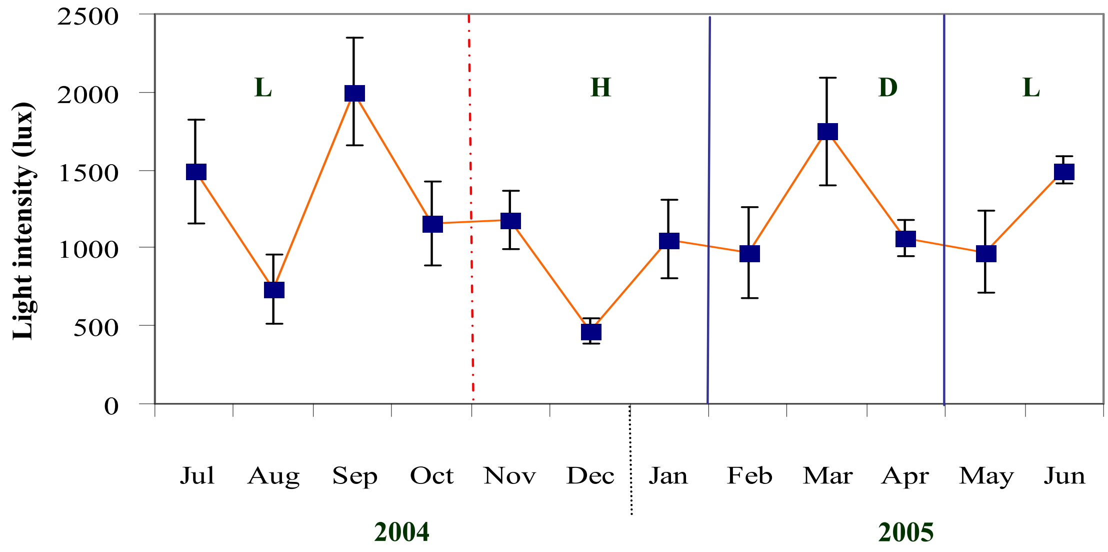


Figure 8. Temporal patterns of light intensity (mean ± SE; n=6) from July 2004 to June 2005. mean values for all sampling locations, L = light rainy period, H = heavy rainy period, D = dry period.

Conductivity

The conductivity of water varied from 21.17±0.32 to 275.80±1.65 µS/cm (Appendix B). The lowest conductivity value was detected in January at location 2, whilst the highest conductivity was in June at location 6. The mean conductivity values at locations 5 (140.28±16.08 µS/cm) and 6 (183.10±18.99 µS/cm) were significantly higher than at the other locations. June and May fall in the light rainy period when conductivity values are high. The mean values in June and May were 141.39±32.48 and 126.97±34.44 µS/cm, respectively. The conductivity values showed high variability in locations 5 and 6. They ranged from 84.50±14.25 to 214.40±0.30 µS/cm with a mean value of 141.59±16.08 µS/cm and 119.13±0.73 to 275.80±1.65 µS/cm with a mean value of 185.15±18.99 µS/cm for locations 5 and 6, respectively. The observed conductivity values in locations 3 and 4 showed moderate changes. They ranged from 46.73±1.15 to 114.50±1.95 µS/cm with a mean value of 67.34±7.30 µS/cm and 38.10±0.70 to 89.33±0.90 µS/cm with a mean value of 57.71±5.58 µS/cm for locations 3 and 4, respectively. In addition, the conductivity of location 2 was the lowest and demonstrated little fluctuation, ranging from 21.17±0.32 to 50.50±1.19 µS/cm, with the mean recorded at 29.61±2.94 µS/cm (Figure 9; Appendix CIV).

pH

The pH values varied greatly from 4.32±0.12 to 8.28±0.13 (Appendix B). The lowest pH value was detected in April at location 2, whilst the highest pH value was in March at location 3. The mean pH value at location 2 (6.00±0.32) was lower than the others, whereas at location 6 the mean pH (6.67±0.28) was higher than the others. The highest mean pH levels were in March (7.86±0.12), followed by July (7.37±0.24) and the lowest in April and May (5.40±0.36 and 5.40±0.20, respectively). The changes in pH values were difficult to explain and were not totally dependent upon seasonal changes. Additionally, pH values generally had a similar pattern in all locations during the sampling period. They ranged from 5.19±0.43 to 7.60±0.21 for location 1, 4.32±0.13 to 7.88±0.12 for location 2, 4.43±0.05 to 8.28±0.13 for location 3, 4.79±0.13 to 8.05±0.10 for location 4, 5.21±0.03 to 8.10±0.08 for location 5 and 5.33±0.04 to

8.02±0.18 for location 6. The mean values for those sampling locations were 6.37±0.23, 6.00±0.32, 6.24±0.33, 6.10±0.24, 6.66±0.26, 6.67±0.28, respectively (Figure 10; Appendix CV).

Dissolved Oxygen (DO)

DO ranged from 2.02±0.55 to 7.86±0.39 mg/L (Appendix B). It was least in December at location 1, and highest in September at location 6. Values at location 4 were generally slightly higher than at the other locations, and the mean value at location 4 was 6.13±0.2 mg/L. The overall mean value of DO was highest in September (7.19±0.22 mg/L), and lowest in April (4.66±0.38 mg/L). DO levels can changed dramatically and appear not to be affected by seasonal changes. DO concentrations in water at different sampling locations during different periods of time appear to be variable. They ranged from 2.02±0.55 to 6.67±0.46 mg/L for location 1, 3.67±1.71 to 7.56±0.10 mg/L for location 2, 3.20±0.42 to 6.91±0.65 mg/L for location 3, 4.98±0.62 to 7.38±0.17 mg/L for location 4, 4.03±0.40 to 7.30±0.17 mg/L for location 5 and 4.50±0.14 to 7.86±0.40 mg/L for location 6. The mean values for those sampling locations were 4.56±0.42 mg/L, 5.97±0.33 mg/L, 5.17±0.32 mg/L, 6.13±0.20 mg/L, 5.68±0.33 mg/L, 5.70±0.30 mg/L, respectively (Appendix CVI). From these observations, it seems that the surface waters were normally saturated with oxygen (> 4 mg/L), except during July and December at location 1 when measurements showed a slightly lower value (Figure 11).

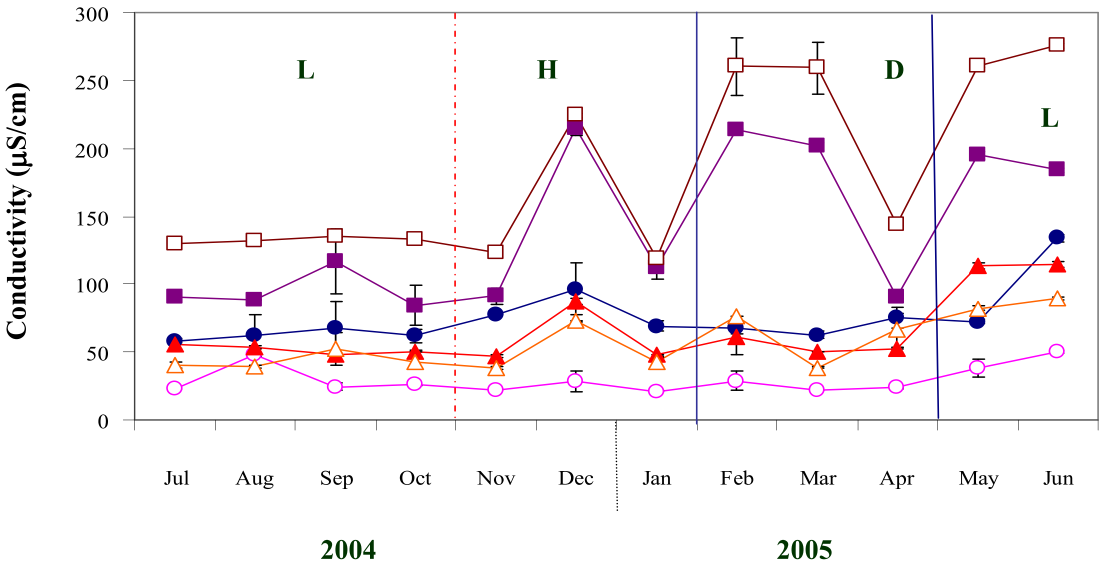


Figure 9. Temporal patterns of conductivity (mean ± SE; n=3) from July 2004 to June 2005.

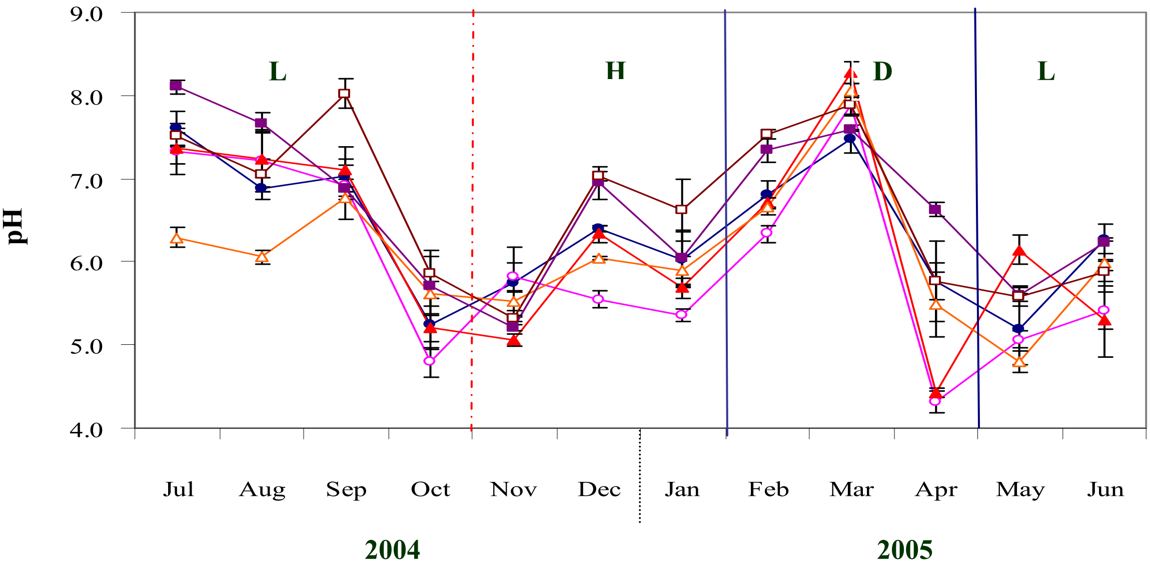


Figure 10. Temporal patterns of pH (mean ± SE; n=3) from July 2004 to June 2005.

location 1, location 2, location 3, location 4,

location 5, location 6,

L = light rainy period, H = heavy rainy period, D = dry period.

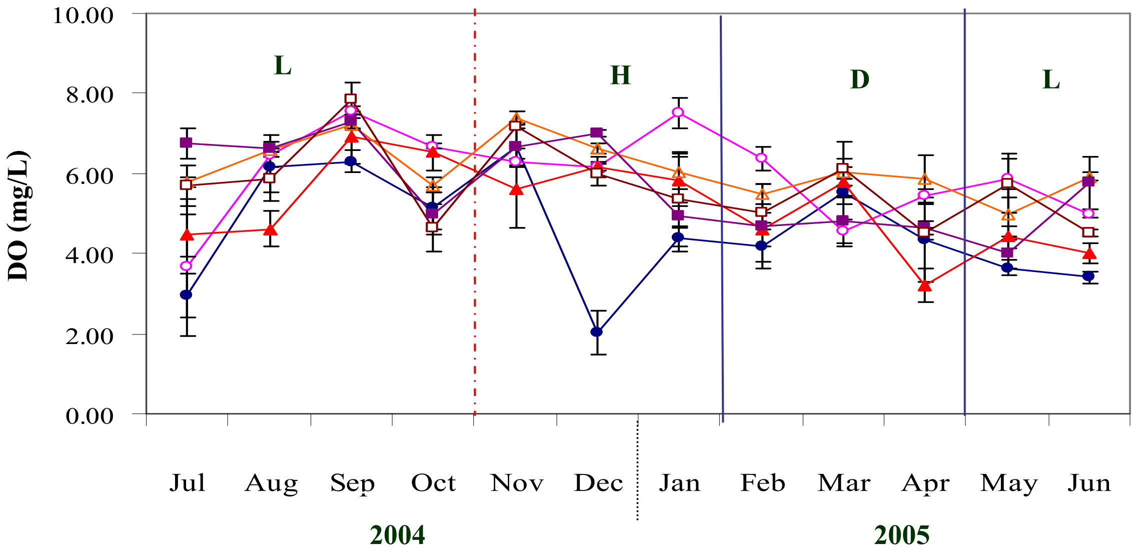


Figure 11. Temporal patterns of Dissolved Oxygen (DO) (mean ± SE; n=3) from July 2004 to June 2005.

location 1, location 2, location 3, location 4,

location 5, location 6,

L = light rainy period, H = heavy rainy period, D = dry period.

Total Suspended Solids (TSS)

TSS values ranged from 1.5 to 296.5 mg/L (Appendix B). Location 5 had a high concentration in October (296.5 mg/L) and November (236.3 mg/L). A low value of 1.5 mg/L was recorded on January at location 4. The mean value of location 5 was the highest (75.4 mg/L), and this was in contrast with other locations where the means were low: 6.6, 7.1, 10.4, 2.9, 9.5 mg/L at locations 1, 2, 3, 4, 6, respectively. The mean value of TSS was highest in October (55.3 mg/L), and lowest in February (6.2 mg/L) (Appendix CVII). TSS values at the sampling locations were generally low during the study period, except at location 5 which was distinctly different to the other locations. TSS values in location 5 generally increased during the rainy periods (both in the light rainy period and the heavy rainy period), whereas there was no differences in TSS values at the other locations during the changes in season. They ranged from 11 to 296.5 mg/L, with a mean value of 75.4±30.0 mg/L for location 5, and 1.5 to 22.1 mg/L, with a mean value of 7.3±0.6 mg/L for the remaining sampling locations (Figure 12).

Biochemical Oxygen Demand (BOD_5)

Maximum-minimum values of BOD_5 were in the range of 3.36 to 5.18 mg/L (Appendix B), respectively. The results showed that the BOD_5 values were highest in May at location 6, and lowest in April at location 4. The highest mean BOD_5 value was at location 3 (2.32 mg/L), whilst location 5 had the lowest mean value (1.77 mg/L). In addition, the mean reached its highest value in May (3.57 mg/L), followed by September (2.58 mg/L) and July (2.51 mg/L), respectively. BOD_5 concentrations tended to increase during May at all sampling locations, and decreased again in June, whereas values in other months seem to have no consistency. BOD_5 values generally showed little variability in space and time. They ranged from 0.90 to 3.36 mg/L for location 1, 0.63 to 3.48 mg/L for location 2, 0.70 to 3.84 mg/L for location 3, 0.20 to 3.39 mg/L for location 4, 0.40 to 3.61 mg/L for location 5 and 0.63 to 5.18 mg/L for location 6. The mean values for those sampling locations were 2.18±0.24, 1.80±0.26, 2.32±0.25, 2.06±0.27, 1.77±0.32 and 2.07±0.34 mg/L, respectively (Figure 13; Appendix CVIII).

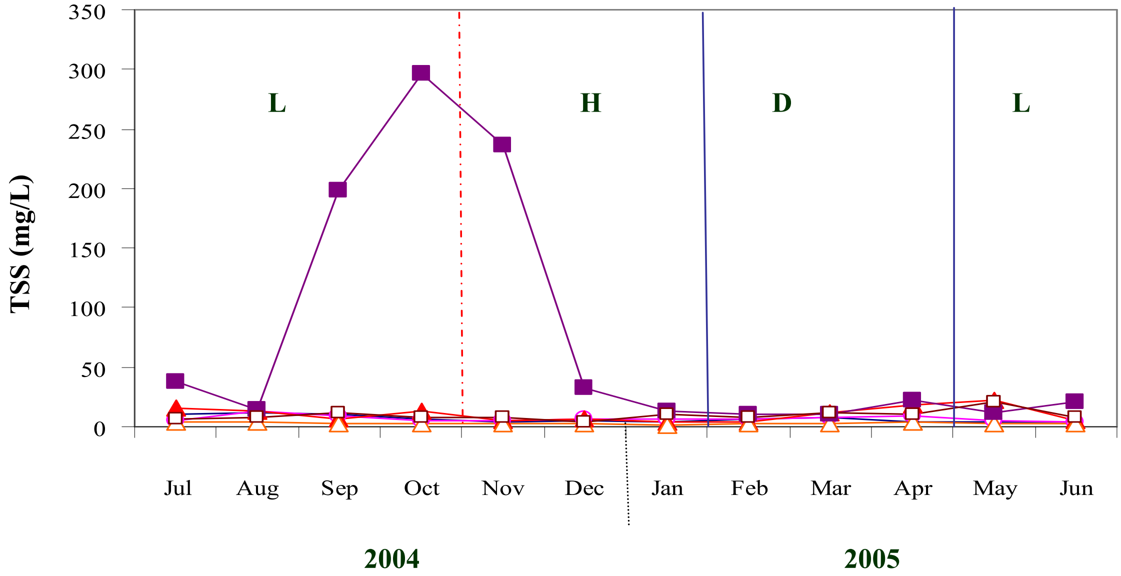


Figure 12. Temporal patterns of Total Suspended Solids (TSS) (mean ± SE; n=3) from July 2004 to June 2005.

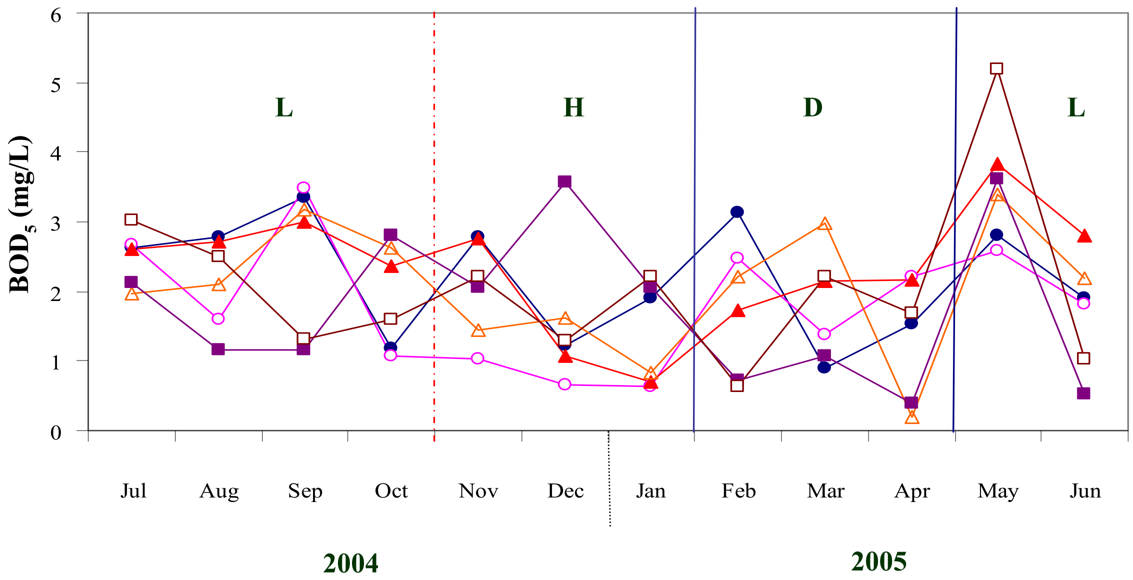


Figure 13. Temporal patterns of Biochemical Oxygen Demand (BOD_5) (mean ± SE; n=3) from July 2004 to June 2005.

location 1, location 2, location 3, location 4,

location 5, location 6,

L = light rainy period, H = heavy rainy period, D = dry period.

Nitrogen

Concentrations of nitrite-nitrogen were always below the detection level of the method used (0.01 mg NO_2^--N/L).

Nitrate-nitrogen concentrations ranged from 0.01±0.000 to 0.24±0.001 mg NO_3^--N/L (Appendix B). The highest value was found in February at location 6. At location 1 values were higher than at the other locations with a mean of 0.08±0.02 mg NO_3^--N/L. The overall mean values of nitrate-nitrogen were highest in February (0.12±0.03 mg NO_3^--N/L), followed by June (0.11±0.03 mg NO_3^--N/L), and lowest in November and December (0.01±0.002 and 0.01±0.005 mg NO_3^--N/L, respectively) (Appendix CIX). The lowest values were generally found during the heavy rainy period (December 2004 to January 2005), except for location 1(Figure 14).

Ammonia-nitrogen concentrations were always low ranging from undetectable values to 0.09±0.005 mg NH_3-N/L (Appendix B). The highest concentration was found in July at location 6, whereas in some months, at all sampling locations, ammonia-nitrogen was below the detectable level. At location 1, ammonia-nitrogen concentrations were higher than at the other locations with a mean value of 0.03±0.01 mg NH_3-N/L. It was also shown that the mean value of ammonia-nitrogen was highest in December (0.06±0.006 mg NH_3-N/L), followed by July (0.04±0.016 mg NH_3-N/L) (Appendix CX). In this study, ammonia-nitrogen levels were slightly higher than those of nitrate-nitrogen. The ammonia-nitrogen tended to be higher in all sampling locations during the heavy rainy period (December), however, nitrate-nitrogen were generally low in December and increased markedly in February (Figure 15).

Overall, nitrate-nitrogen and ammonia-nitrogen are varied from time to time but not obviously from location to location. Nitrate-nitrogen ranged from 0.01±0 to 0.23±0.001, 0.01±0.001 to 0.07±0.001, 0.01±0.000 to 0.12±0.002, 0.01±0.000 to 0.08±0.001, 0.01±0.000 to 0.20±0.003 and 0.01±0.000 to 0.24±0.002 mg NO_3^--N/L for locations 1, 2, 3, 4, 5 and 6, respectively. The mean nitrate-nitrogen values for those sampling locations were 0.08±0.02, 0.04±0.01, 0.05±0.01, 0.04±0.01, 0.06±0.02 and 0.06±0.02 mg NO_3^--N/L, respectively. Additionally, ammonia-nitrogen ranged from 0 to 0.08±0.001 mg NH_3-N/L for location 1, 0 to 0.06±0.001 mg NH_3-N/L for location 2, 0 to 0.06±0.001 mg NH_3-N/L for location 3, 0 to 0.05±0.000 mg NH_3-N/L for location 4, 0 to 0.08±0.001 mg NH_3-N/L for location 5 and 0 to

0.09±0.005 mg NH_3-N/L for location 6. The mean ammonia-nitrogen values for those sampling locations were 0.03±0.01, 0.81±0.01, 0.02±0.01, 0.01±0.00, 0.02±0.01 and 0.02±0.01 mg NH_3-N/L, respectively.

Dissolved phosphorus (PO_4^{3-}-P)

Dissolved phosphorus levels ranged from 0.01±0.000 to 0.24±0.001 mg PO_4^{3-}-P/L (Appendix B). The highest value was found in May at location 5, whereas the lowest values were found in almost all months at location 4 and in some months at locations 2, 5, and 6. Maximum and minimum values of the means were 0.04±0.002, 0.04±0.008 at locations 1 and 5, and 0.01±0.001 mg PO_4^{3-}-P/L at locations 4 and 6, respectively. It was also found that the mean of dissolved phosphorus was the highest in October and May (0.04±0.01 and 0.04±0.01 mg PO_4^{3-}-P/L, respectively), followed by September and March (0.03±0.01 and 0.03±0.01 mg PO_4^{3-}-P/L, respectively) and the lowest values were in July, August, November, December, January, February, April and June (0.02±0.01, 0.02±0.01, 0.02±0.00, 0.02±0.01 0.02±0.01, 0.02±0.01, 0.02±0.01, 0.02±0.00 mg PO_4^{3-}-P/L, respectively). Dissolved phosphorus concentrations changed seasonally at all sampling locations, except location 4. They also tended to increase during the rainy periods (mainly in October and December) (Figure 16).

Of all the sampling locations, location 4 had the lowest dissolved phosphorus values (0.01±0.000 mg PO_4^{3-}-P/L) at all times. Dissolved phosphorus ranged from 0.03±0.001 to 0.06±0.001 mg PO_4^{3-}-P/L for location 1, 0.01±0.000 to 0.03±0.000 mg PO_4^{3-}-P/L for location 2, 0.02±0.001 to 0.05±0.000 mg PO_4^{3-}-P/L for location 3, 0.01±0.000 to 0.10±0.000 mg PO_4^{3-}-P/L for location 5 and 0.01±0 to 0.02±0.002 mg PO_4^{3-}-P/L for location 6. The mean values for those sampling locations were 0.04±0.002, 0.02±0.002, 0.03±0.003, 0.04±0.008 and 0.01±0.001 mg PO_4^{3-}-P/L, respectively (Appendix CXI).

Chlorophyll *a*

Chlorophyll *a* levels were highly variable during the study period ranging between 1.0 ± 0.9 and 71.0 ± 1.0 μg/L (Appendix B), and achieving a maximum value in July at location 3. The lowest value was present in May at location 5 at the time when total suspended solids at that location were at its highest value. The highest mean value of chlorophyll *a* concentrations was 28.3 ± 5.3 μg/L at location 3, whilst the lowest mean value was 4.4 ± 0.6 μg/L at location 4. July had the highest mean value of chlorophyll *a* concentrations at 29.1 ± 11.7 μg/L, and February the lowest mean value of chlorophyll *a* (8.7 ± 2.3 μg/L). Significant levels of chlorophyll *a* were found in locations 1, 2, 3 and 6 (the average values were 21.9 ± 5.3, 10.8 ± 1.1, 28.3 ± 5.3, 23.3 ± 2.5 μg/L respectively). Whereas, the average values in locations 4 and 5 were 5.4 ± 0.6, 4.4 ± 0.9 μg/L respectively. In general, chlorophyll *a* concentrations were relatively low and seemed to follow a similar pattern to the number and density of the phytoplankton during the heavy rainy period (November and December).

For chlorophyll *a* values, locations 1 and 3 varied significantly more than other locations. They ranged from 3.7 ± 0.9 to 58.7 ± 3.8 μg/L with a mean value of 21.9 ± 5.3 μg/L for location 1 and 3.0 ± 0.6 to 71.0 ± 1.0 μg/L with a mean value of 28.3 ± 5.3 μg/L for location 3. Whereas, the chlorophyll *a* of location 2 ranged from 5.0 ± 0 to 17.0 ± 2.5 μg/L, location 4 ranged from 2.0 ± 0.7 to 8.0 ± 0.0 μg/L, location 5 ranged from 1.0 ± 0.0 to 11.3 ± 1.5 μg/L and location 6 ranged from 11.3 ± 0.3 to 39.0 ± 1 μg/L. The mean values of the remaining locations were 10.8 ± 1.1, 4.4 ± 0.6, 5.4 ± 0.9 and 23.3 ± 2.5 μg/L, respectively (Figure 17; Appendix CXII).

Referring to the methods modified by the Applied Algal Research Laboratory, Chiang Mai University (Peerapornpisal *et al.*, 2004), by altering the amounts of DO, BOD, conductivity, nitrate-nitrogen, ammonia-nitrogen, dissolved phosphorus and chlorophyll *a* (Appendix D), all sampling locations seem to have a similar limnological behaviour. According to the magnitude of those parameters, locations 3 and 5 can be classified as having oligo-mesotrophic status, whilst other locations showed some differences in water quality at some sampling periods (Table 3).

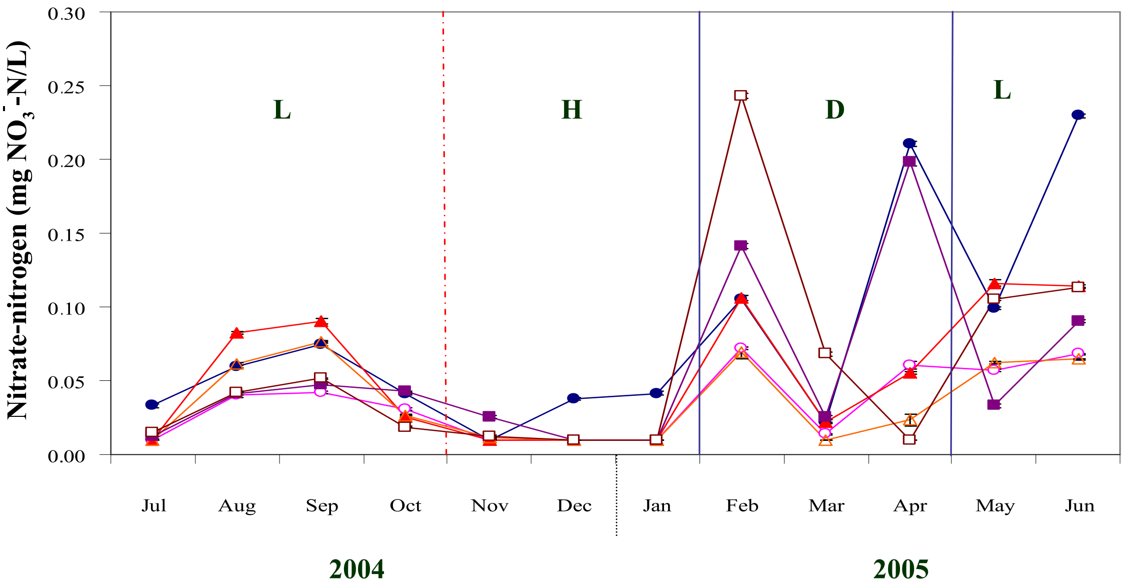


Figure 14. Temporal patterns of nitrate-nitrogen (NO_3^--N) (mean ± SE; n=3) from July 2004 to June 2005.

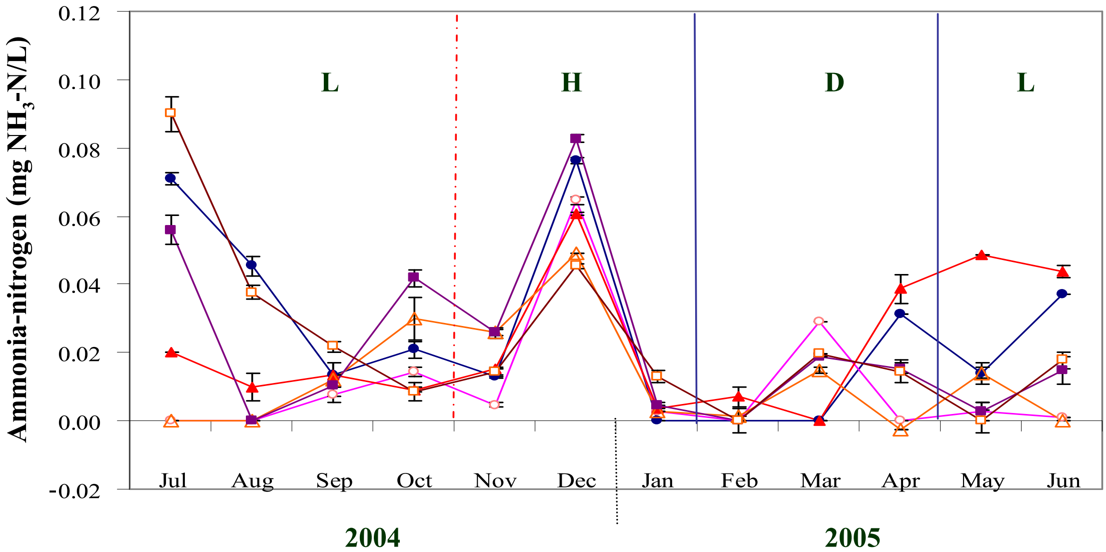


Figure 15. Temporal patterns of ammonia-nitrogen (NH_3-N) (mean ± SE; n=3) from July 2004 to June 2005.

location 1, location 2, location 3, location 4,

location 5, location 6,

L = light rainy period, H = heavy rainy period, D = dry period.

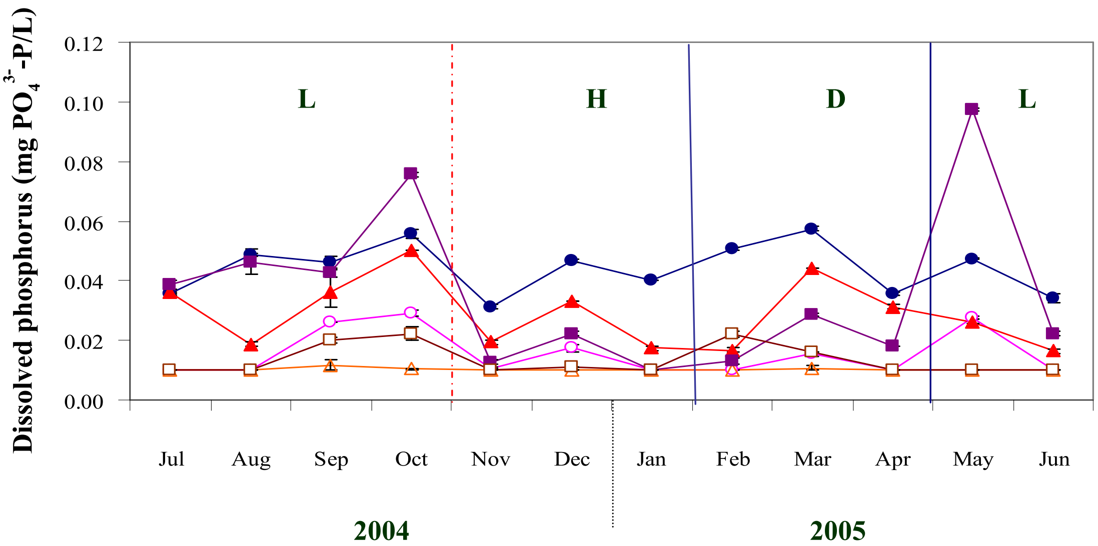


Figure 16. **Temporal patterns of dissolved phosphorus (PO_4^{3-}-P) (mean ± SE; n=3) from July 2004 to June 2005.**

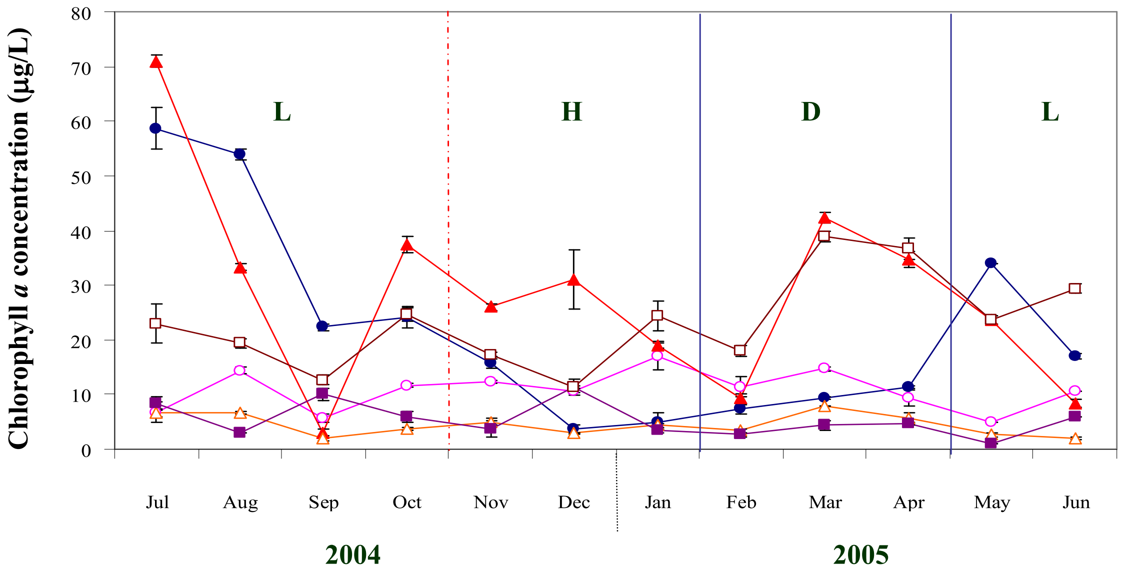


Figure 17. **Temporal patterns of chlorophyll *a* (mean ± SE; n=3) from July 2004 to June 2005.**

location 1, location 2, location 3, location 4,

location 5, location 6,

L = light rainy period, H = heavy rainy period, D = dry period.

Table 3. Water quality status of sampling locations in arsenic contaminated waters determined from July 2004 to June 2005.

Months	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6
July	Mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic
August	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic
September	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic
October	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic
November	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligotrophic	Oligo-mesotrophic	Oligo-mesotrophic
December	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic
January	Oligo-mesotrophic	Oligotrophic	Oligo-mesotrophic	Oligotrophic	Oligo-mesotrophic	Oligo-mesotrophic
February	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic
March	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Mesotrophic
April	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligotrophic	Oligo-mesotrophic	Oligo-mesotrophic
May	Mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Mesotrophic
June	Mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Mesotrophic

3.2 Species composition and diversity of phytoplankton in arsenic contaminated waters

During these investigations, the composition of phytoplankton showed a remarkable diversity. A total of seventy-eight genera of phytoplankton were identified. Of the taxa, Chlorophyceae was the largest group with 40 genera, followed by Cyanophyceae (18 genera), Bacillariophyceae (11 genera), Euglenophyceae (4 genera), Chrysophyceae (3 genera) and Pyrrophyceae (2 genera). A floristic list is given in Table 4. The Chlorophyceae comprised of 51.3 % (Figure 18) of the total taxa, followed by the Cyanophyceae 23.1 %, Bacillariophyceae 14.1 %, Euglenophyceae 5.1 %, Chrysophyceae 3.8 % and Pyrrophyceae 2.6 %. Comparison of the genera number of the phytoplankton flora between High Arsenic Contaminated Ponds (HACP) and Low Arsenic Contaminated Ponds (LACP) revealed little differences. The number of genera in the former was 75 and the latter was 72 genera (Figure 19). The highest number of taxa (64) was recorded in location 1, whereas locations 5 and 6 had the lowest number of taxa (54) (Figure 20).

Obviously, a decrease of phytoplankton species diversity observed in this study was correlated with rain intensity (Figure 21). Chlorophytes and cyanophytes were found mainly in phytoplankton assemblage and their genera number decreased during the heavy rainy period (November to December 2004) (Figures 22-23). During the heavy rainy period, the chlorophytes constituted the richest with 27 genera or 45.8 % of the total genera number. Thirteen genera of cyanophytes were found, constituting around 22.0 % of the total genera number. In the dry period, 17 genera of cyanophytes and 29 genera of chlorophytes were identified adding up to around 25.8 % and 43.9 % of the total genera number, respectively. The number of chlorophyte genera increased remarkably during the light rainy period (40 genera), estimated at 55.6 % of the total genera number, whilst genera number of cyanophytes (13 genera) increased only slightly, estimated at 18.1 % of the total genera number (Table 5 and Figures 24a, b and c).

Table 4. Spatial and temporal occurrence of taxa registered from sampling locations in the arsenic contaminated waters from July 2004 to June 2005 : Jan=January, Feb=Febuary, Mar=March, Apr=April, May=May, Jun=June, Jul=July, Aug=August, Sep=September, Oct=October, Nov=November, Dec=December, HACP=high arsenic contaminated ponds, LACP=low arsenic contaminated ponds, exc=except.

	Spatial occurrence		Temporal occurrence
	HACP	LACP	
Division Cyanophyta			
Anabaena spp.	1,3,5	2,4,6	All months exc Mar, May
Anabaenopsis sp.	5	4,6	Jul, Aug, Feb, Apr, May, Jun
Anacystis sp.	-	6	Jul
Aphanocapsa sp.	1,3	2,4,6	All months exc Nov, Dec, May
Calothrix sp.	5	2	Apr, May
Chroococcus spp.	1,3,5	2,4,6	All months
Cylindrospermopsis sp.	1,3,5	2,4,6	All months exc Dec
Cylindrospermum sp.	1,3,5	2,4,6	All months exc Dec
Gloeocapsa sp.	1,3,5	2,4,6	All months
Microcystis spp.	1,3,5	2,4,6	All months
Merismopedia spp.	1,3,5	2,4,6	All months
Oscillatoria spp.	1,3,5	2,4,6	All months
Phormidium spp.	1,3,5	2,4,6	All months
Raphidiopsis sp.	1,3,5	2,4,6	All months exc Sep, Nov, Dec
Spirulina sp.	1,3	2,6	Oct, Dec, Jan, Feb, Mar, Apr, Jun
Synechococcus sp.	1	6	Mar, May
Tolypothrix sp.	1,5	6	Mar, Apr, May
Trichodesmium sp.	1,3,5	-	Oct, Dec, Feb, Mar, May
Division Chlorophyta			
Ankistrodesmus spp.	1,3,5	2,4,6	All months
Botryococcus sp.	3,5	2,4	All months exc Jul, Dec, May, Jun
Chlorella sp.	1,3,5	2,4,6	All months
Chlorococcum sp.	1,5	2,4,6	Jul, Sep, Oct, Nov, Jan, Apr
Chodatella sp.	1	4	Jul, May
Clamydomonas sp.	1	6	Jul
Closterium sp.	1,3,5	2,4,6	All months exc Jul, Aug, Dec
Coelastrum spp.	1,3,5	2,6	All months

Table 4. (continued)

Cosmarium spp.	1,3,5	2,4,6	All months
Crucigenia spp.	1,3,5	2,4,6	All months
Crucigeniella sp.	1,3	2,4	Oct, Nov, Jan, Feb, Mar, Apr, May, Jun
Cylindrocystis sp.	1	2,4,6	Sep, Jan, Feb, May, Jun
Dictyosphaerium sp.	1,3	4	Jul, Dec, Apr, May
Elakatothrix sp.	-	4	Aug, Feb
Euastrum spp.	1	2,6	All months exc Aug, Apr, May
Eudorina sp.	1,5	6	Feb, Mar
Gloeocystis sp.	3,5	2,4,6	Sep, Jan, Feb, Mar, Apr, May, Jun
Golenkinia sp.	1,3,5	2,4,6	All months
Gonatozygon sp.	1	4	Jan, May, Jun
Micractinium sp.	1,3	2,4	Oct, Feb, Jun
Monoraphidium spp.	1,3,5	2,4,6	All months
Mougeotia spp.	1,3,5	2,6	All months exc Jul, Oct, Jan
Nephrocytium sp.	3	-	Jul
Netrium sp.	5	-	Sep, May
Oedogonium spp.	1,3,5	2,4,6	All months exc Oct
Oocystis spp.	1,3,5	2,4,6	Jul, Aug, Sep, Oct, Feb, Apr, May, Jun
Pandorina spp.	1,3	2	Jul, Mar, Apr, Jun
Pediastrum spp.	1	2,4,6	All months exc Feb, May
Penium sp.	1,5	-	Jul
Phaeodactylum sp.	1	2,6	Aug, Sep, Jun
Scenedesmus spp.	1,3,5	2,4,6	All months
Spirogyra sp.	1,3	2	Nov, Jan, Feb, Mar, Apr, May
Spirotaenia sp.	1	-	Jul, Sep
Staurastrum spp.	1,3,5	2,4,6	All months
Staurodesmus spp.	1,5	2,4,6	Jul, Aug, Sep, Nov, Dec, Jun
Tetraedron spp.	1,3,5	2,4,6	All months
Tetralantos sp.	1	2,4	Oct, Nov, Jan
Treubaria sp.	3	4	Mar, Jun
Ulothrix sp.	1	-	Jul
Zygnema spp.	1,3,5	2,4	Aug, Sep, Jan, Feb, Apr, May, Jun
Division Pyrrophyta			
Ceratium sp.	5	2,4,6	All months
Peridinium spp.	1,3,5	2,4,6	All months

Table 4. (continued)

Division Bacillariophyta			
Caloneis sp.	-	2,4,6	Sep, Dec, Jan, Feb, May, Jun
Cymbella sp.	1,3	2	Nov, Dec, Mar, Apr
Diatomella sp.	1,3,5	2,4,6	Jul, Aug, Sep, Jan, Feb, Mar, May
Fragilaria sp.	1,3,5	2,4,6	All months
Gomphonema spp.	1,3,5	2,4,6	All months
Gyrosigma sp./*Pleurosigma* sp.	5	2	Sep, Oct, Mar
Navicula spp.	1,3,5	2,4,6	All months
Nitzchia spp.	1,3,5	2,4,6	All months
Pinnularia sp.	1,3,5	2,4,6	All months exc Aug, Jun
Surirella spp.	1,3,5	2,4	All months exc Nov, Jan
Synedra sp.	3,5	2,4	Aug, Sep, Dec, Feb, Mar
Division Euglenophyta			
Euglena spp.	1,3,5	2,4,6	All months
Lepocinclis sp.	1,3,5	2,4,6	All months exc Nov
Phacus spp.	1,3,5	2,4,6	All months
Trachelomonas spp.	1,3,5	2,4,6	All months
Division Chrysophyta			
Centritractus sp.	1,3,5	2	All months exc Jul, Oct
Dinobryon spp.	1,3,5	2,4,6	All months
Isthmochloron sp.	1,3,5	2,4,6	All months

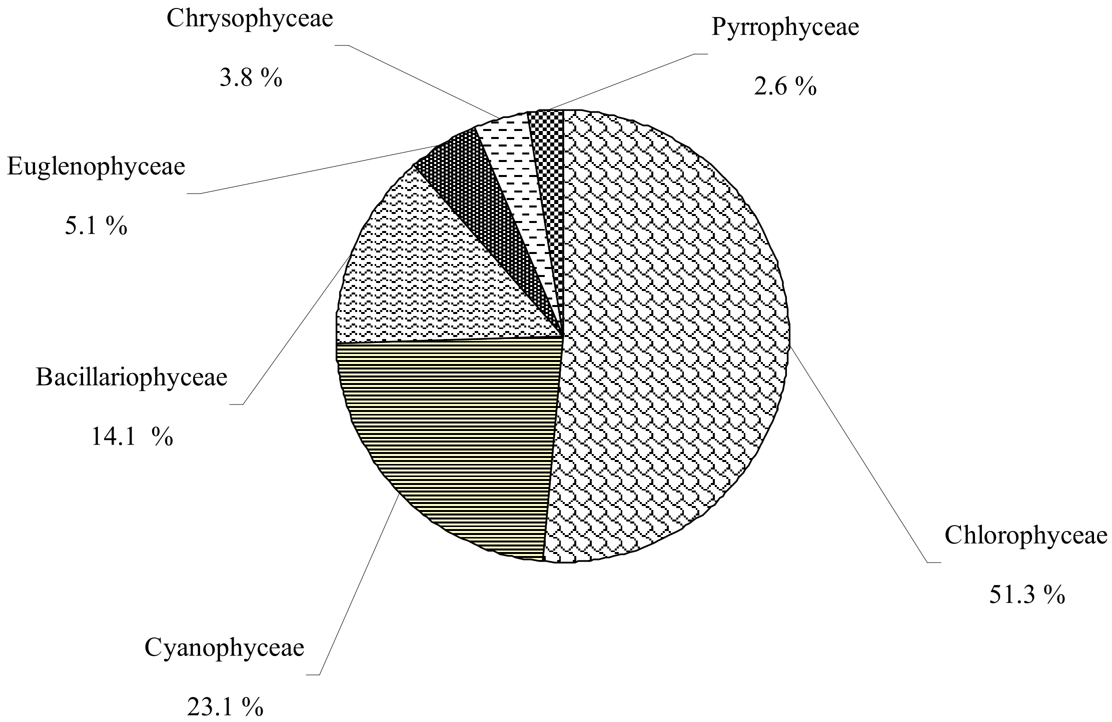


Figure 18. The percentage of the genera numbers of phytoplankton in each class detected in six water ponds designated as arsenic contaminated waters in the Ron Phibun district of Nakhon Si Thammarat province, Thailand.

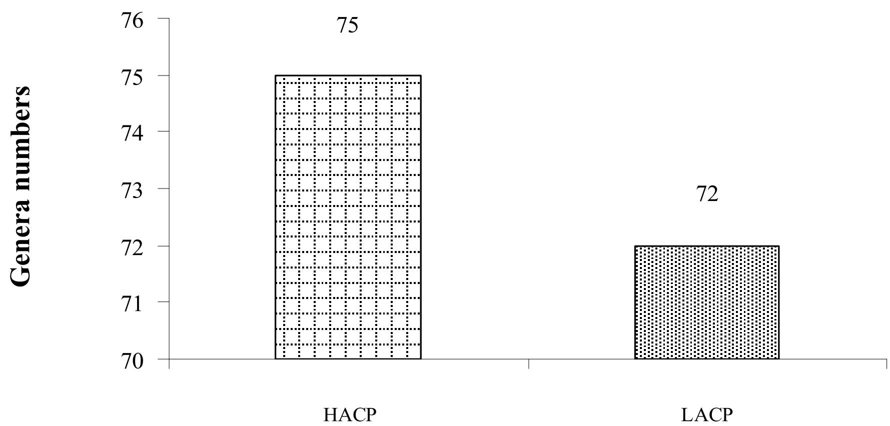


Figure 19. Phytoplankton genera numbers in HACP and LACP waters in the Ron Phibun district of Nakhon Si Thammarat province, Thailand. HACP = high arsenic contaminated ponds, LACP = low arsenic contaminated ponds.

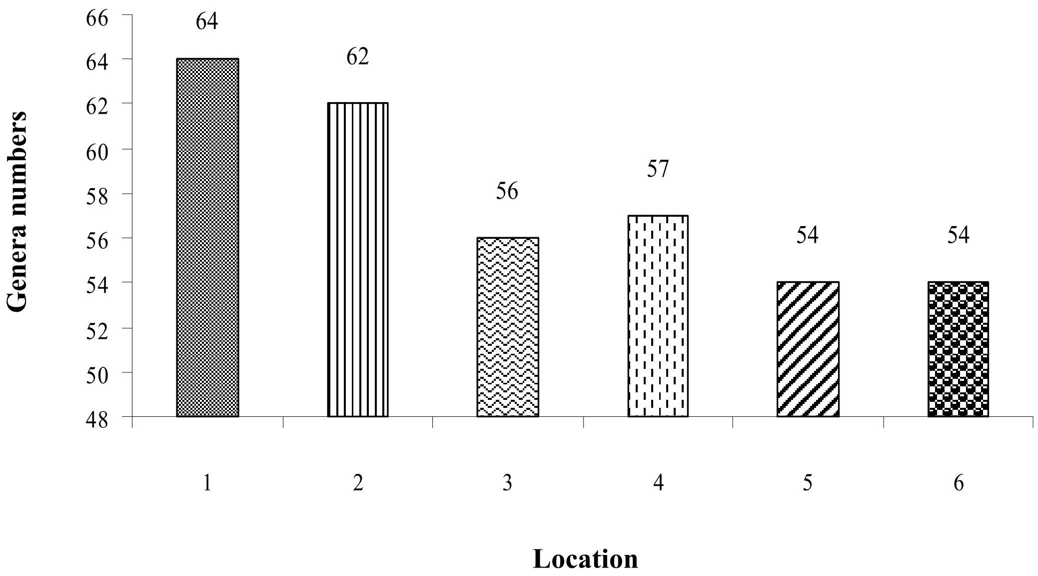


Figure 20. Genera numbers of phytoplankton communities in each arsenic contaminated water pond in the Ron Phibun district of Nakhon Si Thammarat province, Thailand.

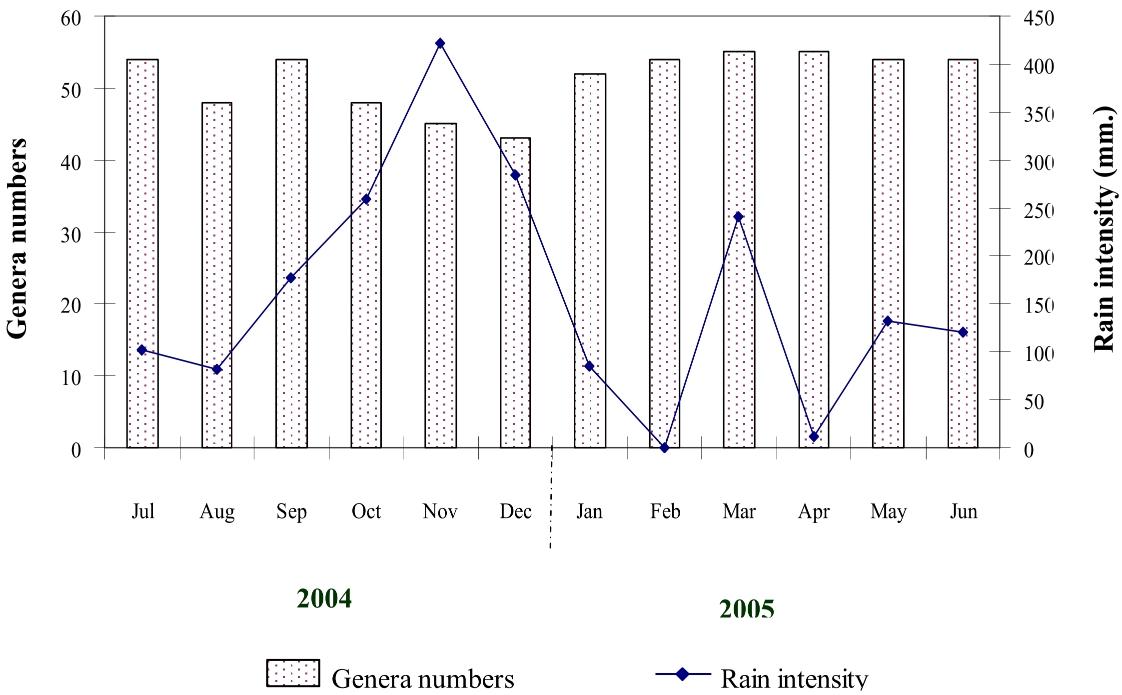


Figure 21. Seasonal occurrence of genera numbers of phytoplankton communities in six arsenic contaminated sampling ponds in the Ron Phibun district of Nakhon Si Thammarat province, Thailand.

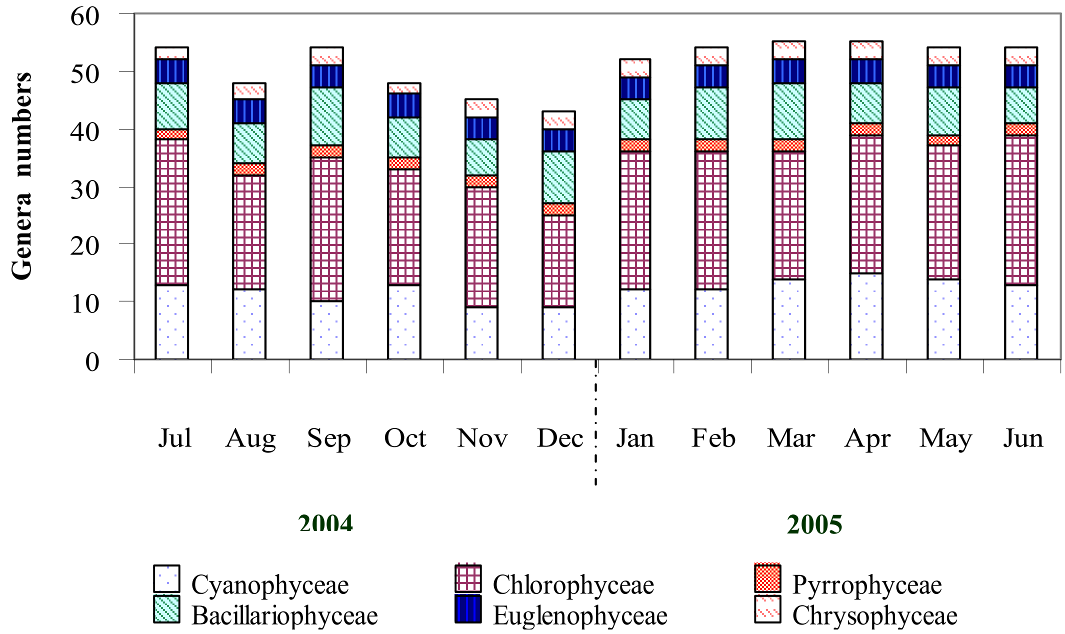


Figure 22. Genera numbers in each class of six water ponds in arsenic contaminated waters in the Ron Phibun district of Nakhon Si Thammarat province, Thailand from July 2004 to June 2005.

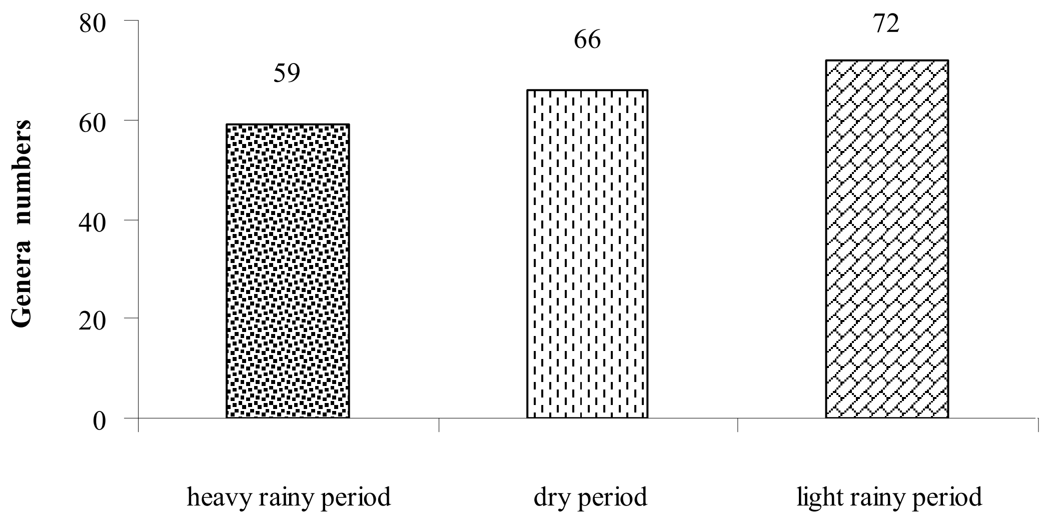
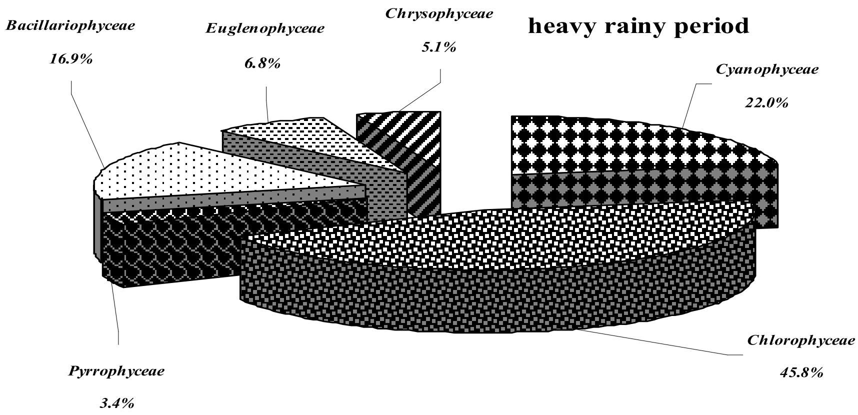


Figure 23. Genera numbers recorded in each seasonal period in arsenic contaminated waters in the Ron Phibun district of Nakhon Si Thammarat province, Thailand.

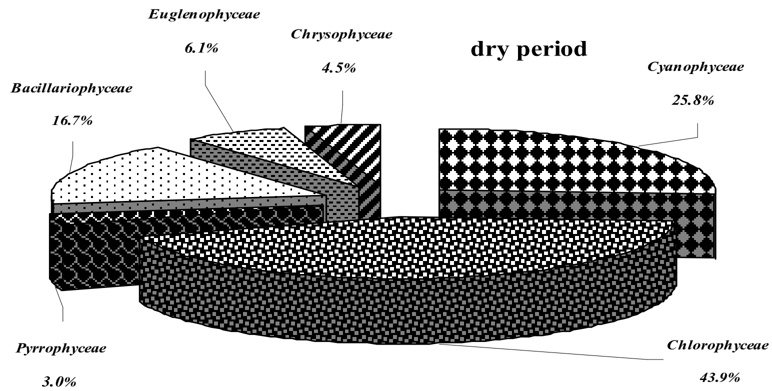
Table 5. Genera numbers recorded in each class during the heavy rainy period, dry period and light rainy period in arsenic contaminated waters in the Ron Phibun district of Nakhon Si Thammarat province, Thailand.

Class	heavy rainy period	dry period	light rainy period
Cyanophyceae	13	17	13
Chlorophyceae	27	29	40
Pyrrophyceae	2	2	2
Bacillariophyceae	10	11	10
Euglenophyceae	4	4	4
Chrysophyceae	3	3	3
Total (taxa)	**59**	**66**	**72**

a)



b)



c)

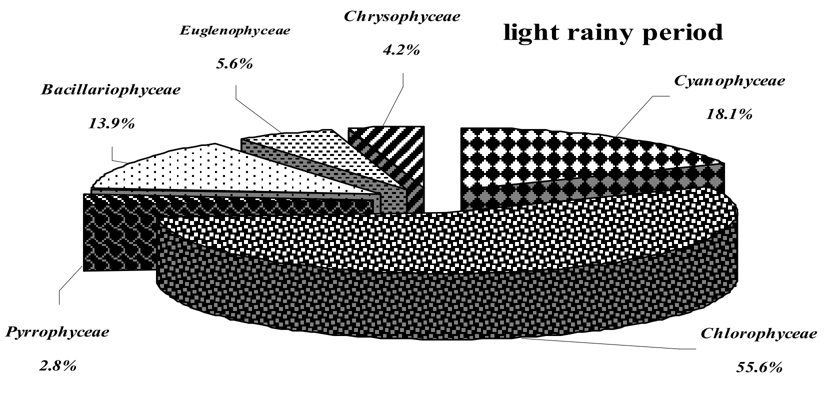


Figure 24. The percentage of the phytoplankton genera numbers in each class during the heavy rainy period, dry period and light rainy period in arsenic contaminated waters in the Ron Phibun district of Nakhon Si Thammarat province, Thailand.

Chlorophyceae

Chlorophytes dominated in the numbers of taxons, comprised more than half of the total number of genera recorded and were by far the most genera-rich group in the phytoplankton community. The most frequent phytoplankton genera isolated from all sampling locations were chlorococcacean and desmids. Desmids were more important in location 4 than in other locations. The desmids most frequently found were *Staurastrum* spp. and *Cosmarium* spp.

Cyanophyceae

Generally, the blue-greens (cyanophyceae) dominated the community. Cyanophytes were also numerous in analysed samples (coccal and filamentous genera). In this study, the most frequent genera isolated throughout the year such as *Chroococcus* spp.*, Gloeocapsa* sp., *Microcystis* spp., *Merismopedia* spp., but some of the taxa were only found in one month such as *Anacystis* sp.

Pyrrophyceae

Taxons in the Pyrrophyceae were less frequently isolated from sampling locations. During the study period, the genera of pyrrophyceae isolated changed little at all sampling location. *Peridinium* spp. were detected at all sampling locations. However, *Ceratium* sp. was commonly found in four locations (locations 2, 4, 5, and 6), but were absent in locations 1 and 3. The armoured algal genera were frequently found (and often together). There were some minor significant groups in the studied ecosystem due to their high biomass and abundance.

Bacillariophyceae

Bacillariophyceae were not very significant in all sampling locations in terms of genera number. They were comprised of almost a quarter of the total number of genera. *Fragilaria* sp. *Gomphonema* spp., *Navicula* spp. and *Nitzchia* spp. were presented all through the year and other genera were found at least a few months that is *Gyrosigma* sp./*Pleurosigma* sp.

Euglenophyceae

Although, euglenophytes genera comprised only 5.0 % of the total number of genera, they are very important in the sampling locations in terms of being a bioindicative parameter. For example, *Euglena* spp., *Phacus* spp. and *Trachelomonas* spp. were present all year round.

Chrysophyceae

This phylum also showed a very low number of genera. However, chrysophytes were consistently found at all sampling locations, especially in *Dinobryon* spp. and *Isthmochloron* sp.

3.3 Species richness, evenness indices and Shannon-Weiner diversity of phytoplankton flora in arsenic contaminated waters

The algal abundance data of each sampling location and each sampling time were analyzed using diversity, evenness and richness values. A summary of the values for these indices can be found in Table 6. Species richness over the study period was the highest in June at location 2 with 41 genera and the lowest was in November at location 1 (11). Comparison of species richness values between HACP and LACP indicated that HACP had higher variation in species richness than LACP. Wide variation in species richness among the samples was found at location 1. The number varied widely from 11 to 40 between November to April.

In general, evenness values were greater in all sampling locations during some months of the rainy period (November and December). Furthermore, Shannan-Weiner's diversity index was also taken into consideration during the rainy period because of its relatively high value compared to other seasonal periods. These represent values between 0.053 and 1.165, with a mean value of 0.531 ± 0.03. However, species richness generally had lower numbers within the same sampling period. The results indicated that the rainy period generally increased the diversity of phytoplankton due to increasing evenness values. Overall there are quite a few differences in the diversity, evenness and richness values for the six sampling locations. Also, the results of these values were more pronounced seasonally than spatially. The maximum value of Shannon-Weiner diversity and evenness indices was recorded in June, at location 4 (H'=1.165, J=0.781, respectively) and the lowest was recorded in November at location 1 (H'=0.053, J=0.051, respectively).

Table 6. Summary of species richness (R), equitability or evenness (J) and Shannon-Wiener diversity (H′) (bits/ind) indices for July 2004 to June 2005 in arsenic contaminated waters.

Location 1	R	J	H′
Jul	35	0.322	0.497
Aug	35	0.275	0.424
Sep	36	0.290	0.452
Oct	22	0.082	0.110
Nov	11	0.051	0.053
Dec	18	0.710	0.892
Jan	32	0.430	0.647
Feb	25	0.370	0.517
Mar	32	0.366	0.551
Apr	39	0.569	0.906
May	24	0.057	0.078
Jun	19	0.097	0.124
Average	27	0.302	0.438

Location 3	R	J	H′
Jul	31	0.415	0.619
Aug	20	0.361	0.470
Sep	18	0.479	0.601
Oct	26	0.261	0.369
Nov	17	0.523	0.643
Dec	13	0.316	0.352
Jan	30	0.261	0.385
Feb	34	0.098	0.150
Mar	26	0.133	0.188
Apr	28	0.221	0.320
May	29	0.441	0.645
Jun	30	0.478	0.705
Average	25	0.332	0.454

Location 2	R	J	H′
Jul	34	0.580	0.888
Aug	32	0.205	0.308
Sep	40	0.272	0.436
Oct	30	0.305	0.450
Nov	33	0.053	0.080
Dec	25	0.672	0.939
Jan	32	0.079	0.118
Feb	33	0.553	0.839
Mar	30	0.256	0.379
Apr	34	0.353	0.540
May	31	0.177	0.265
Jun	41	0.630	1.017
Mean	33	0.345	0.522

Location 4	R	J	H′
Jul	25	0.612	0.856
Aug	32	0.253	0.382
Sep	33	0.644	0.977
Oct	29	0.517	0.756
Nov	25	0.610	0.853
Dec	17	0.609	0.750
Jan	24	0.593	0.818
Feb	31	0.235	0.350
Mar	26	0.572	0.809
Apr	33	0.524	0.796
May	23	0.776	1.056
Jun	31	0.781	1.165
Mean	27	0.561	0.797

Location 5	R	J	H′
Jul	27	0.513	0.735
Aug	23	0.156	0.213
Sep	35	0.404	0.623
Oct	21	0.206	0.272
Nov	12	0.327	0.353
Dec	14	0.576	0.660
Jan	18	0.288	0.361
Feb	14	0.303	0.348
Mar	23	0.253	0.345
Apr	24	0.381	0.526
May	25	0.336	0.469
Jun	17	0.374	0.460
Mean	21	0.343	0.447

Location 6	R	J	H′
Jul	33	0.268	0.406
Aug	28	0.091	0.131
Sep	25	0.648	0.906
Oct	24	0.377	0.520
Nov	25	0.662	0.926
Dec	19	0.663	0.848
Jan	31	0.424	0.632
Feb	23	0.126	0.172
Mar	26	0.234	0.332
Apr	22	0.360	0.483
May	21	0.331	0.438
Jun	22	0.441	0.592
Mean	25	0.385	0.532

3.4 Relative abundance and density of phytoplankton

The relative abundance of phytoplankton assemblages in each sampling location studied was variable. It varied from 0% to 99.66%, among cyanophytes, from 0.04% to 98.65% for chlorophytes, from 0% to 59.94% for pyrrophytes, from 0% to 91.85% for bacillariophytes, from 0% to 18.63% for euglenophytes, and from 0% to 98.18% for chrysophytes. In most of the samples taken, cyanophytes were the most abundant group, representing 77.55% of the total phytoplankton assemblages.

Cyanophytes contributed relatively high proportions at all sampling locations and sampling times, except location 4 and during the rainy period. In location 4, chlorophytes generally were found as the most abundant group in several months (except October, November, and June), representing more than 50% of the total. Also, note that the changes in relative abundance occasionally occurred during the rainy period (mainly from November to December). During the rainy period, several algal groups were recorded with highly relative abundance such as chrysophytes in location 1 (98.18% in November), chlorophytes in locations 2, 4, and 5 (98.65% in November, 72.57% in December and 79.55% in November, respectively), and bacillariophytes in location 3 (91.85% in December).

Mean total phytoplankton density ranged from 8.08 x 10^4 to 1.24 x 10^6cells/L. The overall mean numbers per litre of phytoplankton collected throughout the study period were 1.24 x 10^6; 7.89 x 10^5; 5.16 x 10^5; 4.92 x 10^5; 9.87 x 10^4 and 8.08 x 10^4 cells/L in locations 3, 6, 1, 2, 4 and 5, respectively (Figure 25). Comparison of phytoplankton communities at each location indicated that the highest density varied depending on seasonal effect. It was apparent that the mean density of phytoplankton recorded in all locations generally were lower during the rainy period (November to December). Density also showed monthly variations, with high values and peaks sometime above 1.2 x 10^6 cells/L in September, March and May at location 1, and higher than 2 x 10^6 cells/L in July and August at location 6. The highest density occurred in March at location 3 (5.59 x 10^6 cells/L), whilst the lowest occurred in December at location 1 (976 cells/L). In addition, the highest density occurred in May (1.58 x 10^6cells/L) for location 1, January (1.84 x 10^6 cells/L) for location 2, and August (4.87 x 10^5; 2.50 x 10^5; 2.49 x 10^6 cells/L) for locations 4, 5 and 6, respectively.

Cyanophytes made up the highest density group, accounting for 89.58, 25.88, 84.73, 28.49, 81.99 and 95.6 % of the total densities at each location (locations 1, 2, 3, 4, 5 and 6, respectively). The 2nd highest density group were chlorophytes which accounted for 1.01, 60.49, 5.85, 66.06, 1.01 and 0.75 % of the total density at each location (locations 1, 2, 3, 4, 5 and 6, respectively). The 3rd highest density group were chrysophytes which accounted for 3.61, 12.57, 5.50, 1.27, 14.97 and 0.42 % of the total density at each location (locations 1, 2, 3, 4, 5 and 6, respectively). The 4th highest density group were pyrrophytes which accounted for 2.35, 0.57, 1.73, 3.92, 1.20 and 2.73 % of the total density at each location (locations 1, 2, 3, 4, 5 and 6, respectively). The 5th highest density group was bacillariophytes which accounted for 2.01, 0.16, 1.70, 0.21, 0.53 and 0.10 % of the total density at each locations (locations 1, 2, 3, 4, 5 and 6, respectively). The 6th highest density group were euglenophytes which accounted for 1.44, 0.34, 0.49, 0.05, 0.30 and 0.41 % of the total density at each location (locations 1, 2, 3, 4, 5 and 6, respectively) (Figure 26).

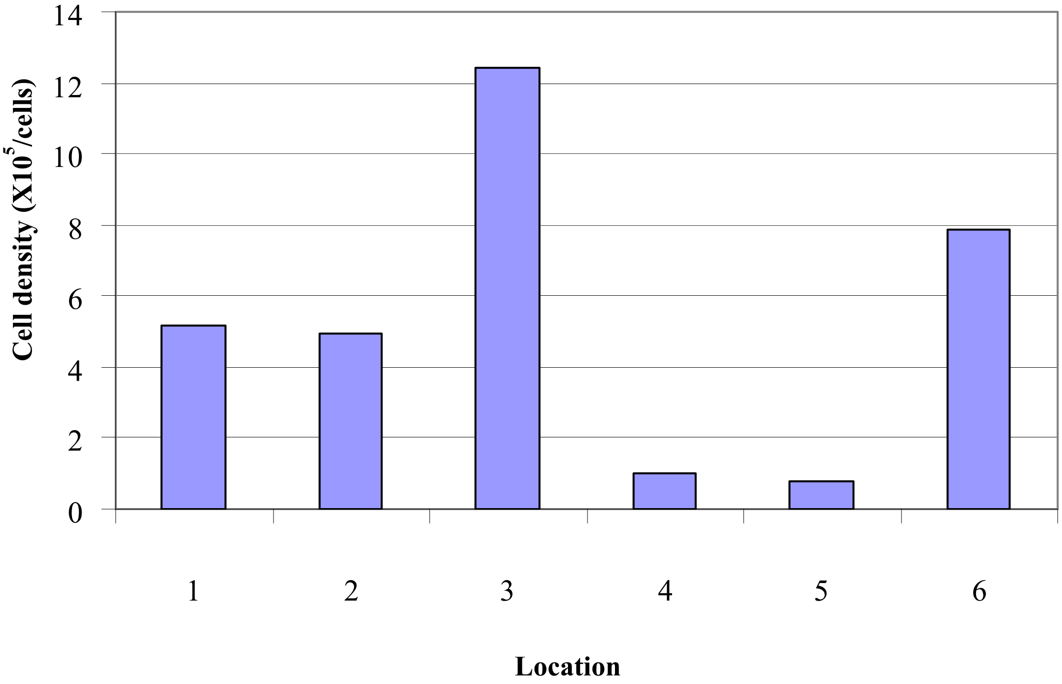


Figure 25. Chart of the phytoplankton densities of six sampling locations in the arsenic contaminated waters at the Ron Phibun district of Nakhon Si Thammarat province, Thailand.

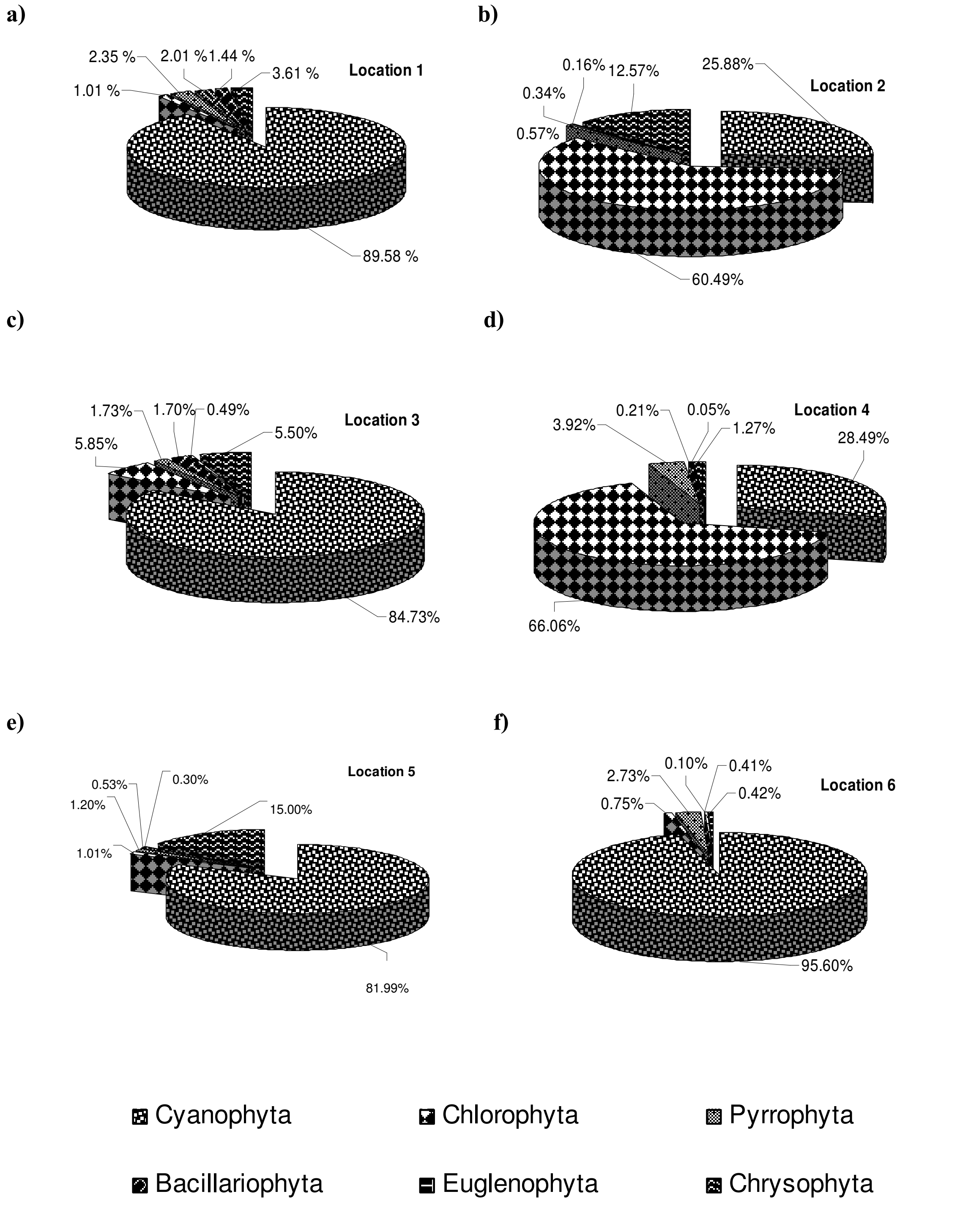


Figure 26. The percentage of phytoplankton densities in each sampling locations of arsenic contaminated waters in the Ron Phibun district of Nakhon Si Thammarat province, Thailand.

Chlorophyceae

Chlorophytes were very significant in the sampling ponds in terms of genera number. However, in terms of density, chlorophytes were second in order of phytoplankton density during this study period. The highest density of chlorophytes was recorded in January (1.76×10^6 cells/L) at location 2, of which *Botryococcus* sp. (1.75×10^6 cells/L), contributed 99.28 % of the total chorophytes, respectively.

The most predominant chlorophytes genera with each sampling locations were *Scenedesmus* spp. (1.09×10^3 cells/L) and *Coelastrum* spp. (6.58×10^2 cells/L) for location 1, *Botryococcus* sp. (2.88×10^5 cells/L) for the location 2, *Botryococcus* sp. (4.78×10^4 cells/L) and *Staurastrum* spp. (1.81×10^4 cells/L) for location 3, *Botryococcus* sp. (4.76×10^4 cells/L) for location 4, *Botryococcus* sp. (4.63×10^2 cells/L) for location 5, and *Staurastrum* spp. (1.53×10^3 cells/L) for location 6.

Cyanophyceae

Cyanophytes contributed considerably to the overall cell number. At certain times of the sampling period, they dominated the total phytoplankton cell number. In terms of species number, cyanophytes were not the most significant in all sampling locations. The highest density of cyanophytes was recorded in March (5.59×10^6 cells/L) at location 3. These high density were due in the most part to the cyanophytes assemblage represented by *Oscillatoria* spp. (4.91×10^6 cells/L), accounting for 88.91 % of the cyanophytes by number.

The most predominant phytoplankton genera at each water location were *Raphidiopsis* sp. (1.39×10^5 cells/L) and *Cylindrospermum* sp. (1.33×10^5 cells/L) for location 1, *Cylindrospermopsis* sp. (5.26×10^4 cells/L) and *Oscillatoria* spp. (6.20×10^4 cells/L) for location 2, *Oscillatoria* spp. (4.83×10^5 cells/L) and *Raphidiopsis* sp. (3.45×10^5 cells/L) for location 3, *Oscillatoria* spp. (7.58×10^3 cells/L) and *Gloeocapsa* sp. (4.94×10^3 cells/L) for location 4, *Cylindrospermopsis* sp. (2.49×10^4 cells/L) and *Oscillatoria* spp. (2.92×10^4 cells/L) for location 5, *Cylindrospermopsis* sp. (4.92×10^5 cells/L) and *Oscillatoria* spp. (1.96×10^5 cells/L) for location 6.

Pyrrophyceae

Throughout the study period, pyrrophytes were poorly diversified. However, species composition and dinoflagellate densities were one of the most important phytoplankton assemblage along the arsenic contaminated waters. Pyrrophyceae were a frequent algal group in many sampling locations during the study period. They consisted mainly of two genera, *Peridinium* and *Ceratium*. These genera made up 1.95 % of the total phytoplankton density. The highest mean value of dinoflagellate density occurred in July at location 6 (2.01×10^5 cells/L). The highest density of dinoflagellates corresponded with *Peridinium* spp., which is common in the arsenic contaminated waters and was found in 100 % of all dinoflagellate densities.

The most predominant pyrrophytes genera within all sampling locations were *Peridinium* spp. The mean density of *Peridinium* spp. was 1.22×10^4; 8.37×10^3; 2.15×10^4; 3.51×10^3; 7.00×10^2 and 2.15×10^4 cells/L for locations 1, 2, 3, 4, 5 and 6, respectively.

Bacillariophyceae

The bacillariophytes were considerable in number throughout most of the study period. Incidences of bacillariophytes densities were low for all species, except *Fragilaria* sp. and *Navicula* sp. During the study period, cell densities showed the highest value of 2.21×10^5 cells/L in October at location 3. The high contribution of bacillariophytes made by *Fragilaria* sp. was 98.95 %.

The most predominant bacillariophytes genera within each sampling locations were *Navicula* spp. (8.86×10^3 cells/L) for location 1, *Navicula* spp. (3.34×10^2 cells/L) for location 2, *Fragilaria* sp. (2.04×10^4 cells/L) for location 3, *Navicula* spp. (6.70×10^1 cells/L) for location 4, *Fragilaria* sp. (1.64×10^2 cells/L) for location 5, and *Navicula* spp. (5.97×10^2 cells/L) for location 6.

Euglenophyceae

In general, euglenophytes were found in relatively low density during the study period, but they are a very important algal group in terms of indicative parameter along contaminated waters. The highest density was observed in September (5.57×10^4 cells/L) at location 1. Fewer but appreciable numbers were collected of *Trachelomonas* spp. at 98.56 % of the total euglenophytes density. These taxa are characteristic of contaminated waters.

The most predominant euglenophytes genera within all sampling location were *Trachelomona* spp. The mean density of *Trachelomona* spp. was 6.81×10^3; 1.07×10^3, 4.79×10^3; 2.50×10^1; 1.13×10^2 and 2.47×10^3 cells/L for locations 1, 2, 3, 4, 5 and 6, respectively.

Chrysophyceae

Chrysophytes is one of the minor groups in terms of density. They were dominated numerically by *Dinobryon* spp. which collectively represented approximately 4.87 % of the total densities. The highest density of chrysophytes within the period of investigation was registered in January (8.02×10^5 cells/L) at location 3. Chrysophytes highest density due to *Dinobryon* spp. comprising 79.05 % of the total chrysophytes density.

The most predominant chrysophytes genera within all sampling locations were *Dinobryon* spp. The mean density of *Dinobryon* was 1.20×10^4; 6.16×10^4; 6.81×10^4; 1.13×10^3 ; 1.20×10^4 and 3.26×10^3 for locations 1, 2, 3, 4, 5 and 6, respectively.

Tables 7 and 8 show the dominant phytoplankton genera along arsenic contaminated waters at each location and each sampling period. Cyanophytes were the most abundant of algal flora. In addition, chlorophytes seem to be an important algal group in location 4, whilst chrysophytes were also presented as a dominant algal group during some months of the sampling period, particularly in locations 2 and 5. Changes in phytoplankton abundance were more pronounced seasonally than spatially. The diminished growth of the algal flora was noticed during the rainy period. Detailed changed in the main populations are presented separately for each sampling location as follows:

Location 1

In location 1, cyanophytes generally were the dominant group in all sampling periods, except in November (Figure 27). The highest total abundance was attained in May with growth of *Raphidiopsis* sp. comprising 97.16% of the total. Minor peaks occurred in September and March, due to a large number of *Cylindrospermum* sp. in those periods, constituting about 62.77% and 53.37% of the total, respectively. However, the pattern in the rainy period (November and December) was very different. A significant number of phytoplankton flora was detected during the rainy period. In subsequent periods, the total abundance decreased with a fall in the numbers of mostly phytoplankton assemblages. During November, chrysophytes in the genus *Dinobryon* spp. were most conspicuous with a relatively high abundance of 98.14% of the total. In December, phytoplankton assemblages seemed to decrease distinctly as the rain intensity decreased slightly. The population of dinoflagellates dominated with only small quantities of *Peridinium* spp., found (21.41%). When rain intensity sharply increased, the phytoplankton identified was mostly dominated by cyanophytes. Phytoplankton rich waters in those periods were generally dominated by *Oscillatoria* spp.

Location 2

In location 2, different phytoplankton groups alternated dominance in each period. Cyanophytes were dominant in July, August, February, April and May, and a small number were also found in December. Chlorophytes were dominant in November, January and March and chrysophytes in September (Figure 28). The investigations showed that the lowest density was observed in December. *Microcystis* spp. dominated but with only small quantities, or 37.67% of the total. In the following month, January, the highest numbers were observed with *Botryococcus* sp. achieving 61.17% of the total.

In general, all sampling locations had their highest cell density in the early rainy period. However, it was found that the highest cell density occurred in January, the rainy period. The Meteorological Department of Thailand has reported that the annual rain intensity was not high during the study period, when compared with previous investigations.

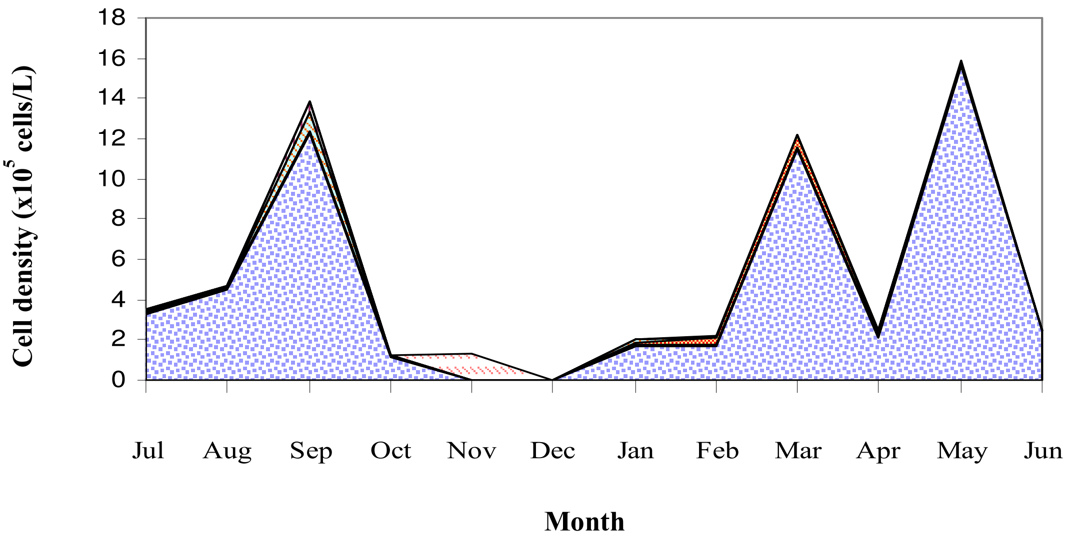
Table 7. Dominant phytoplankton genera in each location of arsenic contaminated waters at the Ron Phibun district of Nakhon Si Thammarat province, Thailand during July to December 2004.

Location	Year 2004					
	July	August	September	October	November	December
1	*Cylindrospermopsis* sp.	*Cylindrospermopsis* sp.	*Cylindrospermum* sp., *Oscillatoria* spp.	*Raphidiopsis* sp.	*Dinobryon* spp.	*Peridinium* spp., *Dinobryon* spp., *Oscillatoria* spp.
2	*Cylindrospermopsis* sp.	*Cylindrospermopsis* sp.	*Dinobryon* spp., *Botryococcus* sp.	*Botryococcus* sp., *Dinobryon* spp.	*Botryococcus* sp.	*Microcystis* spp.
3	*Cylindrospermopsis* sp., *Microcystis* spp. *Raphidiopsis* sp.	*Microcystis* spp. *Raphidiopsis* sp., *Oscillatoria* spp.	*Staurastrum* spp.	*Raphidiopsis* sp., *Fragilaria* sp., *Peridinium* spp.	*Anabaena* spp.	*Fragilaria* sp.
4	*Cosmarium* spp.	*Botryococcus* sp.	*Cosmarium* spp., *Staurastrum* spp., *Gloeocapsa* sp., *Chroococcus* spp.	*Raphidiopsis* sp., *Gloeocapsa* sp.	*Microcystis* spp. *Oscillatoria* spp., *Botryococcus* sp.	*Staurastrum* spp., *Ankistrodesmus* spp.
5	*Raphidiopsis* sp., *Oscillatoria* spp., *Anabaena* spp., *Chroococcus* sp.	*Cylindrospermopsis* sp.	*Cylindrospermopsis* sp., *Oscillatoria* spp., *Dinobryon* spp.	*Oscillatoria* spp.	*Botryococcus* sp.	*Phormidium* spp., *Fragilaria* sp.
6	*Cylindrospermopsis* sp., *Peridinium* spp., *Oscillatoria* spp.	*Cylindrospermopsis* sp.,	*Cylindrospermopsis* sp., *Phormidium* spp., *Chroococcus* spp., *Cylindrospermum* sp.	*Cylindrospermopsis* sp.,	*Peridinium* spp., *Oscillatoria* spp.	*Chlorella* sp., *Gomphonema* sp., *Trachelomonas* spp.

Table 8. Dominant phytoplankton genera in each location of arsenic contaminated waters at the Ron Phibun district of Nakhon Si Thammarat province, Thailand during January to June 2005.

Location	Year 2005					
	January	Febuary	March	April	May	June
1	*Oscillatoria* spp.	*Oscillatoria* spp.	*Cylindrospermum* sp., *Oscillatoria* spp., *Phormidium* spp.	*Oscillatoria spp., Phormidium* spp.	*Raphidiopsis* sp., *Phormidium* spp.	*Oscillatoria* spp.
2	*Botryococcus* sp.	*Oscillatoria* spp., *Cylindrospermopsis* sp.	*Botryococcus* sp.	*Oscillatoria* spp., *Cylindrospermopsis* sp.	*Oscillatoria* spp.	*Dinobryon* spp., *Oscillatoria* spp.
3	*Dinobryon* spp.	*Oscillatoria* spp.	*Oscillatoria* spp., *Botryococcus* sp.	*Raphidiopsis* sp., *Oscillatoria* spp.	*Cylindrospermopsis* sp., *Oscillatoria* spp.	*Peridinium* spp., *Oscillatoria* spp.
4	*Peridinium* spp., *Cosmarium* spp.	*Botryococcus* sp.	*Ankistrodesmus* spp., *Oscillatoria* spp.	*Botryococcus* sp.	*Chroococcus* sp., *Ankistrodesmus* spp.	*Oscillatoria* spp., *Anabaenopsis* sp.
5	*Dinobryon* spp.	*Dinobryon* spp., *Oscillatoria* spp.	*Oscillatoria* spp., *Dinobryon* spp.,	*Oscillatoria* spp., *Raphidiopsis* sp., *Dinobryon* spp.,	*Oscillatoria* spp., *Peridinium* spp.,	*Oscillatoria* spp., *Dinobryon* spp., *Raphidiopsis* sp.
6	*Cylindrospermopsis* sp., *Oscillatoria* spp.	*Oscillatoria* spp.	*Oscillatoria* spp.	*Cylindrospermopsis* sp., *Cylindrospermum* sp.	*Oscillatoria* spp., *Cylindrospermopsis* sp.	*Cylindrospermopsis* sp.

a)



b)

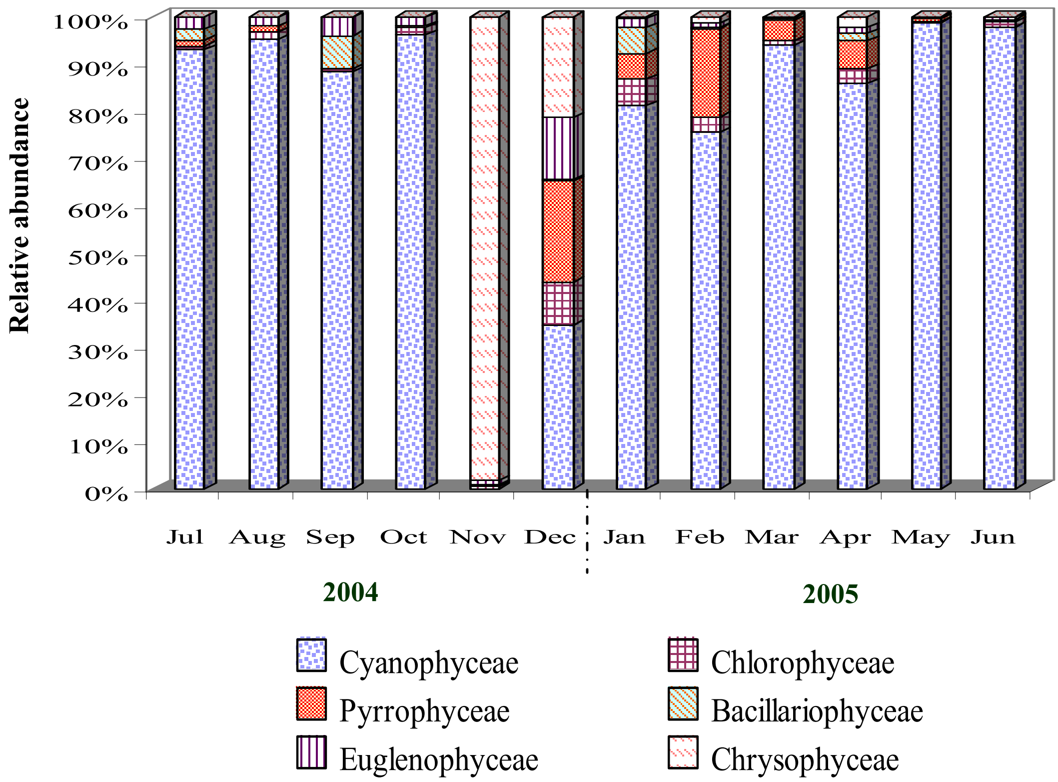
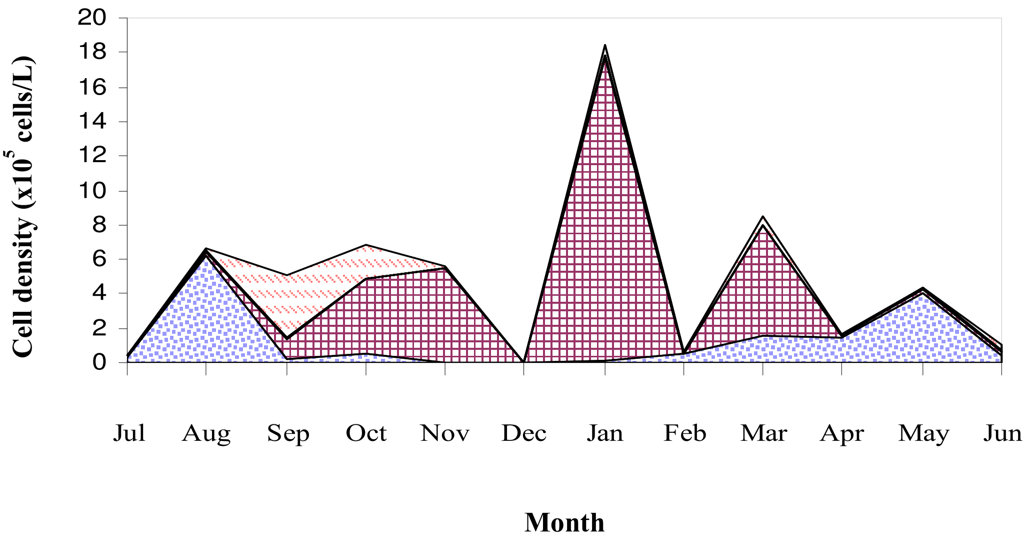


Figure 27. Changes in phytoplankton densities (a) and relative abundance (b) of phytoplankton assemblages in location 1 at the arsenic contaminated waters, during the period July 2004 to June 2005.

a)



b)

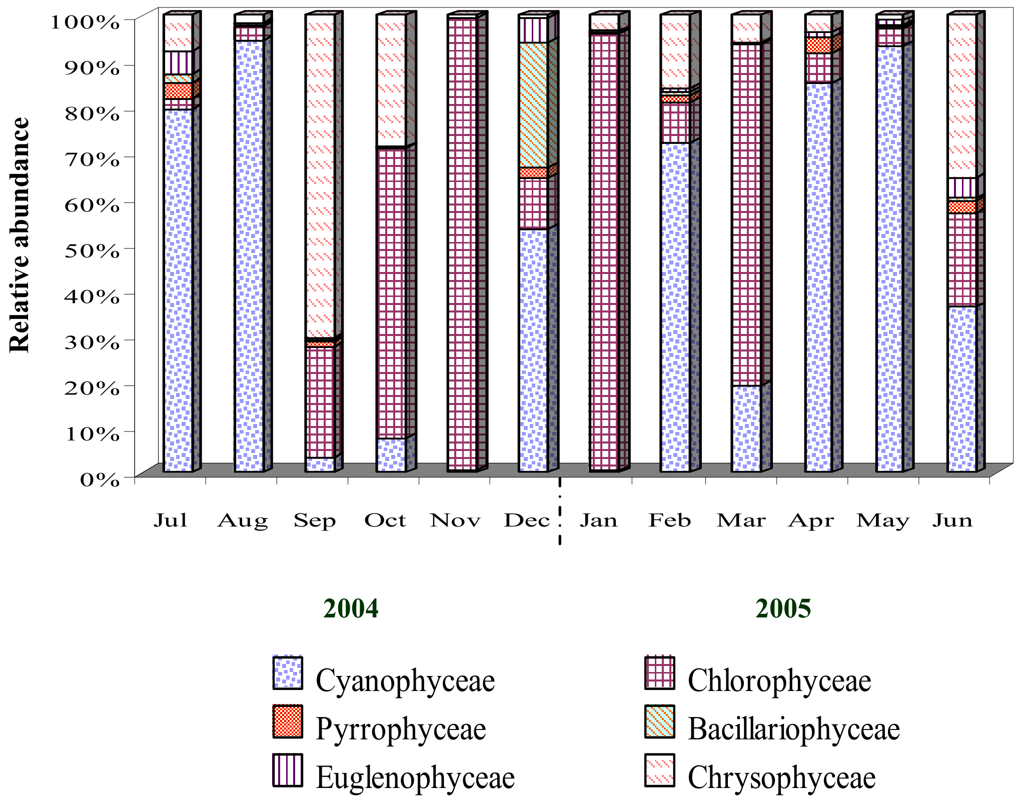


Figure 28. Changes in phytoplankton densities (a) and relative abundance (b) of phytoplankton assemblages in location 2 at the arsenic contaminated waters, during the period July 2004 to June 2005.

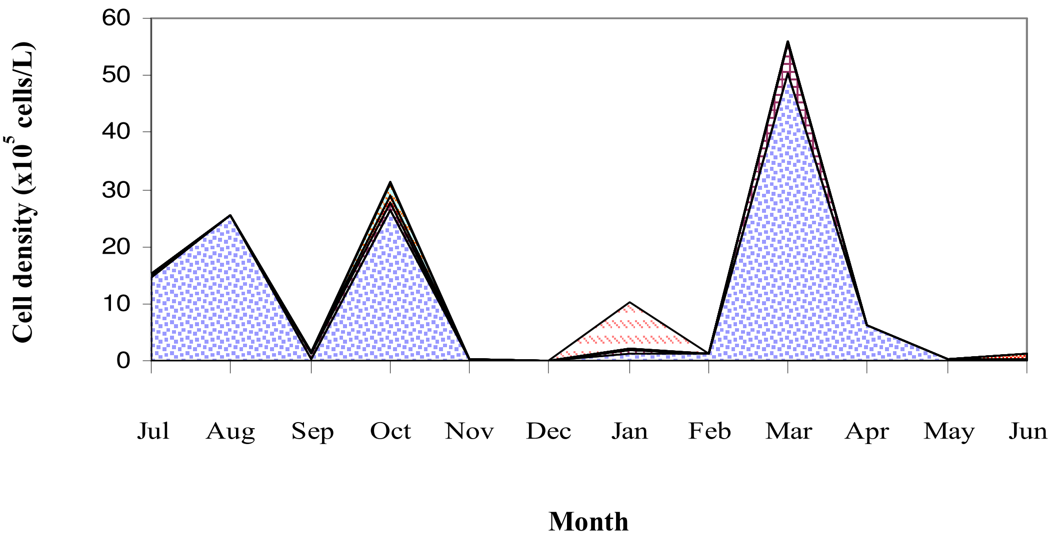
Location 3

Cyanophytes were the most abundant group of phytoplankton in location 3 in August, October and March, whereas chlorophytes were the most abundant in January (Figure 29). Each sampling periods above had one dominant genera of phytoplankton with the highest peak observed in March when *Oscillatoria* spp. accounted for 88.91% of the total. Other genera dominated at other times. Thus, *Raphidiopsis* sp. was dominant in October and *Microcystis* spp. was dominant in August, whereas *Dinobryon* spp. was dominant in January. In addition, there was a noticeable decrease in the total cell densities of phytoplankton assemblages during the rainy period (November and December). In December, cell densities were at their lowest level when *Fragilaria* sp., which was dominant at 79.94% of the total.

Location 4

Compared with the other sampling locations, location 4 had a dominant algal group that differed from the other locations. Generally, chlorophytes were the dominant algal group at all sampling periods, except for October and November (Figure 30). In October and November, cyanophytes were occasionally dominant and they alternated in dominance during the following months. The highest peak of phytoplankton abundance was in August, with *Botryococcus* sp. making up 79.82% of the total. A small peak of the same genus was found in Febuary, with 79.82% of the total. The high total abundance levels (above 1.5 $x10^5$ cells/L) only occurred in those periods. In December, again this had the lowest total population. At that time, the phytoplankton was dominated by *Staurastrum* spp., accounting for 40.12 % of the total. In January pyrrophytes in the genus *Peridinium* spp. and chlorophytes in the genus *Cosmarium* spp. had small increases. In particular, the phytoplankton present during the remaining months in 2005 was frequently characterized by the presence of chlorophytes and cyanophytes such as *Botryococcus* sp., *Ankistrodesmus* spp. and *Oscillatoria* spp.

a)



b)

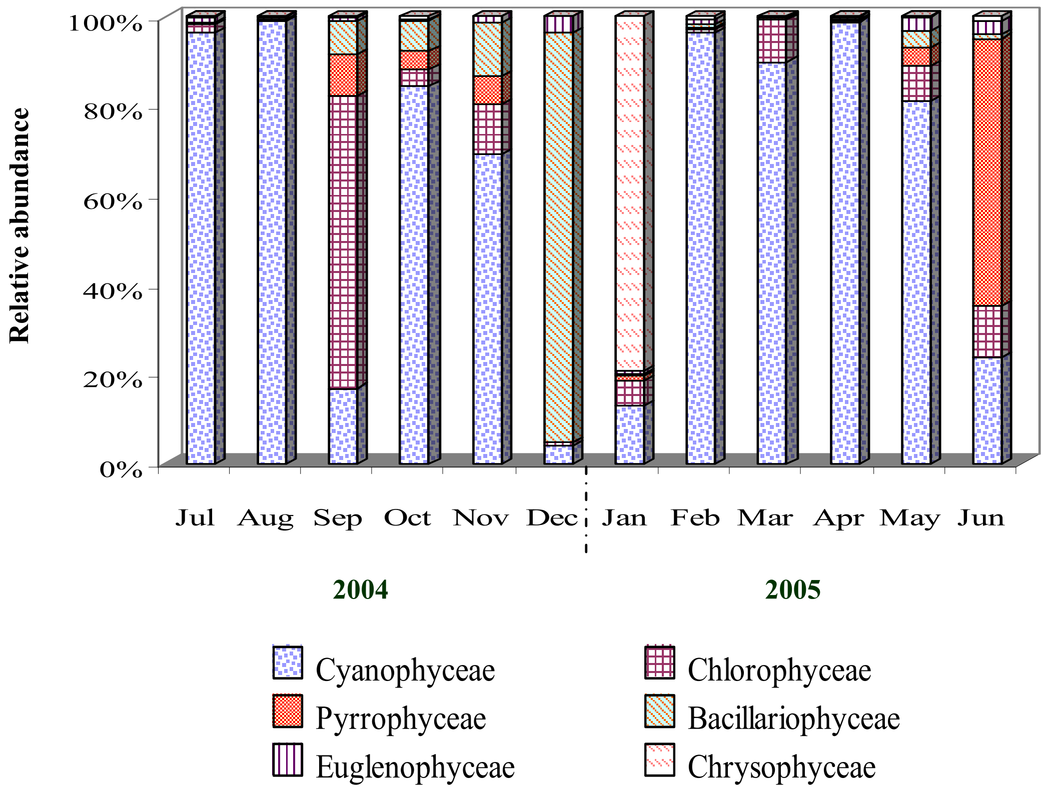


Figure 29. Changes in phytoplankton densities (a) and relative abundance (b) of phytoplankton assemblages in location 3 at the arsenic contaminated waters, during the period July 2004 to June 2005.

a)

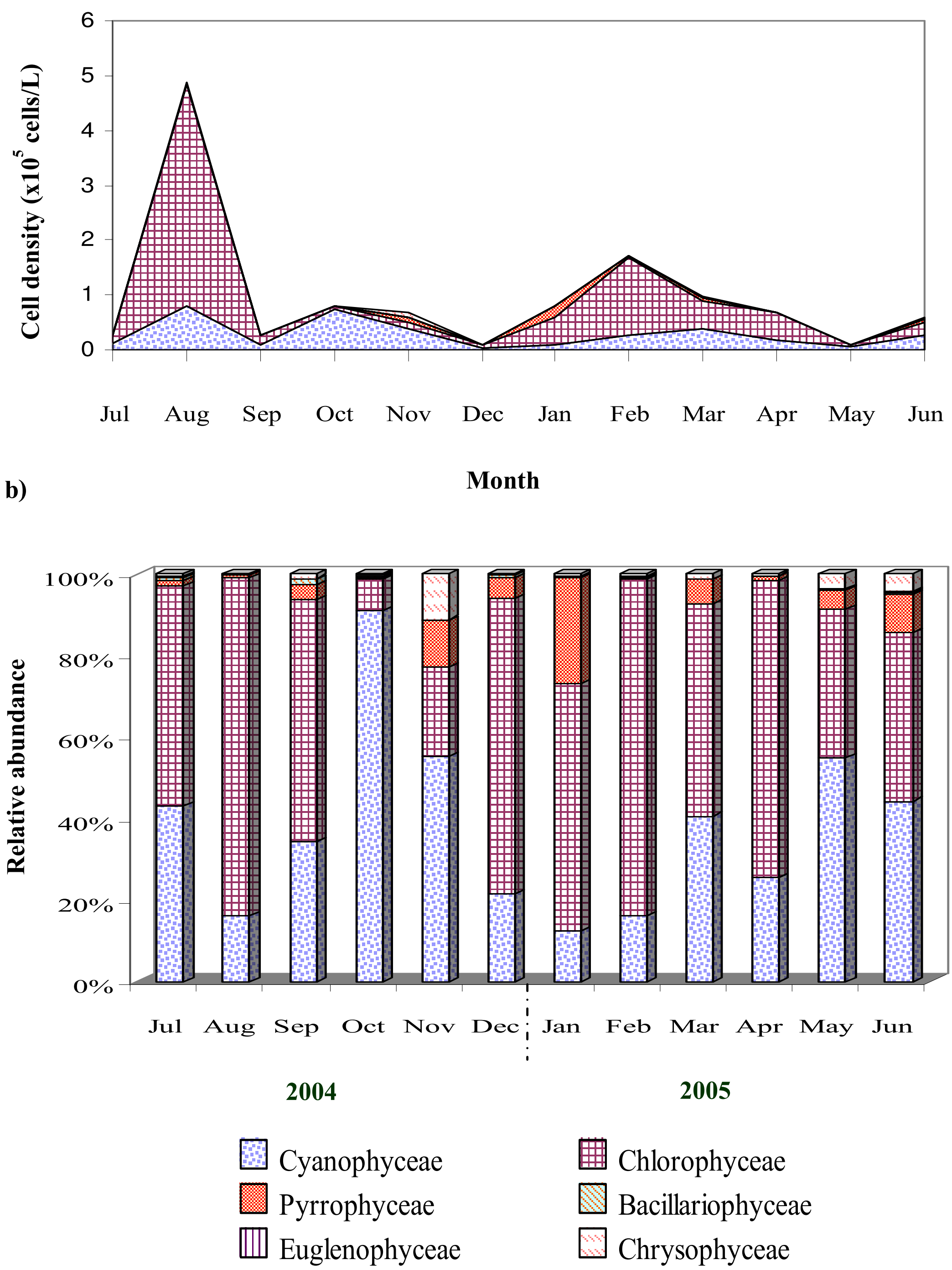


Figure 30. Changes in phytoplankton densities (a) and relative abundance (b) of phytoplankton assemblages in location 4 at the arsenic contaminated waters, during the period July 2004 to June 2005.

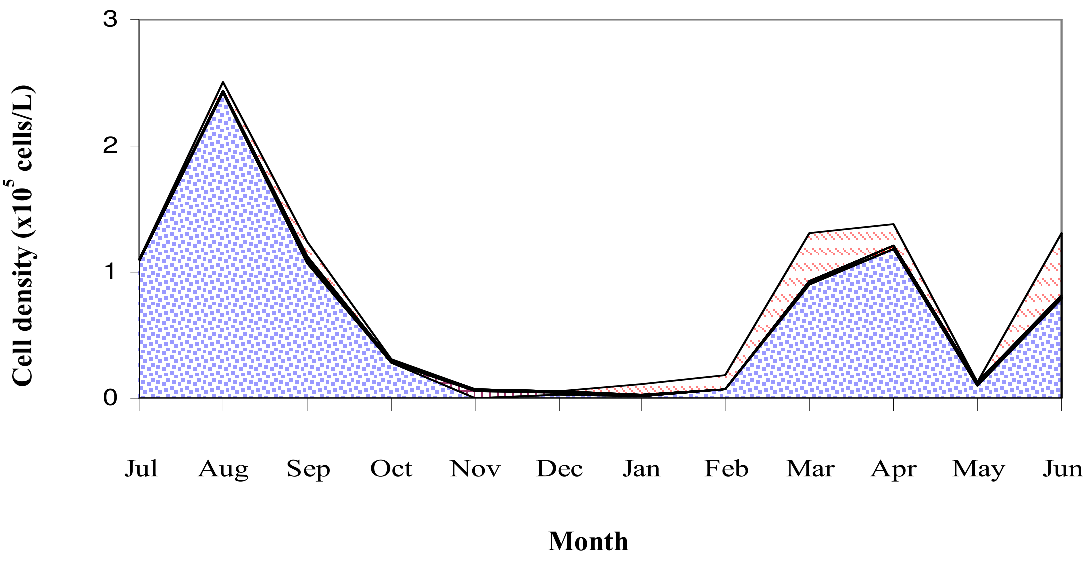
Location 5

During the early rainy period in location 5, except for February, cyanophytes play an important role in the phytoplankton population (Figure 31). In August *Cylindrospermopsis* sp. accounted for 90.90% of the total, whilst *Oscillatoria* spp. and *Dinobryon* spp. were dominant in October. Cell density declined distinctly during the rainy period (November and December) and then seemed to increased when the rain intensity decreased slightly in January. In those sampling periods, many different groups were found to be dominant such as chlorophytes in November (mainly *Botryococcus* sp.), cyanophytes in December (mainly *Phormidium* spp.) and chrysophytes in January (mainly *Dinobryon* spp.). In addition, *Dinobryon* spp. was also the dominant phytoplankton in February during the early part of the rainy period. During the dry period, in which there was a considerable increase in the total amount of arsenic, the cell density of phytoplankton increased compared to the previous months and cyanophytes were the dominant group. Generally, filamentous cyanobacteria and chrysophytes were the abundant organisms during dry periods such as *Oscillatoria* spp. and *Dinobryon* spp.

Location 6

In location 6, cyanophytes were always the dominant group with filamentous cyanobacteria being the major genera (Figure 32). At the beginning of the sampling period, phytoplankton abundance steadily increased from July to August and then decreased immediately in September. However, phytoplankton abundance increased again slightly in October. The main genera found in those periods was *Cylindrospermopsis* sp. with the highest peak occurring with 94.98% of the total population. A later peak was found in May and the present study also shows filamentous cyanobacteria still being the dominant genera with *Oscillatoria* spp. and *Cylindrospermopsis* spp. constituting 46.10% and 44.43% of the total respectively. During November and December, the proportion of phytoplankton assemblages seemed to have changed considerably and the phytoplankton density also declined, compared with other months. Many other genera were encountered during November and December in small numbers such as pyrrophytes, chlorophytes, cyanophytes and euglenophytes. In the genus *Peridinium* spp. a member of the pyrrophytes were dominant in November, accounting for 31.87% of the total, whilst chlorophytes in the genus *chlorella* sp. were dominant in December, accounting for 30.19% of the total.

a)



b)

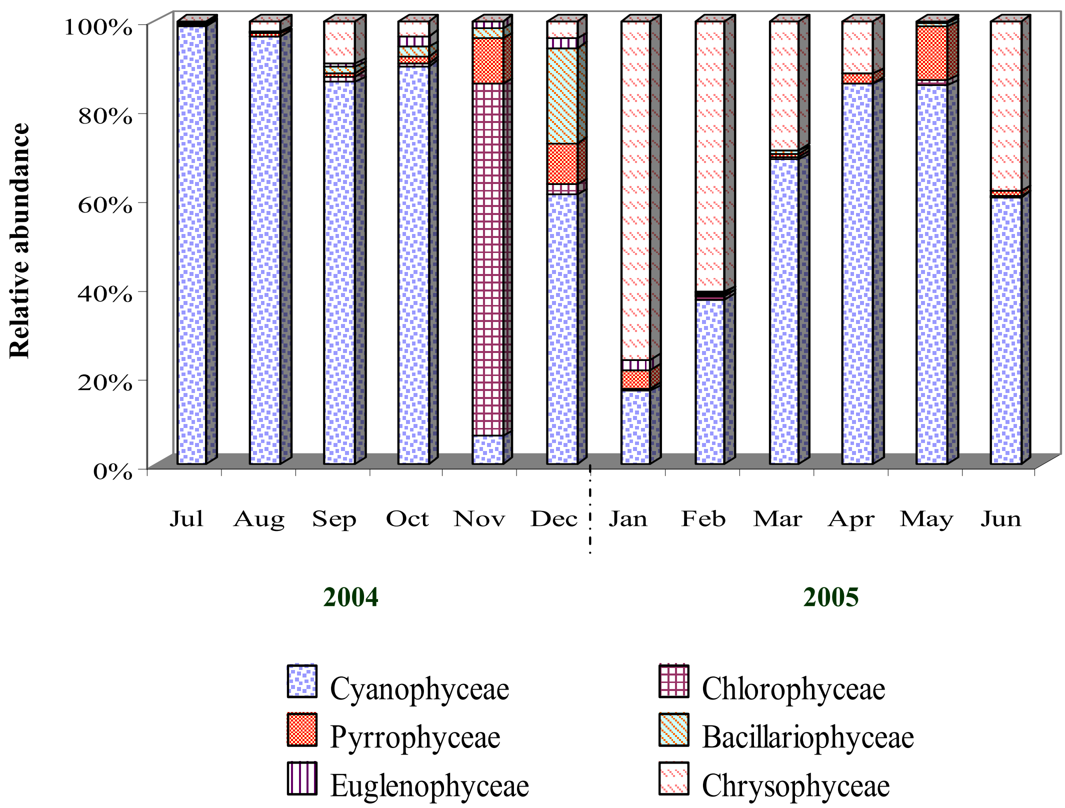


Figure 31. Changes in phytoplankton densities (a) and relative abundance (b) of phytoplankton assemblages in location 5 at the arsenic contaminated waters, during the period July 2004 to June 2005.

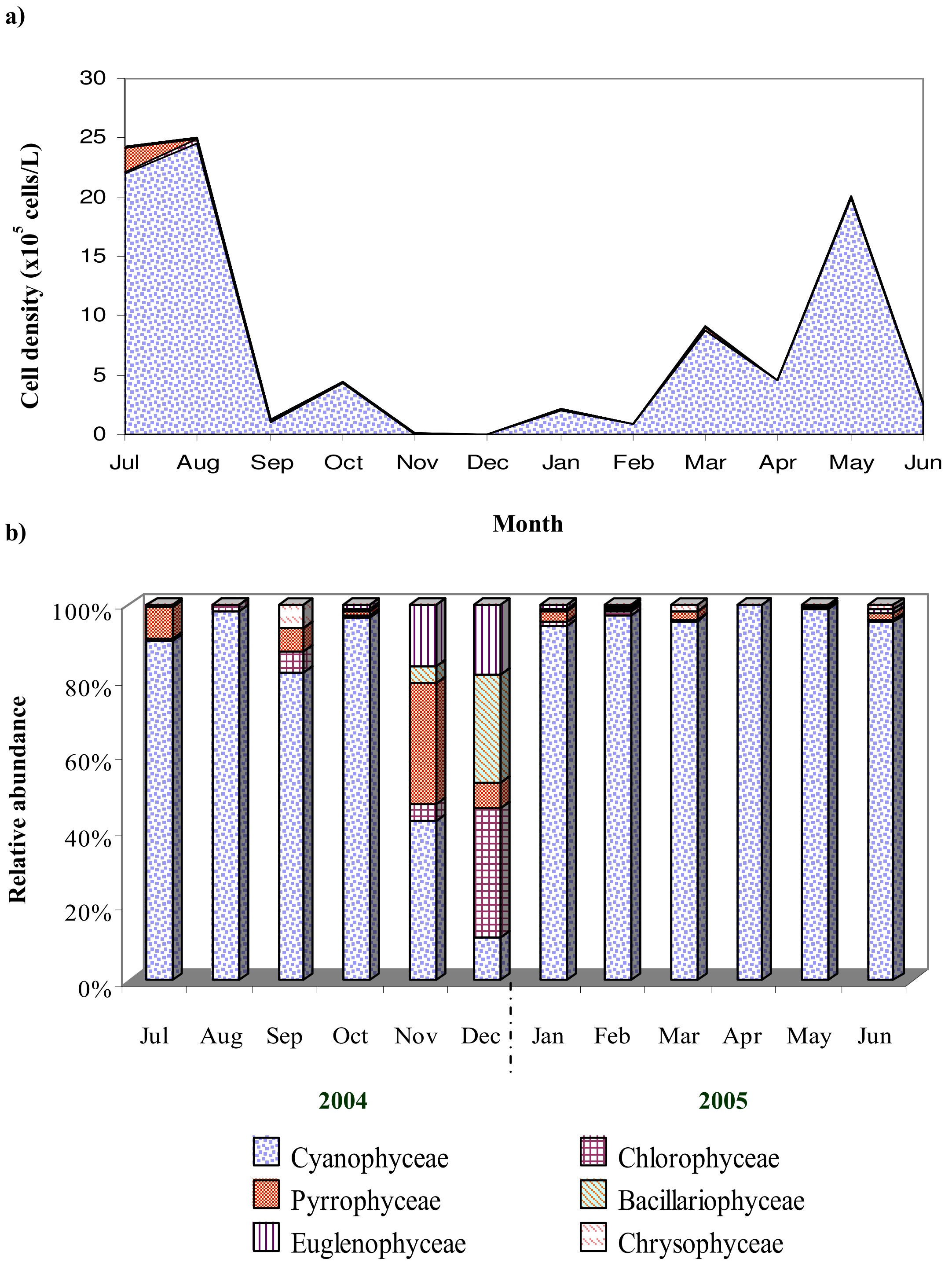


Figure 32. Changes in phytoplankton densities (a) and relative abundance (b) of phytoplankton assemblages in location 6 at the arsenic contaminated waters, during the period July 2004 to June 2005.

3.5 The classification of six water bodies based on phytoplankton communities

The analysis of the phytoplankton abundance by Unweighted Pair Group Method Algorithm (UPGMA), clustering, and application of percent similarity, failed to show any significant group with 50% of similarity (Figure 33). Cluster analysis of phytoplankton density averaged for each sampling location showed distinct cluster groupings, indicating dissimilar phytoplankton communities among the locations. The results demonstrated that location 2 was most similar to location 3 in phytoplankton communities at a 33.15 % similarity level while those two locations were 28.08 % similar to location 6. Location 6 was similar to location 2 at a level of 25.10%. In addition, location 4 had a 23.21% similarity level to location 5 and those two locations were 15.95% similar to location 2. Accordingly, all sampling locations showed dissimilarity levels and indicated that those locations were not grouped together. However, such dissimilarities could be categorized into two common groups; locations 1, 2, 3& 6 (cluster I) and 4 and 5 (cluster II). This was believed to be the density level that identified two distinct categories. Cluster I is represented mainly by locations 1, 2, 3 and 6. Seventy-six genera were identified and they were composed of chlorophytes and bacillariophytes as characteristic groups. Specific genera were characterized by *Anacystis* sp., *Euastrum* spp. and *Cymbella* sp. The dominant phytoplankton in this cluster consisted of members of the *Cylindrospermopsis* sp. and *Oscillatoria* spp. A second cluster contained mainly samples from locations 4 and 5, characterized by chlorophytes. Specific genera in cluster II included *Elakatothrix* sp. and *Netrium* sp. This cluster showed a lower number of phytoplankton species with 65 genera.

Additionally, the cluster analysis of the mean environmental variables data set for all sampling locations gave the dendrogram as shown in figure 34. Cluster analysis of the environmental variables averaged for each sampling locations did not form distinct cluster groupings, indicating similar limnological behaviour among the locations (Figure 34). That is those locations clustered together will share characteristics, and the results exhibit some resemblance from this cluster being related to cluster grouping of phytoplankton abundance above. The first one includes the samples in locations 1, 2, 3 and 6, whereas the second belongs to the remaining samples from other locations (locations 4 and 5). Accordingly, locations 1, 2, 3 and 6 were quite similar to one another in environmental variables and as a result categorized in cluster I due to their adjacent similarity level. In addition, the outcome indicated that locations 4 and 5 were obviously the same and were grouped as cluster II. The mean environmental variables from cluster I were as follows: pH 6.32±0.15, DO 5.26±0.19 mg/L, BOD 2.09±0.14 mg/L, total arsenic 34.26±3.94 μg/L, nitrate-nitrogen 0.06±0.01 mg/L, dissolved phosphorus 0.03±0.002 mg/L, conductivity 88.30±9.84 μS/cm, TSS 8.31±0.63 mg/L, ammonia-nitrogen 0.02±0.003 mg/L. In the meantime, the mean of environmental variables in cluster II is shown as follows: pH 6.43±0.26, DO 5.90±0.27 mg/L, BOD 1.96±0.30 mg/L, total arsenic 40.58±15.48 mg/L, nitrate-nitrogen 0.05±0.01 mg/L, dissolved phosphorus 0.02±0.01 mg/L, conductivity 99.74±16.78 μS/cm, TSS 37.87±22.93 mg/L, ammonia-nitrogen 0.02±0.01 mg/L. Of 11 environmental variables, TSS values differ considerably between cluster I and II.

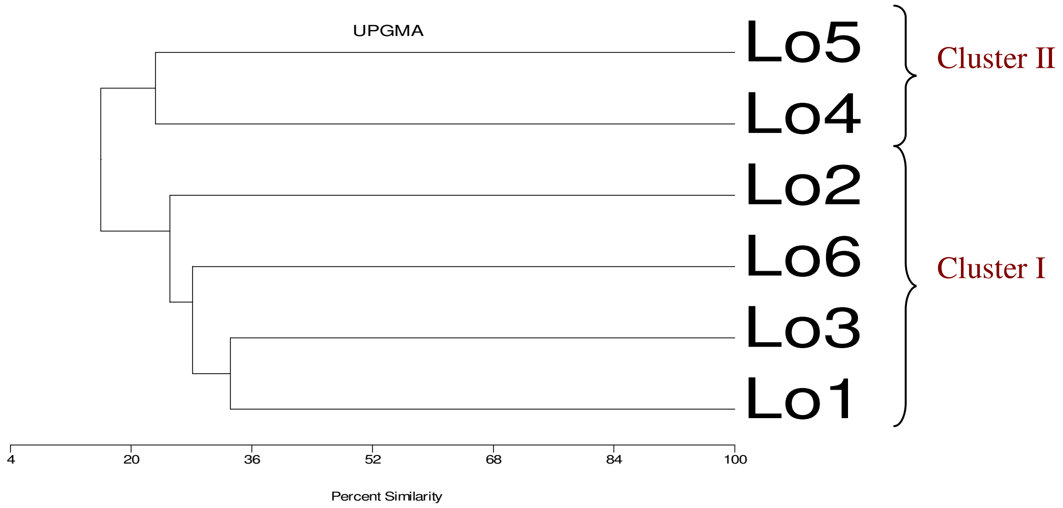


Figure 33. Cluster of dissimilarity (Percent similarity) among phytoplankton samples averaged for each sampling locations obtained by UPGMA: Lo = location.

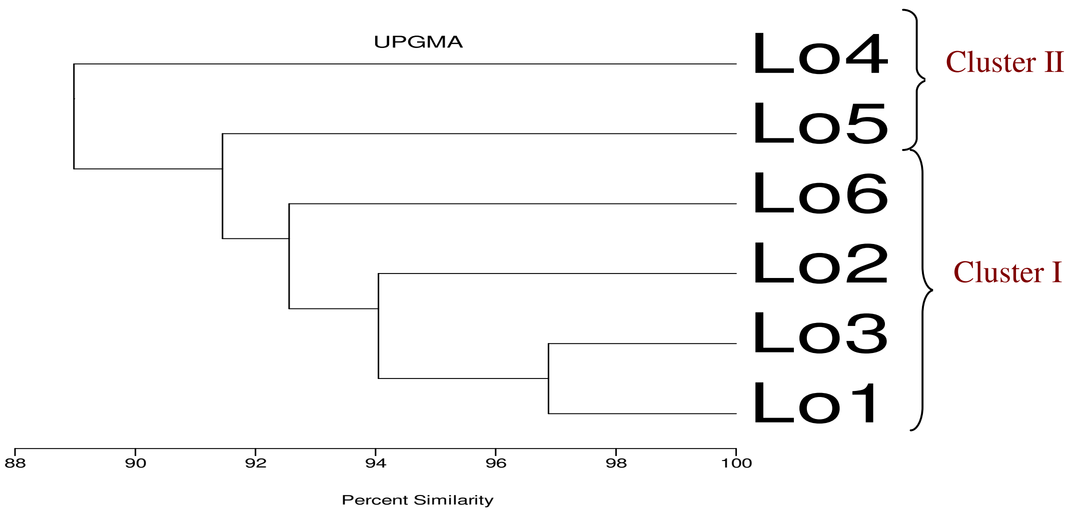


Figure 34. Cluster of dissimilarity (Percent similarity) among environmental variables averaged for each sampling locations obtained by UPGMA: Lo = location.

3.6 Canonical Correspondence Analysis (CCA)

Canonical Correspondence Analysis (CCA) is used to produce bi-plots for sample scores and was performed on the selected environmental and phytoplankton species datasets. Eigenvalues of axes 1 and 2 were 0.61 and 0.54, respectively. The CCA explained a small proportion of the variance in the genera data (Table 9). The first two dimensions of the CCA accounted for 29.29 % of the total variance of phytoplankton species and environmental data. The first axis accounted for 15.23 % of the total variance and the second axis for 14.07 % of the total variation in the data set. This low percentage is typical for noisy datasets containing many zero values. Specie and environmental correlations showed 0.88 and 0.83 explained by axes 1 and 2, respectively. The outcome from CCA analysis showed that pH, DO, BOD, total arsenic, nitrate-nitrogen, dissolved phosphorus, conductivity, TSS and ammonia-nitrogen were found to correlate with phytoplankton flora in arsenic contaminated waters (Figure 35).

In the CCA diagram of environmental variables, conductivity and BOD were strongly associated with Axis 1 (right hand side of ordination). pH, total arsenic, nitrate-nitrogen, TSS, and dissolved phosphorus were moderately associated. Ammonia-nitrogen was weakly associated. Dissolved oxygen had moderate negative associations with this axis. The variables with positive loading on Axis 2 (left hand side of ordination) were dissolved phosphorus (strongly associated), total arsenic (moderately associated), nitrate-nitrogen and ammonia-nitrogen (weakly associated). In addition, pH and conductivity had moderately negative associations and DO, BOD and TSS had weak negative associations with this axis (Table 10).

Many phytoplankton assemblages were reported to coincide with the following environmental variables as per below:

1. Group I consisting of cyanophytes (e.g. *Raphidiopsi* sp., *Microcystis* spp.), coincided with high dissolved phosphorus, total arsenic, ammonia-nitrogen, nitrate-nitrogen and TSS.

2. Group II consisting of cyanophytes (e.g. *Cylindrospermopsis* sp., *Cylindrospermum* sp., *Oscillatoria* spp.) and Pyrrophytes (e.g. *Peridinium* spp.) associated with high conductivity, BOD and pH.

3. Group III was situated at the higher part of the centre on the left hand side, characterized by lower conductivity and more acid. This group consisted of chrysophytes (i.e. *Dinobryon* spp.).

4. Group IV consisted of chlorophytes (i.e. *Botryococcus* sp.). It seemed to prefer an environment with more dissolved oxygen.

Comparing phytoplankton genera with the spatial and temporal dynamics of phytoplankton communities, all groups seemed to indicate both spatial and temporal effects with those phytoplankton assemblages.

Table 9. Summary of the results from the CCA (Canonical Correspondence Analysis). Eigenvalues, % of variance explained and species environmental correlation.

	Axis 1	**Axis 2**	**Axis 3**	**Axis 4**
Eigenvalues	0.579	0.535	0.230	0.192
Percentage	15.225	14.069	6.060	5.036
Cum. Percentage	15.225	29.294	35.353	40.390
Cum.Constr.Percentage	36.156	69.568	83.959	95.919
Spec.-env. correlations	0.867	0.829	0.676	0.595

Table 10. Biplot scores for environmental variables.

	Axis 1	**Axis 2**	**Axis 3**	**Axis 4**
pH	0.324	-0.498	0.687	-0.192
DO	-0.401	-0.228	0.005	-0.342
BOD	0.671	-0.024	-0.122	0.443
Arsenic	0.268	0.470	0.096	-0.482
Nitrate	0.386	0.116	0.076	0.004
Phosphorus	0.381	0.624	0.305	-0.426
Cond	0.715	-0.434	-0.307	0.092
TSS	0.421	0.005	0.230	0.420
Ammonia	0.095	0.062	-0.240	0.307

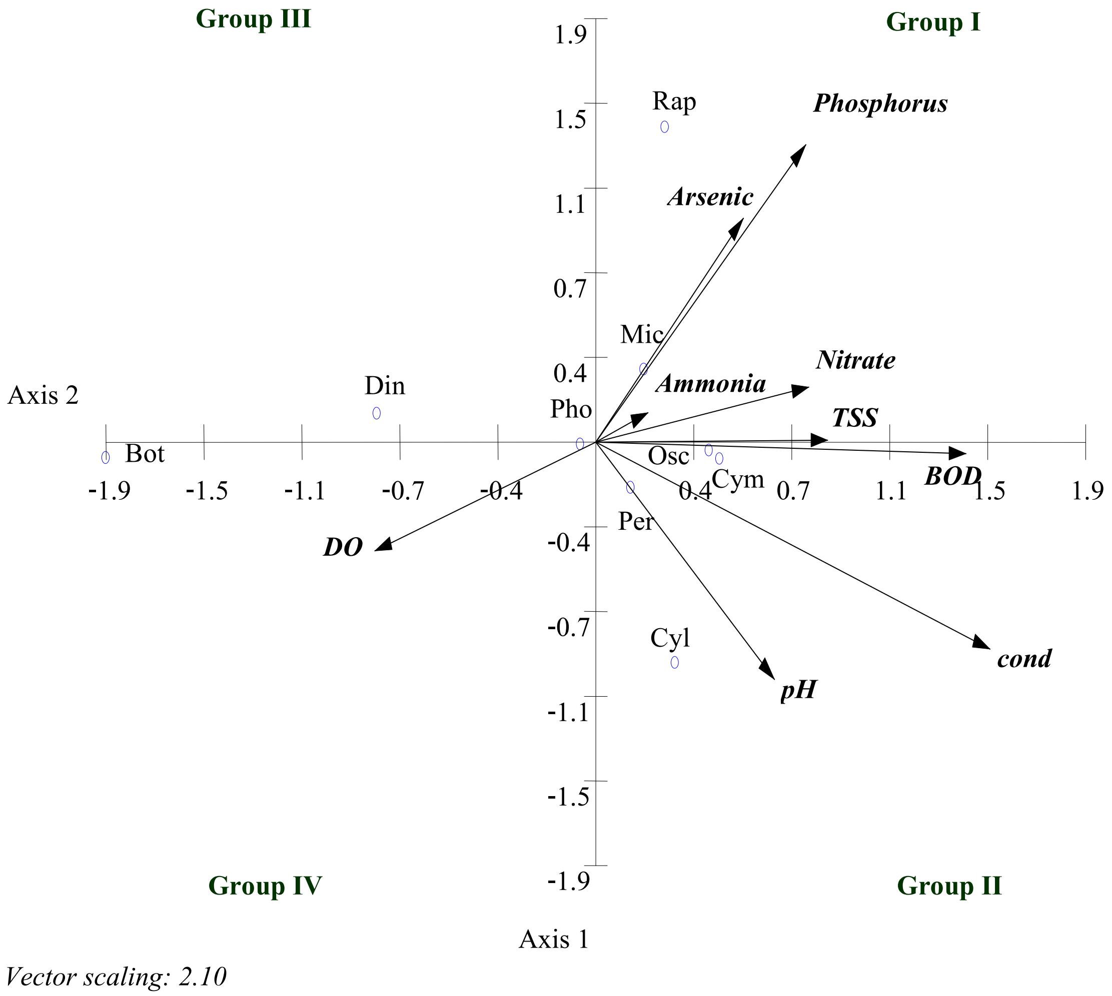


Figure 35. Ordination biplot of phytoplankton genera and environmental variables in the arsenic contaminated waters. The codes for the genera are shown in Table 11.

Table 11. Genera code of phytoplankton communities in arsenic contaminated waters at the Ron Phibun district of Nakhon Si Thammarat province.

Taxa	Genera code
Division Cyanophyta	
Cylindrospermopsis sp.	Cyl
Cylindrospermum sp.	Cym
Microcystis spp.	Mic
Oscillatoria spp.	Osc
Phormidium spp.	Pho
Raphidiopsis sp.	Rap
Division Chlorophyta	
Botryococcus sp.	Bot
Division Pyrrophyta	
Peridinium spp.	Per
Division Chrysophyta	
Dinobryon spp.	Din