THE USE OF PHYTOPLANKTON BIODIVERSITY FOR MONITORING WATER QUALITY IN RAMA IX LAKE, PATHUMTHANI PROVINCE

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การใช้ความหลากหลายทางชีวภาพของแพลงก์ตอนพืชตรวจสอบ
คุณภาพน้ำในสระเก็บน้ำพระราม 9 จังหวัดปทุมธานี

นางสาวสิริแข พงษ์สวัสดิ์

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สิริแข พงษ์สวัสดิ์ : การใช้ความหลากหลายทางชีวภาพของแพลงก์ตอนพืชตรวจสอบ
คุณภาพน้ำ ในสระเก็บน้ำพระราม 9 จังหวัดปทุมธานี (THE USE OF
PHYTOPLANKTON BIODIVERSITY FOR MONITORING WATER QUALITY IN
RAMA IX LAKE, PATHUMTHANI PROVINCE) อ.ที่ปรึกษา : รศ. ดร. สมพงษ์
ธรรมถาวร, 260 หน้า. ISBN 974-533-215-1

การศึกษาความหลากหลายทางชีวภาพของแพลงก์ตอนพืช   เพื่อเป็นดัชนีบ่งชี้คุณภาพน้ำ
ในสระเก็บน้ำพระราม 9 จังหวัดปทุมธานี ระหว่างเดือนกุมภาพันธ์ 2543 - มกราคม 2544

ผลการทดลองพบแพลงก์ตอนพืชทั้ง 2 สระ สามารถจัดจำแนกได้รวมทั้งสิ้น 6 divisions,
12 orders, 28 families, 62 genera และ 95 species คุณภาพน้ำในสระเก็บน้ำที่ 1 เมื่อจัดตามระดับ
สารอาหารอยู่ในระดับสารอาหารปานกลาง   (mesotrophic)   จนถึงสารอาหารมาก   (eutrophic)
แพลงก์ตอนพืชที่สามารถใช้เป็นดัชนีบ่งชี้แหล่งน้ำที่มีสารอาหารปานกลางจนถึงสารอาหารมาก
คือ *Cylindrospermopsis raciborskii* (Wolosz.) Seenayya & Subba, *Peridinopsis cunningtonii*
Lemmermann, *Trachelomonas volvocina* Ehrenberg, *Peridinium* sp. 1 และ *Ceratium furcoides*
(Levander) Langhans ในสระเก็บน้ำที่ 2 อยู่ในระดับสารอาหารน้อย (oligotrophic) จนถึงสาร
อาหารปานกลาง   แพลงก์ตอนพืชที่สามารถใช้เป็นดัชนีบ่งชี้แหล่งน้ำที่มีสารอาหารน้อยจนถึงสาร
อาหารปานกลาง   คือ   *Cylindrospermopsis raciborskii* (Wolosz.) Seenayya & Subba,
Trachelomonas volvocina, Peridinium sp. 1, *Peridinopsis cunningtonii* Lemmermann, *Ceratium
furcoides* (Levander) Langhans และ *Anomoeoneis vitrea* (Grunow) Ross และเมื่อจัดคุณภาพน้ำ
ในสระเก็บน้ำพระราม 9 ทั้ง 2 สระ ตามมาตรฐานคุณภาพน้ำในแหล่งน้ำผิวดิน จัดอยู่ในประเภท 2
แต่น้ำทั้ง 2 สระ มีค่าความกระด้างของน้ำสูงเกินค่ามาตรฐานในการทำน้ำประปา

สาขาวิชาชีววิทยา	ลายมือชื่อนักศึกษา _____
ปีการศึกษา 2545	ลายมือชื่ออาจารย์ที่ปรึกษา _____
	ลายมือชื่ออาจารย์ที่ปรึกษาร่วม_____
	ลายมือชื่ออาจารย์ที่ปรึกษาร่วม_____

SIRIKHAE PONGSWAT : THE USE OF PHYTOPLANKTON BIODIVERSITY FOR MONITORING WATER QUALITY IN RAMA IX LAKE, PATHUMTHANI PROVINCE. THESIS ADVISOR : ASSOC. PROF. SOMPONG THAMMATHAWORN, Ph.D. 260 PP. ISBN 974-533-215-1

PLANKTON BIODIVERSITY / MONITORING WATER / RAMA IX LAKE

A study of the biodiversity of phytoplankton was conducted in order to monitor water quality in Rama IX lake, Pathumthani province from February 2000 to January 2001.

The study found phytoplankton in both lakes and they were classified into 6 divisions, 12 orders, 28 families, 62 genera and 95 species. Assessment of water quality indicated that the first lake was mesotrophic to eutrophic. The phytoplankton which could be used to indicate mesotrophic to eutrophic status were *Cylindrospermopsis raciborskii* (Wolosz.) Seenayya & Subba, *Peridinopsis cunningtonii* Lemmermann, *Trachelomonas volvocina* Ehrenberg, *Peridinium* sp. 1 and *Ceratium furcoides* (Levander) Langhans. The second lake was oligotrophic to mesotrophic. The phytoplankton, which could be used to indicate oligotrophic to mesotrophic status, were *Cylindrospermopsis raciborskii* (Wolosz.) Seenayya & Subba, *Trachelomonas volvocina* Ehrenberg, *Peridinium* sp. 1, *Peridinopsis cunningtonii* Lemmermann, *Ceratium furcoides* (Levander) Langhans and *Anomoeoneis vitrea* (Grunow) Ross. Considering the water quality of both lakes as classified by surface water quality standards of Thailand, the water in Rama IX lake could be placed in the second category, but the water hardness exceeded the water quality standards for water supply.

School of Biology	Signature of Student _____
Academic Year 2002	Signature of Advisor _____
	Signature of Co-advisor _____
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ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

BOD $\quad$ = $\quad$ Biochemical oxygen demand

DO $\quad$ = $\quad$ Dissolved oxygen

MPN $\quad$ = $\quad$ Most Probable Number

ND $\quad$ = $\quad$ Non – detectable

NH_3-N $\quad$ = $\quad$ Ammonia-nitrogen

NO_3-N $\quad$ = $\quad$ Nitrate-nitrogen

NTU $\quad$ = $\quad$ Nephelometric turbidity unit

P $\quad$ = $\quad$ Probability

Ptot $\quad$ = $\quad$ Total phosphorus

SRP $\quad$ = $\quad$ Soluble reactive phosphorus

TDS $\quad$ = $\quad$ Total dissolved solids

CHAPTER I
INTRODUCTION

1.1 The importance of problems

Water is the essence of life on earth and totally dominates the chemical composition of all organisms. The ubiquity of water in biota, as the fulcrum of bio-chemical metabolism, rests on its unique physical and chemical properties. Humans use water for household consumption whilst agriculture uses water in cultivation and animal husbandry. Furthermore water is used for various purposes namely in industrial supply, transport, recreation, sports, power generation, commercial fisheries and etc. Monitoring of water quality suitable for each usage is therefore essential.

The parameters study of water quality can be done physically, chemically and biologically. The advantages of the physical and chemical study result in quick analysis and shorter time use. The disadvantages are higher costs and the validity of the analysis is restricted only to the day the test is conducted. On the other hand the biological study has proved to be of greater advantage because biological factors such as phytoplankton, zooplankton, benthos, aquatic plants and bacteria can be measured cheaply. In this process, expensive chemicals are not necessary and analysis results can be obtained fairly quickly. The water quality of previous days can also be detected. In addition, these biological factors are highly sensitive to even the slightest change of organic matter existing in the water.

In this investigation, phytoplankton are chosen as an indicator of water quality in Rama IX lake. The study of these phytoplankton are done parallel with the physical and chemical studies. Phytoplankton can serve as a good water quality indicator in standing water. Phytoplankton are microorganisms which drift in the water. They are able to photosynthesise because they have chlorophyll. There are various species, such as blue green algae, green algae, diatom etc. The suitability and benefits of using phytoplankton is that they indicate water quality because phytoplankton are high potential living organisms and they respond to chemical and physical changes in the habitat. Different environments or ecosystems determine the species of

phytoplankton that can be found. For example, some species grow in high nutrient water, other species flourish in low nutrient water. The presence of a particular species of phytoplankton indicates the quality of that water.

Furthermore, phytoplankton can be used as a good indicator and the objective of this research is to study the biodiversity of Rama IX lake as there has been little research on phytoplankton in Thailand published up to now. Some studies have been conducted in various universities and some organizations, for example, 1,700 species of blue green algae are known worldwide, however in Thailand only 700 species have been identified and it has been estimated that 1,000 species have still not been categorized. Another example is green algae of which over 7,000 species are well-known in the world whereas in Thailand only 1,500 species have been identified and over 1,000 are still undiscovered. (Thailand Country Study on Biodiversity, 1992).

Phytoplankton are important in many ways, for example they are producers in the ecosystems and play important roles in the foodchain, they can also be consumed as food such as *Spirulina* which is one genus of blue green algae. It has high protein which can be used as a food supplement. In agriculture, many blue green algae such as *Anabaena* and *Nostoc* which convert nitrogen from the air into nitrate are useful for the synthesis of proteins of plants. In medicine, chlorellin is extracted from *Chlorella* (one genus of green algae), it can inhibit the growth of the bacteria, *Staphylococcus aureas*. Furthermore phytoplankton can serve as an indicator of good water quality.

This research is based on a study of the biodiversity of phytoplankton in Rama IX lake, a man - made lake. It is one of His Majesty's Royal Projects to provide a water supply for the public in Pathumthani province and in some parts of Bangkok. It is a project with the cooperation of the Royal Irrigation Department, Chaipattana Foundation and related government offices. The capacity of this lake is about 16,100,000 cubic meters. It supplies water for growing rice and vegetables during the dry season. It also serves as storage for excess water during floods which reduces the damage caused by floods. During the dry season, the water from this lake is irrigated to different canals in Bangkok's suburbs in order to decrease water contamination in those canals. (โครงการส่งน้ำและบำรุงรักษารังสิตเหนือ, 2541). So, it is necessary to assess and monitor the water quality regularly.

The researcher hopes that this study will benefit other studies in biodiversity which will increase the data base on phytoplankton in Thailand and government offices concerned with the environment can use the species of phytoplankton as water quality indicators.

1.2 The objectives of study

1.2.1 To study the biodiversity of phytoplankton in Rama IX lake in Pathumthani province.

1.2.2 To study the correlation between physical, chemical and biological parameters of water quality according to the changes in phytoplankton in order to find out the trends for mornitoring water quality in terms of the biological quality of the water in Rama IX lake.

1.3 The hypothesis of study

The water resources of Rama IX lake have different physical, chemical and biological properties. They affect different species and the quantitatives of phytoplankton which can be regarded as water quality indicators. Furthermore, the different properties of water will be affected by the biodiversity of phytoplankton in this lake.

1.4 The scopes of study

1.4.1 The scope of the study area

Rama IX lake is located in Pathumthani province. It is a big lake and it consists of 2 parts.

1. The first lake covers an area of about 790 rai. (1 rai = 1,600 square meters)
2. The second lake covers an area approximately 1,790 rai.

The water samples of both lakes were collected vertically at 15 different levels of depth starting from the surface of the waters downward. Then water samples were collected at every one meter for the space of three meters down, after that every five meters until reaching the bottom of both lakes.

1.4.2 The scope of content

This study covered lake's morphometry, the correlation between physical, chemical and biological properties of the water resources based on the species and quantities of phytoplankton found in Rama IX lake. It is aimed at finding out how to used phytoplankton to indicate water quality. The result obtained from this study can reveal the biodiversity of phytoplankton in this lake.

1.4.3 The scope of time

Collection of water samples in the field and analysis of the water quality both in the field and in the laboratory had been investigated every 2 weeks per month from February 2000–January 2001.

1.5 Educational advantages

1.5.1 The biodiversity of phytoplankton can be estimated in Rama IX lake.

1.5.2 The physical, chemical and biological changes in the species composition in Rama IX lake reflect the variations in water quality.

1.5.3 The data obtained will be useful for improving the water quality in Rama IX lake and the related government departments. The data can be used for furthering related study and research of phytoplankton biodiversity as well as being used as a bioindicator.

1.6 Keywords: Biodiversity, Phytoplankton, Monitoring and Lake

Biodiversity is the variety of organisms considered at all levels from genetic variants belonging to the same species through arrays of species to arrays of genera, families and still higher taxonomic levels; includes the variety of ecosystems, which is comprised of both the communities of organisms within particular habitats and the physical conditions under which they live. (Wilson, 1992)

Phytoplankton are microscopic plants. They live in the upper layers of fresh and salt water environments, and are moved around by wind, waves and currents. They consist mainly of unicellular algae, such as diatoms. Because of their light requirements, they are found mainly in

the upper 5 to 100 m. of the water – the photic zone – into which light can penetrate. Containing chlorophyll, phytoplankton are capable of photosynthesis, and as primary producers they provide a base for aquatic food chains. Their nutrient requirements are met by the natural flow of nutrients into the ocean from the land, or by the upwelling of nutrient-rich waters from deeper parts of the ocean – for example, off the coast of Peru. A rapid increase in the availability of nutrients, particularly nitrates and phosphates, can lead to massive algal blooms, that can cause the release of toxins into the water and create serious environmental problems. During their seasonal blooms, phytoplankton also release dimethyl sulphide into the atmosphere in quantities sufficiently large to contribute to acid precipitation. Phytoplankton are also involved in the carbon cycle, through their consumption of carbondioxide (CO_2) during photosynthesis, thus helping to maintain the atmosphere's oxygen/carbondioxide balance (Kemp, 1998).

Monitoring continous or regular assessment of the quality of emissions or effluents or sources that lead to these, or specific places in the environment possibly subjected to them. For the latter, this can involve both chemical and biological assessment (Calow, Falk, Grace, Moore Shorrocks and Stearns, 1998).

A lake is a relatively isolated stretch of water which fills a ground depression. From this point of view, a lake consists of two distinct parts – the basin and the water body. Lakes may have a very wide range of surface areas, from a few thousands of square meters to hundreds of thousands of square kilometers (e.g. the Caspian Sea, the largest lake in the world, 371,000 km^2). Natural lakes cover some 2.7 million km^2 (1.8% of the Earth's surface) encompassing a water volume of about 176,400 km^3 (0.013% of the planetary water volume). Lakes may be grouped into natural lakes, with a great many genetic types of lake basin (formed by tectonic, volcanic, glacial, karst, fluviatile, marine and wind action, etc.), and artificial lakes, created to meet various needs (power generation, fresh water and industrial water supply, navigation, fish farming, flood control, etc). (Herschy and Fairbridge, 1998).

1.7 Details of the study area

1.7.1 Study area

This study area is Rama IX lake. The lake is located at $14^O\ 02'$ latitude and 100°

44$'$ N. longitude in Amphur Khlongluang and Amphur Thanyaburi, Pathumthani province. The entrance of the lake can be approached from 2 directions, firstly from Rangsit – Nakornnayok road on highway number 305 along North Khlong 5 about 2 kilometers from the highway. Secondly along North Khlong 6 about 2.3 kilometers from the highway. The lake is located 40 metres above sea level. Rama IX lake is a big lake and it consists of 2 sections.

1. The first lake receives water from Khlong 6, and it covers an area of about 790 rai. The capacity of this lake is 6,000,000 cubic meters.

2. The second lake receives water from Khlong 5, and it covers an area of approximately 1,790 rai. The capacity of this lake is 11,100,000 cubic meters (โครงการส่งน้ำและบำรุงรักษารังสิตเหนือ, 2541).

Many government offices are located around Rama IX lake, such as Technopolis, Rajamangala Institute of Technology, National Aquaculture Genetics Research Institute, Thanyaburi Women Correctional Institution for Drug Addicted Prisoners, Department of Corrections Ministry of Interior, Pathumthani Skill Development Centre, Rangsit Home For Babies, Public Welfare Development Center, Pathumthani Central Prison, Institute of Admistration Development, Queen Sirikit's 60th Anniversary Stadium. In addition there are many residential homes around the lake.

1.7.2 Climate of the study area

The climate of the area of Rama IX lake consists of 3 seasons over the year. The rainy season (May–The middle of October) is influenced by southwest monsoons. The cold season (The end of October–February) is influenced by northeast monsoons and the summer season (March–May). The data of climate of the study area as shown in Table I-1; Appendix I.

1.7.3 Precipitation

The amount of precipitation during 2000–2001 were obtained from Pathumthani Rice Research Center. It is located at the south of Rama IX lake. The maximum precipitation (221.40 mm^3) occurred in May and the minimum (0.20 mm^3) fell in November as shown in Table I-2; Appendix I.

1.7.4 The various uses of the study area

1.7.4.1 The water from Rama IX lake supplies water for growing rice and vegetables during the dry season in areas around this lake and nearby environs.

1.7.4.2 Rama IX lake has also served as storage for excess water during floods.

1.7.4.3 The water from this lake is irrigated to different canals in Bangkok's suburbs in order to decrease water contamination in those canals.

1.7.4.4 This lake is also used for recreation by the general public.

CHAPTER II
LITERATURE REVIEW

2.1 Phytoplankton knowledge

Phytoplankton are living organisms forming one group of algae which drift in the water currents and they do not attach themselves to any substrate. Autotrophic organisms are thallophytes (plants lacking roots, stems and leaves) that have chlorophyll a as their primary photosynthetic pigment and lack a sterile covering of cells around the reproductive cells (Van Dan Hoek, Mann and Jahns, 1995; Vymazal, 1995).

Phytoplankton consist of small algae composed of 7 divisions i.e. Cyanophyta (blue green algae), Chlorophyta (green algae), Bacillariophyta (diatoms), Chrysophyta (yellow-green algae), Pyrrophyta (dinoflagellates), Euglenophyta (euglenoids) and Cryptophyta (cryptomonad) (Wetzel, 1975). Phytoplankton have several types such as single cells, colony, filament, movement by using flagella or the current (กาญจนภาชน์ ลิ่วมโนมนต์, 2527; ลัดดา วงศ์รัตน์, 2538). Phytoplankton can be found all over the world. They can exist in temperate regions and tropical regions however the effects of different altitudes are not clear as to the distribution of phytoplankton. Some species of phytoplankton i.e. *Cylindrospermopsis raciborskii* and *C. philippinensis* can be found in tropical regions (Peerapornpisal, 1996), but some species of phytoplankton can be found in temperate lakes such as *Asteroinella formosa* (Talling, 1987).

2.2 The effects of the environments on the growth of phytoplankton

2.2.1 Physical environment

2.2.1.1 Lake's morphometry

A lake's morphometry is a function of underwater coutour lines, the shape of the lake, and its geologic origin. The lake's morphometry is basic to its structure; for example, deep, steepsided lakes are quite different in almost all respects from shallow ones (Horne and Goldman, 1994). The geomorphology of lakes is intimately reflected in physical,

chemical and biological events, within the basins and plays a major role in the control of a lake's metabolism, within the climatological constraints of its location (Wetzel, 1975). The importance of data of the lake's morphometry helps us to know the characteristics and the origin of the lake. The change in morphometry of the lake caused by its age affects all living organisms present in the lake (นันทนา คชเสนี, 2539). Lake's morphometry relates to the climate factor and other external factors such as the depth of the lake, the volume of the lake, the location and the water catchment area (Peerapornpisal, 1996). The shape and the size of the lake play an important role in the distribution of phytoplankton. Other factors to be considered concerning the distribution of phytoplankton in natural water resources are: the level of water and the outgoing & incoming water to and from other water resources. In the small lakes there is little change in species composition throughout the year, but the changes of phytoplankton in larger and deeper lakes are extreme. Thermal stratification and water condition divided vertically play an important role in the distribution of phytoplankton (ลัดดา วงศ์รัตน์, 2538). Furthermore, Talling (1995) said that the essential factor for a study of limnology in tropical regions is a sound knowledge of geology which relates to the data in lake morphometry. Others have commented on the results of exposure to the destabilizing effects of wind, by influencing water – column stability, plays a major role in determining seasonal changes in the phytoplankton composition of lakes the example was from Julius and Moondarra lake in Australia (Boland and Griffiths, 1996).

2.2.1.2 Color

The observed color of natural water is the results of light being scattered upward from the water after it has passed through the water to various depths and undergone selection absorption en route. Because molecular scattering of light in the water is a function of the fourth power of the frequency, observed light and therefore color is greater for shorter than for longer wavelengths, and blue dominates in the visible portion of the spectrum. Scattering of light from particulate suspensoids; however, is increasingly less selective with increasing particle size (Hutchinson, 1957 quoted in Wetzel, 2001). The color of the water is formed by dead plants and dead animals. The decomposition of the plants and the animals gives off tannin, humic acid and humates which cause the water to be flaming yellow. In addition, the color of the water can also be derived from ions of metals such as Fe, Mn, etc. present in the water and from industry wastewater. There are two types of colors in the water : true color and apparent color. True color

is caused by protein, fat and carbohydrate from the decomposition. Apparent color is formed by different particulate materials present in the water such as phytoplankton, zooplanktons and non-living organisms (กรรณิการ์ สิริสิงห์, 2525; เปี่ยมศักดิ์ เมนะเศวต, 2538; มั่นสิน ตัณฑุลเวศน์, 2538). The color of the water is normally checked because it shows productivity, the environment and suspension in the water resources. In general the water of water resources is yellow to brown. However, the color of water may change according to the environment, type, quantity, the concentration of solution, suspension and light quality, one example would be if the water contains limestone or calcium carbonate it will be green. In general, the yellow to brown water shows rich and high productivity because it has high organic matter. Green to blue water shows low productivity, because it has low organic matter (ไมตรี ดวงสวัสดิ์ และจารุวรรณ สมศิริ, 2528). Dark green and more turbid water shows dense phytoplankton (blue green algae) growth and eutrophication or nutrient enrichment (nitrogen and phosphorus) (Harper, 1992).

2.2.1.3 Light

Light is energy. It is something capable of doing work and capable of being transformed from one form into another. It can neither be created nor destroyed (Wetzel, 1975). Light is an essential factor for photosynthesis of phytoplankton. When sunlight penetrates the water. The water absorbs some light radiation and phytoplankton use the remaining light for photosynthesis (Shirota, 1966). Each phytoplankton requires different light intensity (Smith, 1950). Phytoplankton can use light wave length 400-650 mm for photosynthesis. The rate of photosynthesis is highest on the surface of the water and decrease with the increasing depth of the water (Moss, 1980). When the light intensity is optimum, phytoplankton will grow well but in case of high light intensity phytoplankton will move in a vertical migration into the deep areas of the water (Lorenzen, 1963). From the study of Green (1968) in a laboratory using stable light intensity, *Euglena* moved to the surface of the water for brief periods, then it gradually sank using regular movements. When there was no light. *Euglena* sank into the mud and didn't rise anymore. Several possible advantages of vertical migration have been postulated. These include avoiding nutrient limitations by obtaining access to deeper reserves of nutrients (Jones, 1991) and avoiding high surface light intensities (Heaney and Furnass, 1980). From the study of Whittington, Sherman, Green and Oliver (2000), a study of Chaffey reservoir in subtropical Northern New South Wales, Australia revealed that at high incident irradiance, *Ceratium*

migrated downwards from the near surface waters, avoiding the high-light induced. Overnight deepening of the surface mixed layer by convective cooling produced homogenous distributions of *Ceratium Ceratium* migrated towards the surface from suboptimal light intensities at a velocity of 1.6-2.7 x 10^{-14} ms^{-1} Regarding the measurement of transparency, a study showed that an estimation of 16% of the sunlight can penetrate into the water (Smith, 1950). The water resources have transparency value from 30-60 cm it is optimum for the growth of aquatic animals. If this value is lower than 30 cm It shows, the water is very cloudy or it has too many phytoplankton. This will cause a decrease in the amount of oxygen. If this transparency valve is higher than 60 cm It shows low productity of the water resources. (ไมตรี ดวงสวัสดิ์ และ จารุวรรณ สมศิริ, 2528). The transparency effects on the growth of some phytoplankton are varied, Some species may not be able to grow whereas others can grow well only on the surface of the water (Hynes, 1970). However, some species of phytoplankton can grow in low light conditions such as *Batrachospermum, Cladoflora* (Darley, 1982).

2.2.1.4 Temperature

Changes in temperature of the water resources are due to the sunlight penetrating the water. This results in a change of light energy to heat energy. It causes different temperatures in the water (เปี่ยมศักดิ์ เมนะเศวต, 2539). Deep water oxygen depletion is a function of lake productivity, morphometry and water temperature (Vollenwieder & Janus, 1982). Rates of dissolved oxygen depletion in the hypolimnion tend to increase with the trophic status of the lake (Wetzel, 1983). Deoxygenation is attributed primarily to the reservoir's elevated temperatures 25-30°C and its effect on microbial metabolism. The effect of temperature on hypolimnetic dissolved oxygen depletion rates in lakes is probably more significant than either morphometry or productivity (Townsend, 1995). The temperature is essential for any increase and decrease of the rate of growth and reproduction of algae (Smith, 1950). Various algae will grow well in different temperatures, such as diatom will grow well at 20-28°C, green algae will grow in abundance at 30-35°C and blue green algae will flourish at 34-35°C (Welch, 1952). Furthermore, Pyrrophyta such as *Gymnodinium* can be found in high radiation water resources, and it can grow well in high temperature water (Bunkhreuang, 1974, quoted in Keolek, 1983). Phytoplankton will grow well at optimum temperature (25-35 $^{\circ}$C) (Boney, 1975).

2.2.1.5 Turbidity

Turbidity in the water is caused by suspended matter such as clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds and plankton and other microscopic organisms. Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample (APHA, AWWA and WPCF, 1992). In running water such as rivers, brooks there is more turbidity than standing water (Hynes, 1970). The light can penetrate only a little into the water. It causes low algae growth because the algae has low photosynthesis (Hobson, 1966). Furthermore, the cloudy water causes a decrease in productivity of the water resources. (ไมตรี ดวงสวัสดิ์ และจารุวรรณ สมศิริ, 2528). Turbidity limits the growth of benthic algae in both freshwater and the sea (Round, 1973). The rate of turbidity will also increase or decrease the number of diatoms. If the water is very turbid there will be less diatoms present although the river has more nutrients (Kaweeka, 1980). The increase in human activities, particularly urbanization agricultural and industrial activities has led to increasing eutrophication i.e. to an increase of nutrients (NO_2, NO_3, NH_4, PO_4), the proportions of which depend on the type of wastes, and a higher level of suspended solids make the water increasingly turbid (Lundin and Linden, 1993).

2.2.1.6 Conductivity

Conductivity is a measure of the dissolved salts in water (Daniels, 2001) or conductivity is a measure of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions; an their total concentration , mobility and valence; and on the temperature (APHA, AWWA and WPCF, 1992). Conductivity in the water is favorable at 25°C. Factors that affect the value of conductivity are pH, the chemical characteristics of the soil, pecipitation, landscape conditions and the activity of humans (ไมตรี ดวงสวัสดิ์ และจารุวรรณ สมศิริ, 2528). This value doesn't indicate the type of substances in the water, but shows only the increase and decrease of ion solutes in the water. If the value of conductivity increases, this indicates an increase of ionization of substances, correspondingly, if the value decreases, it means a decrease of ionization of substances in the water (กรรณิการ์ สิริสิงห์, 2525). In natural water resources have a conductivity from 150-300 μs/cm (ไมตรี ดวงสวัสดิ์ และจารุวรรณ สมศิริ, 2528).

2.2.2 Chemical environment

2.2.2.1 pH

Measurement of pH is one of the most important and frequently used tests in water chemistry. Practically every phase of water supply and wastewater treatment, e.g., acid – base neutralization, water softening, precipitation, coagulation, disinfection, and corrosion control, is pH–dependent (APHA, AWWA and WPCF, 1992). pH is defined as the negative log of the hydrogen–ion concentration. An acid solution is one with pH of 0 to 7 and alkaline from 7 to 14. Most lakes have a pH of 6 to 9; naturally acid lakes have a pH of 5 to 6; and leachate from mine tailings can be as low as pH 2. Some very eutrophic lakes and some soda lakes have pH valves as high as 10 to 11.5 (Horne and Goldman, 1994). The pH of the water can control the activity of living organisms in the water (ไมตรี ดวงสวัสดิ์ และจารุวรรณ สมศิริ, 2528). Optimum pH (6-8) is suitable for living organisms in the water (นันทนา คชเสนี, 2539). The value of pH is very important for the variables of each species and the quantity of phytoplankton. In acid water, there are dominant phytoplankton i.e. desmid but there are also some species of blue green algae such as *Scytonema ocellatum, Hapalosiphon pumilus* and *Chroococcus prescotti* and there are a few green algae filaments such as *Microspora* and *Oedogonium* In water resources with a pH lower than 4.5 blue green algae could not be found but there were some species of desmid in the water (Prescott, 1962). In studies of species composition, Brock (1973) reported that the blue green algae were never dominant in acidic lakes. Phytoplankton communities in acidic lakes commonly show increased biomass of dinoflagellates, especially *Peridinium* spp. and *Gymnodinium* spp. (Yan, 1979). Yan and Stokes, (1978) reported that there was an increase in the biomass of chrysophytes such as *Dinobryon* spp. and *Chromulina* spp. (Hendrey, 1980) and occasionally cryptophytes such as *Cryptomonas* spp.. Other reports indicate that diatoms such as *Eunotia exigua, Pinnularia termitina, Frustulia rhombodies, Tabellaria fenestrata, Tabellaria flocculosa, Tabellaria quadriseptata, Nitzschia* spp. and *Rhizosolenia eriensis* were present (Hendry and Wright, 1976). Scagel (1967) studied the distribution of diatoms related to pH of the water. In acidic water (pH = 4-6.5), there were many species of diatoms but less in quantity, whereas in alkaline water (pH = 7.5-9) each species was found in abundance but there were very few species of diatoms. In low acidic water (pH = 6-6.50) some species of phytoplankton were found such as *Botryococcus braunii, Ceratium hirundinella* and

Dinobryon was found in acidic water (pH = 4-4.8) (Round, 1973). Furthermore some species of phytoplankton can tolerate water with pH 3-5 i.e. *Euglena* (Round, 1981).

2.2.2.2 Alkalinity

Alkalinity of a water is its acid–neutralizing capacity (APHA, AWWA and WPCF, 1992). The property of alkalinity is usually imparted by the presence of bicarbonates, carbonates and hydroxides, and less frequently in inland waters by borate, cilicate, and phosphates. The CO_2-HCO_3^- - CO_3^- equilibrium system is the major buffering mechanism in freshwaters (Wetzel, 1975). Bicarbonates and carbonates are mostly ions in the water and they function as a buffer in the water. Bicarbonates and carbonates are found in abundant in natural water while hydroxide levels are rather low. The value of these three alkalines combined is called total alkalinity. In natural water alkalinity varies between 10-200 mg.l^{-1} (นันทนา คชเสนี, 2539). Alkalinity measurements are used in the interpretation and control of water and wastewater treatment processes (APHA, AWWA and WPCF, 1992). Hyne (1970) reported that some species of algae can adapt to alkaline water and acid water such as *Lemanea*, *Stigeoclonium* and *Batrachospermum* but *Phormidium, Cladophora glomerata* can grow only in alkaline water. In addition in running water of alkaline condition many species of diatom i.e. *Amphora ovalis, Calonies amphisbaena, Navicula crytocephala, Navicula gregaria, Navicula radiosa, Cymatopleura soleci, Cymtopleura* sp., *Gyrosigma acuminatum* and *Nitzschia sigmoidea* whereas in acidic streams *Eunotia* sp., *Actinella punetata, Frustulia rhomboides, Pinnularia* sp. and *Surirella* sp. can be found.

2.2.2.3 Dissolved oxygen (DO)

Dissolved oxygen is obviously essential to the metabolism of all aquatic organisms that possess aerobic respiratory biochemistry (Wetzel, 1975). Both plants and animals have to use oxygen for respiration (Horne and Goldman, 1994). Furthermore, the amount of dissolved oxygen can be used as an indication of the quality of water resources (เปี่ยมศักดิ์ เมนะเศวต, 2539). And the content of dissolved oxygen can act as a parameter reflecting the degree of organic pollution (Loigu and Leisk, 1996). Dissolved oxygen comes from the air or in the last product of photosynthesis of aquatic plants and phytoplankton. Dissolved oxygen is used for respiration and the metabolism of inorganic compounds. In general the optimum of dissolved oxygen value of 5 mg.l^{-1} is suitable for living organisms in the water but dissolved oxygen at a

low of 3 mg.l^{-1} is dangerous for living organisms in the water (นันทนา คชเสนี, 2539). The amount of dissolved oxygen depends on many factors such as temperature, the pressure of the air the velocity of the water and the rate of respiration of living organisms in the water resources (Maitland, 1978). Phytoplankton use different amounts of oxygen to live such as *Achnanthes minutissima* needs high oxygen levels for survival but *Navicula* s*eminulum* and *Nitzschia amphibia* can adapt to low oxygen levels (Patrick, 1977). In highly polluted water the amount of oxygen is very low. If the amount of oxygen cannot be measured algae will not be found (Round, 1973), except for the diatoms such as *Nitzschia* and *Pleurosigma* and etc. They are capable of producing slime to enclose their cells (Green, 1968).

2.2.2.4 Biochemical oxygen demand (BOD)

BOD is the quantity of oxygen utilised expressed in mg.l^{-1}, by the effluents during the microbial degradation of its organic content (Abel, 1989). This value is used to determine the relative oxygen requirements of wastewaters, effluents, and polluted waters (APHA, AWWA, and WPCF, 1992). The BOD shows the level of contamination or waste water by organic substances. If the water has high levels of BOD, it shows there is a corresponding high level of organic substances in the water. BOD values are generally useful as indicators of the organic loading of water. They typically range from one or two milligrams per litre in unpolluted water, to 50,000 milligrams per litre or more in effluents or severely polluted receiving waters (Abel, 1989). Furthermore, BOD is a good indicator of organic pollution in rivers (Loigu and Leisk, 1996).

2.2.2.5 Hardness

The hardness of a water is governed by the content of calcium and magnesium salts, largely combined with bicarbonate carbonate (temporary hardness or carbonate hardness) and with sulfates, chlorides and other anions of mineral acids (permanent hardness or non carbonate hardness) (APHA, AWWA and WPCF, 1992; Wetzel, 1975). Temporary hardness can be removed by boiling. The second type is permanent hardness a result of sulphates and chlorides in the water such as $CaSO_4$, $CaCl_2$, $MgSo_4$ and $MgCl_2$. Permanent hardness cannot be allieviated by boiling and chemical methods have to be used (มั่นสิน ตัณฑุลเวศม์, 2538; Wetzel, 1975). In natural water resources, total hardness affects the rate of productivity of the water resources. Soft water does not preserve CO_2 which is used in photosynthesis of plants. The

rate of productivity of water resources will increase when total hardness does not exceede 130 ppm of $CaCO_3$. Total hardness will cause a decrease in productivity in the water resources (สถาบันประมงน้ำจืด, 2521). Water hardness affects species and the quantity of phytoplankton in water resources. In high levels of water hardness, green algae can be found in Order Volvocales i.e. *Volvox* and *Pandorina*. In high calcium water in tropical regions, yellow-green algae exists in the form of the coccolithophorids group (Prescott, 1962) but in low water hardness mainly desmids and some species of blue green algae and green algae can be found (Champman, 1969). Furthermore, calcium has been shown to stimulate the growth of diatoms in oligotrophic waters (Chu, 1942). Pearsall (1922 and 1923) stated that if monovalent : divalent ratio (M : D) < 1.5, conditions would be favourable for diatoms. If the ratio is M : D > 1.5, desmids and some crysophytes would benefit.

2.2.2.6 Nutrients

Nutrients are important and essential for the growth of phytoplankton. The increase of nutrients in the water depends on the circulation of water which beings the nutrients up from the bottom of the lake to the surface and input nutrients from the external system to the water resources. Macronutrients are C, H, O, N, P, K, S, Si, Mg, Na and Ca whereas Cl and Fe, Mn, Zn, Cu, Mo and Bo are micronutrients. They are consumed in small amounts by phytoplankton but they are essential nutrients. In nature, nutrients come from rain exposed minerals, stone and soil. Nitrogen and phosphorus are essential nutrients for the growth of algae (Harper, 1992; Talling, 1962; Wetzel, 1975). In addition numerous studies have shown that phytoplankton's taxonomic composition and species diversity change with increasing nutrient levels (Lazerte and Watson, 1981), and that these changes are related to differences among taxa in nutrient uptake, storage, growth and loss rates (Kalf and Knoechel, 1978).

2.2.2.7 Nitrogen

Nitrogen is a very essential nutrient. Phytoplankton can use nitrogen for protein and amino acid synthesis. Phytoplankton can consume various types of nitrogen such as nitrate, ammonia, urea and amino acid (Carpenter, Remsen and Watson, 1972). Phytoplankton can use nitrate and amonia more than other forms (Keeney, 1970). Nitrogen limitations are more likely to occur in tropical lakes that stratify (Lewis, 1990). Similar to conditions in the ocean, nitrogen limitation in deep tropical lakes is explained by the dependence of phytoplankton to

recycled nutrients. Especially in lakes with high flushing rates and low N:P ratios in the anoxic intermediate and deep waters, tropical lakes which are dependent on internal cycling of nutrients are more frequently N limited (Hecky & Kling, 1981 and Hecky & Kilham 1988). Postius and Boger (1998) suggest that some picocyanobacteria (0.2-2 µm. cell diameter) can overcome nitrogen–limitation by fixing atmospheric nitrogen. In natural water resources, some species of diatoms such as *Melosira varians*, *Synedra ulma* and *Navicula viridis* can grow in high nitrate water (2-3 mg.l^{-1}) but *Navicula cryptocephala* and *Nitzschia palea* can adapt to waste water consisting of high nitrogen phosphorus and carbon (Patrick, 1977). Ahlgreen (1967) said that *Microcystis* sp. bloomed in the nitrogen-deficient environment, but *Planktothrix agardhii* dominated in nitrogen–sufficient and rather phosphorus–deficient waters. Coexistence of *Chaetoceros elmorei*, *Cyclotella quillensis* and *Cymbella pusilla* occurred at the two lowest N/P ratios (6:1) but *Anomoeoneis costata*, had the highest nitrogen requirements from saline lakes in the Northern Great Plains of North America (Soros and Fritz, 2002). In general, water resources have the mean ratio of important nutrients i.e. 40C:7N:1P per 100 dry weight. This ratio is the optimum ratio for phytoplankton and aquatic macrophytes (Wetzel, 1975). Nutrient supply ratios did not directly increase algae abundance and biomass, but were responsible for controlling the species composition of the phytoplankton. High total N:P ratios were found to result in an increase in cryptophyte and chrysophyte populations and coupled with high Si:P ratio resulted in a marked increase in diatoms. (Anton, Kusnan, Yusoff and Ong, 1995) A high N:P ratio (nitrogen concentration of 0.6 mg.l^{-1} and reactive phosphate of 0.03 mg.l^{-1}) favors the development of green algae and suppresses blue–green algae in the water (Smith, 1983).

2.2.2.8 Phosphorus

Phosphorus is essential for all living organisms; living matter contains about 0.3 percent dry weight phosphorus. It plays an irreplaceable structural like role in the genetic materials DNA and RNA. In adenosine triphoshpate (ATP) phosphorus is involved as short term energy "currency" in biochemical reactions and it is a component in the phospholipid membranes of cell walls. So phosphorus is a common growth limiting factor for phytoplankton in lakes because it is often present in low concentrations. Phytoplankton can use only soluble phosphate for growth (Horne and Goldman, 1994). Furthermore phosphorus has been reported as being limited in most temperate lakes; however, there is growing evidence that nitrogen plays an

important role in structuring phytoplankton communities in tropical water bodies (Vincent, Wurtsbaugh, Vincent and Richerson, 1984) More recently, nutrient supply ratios have been shown to influence algae biomass in lakes and that this effect was greatest at high concentrations of total phosphorus (TP). (Downing and McCauley, 1992). In oligotrophic lakes (<10 μg TP l^{-1}), the low total phytoplankton biomass is fairly evenly divided among Cryptophyceae, Chryso-phyceae and Bacillariophyceae but in mesotrophic lakes (10–30 μg TP l^{-1}) diatoms, cryptophytes and green algae were found. Finally, in higly eutrophic regions (>~60 μg TP l^{-1}), individual taxonomic groups diverge, and average total biomass is progressively dominated by fewer groups. Most conspicuously blue green biomass exhibits the most rapid increase in this region. (Watson, McCauley and Downing, 1997). From a study of vertical movements of cyanobacteria during summer stratification in Cauldshiels Loch, a small dimictic temperate lake in Scotland, it was found that cyanobacteria filaments moving from the hypolimnion were translocating phosphorus to the epilimnion. (Head, Jones and Bailoy-Watts, 1999). Furthermore, algae have developed special mechanisms to reduce the severity of phosphorus limitation. When supplies are low, phytoplankton can excrete extracellular enzyme called alkaline phosphatases, which can cleave to the chemical bond between PO_4 and organic molecules. In times of high PO_4, such as early spring, it can store excess phosphorus in polyphosphate granules. This luxury consumption allows the cell to divide several times when external PO_4 supplies are depleted (Horne and Goldman, 1994).

    2.2.3 Biological environment

        2.2.3.1 Primary production

            Primary production is the quantity of new organic matter created by photosynthesis (or chemosynthesis), or the stored energy which this material represents (Wetzel, 1975). The major study of primary productivity of water resources stress the rate of photosyn-thesis of phytoplankton (นันทนา คชเสนี, 2539). Primary production can be estimated fairly well from changes in biomass over time (Wetzel, 1975). The value of primary production can indicate the trophic type of resevoir i.e. this valve exceeds 1,000 mg Cm^{-2} day^{-1} in eutrophic reservoirs, 300-1,000 mg Cm^{-2} day^{-1} in mesotrophic reservoirs and lower than 300 mg Cm^{-2} day^{-1} in oligotrophic reservoirs (Wetzel, 1975). The planktonic cyanobacteria *Trichodesmium* spp. were abundant throughout in a tropical coastal ecosystem, Zanzibar, Tanzania Africa. *Trichodesmium*

spp. can fix nitrogen and release it as dissolved organic nitrogen (DON). This DON release is likely to stimulate microbial activity and phytoplankton primary production (Lugomela, Wallberg and Nielsen, 2001).

2.2.3.2 Chlorophyll a

The algal have three kinds of photosyntetic pigment:chlorophylls, carotenoids and phycobiliproteins or phycobilins. Chlorophylls are the basic pigments involved in light absorption and photochemistry in algae, plants and photosynthetic bacteria (Vymazal, 1995). The algae have four types of chlorophyll-a, b, c and d (Vymazal, 1995). Chlorophyll a is the primary photosynthetic pigment of all oxygen–evolving photosynthetic organisms and is present in all phytoplankton (Wetzel, 1975). The other algal chlorophylls have a more limited distribution and function as accessory pigments (Vymazal, 1995). The charactheristic of chlorophyll a is its solubility in alcohol, diethyl ether, benzene, acetone and its insolubility in water. The chemical formula is $C_{55}H_{27}O_5N_4Mg$ (Fogg, 1975; Vymazal, 1995). Furthermore, it is the most abundant photosynthetic pigment and it is relatively easy and quick to quantify. Consequently, its concentration is used extensively for estimating phytoplankton biomass (Vöroš and Padisk, 1991). The chlorophyll content of phytoplankton is usually about 0.5-1.5 percent of the dry weight. There is considerable variation in the content of chorophyll a and b in Chlorophyceae. The former is the dominant. Others groups except chlorophyceae contain only chlorophyll a , but the chlorophyll a present is less than 1 percent of dry weight (most frequently the analyses range between 0.1-0.3 percent) (Round, 1973). Chlorophyll a is a majority pigment in cells of phytoplankton. So chlorophyll a is commonly used as an indication of the productivity of water resources (ลัดดา วงศ์รัตน์, 2538). Estimation of trophic status and saprobity of the reservoir was based on phytoplankton biomass, species composition and chlorophyll content. An increase in saprobity and the inverse relationship between chlorophyll, biomass–ratio and water transparency demonstrate progressive eutrophication in the central part of the reservoir (Korneva and Mineeva, 1996). Sarvala, Helminen, Saarikari, Salonen, and Vuorio, (1998) reported that in lake Pyhäjärvi, late summer chlorophyll concentration was predictable from the amount of phosphorus in the water, phytoplankton chlorophyll showed positive correlation with both total phophorus in the water and planktivorous fish abundance.

2.2.3.3 Coliform bacteria

Coliform bacteria are the facultative, gram negative, rod-shaped, non-spore forming bacteria that can ferment lactose with gas production within 48 hours at 35°C (Abel, 1989; Bott, 1973; Horne and Goldman, 1994). Bacteria have been used in the assessment of water quality largely to indicate the presence of fecal pollution, and the reliability of coliform detection has been of great benefit to public health (Ahas, 1989; Bott, 1973). Members of the coliform group are normally present in large numbers in the fecal flora of warm–blooded animals, whereas only a small percentage of the population will carry pathogens at a given time. In addition, techniques for the isolation and identification of pathogens are less amenable to routinization than those used for coliforms. Therefore, coliform detection is used to indicate fecal pollution and potential exposure to pathogens (Bott, 1973). Distribution of bacteria in the water resources can be studied and indicate water quality especially the distribution of intestinal bacteria i.e. *Escherichia coli* and *Enterobacter aerugenus* etc. (NWC, 1983). WHO (1971) determined the standard of coliform bacteria in the water 2.2 cell/water 100 ml., total bacterial plate count which incubate at 37°C not exceeding 500 colony/ml. at water with no indication of *E. coli* From the study of รัฐภูมิ นิลคูหา และอุษา กิตติอนงค์, 2540, the monitoring water quality in Rama IX lake and underground water in the center of Rajamangala Institute of Technology from October 1997–Febuary 1998 *E. coli* was found in both water resources, *E. coli* were found at a mean <3 (MPN/ml) from every sample point which meant it exceeded the standard limits of underground water when used for household comsumption (not find *E.coli*). The biological analysis of water quality using phytoplankton and coliform bacteria was carried out in Ang Kaew Reservoir, Chiang Mai University from April, 1996 to March, 1997. The coliform bacteria was found to be between 23-1,100 MPN/100 ml. indicating the water quality to be in the second category or lower (Chorum, 1998). The analysis of water quality using phytoplankton and coliform bacteria including some physical and chemical properties of water in Huai Mae Yen Reservoir, Chiang Mai, Thailand were caried out from June to September, 1998. Assessment of the water quality on the trophic level indicated that the reservoir was oligotrophic to mesotrophic. The coliform bacteria ranged from 4-$\geq$ 2,400 (MPN/100 ml.) during of the sampling (Wannasai , 1999).

2.3 The study of the biodiversity of phytoplankton in water resources

Studied of biodiversity of phytoplanktion have been conducted for over 100 years. Thompson, the first limnologist studied the quantity of phytoplankton by using a plankton net at Cork Island, Island (Thompson, 1959). The first publication of a phytoplankton study in Thailand was written by Schmidt (1900-1916). He published "Flora of Koh Chang" based on materials collected by the Danish Expedition to Siam 1899-1900, in which 161 genera, 1001 speicies, 287 varieties and 63 forms of Cyanobacteria, Chlorophyta and Chromophyta were reported (ลัดดา วงศ์รัตน์, 2542). Since 1974, Thai scientists have researched increasingly the study of biodiversity of phytoplankton, including studies of the environment and environmental impact assessment (สรวิศ เผ่าทองสุข, 2543). The phytoplankton of most of the world's lakes are subject to strong seasonal influence. In the temperate and polar zones, there is great contrast between summer and winter in the tropical areas between the ranging and dry seasons (Goldman and Horne, 1983). In temperate latitudes, the growth of phytoplankton depends on the seasonal cycle. The driving force and mechanisms of seasonal changes are related to variations in the physical, chemical and biotic environment, e.g. changes in solar irradiance and nutrient levels (Harris, 1986). However, in tropical latitudes, the seasonal succession of phytoplankton species is noticeably weaker than in temperate latitudes (Harris, 1986, quoted in Peerapornpisal, 1996). It seems that the growth of phytoplankton in tropical latitudes depends on ambient nutrient levels more than on other environmental factors (Morris, 1980).Minimal seasonal variation in day length and heat income does not prevent remarkable phytoplankton seasonal cycles in the tropics, where the fluctuations in phytoplankton biomass and composition are related mainly to changes in hydrological and hydrographical conditions, including variations in water level in lakes (Ibañez, 1998; Train and Rodrigues, 1998).

Rott (1983) studied the phytoplankton species composition of Parakrama Samudra, an ancient man-made lake in Sri Lanka. The algae flora showed a total number of approx. 84 different taxa. The taxonomic groups most rich in species were Chlorococcales with 30, Cyanophyceae with 22 and Zygnemaphyceae with 11 diffferent taxa. The dominant species were *Microcystis* sp. *Anabaenopsis raciborskii. Melosira granulata* and a *Mougeotia* sp.. Kebede and Belay (1994) studied the species composition and phytoplankton biomass in a tropical African

lake (Lake, Awassa, Ethiopia) from September 1985 to July 1986. A total of 100 phytoplankton species were identified with 48% of the taxa represented by green algae, 30% by blue green algae, 11% by diatoms, and the rest by chrysophytes, dinoflagellates, cryptomonads and euglenoids. The dominant phytoplankton species were *Lyngbya nyassae*, *Botryococcus braunii* and *Microcystis* species. A study of planktonic centric diatoms from the Volcanic lake, Taal, Philippines was conducted by Rott, Kling and Perez, 2001 from 26 February to 4 March 1999. The dominant phytoplankton were found to be centric diatom. Secondary components of the phytoplankton consisted of flagellates (*Ceratium furcoides*, *Rhodomonas minuta* and *Cryptomonas marssohii*), several small coccals, capsal blue–green and green algae. A large portion of the dominant centric diatom taxa (*Thalassiosira visurgis*, *Actinocyclus normanii*, *Cyclotella* cf. *meneghiniana* and *Thalassiosira weissflogii*) are known to be halophilic (or moderately salt–tolerant) and are most commonly found in brackish waters or in downstream (potomal) sections of large rivers. However, centric diatom are common components of phytoplankton found in many tropical lakes, where in many cases *Aulacoseira*–species (often *A. granulata*) are dominant, under favourable couditions (Dokulil, Baner and Silva, 1983; Lewis 1978 a, b).

In Thailand, Peerapornpisal, Sonthichai, Somdee and Rott, (1999) studied water quality and phytoplankton in the Mae Kuang Udomtara reservoir, Chiang Mai, Thailand for 18 months from August 1996 to January 1998. One hundred and twenty two species of phytoplankton were found. The greatest number of species was in the Chlorophyceae (35%), followed by Zygnemaphyceae (20%), Diatomophyceae (14%), Cyanophyceae (9%) Cryptophyceae (6%) Dinophyceae (5%) and Xanthophyceae (2%) respectively. A large proportion of phytoplanktons were cosmopolitan, a minority were tropical or warm temperate and tropical species. The dominant species was *Microcystis aeruginosa* which could be used to indicate the eutrophic quality. In another reported by Peerapornpisal, Pekthong, Waiyaka and Promkutkaew, (2000) who intvestigated diversity of phytoplankton and benthic algae in Mae Sa stream, Doi Suthep-Pui National Park, Chiang Mai from April 1997 to February 1998. Eighty seven species of phytoplankton were found which could be classified into 5 phyla, 8 orders, 19 families and 31 genera. The majority of the phytoplankton were diatoms in the Order Pennales and the most abundant species were *Melosira varians*, *Fragilaria ulma*, *Cymbella tumida* and *Nitzschia*

linearis. A total of 172 species of benthic algae were found, of which 68 species had never been recorded in Thailand before. They represented 9 familiies and 25 genera. The most abundant species were also diatoms in the Order Pennates. The majority of the species belonged to the genera *Navicula* (38 species), *Nitzschia* (23 species), *Fragilaria* (16 species) and *Gomphonema* (15 species). A survey and collection of freshwater microalgae strain in Bangkok and its vicinity was under taken by Mahakhant, Chalermsiri, Kunyalung, Tungtananuwat and Arunpairojana (2001), covering 23 districts in 6 provinces. Algae were distributed among 4 divisions, 16 orders, 38 families, 91 genera and 230 species. The algae in division Chlorophyta occurred in 8 orders, 18 families, 40 genera and 82 species; indivision Chrysophyta, 3 orders, 10 families, 17 genera and 26 species, in division Cyanophyta, 4 orders, 9 families, 32 genera and 121 species and in division Euglenophyta, 1 order, 1 family, 2 genera and 1 species. Approximately 50% of the genera were found in from 1 to 5 samples. Algae found in more than 20% of samples were in the genera, *Chorella* (34.7%), *Phormidium* (25%), *Scenedesmus* (23.7%) and *Oscillatoria* (22.7%). Furthermore, Wongrat, Wongrat and Ruangsomboon (2001), studied the diversity of freshwater phytoplankton in the central part of Thailand from October 1999 to September 2000 in 10 provinces, namely Bangkok, Nonthaburi, Pathum Thani, Nakhon Pathom, Sara Buri, Samut Prakarn, Samut Songkram, Samut Sakorn, Ratchaburi and Petchaburi. Phytoplankton comprised 124 genera, 429 species, 70 varieties and 14 forms. The major groups of phytoplankton were the class Chlorophyceae and Euglenophyceae in the division Chlorophyta. Two important orders in the class Chlorophyceae were Chlorococcales and Zygnematales consisting of 102 spcies and 105 species, respectively. For the class Euglenophyceae, the order Euglenales was the most important group consisting of 103 species. From their report total of 15 genera, 128 species, 43 varieties and 8 forms have been recorded in Thailand for the first time.

2.4 The study of using phytoplankton as an indicator of water quality

Algae possess many desiriable attributes as indicators of ecosystem integrity and environmental change, most notably the following: algae are a ubiquitous and ecologically important group in most aquatic ecosystems; algae are sensitive to a broad range of environmental stressors; algae provide relatively unique information regarding ecosystem

conditions compared to animal indicators; algae respond rapidly to changes in environmental conditions, the use of algae assemblages facilitates the establishment of a historical benchmark or other reference point for estimating predistrurbance conditions; and algae provide a cost–effective monitoring tool in terms of information gained per unit effort. (McCormick and Cairns, 1994).

Reynoids, (1980, quoted in Harper, 1992) nutrient levels are one of the most important determinants of the detailed pattern of species change because the same taxa of algae tend to dominate the changes in lakes of similar trophic status, but phytoplankton vary in lakes of different trophic status. For example, in oligotrophic lakes desimid i.e. *Staurastrum, Cosmarium, Staurodesmus,* diatom. i.e. *Tubellaria, Cyclotella, Melosira* and *Rhizosolenia,* chrysophyte i.e. *Dinobryon* were found. In mesotrophic lakes desmid was found i.e. *Straurastrum* and *Closterium,* diatom i.e. *Cyclotella, Stephanodiscus, Asterionella,* green algae i.e. *Pediastrum, Eudorina,* dinoflagellates i.e. *Peridinium* and *Ceratium* In eutrophic lakes diatom was found i.e. *Melosira, Asteroinella* and *Stephanodiscus,* green algae i.e. *Scenedesmus* and *Eudorina* and blue green algae i.e. *Aphanizomenon, Microcystis* and *Anabaena.* However, there were some genus of phytoplankton living in both clean water and polluted water. e.g. *Navicula, Phormidium, Agmenellum, Ulothrix, Eglena, Pinnularia, Cyclotella,* and *Cladophora* etc. (Palmer, 1977).

It should be noted that a study of limnology at the species level revealed clear and marked a difference between the species of algae in clean and polluted water. According to Palmer (1977), in oligotrophic lakes, blue green algae were found in the form of *Phormidium inundatum, Agmenellum quandriduplicatun* var. *glauca* etc. Green algae were presented for example: *Micrasterias truncata,* and *Ankistrodesmus falcatus* var. *acicularis,* etc. Diatom were found, such as: *Cyclotella bodanica, Navicula gracilis, Nitzschia linearis,* and *Surirella spiendida* etc. Flagellates existed e.g. *Euglena charenberqi, E. spirogyra,* and *Phacus longicauda* etc. In eutroplic lake, blue green algae were found, for example: *Agmenelium quadriduplicatun* var. *tenuissima, Phormidium autumnale* etc. For the green algae, they existed as *Ankistrodesmus falcatus, Micrascilnium pusillum,* and *Coelastrum microporum* etc. *Cyclotella meneghinian, Navicula viridula, Nitzschia palea,* and *Surirella ovata* were found as diatom. The flagellates were found as *Euglena acus, E. elegans, E. viridis,* and *Phacus pyrum* etc. So from the above it is clearly apparent a study of algae must be performed at the species level to

differentiate the various species according to clean and polluted water. A less refined study will result in important autecological information being either lost or missed (Stoermer, 1978). Ecological investigations in North American lakes (e.g. Dixit, Dixit and Smol, 1989; Wolin, Stoermer and Schelske, 1988) illustrate extreme variations in environmental optima among diatom and chrysophycean species of the same genus. Coste, Bosca and Dauta (1991) found an overall high correlation between a species and genus level diatom index of water quality in French watersheds, but noted that the correspondence between those two indicators decreased markedly with deteriorating water quality conditions. However, considerable resources and eopertise are required to perform identifications at the species level, and pollution indicators based on algal genera may provide a feasible alternative to species level indices in some instances (Prygiel & Coste, 1993).

In oligotrophic lakes, the potential of picocyanobacteria (0.2-2 μm. cell diameter) as early indicators of changes in nutrient loading and trophic status was examined in an ultra-oligotrophic lake (Lake Wakatipu, South Island, New Zealand). Experimental additions of small amounts of ammonium-N and phosphate-P did not stimulate picocyanobacterial growth, and phosphate additions often reduced picocyanobacterial growth rates. The results show that picocyanobacteria in an oligotrophic lake are sensitive to extremely small changes in nutrient availability and they can respond in complex ways (Schallenberg and Burns, 2001). It has been hypothesized that aggregated forms of picocyanobacteria are favoured under limitations (Stockner & Shortreed, 1994). Picocyanobacteria increased in abundance at low nitrate concentration by contributing to nitrogen fixation in the open waters of the lake (Postius & Böger, 1998). Although we were unable to distinguish any difference in any of the morphology of aggregated and single-cell picocyanobacteria under epifluorescence microscopy, aggregated cells may represent distinct taxa exhibiting unique nutrient interaction (Stockner, Callieri and Cronberg, 2000). Some species of *Synechococcus* (picocyanobacteria) can fix nitrogen directly (Phlips, Zeman and Hansen, 1989) and indirectly by producing polysaccharides that specifically stimulate nitrogen fixation by diazotrophic planktonic bacter (Postius & Böger, 1998). These mechanisms may influence the nitrogen dynamics in Lake Wakatipu and would account for the higher concentration of aggregated cells observed at low nitrate concentrations and TN:TP ratias (Schallenberg and Burns, 2001). Furthermore, the field data on chlorophyll content and

photosynthetic rates for the phytoplankton community in an oligotrophic lake–Loch Ness, Scotland are somewhat ambiguous with respect to the light limitations of phytoplankton development in the Loch. Although phytoplankton cells grown under low irradiance may adapt by increasing their pigment content. The dominant phytoplankton in Loch Ness are diatoms and cryptophytes, both of which have important accessory pigments (respectively, fucoxanthin and phycobiliproteins) which absorb light strongly in the green window between the chlorophyll blue and red absorption maxima (Jones, Young, Hartley and Watts, 1996).

In eutrophic lakes, blue-green algae (cyanobacteria) such as *Aphanizomenon, Anabaena*, and *Microcystis* are most common in eutrophic lake in the warm waters of summer and fall. They overwinter as akinetes, sporelike resting stages. Planktonic blue green algae succeed because they regulate their position in the water column to the depths most favorable for growth. This occurs by a two–step process: (1) production of relatively permanent minute gas vacuoles that give a slight positive buoyancy in starved cells; and (2) photosynthetic production of dense carbohydrate during the day, which acts as ballast to cause sinking. The ballast is used up overnight and the algae float to the surface in the morning to resume the cycle. Floating near the surface shades out competing algae. Large colonies rise or sink much faster than single filaments, and large colonies of blue green algae dominate the summer-fall plankton in eutrophic lakes. A few genera of blue–green algae, such as *Aphanizomenon*, can fix dissolved atmospheric N_2 gas. All other algae groups and many blue-greens lack this ability (Horne and Goldman, 1994).

Based on Odum (1971) it has been found that there is a small amount of various nutrients in mildly contaminated natural water resources. This condition facilitates the growth of various species in balance. Such phenomenon is known as high diversity of phytoplankton species. In contrast, natural water resources with high contamination highly activates the growth of some species of phytoplankton. This situation causes low diversity of phytoplankton species.

The study of phytoplankton in eutrophic lakes, Lavgaste and Pork (1996) studied diatoms in Lake Peipsi–Pihkva in Russia. This typical eutrophic plain lake has many common features with large lakes of both Central and North Europe. In spring and autumn, the plankton of lake Peipsi is dominated by *Aulacoseira islandica* while *Asteroinella formosa, Tabellaria fenestrata* and *Stephanodiscus astraea* are subdominants. In Lake Pihkva; however,

Stephanodiscus binderanus is dominant followed by *Asteroinella formosa, Tabellaria fenestrata, Aulacoseira granulata* and *Fragilaria crotonensis*. A study of the same lake by, Laugaste, Jastremskij and Ott (1996) examined the phytoplankton of Lake Peipsi–Pinkva: species composition, biomass and seasonal dynamics. About 500 algae species were found in plankton by different reseachers. In different seasons and years 35 main species (dominants and subdominants) formed 68-96% of biomass in the southern part of Lake Pinkva (the more eutrophic part) and 60-97% in the northern part of Lake Peipsi (the less eutrophic part). Lake Lämmijärv, connecting the two parts is similar to Lake Pihkva in respect to phytoplankton and the trophic state. Diatoms and blue–green algae prevail in biomass, diatoms and green algae, in the species number. The oligo–mesotrophic *Aulacoseira islandica* is characteristic of the cool peroid; *Aulacoseira granulata* and *Stephanodiscus binderanus* prevail in summer and autum, the latter being most abundant in the southern part. *Gloeotrichia echinulata* and *Aphanizomenon flos-aquae* dominate in summer causing water bloom. Periods of high biomass occurred in the periods 1960-1969 and 1970-1979 and in 1988-1994; however, there was low biomass in 1981-1987. The first periods concided, in general, with periods of low water level and high water temperature. Many countries are now either using diatoms as part of routine monitoring programs, or are in the process of developing techniques. Within Europe, these programs encompass assessment of general water quality, as well as acidification and eutrophication (Whitton and Rott, 1996). In recent years, diatom-based monitoring has also been used for monitoring associated with directives of the European Union (EU). The EU has now set environmental laws for 16 states in Europe and this number is likely to increase over the next few years. (Kelly et al. 1998) and Subater (2000) researched diatom communities as indicators of environmental stress in the Guadiamar river, S-W. Spain, following a major mine tailings spill. An accident in a mine tailings dam caused on outflow of mud and water rich in heavy metals in April 1998 that flooded the near Guadiamar river and its floodplain, in the vicinity of Donana National Park. The impact on the periphytic communities was evaluated by analyzing the evolution of the diatom communities after seven (November 1998) and fourteen months (June 1999) of the accident. The comparison between the reference and affected site showed a shift from a diatom community dominanted by *Fragilaria construens, Achnanthes minutissima* and *Amphora pediculus* to another dominateed by *Nitzschia palea* and *Gomphonema parvolum*

There was a complete substitution of the diatom community in the zone affected by the mine tailings spill. A community characterised by nutrient-rich, high mineral content waters (Sabater, Armengol, Marti, Sabater and Guasch, 1991) was replaced by another of pollution–tolerant taxa *Nitzchia palea* and *Gomphonema parvolum* which were almost the only taxa able to withstand the polluted condition of the sites most affected by the spill. *Achnanthes minutissima* var. *saprophila* were also abundant downstream the mine spill. All of these taxa have been included among those most resistant to heavy metal pollution (Deniseger, Austin and Lucey, 1986). Furthermore, Ibañez (1998) studied the phytoplankton compositon and abundance of a central Amazonian floodplain lake. The phytoplankton community of Lake Camaleao, a small flood plain lake influenced by a large white water river, the Solimoes, was investigated monthly for the composition and abundance of its phytoplankton. The phytoplankton comprised 262 taxa, high standing crops of *Euglena* sp. were registered during low water (September–November 1987), together with filamentous Cyanophycea. Diatom blooms too occurred in the months of lowest precipitation, mainly October 1988, when a high biomasss of *Nitzschia palea* was in evidence.

In Thailand, a biological analysis of water quality using phytoplanktons and coliform bacteria was carried out in Ang Kaew reservoir, Chiang Mai University during April 1996-March 1997. The phytoplanktons found at the lower water quality period were *Coelastum reticulatum, Aulacoseira granulata, Phacus meson, Phacus pleuronectus* and *Peridinium inconspicuum* They were an indication of the medium to low quality of the water. When the quality of water improved, these phytoplanktons decreased and *Dinobryon divergens* appeared. (Chorum, 1998). Furthermore, an analysis of water quality using phytoplankton and coliform bacteria including some physical and chemical properties of water in Huai Mae Yen Reservoir, Chiang Mai, Thailand were carried out from June to September 1998 (Wannasai, 1999). Assessment of the water quality on the trophic level indicated that the reservoir was oligotrophic to mesotrophic. There were 6 divisions 13 orders 20 families 41 genera 84 species of phytoplankton. The phytoplankton which would indicate the oligotrophic status was *Peridinium cinctum* (Müller) Ehrenberg whereas *Botryococcus braunii* and *Aulacoseira alpigena* could indicate mesotrophic status. The study of phytoplankton bloom, Peerapornpisal, et al. (1999) was investigated *Microcystis aeruginosa* in the reservoir of Mae Kuang Udomtara dam, Chiang Mai,

Thailand from August 1996 to January 1998. The water quality in the reservoir classified by trophic level was found to be mesotrophic to eutrophic. The main problem of water quality in the reservoir was the proliferation of phytoplankton, *Microcystis aeruginosa* which secreted microcystin (hepatex in). It was found throughout the investigation in large amount during July 1996 to January 1997. The factors effecting the proliferation were the amount of soluble reactive phosphorus and the total phosphorus which showed a negative correlation with the volume of water in the reservoir.

2.5 The research studied the water quality in Rama IX lake

From the study of รัฐภูมิ นิลคูหา และอุษา กิตติอนงค์ (2540) monitoring the water quality in Rama IX lake and underground water in the center of Rajamangala Institute of Technology from October 1997 to February 1998 reported that parameters such as pH, nitrate–nitrogen, ammonia–nitrogen and the amount of metal did not exceed the standard of the surface water second category, but when various parameters were compared to the quality of piped water *E. coli* and COD (chemical oxygen demand) were found to exceed the standards of water resources when used for household consumption. Studies from วีระศักดิ์ จำรูญวัฒน์ และ เจียมจิตร ขวัญแก้ว (2541) of the water quality in Rama IX lake from 1995 to 1997, examining 2 ponds (2 and 4) found the same characteristics in both ponds, namely noncarbonate hardness. In 1995 the water's properties were acidic but in 1996 and 1997 they changed from weak acid to weak alkaline (pH 6.9-7.2). The salt level in the water in 1995 from January to July was very high, ranging from 9,160–20,550 micromhos/cm. perhaps due to the acid nature of the soil, which is unsuitable for the growth of plants and the water is not fit for human consumption. In 1995 the amount of salt in the water decreased from 1,525 to 786 micromhos/cm. and the water could be used for agriculture and household consumption. In 1995 the amount of heavy metal, dissolved iron in the water exceeded the standard for human consumption. However, in 1996 the amount of manganese in the fourth pond was less than the limit set for the standard of the surface water.

CHAPTER III
RESEARCH METHOD

3.1 Study methods

This study covers important factors relating to the study of the lake's morphometry, physical, chemical and biological parameters, the species, quantity and biodiversity of phytoplankton in Rama IX lake.

3.1.1 The lake's morphometry

The study of the lake's morphometry focused on the deepest points, the surface areas and the capacities of both lakes.

3.1.2 The physical parameters of water quality

The study was concerned with the depth of the lakes, transparency, color, odor, turbidity, conductivity, total dissolved solids, the temperature of the water and the temperature of the air.

3.1.3 The chemical parameters of water quality

The study was also concerned with chemical parameters such as pH, alkalinity, dissolved oxygen (DO), biochemical oxygen demand (BOD), hardness, nitrate-nitrogen, nitrite-nitrogen, ammonia-nitrogen, total phosphorus and orthophosphate or soluble reactive phosphorus (SRP).

3.1.4 The biological parameters of water quality

3.1.4.1 Primary production

The measurement of primary production was analysed from the dissolved oxygen produced by photosynthesis of phytoplankton in natural conditions. This method was one way to estimate the number of phytoplankton.

3.1.4.2 Chlorophyll a

Measuring the amount of chlorophyll an extraction by the ethanol method (ISO 10260, 1922) was another technique to estimate the number of phytoplankton and the amount of primary production.

3.1.4.3 Coliform bacteria

The study of facultative anaerobic bacteria which live in the intestines of living organisms. They are rod shaped and unable to sporulate. They are of gram negative, aerobic or anaerobic bacteria. They ferment in lactose at a temperature of 35^oC and the by - products of this fermentation are acid and gas formed within 24-48 hours of the fermentation process. The formation of acid and gas is an indicator showing that the water is contaminated, not suitable for consumption.

3.1.4.4 Phytoplankton investigations

3.1.4.4.1 Identification of all the species of phytoplankton was based on the relevant books, monographs and special publications.

3.1.4.4.2 Counting the number of phytoplankton.

3.1.4.4.3 Calculations of the quantity of each species of phytoplanktons and calculations in biovolume

3.2 Population and sample group

3.2.1 Population

The study was concerned with the population of phytoplankton and coliform bacteria in Rama IX lake which is standing water.

3.2.2 Sample group*

The water was collected from 2 different sites (from a total of 15 sample spots) correlating the physical, chemical biological parameters, phytoplankton and coliform bacteria. The sample water represented the whole lake and the study water area was collected from 2 different sites.

Site 1 = The deepest point of the first lake was collected from the water surface and every meter for the first three meters depth and then for every 5 meters to the bottom of the lake.

Site 2 = The deepest point of the second lake was collected from the water surface and every meter for the first three meters depth and then for every 5 meters to the bottom of the lake.

Sample group* = The water of both lakes was collected only from the annual rainfall and neither lakes had true inflows nor outflows.

3.2.3 The study areas

3.2.3.1 Rama IX lake is located in Amphur Khlongluang and Amphur Thanyaburi, Pathumthani province.

3.2.3.2 Chemical Research Institute Laboratory, Pathumthani province.

3.2.3.3 Inland Fishery Environment Center Laboratory, Natural Inland Fishery Institute.

3.2.3.4 Applied Algae Research Laboratory, Department of Biology Faculty of Science, Chiang Mai University.

3.2.3.5 Biology Laboratory, Department of biology, Faculty of Science, Rajamangala Institute of Technology.

3.2.3.6 Electron Microscope Laboratory, The Center for Scientific and Technological Equipment, Suranaree University of Technology, Nakhon Ratchasima province.

3.2.4 Period of sample collection

The water samples were collected from Febuary 2000–January 2001

3.3 Parameters for study

3.3.1 The primary parameters were physical chemical and biological.

3.3.2 The secondary parameters were the species and quantity of phytoplankton.

3.4 The equipment used in this study

3.4.1 Equipment used to collect the data of the lake's morphometry.

3.4.1.1 Rama IX lake's map of โครงการส่งน้ำและบำรุงรักษารังสิตเหนือ, 2541 scale 1:5000

3.4.1.2 A measuring tape

3.4.1.3 Two electronic total stations

3.4.1.4 A refractor

Site 1 = The deepest point of the first lake

Site 2 = The deepest point of the second lake
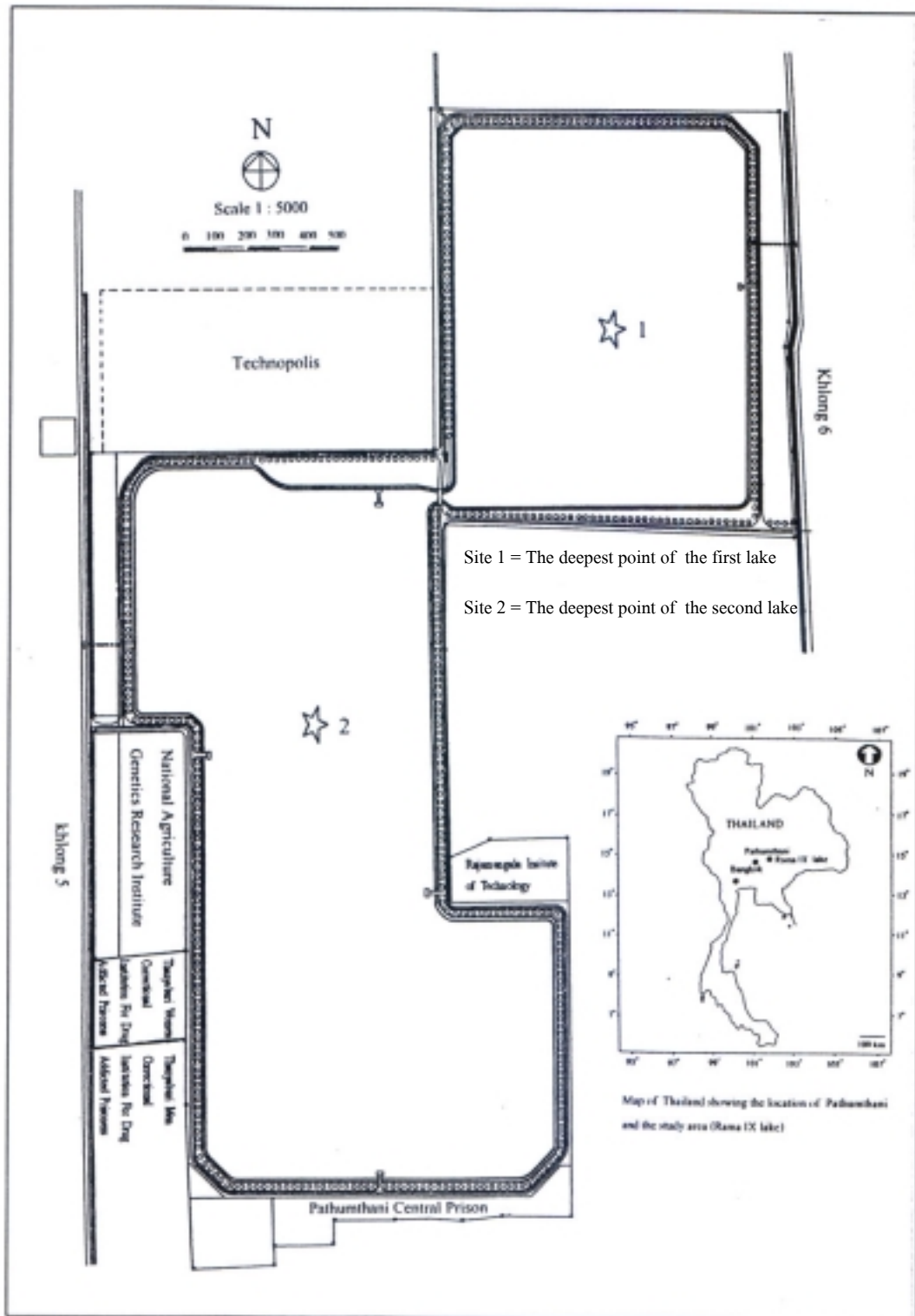
Figure 31 The map of Rama IX lake shows 4 different sample sites

3.4.1.5 A plumb

3.4.1.6 A walkie – talkie

3.4.1.7 Spry paint

3.4.1.8 Nails and Concrete nails

3.4.1.9 Wood pegs (size 1 x 1 inch and 1.5 x 1.5 inches)

3.4.1.10 A Echo sounder recording

3.4.1.11 A long – tailed outboard motor boat

3.4.2 Equipment to collect the water samples, phytoplankton and coliform bacteria samples.

3.4.2.1 Polyethylene bottles (size 1 and 2 liters)

3.4.2.2 A water sampler verticle (size 1 liter)

3.4.2.3 BOD bottles

3.4.2.4 Dark glass bottles size 100 ml.

3.4.2.5 Medical flat were used to collected water samples to study coliform bacteria.

3.4.2.6 Plankton nets (mesh size 10 mm.)

3.4.2.7 Lugol's solution for sedimentation of phytoplankton

3.4.2.8 A vacuum bottle to preserve water samples

3.4.3 Equipment used to analyze the water quality in terms of physical, chemical and biological parameters

3.4.3.1 A Secchi disc

3.4.3.2 A measuring tape

3.4.3.3 A turbidimeter

3.4.3.4 A conductivity meter

3.4.3.5 A pH meter

3.4.3.6 A Thermometer

3.4.3.7 Chemical reagents used to analyse DO value were manganese sulfate, alkalide iodine azide, conc. sulfuric acid and sodium thiosulfate.

3.4.3.8 Chemical reagents used to analyse the alkalinity of the water sample were phenolphthalein, methyl orange and conc. sulfuric acid.

3.4.3.9 Chemical reagents used to analyse the hardness of the water sample were ammonium hydroxide, anhydrous calcium carbonate, hydroxylamine hydrocholine, eriochrome back T (sodium salt of 1 (1-hydroxy-2-naphthylazo) -5 nitro-2 naphtol-4-sulfonic acid) and ethyl alcohol.

3.4.3.10 A titration set consisting of a burette, flasks, beakers, pipettes and pipette fellers

3.4.3.11 A filtration set

3.4.3.12 Whatman GF / C glass fiber filter, Whatman No. 1 fiber filter and aluminium foil.

3.4.4 Equipment for the analysis nutrients

3.4.4.1 A spectrophotometer

3.4.4.2 A hot plate

3.4.4.3 Sulphanilamide

3.4.4.4 N-1-(naphthyl) ethylendiamine dihydrochloride (NNED)

3.4.4.5 Phenol reagent

3.4.4.6 Sodium nitrite

3.4.4.7 Disodium dihydrate

3.4.4.8 Sulfuric acid

3.4.4.9 Nitric acid

3.4.4.10 Phenolphthalein

3.4.4.11 Sodium hydroxide

3.4.4.12 Methyl orange

3.4.4.13 Ethyl alcohol

3.4.4.14 Ammonium chloride

3.4.4.15 Sodium nitroprusside reagent

3.4.4.16 Sodium citrate

3.4.4.17 Sodium hypochlorite

3.4.4.18 Sodium tetraborate

3.4.4.19 Hydrochloric acid

3.4.4.20 Potassium nitrate

3.4.4.21 Cupric sulphate solution

3.4.4.22 Cadmium copper reducing column

3.4.4.23 Ascorbic acid

3.4.4.24 Acid molybdate

3.4.4.25 Ammonium paramolybdate

3.4.4.26 Antimony potassium tartrate

3.4.4.27 Deionized water

3.4.5 Equipment for the analysis of chlorophyll a

3.4.5.1 A spectrophotometer

3.4.5.2 A mortar

3.4.5.3 A water bath

3.4.5.4 Ethyl alcohol 90%

3.4.5.5 Hydrochloric acid

3.4.5.6 Automatic micropipette

3.4.6 Equipment for the analysis of coliform bacteria

3.4.6.1 Lauryl trytose broth

3.4.6.2 Pipettes

3.4.6.3 Durhum tubes

3.4.6.4 Test tubes

3.4.6.5 Refrigerated incubater $35^{\circ}C$

3.4.6.6 Bunsen burner

3.4.7 Equipment for studying the various species and the quantity of phytoplankton

3.4.7.1 An inverted microscope

3.4.7.2 A compound microscope equipped

3.4.7.3 Slides, cover slides and sedimentation slides

3.4.7.4 A compound microscope with an ocular micrometer for measuring the size of phytoplankton

3.5 Data collection

3.5.1 The study of the environment parameters in terms of the lake's morphometry

This study was made by doing a survey of and doing close tranverse outlines of the area of both lakes. The data of the lines of the edges of the lakes was collected by using an Electronic Total Station. The elevation of the depths of the water was conducted by using an Echo Sounder Recording to measure every 50 x 50 grid square meters covering the area of both lakes. The data obtained from this study was then processed in a computer by using CARTOMAP SURVEYING the program to construct a map of contour lines of the lakes illustrating the deepest points, the surface areas and the capacity of both lakes. The above survey was assisted by students of the Civil Engineering Department, Faculty of Engineering, Rajamangala Institute of Technology. After locating the deepest points of both lakes, the locations were marked by floats which then become the spots for collecting all the samples.

3.5.2 The study of the environmental parameters in terms of the aspects of the physical parameters of the water.

3.5.2.1 The color and odor of water samples

The water samples were collected from 15 different sample points in the field. They were examined by personal observation.

3.5.2.2 Transparency

A Secchi disc (diameter 9 inches) was dipped into the water until the black and white bands were invisible on it and the value from the length of the rope was measured.

3.5.2.3 The temperature of the water and the temperature of the air

By use of thermometer the temperature of the air was measured and thermometer placed inside a pH meter read the temperature of the water sample in the field.

3.5.2.4 Turbidity

A turbidity of the Hach Company model 2100 A measured instantly the turbidity of the water sample when it reached the laboratory.

3.5.2.5 Conductivity

The conductivity of the water sample in the field was very quickly recorded by a conductivity meter manufactured by the Hach Company model 44600 unit $\mu s.cm^{-1}$ and

mg.l^{-1}.

3.5.2.6 Total dissolved solid (TDS)

The TDS of the water sample in the field was measured by the use of a conductivity meter of the Hach Company model 44600 unit μs.cm^{-1} and mg.l^{-1}.

3.5.3 The study of environmental parameters in terms of the chemical parameters of the water.

3.5.3.1 A pH meter of the Hach Company model session 1 was used to measure the pH of the water sample in the laboratory.

3.5.3.2 Alkalinity

Alkalinity was measured by the application of the phenolphthalein methyl orange indicator method in the laboratory.

3.5.3.3 Dissolved oxygen

Dissolved oxygen was detected by the use of the azide modification method in the field.

3.5.3.4 Biochemical oxygen demand

Biochemical oxygen demand was measured by employment of the azide modification method in the laboratory.

3.5.3.5 Hardness

Water hardness was assessed by the use of the EDTA titration method in the laboratory.

3.5.3.6 Nitrate–nitrogen (NO$_3$-N)

NO$_3$-N was measured by applying the cadmium reduction method and a spectrophotometer of the Shimadzu company model UV-160 A in the laboratory.

3.5.3.7 Ammonia–nitrogen (NH$_3$–N)

NH$_3$-N was appraised by using the phenate method and spectrophoto-meter of the Shimadzu company model UV-160 A in the laboratory.

3.5.3.8 Total phosphorus

Total phosphorus was measured by the application of the persulfate digestion method and a spectrophotometer of the Shimadzu company model UV-160 A in the laboratory.

3.5.3.9 Orthophosphate or Soluble Reactive Phosphorus (SRP)

SRR was monitored by the ascobic acid method and a spectrophometer of the Shimadzu company model UV-160 A in the laboratory.

Number 3.5.3.2-3.5.3.9 were measured according to the method described by APHA, AWWA and WPCF, (1992).

3.5.4 The study of environmental parameters in terms of the biological quantities of the water.

3.5.4.1 Primary production

Primary production is the quantity of new organic matter created by photosynthesis (or chemosynthesis), or the sorted energy which this material represents (Wetzel, 1975). Gross and net primary production were determined in the field using the light and dark bottle technique and the oxygen method (Strickland and Parson, 1968). Water samples were collected at a depth of 30 cm. below the surface of the water, a depth where light still penetrated both lakes, the bottles were then incubated for two hours at the deepest area of both lakes. The amount of oxygen present before and after incubation was analyzed by titration. The result of the analysis was then converted into mg o_2 $l^{-1}.hr^{-1}$.

The equations for the calculations of the primary production are as follows:

Net primary production	=	light bottle DO – initial DO
Respiration	=	initial DO – dark bottle DO
Gross primary production	=	light bottle DO – dark bottle DO
Where DO	=	Dissolved oxygen

3.5.4.2 Chlorophyll a analysis

As a second measure of phytoplankton biomass, the chlorophyll a content was determined after 2 filtrations water samples of 3 liters in the first lake and 5 liters in the second lake over firstly Whatman GF/C filters and secondly over Whatman No. 1 fiber filters. For the extraction and evaluation of the chlorophyll a the ethanol method (ISO 10260, 1992) was used. The water was collected every meter for the first three vertical meters from the surface and then for every 5 meters to the bottom of both lakes.

3.5.4.3 Coliform bacteria

To study the number of coliform bacteria in the laboratory by using the

multiple tube method (MPN, Most Probable Number) (APHA, AWWA and WPCF, 1992). The water samples were collected from 30 cm. below the surface at the deepest area of both lakes, the inflow–outflow drain of Khlong 6 and the inflow–outflow drain of Khlong 5 by using medical flats.

3.5.4.4 Phytoplankton investigation

1) Phytoplankton were collected using 2 techniques.

1.1 Firstly, phytoplankton were collected for identification.

All the species of phytoplankton were collected at the deepest point of both lakes by using a plankton net (mesh size 10 mm.) and pulled up vertically to the surface. The water sample from the plankton net was placed into approximately 100 ml. bottle, this process required 2-3 samples to full the bottle. The water sample was pored into a dark glass bottle and the phytoplankton was preserved in 2 ml. of Lugol's solution per 100 ml of sample.

1.2 Secondly, phytoplankton were collected to assess the number of phytoplankton.

By using the water sampler, the water samples at the deepest point of both lakes were collected from the surface water and every meter for the first three meters depth and every 5 meters from then on to the bottom of the lake. The water sample was poured into dark glass bottles and was preserved in 2 ml. of Lugol's solution per 100 ml. of sample.

2) Identification

Identification of phytoplankton from the net samples was used for morphology and identification. Each species was drawn from a microscope or photographed. Photographs and drawings of each species are shown in Chapter IV (Figure 4.38-4.50). Identification was based on relevant books, monographs and species publications.

To roughly specify the algal divisions, classes, orders and families, the relevant compendia of Prescott (1962, 1970) were used. In some cases the genera were identified from various volumes of flora by Huber–Pestalozzi (1938, 1941, 1942, 1955, 1961, 1968, 1982 and 1983) and from Whitford and Schumacher (1969). For detailed identification of the genera and species, these floras, which inhabit mainly temperate environments, were not suitable as material from tropical environments. Identification is based on relevant books, monographs and special publications.

The Cyanophyceae were the dominant group in this study; Desikachary (1959), Hindák and Moustaka (1988), Hirano (1967 and 1975), John, Whitton and Brook (2002), Komárek and Anagnastidis (1999), Peerapornpisal (1996), Rott (1983), Rott and Lenzenweger (1994), Ruiz and Pum (1987) and Yamagishi and Hirano (1973) were used for identification. For the dominant species, *Cylindrospermopsis raciborskii*, the species identification was checked from the works of Komárek and Kling (1991). The identification of *Cyiindrospermopsis phillippinensis* follows Komárek (1984).

The Cryptophyceae, identification was mostly based on John, Whitton and Brook (2002), Prescott (1970) and Whitford and Schumacher (1969).

The group of Dinophyceae were identified according to the findings of Huber Pestalozzi (1968), John, Whitton and Brook (2002), Peerapornpisal (1996), Popovsky and Pfiester (1990), Presscott (1962, 1970), Rott (1983) and Yamagishi and Hirano (1973). Dr. Barbara Meyer (Max–Planck Institut für Limnologie, Plön, Germany, kindly helped to identify some species in this group.

For the Diatomophyceae were identified from Cox (1996), Krammer and Lange Bertarot (1986, 1991), Prescott (1962, 1970) and Round, Cranford and Mann (1990).

The Chrysophyceae were based on Prescott (1962, 1970), and Whitford and Schumacher (1969).

The Xanthophyceae were identified according to Prescott (1970), Whitford and Schumacher (1969) and Yaniagishi and Hirano (1973).

Regarding Chlorophyceae, the most species-rich group in this investigation, Huber–Pestalazzi (1983), John, Whitton and Brook (2002) and Prescott (1962, 1970), were the researchers most frequently referred to, supplemented sometimes by ลัดดา วงศ์รัตน์ (2542), Hirano (1967, 1975), Peerapornpisal (1996), Rott (1981, 1983), Ruiz and Pum (1987), Yamagishi and Hirano (1973) and Yamagishi and Kanetsuna (1987). For detailed identification of some genera, such as the *Scenedesmus* group, special publications for tropical regions were consulted such as Hegewald, Hindák and Schhepf (1990) and Komárek (1983).

The studies of the Zygnemaphyceae were based on Croasdale and Flint (1988), Croasdale, Flint and Racine (1994), Hirano (1975), John, Whitton and Brook (2002), Lenzenweger (1997, 1999) and Yamagishi and Kanetsuna (1987). Rupert Lenzenweger (Ried im

Innkreis, Austria) kindly helped to identify *Staurastrum*

Identification of the Euglenophyceae was based mostly on Hyuber-Pestalozzi (1955). In addition Hirano (1975), John, Whitton and Brook (2002) and Yamagishi and Kanetsuna (1987) were referred to.

3) Counting and biovolume estimate

3.1 The number of phytoplankton were counted by using sedimentation the Utermöhl method (Utermöhl, 1958) and studied with an inverted microscope.

3.2 The thickness, length width and process of each phytoplankton were examined under a compound microscope and the biovolume was calculated by using the Rott method (Rott, 1981)

3.3 The biovolume of the total phytoplankton was calculated from the abundance and volume approximations for each species (Rott, 1981 see Table 4.2). A computer programme of the Arbeitsgruppe Hydrobotanik, Institute of Botany, Innsbruck University, Austria was used for the final calculations.

3.6 Data analysis

The computer statistical package Microsoft and SPSS for Window Version 10 were used to perform the following statistical analysis.

3.6.1 The mean and standard deviation were used to analyse the water quality in terms of physical, chemical and biological parameters.

3.6.2 Two–tailed significance of the simple correlation analysis was used to determine the interrelationship between the difference of the physical, chemical and biological parameters on the surface of the water of both lakes.

3.6.3 Analysis of water quality in terms of physical, chemical and biological parameters at each depth for each lake, the F-test was used to compare the differences of the mean of each depth of each lake, therefore Ducan's new multiple range was selected.

3.6.4 The F-test was used to analyse the water quality in terms of physical, chemical and biological parameters on the surface of the water in each lake.

CHAPTER IV
RESULTS AND DISCUSSION

Based on a study of water quality using phytoplankton as the monitoring indicator, combined with a study of water quality using physical, chemical and other biological parameters in Rama IX lake, Pathumthani province, Thailand from February 2000-January 2001 the following results were obtained :

4.1 Lake's morphometry

A study of the contour lines of both lakes produced a bathymatric map of the point of both lakes which showed the deepest points of both lakes. The data is shown in Figure 4.1. It was found that in the first lake, the widest part was 1,110 metres and the longest part was 1,195 metres. The surface area of this lake was 1,264,000 square metres and the capacity of this lake was 7,820,000 cubic metres. The mean depth was 6.187 metres and the deepest point was 19.63 metres. For the second lake, at its widest was 1,150 metres, at its longest was 2,215 metres, the surface area was 2,864,000 square metres and the capacity was 17,400,000 cubic meters. The mean depth was 6.075 metres and the deepest point was 21.63 metres.

A study of the two lakes morphometry was done by making contour lines of both lakes to find the deepest points of both lakes. Samples were collected throughout the research. These points are the best points for mixed water (¡ÃÁÍ ¹ ÒÁ¸ Ñ 2539). Accordingly, the deepest point can indicate the changes of the shape of future resources. For example, sedimentation causes water resources to become shallow and also changes the deepest point of the water resources (à»ÃÁÈ Ñ ÇÒÁ ¹ ÐÈÇµ, 2539). Rama IX lakes are big lakes and they have a wide surface area. Wave action is easily caused by the wind, resulting in soil erosion with the soil sinking to the bottom of the water resources (»ÃÐÇ Ò¾ÒÅÈ ØÃ¸ÔÉ• 2539). The lake subsequently has become shallow and the effect of strong wave action made working in the lake dangerous such as this reseacher found in this investigation.

Site 1 = The deepest point of the first lake

Site 2 = The deepest point of the second lake
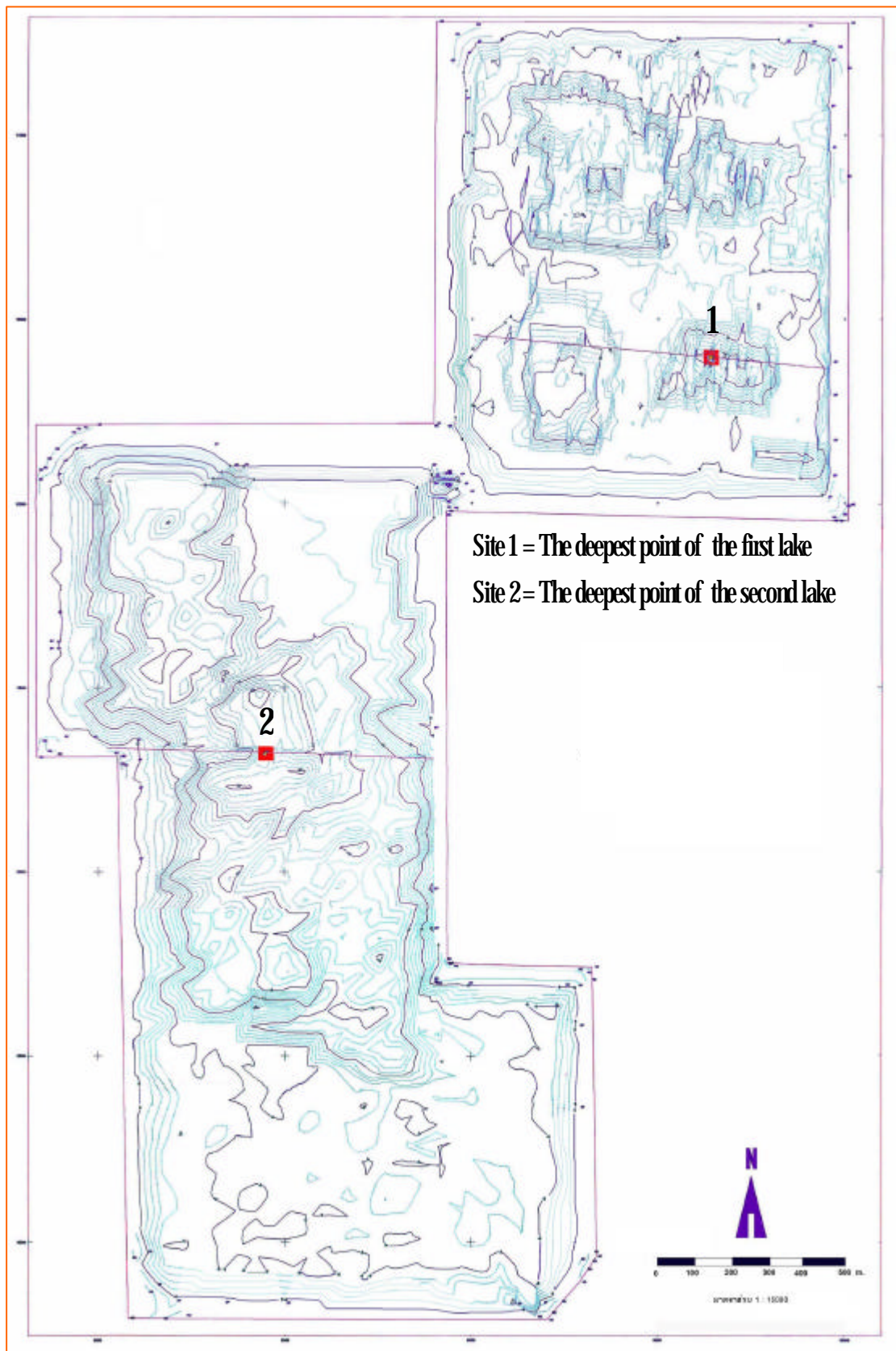
Figure 4.1 The map shows the contour line of Rama IX lake.

4.2 Physical parameters of water quality

4.2.1 Water level (The depth of the water)

The depth of water in the first lake varied from 15.00-18.40 metres. The average depth was 16.40 metres. The highest water level was 18.40 metres in April 2000. The lowest water level was 15 metres in January 2001 (Figure 4.2; Table II-1, Appendix II). For the second lake, the water level was between 18.32-22.43 metres, the mean depth was 20.33 metres. The highest water level was 22.43 metres in April 2000 and the lowest water levels was 18.32 metres in March 2000. (Figure 4.3; Table II-1, Appendix II). The water levels of the second lake were higher than the first lake and the water levels varied significantly between the lakes. The water levels in both lakes fluctuated and were not correlated with the season.

The study of the depth of water in the first lake had negative correlations with the water hardness and there was significant difference. The water levels were positively correlated with a significant difference between pH with alkalinity and BOD (Table II-2, Appendix II). The second lake had positive correlations with the temperature and there was significant difference (Table II-3, Appendix II).

The depth of water in both lakes peaked in the summer (April 2000) because rainfall, out of season, caused the rise in the water levels. The depth of water fluctuated in each month with no correlation between the season and rainfall because government offices such as Rajamangala Institute of Technology, Technopolis and many residential homes around the lakes consume the water from this lake for household consumption although the majority of the inflow –outflow drains of Khlong 6 and Khlong 5 were closed. Furthermore, the water levels of the first lake were positively related between pH and alkalinity because rainfall washed down the soil from the land around the lake into the water resources and replenishment from the hypolimnion increase the nutrients in the rainy season (Home and Goldman, 1994). The water hardness or the dissolved salts in the water decreased with rainfall. When the nutrients increase the phytoplankton will grow well because the rate of photosynthesis of phytoplankton increases.

The photosynthesis of phytoplankton causes an increase in the amount of oxygen in the water; hence pH and alkalinity in the water will increase as well. This result corresponds with the report of Jeffereies and Mills (1994) who found that many high pH values occur due to

the intense photosynthetic activity of phytoplankton and Chorum (1998) reported that when phytoplankton have a marked increase in the rate of photosynthesis. It shows the increased use of carbon dioxide in the water resources. So pH and alkalinity will increase too.

Furthermore, the water levels had a positive correlation with BOD because the rainfall washed down the soil around the lake into the water resources resulting in an increase of coliform bacteria and turbidity into the water resources. Furthermore, the bacteria increased the use of the amount of oxygen in the digestion of organic matters in the water resources. This resulted in increasing BOD, which is a finding which corresponds with the work of Geladrich, Best, Kenneru and Dosel (1968) who found that during the rainy season with a high rainfall the water is contaminated by bacteria more than in other seasons.

In the second lake, the water level showed a positive correlation with the temperature because this lake received precipitation from the precipitation in the summer and also in the rainy season. It caused an increase in the water level in this lake which changed the temperature correlation with the seasons. Although, the water level was not correlated with the seasons.

4.2.2 Secchi depth (Transparency)

In the first lake, Secchi depth varied from 0.67-1.32 metres. The average Secchi depth was 0.96 metres. The maximum of Secchi depth was 1.45 metres in January 2001 and the minimum was 0.72 metres in March 2000 (Figure 4.2; Table II-1, Appendix II). For the second lake, Secchi depth was from 1.50–2.40 metres. The average of this value was 1.86 metres. The highest depth was 2.40 metres in Febuary 2000 and the lowest was 1.50 metres in March 2000 (Figure 4.3; Table II-1, Appendix II). The Secchi depth in the second lake was higher than the first lake and this value significantly varied between the lakes. In the first lake, Secchi depth at the surface layer of the water had negative correlations between turbidity and primary production (P = 0.01). Secchi depth had positive correlations between conductivity, total dissolved solids (P = 0.01) and hardness (P = 0.05) (Table II-2, Appendix II). For the second lake, Secchi depth had negative correlation with turbidity (P = 0.05) (Table II-3, Appendix II). The Secchi depth in the second lake was higher than the first lake and there was significantly varied between both lakes.

The Secchi depth had negative correlation with turbidity in both lakes because the water was very cloudy, it showed marked suspended and colloidal matter in the water which
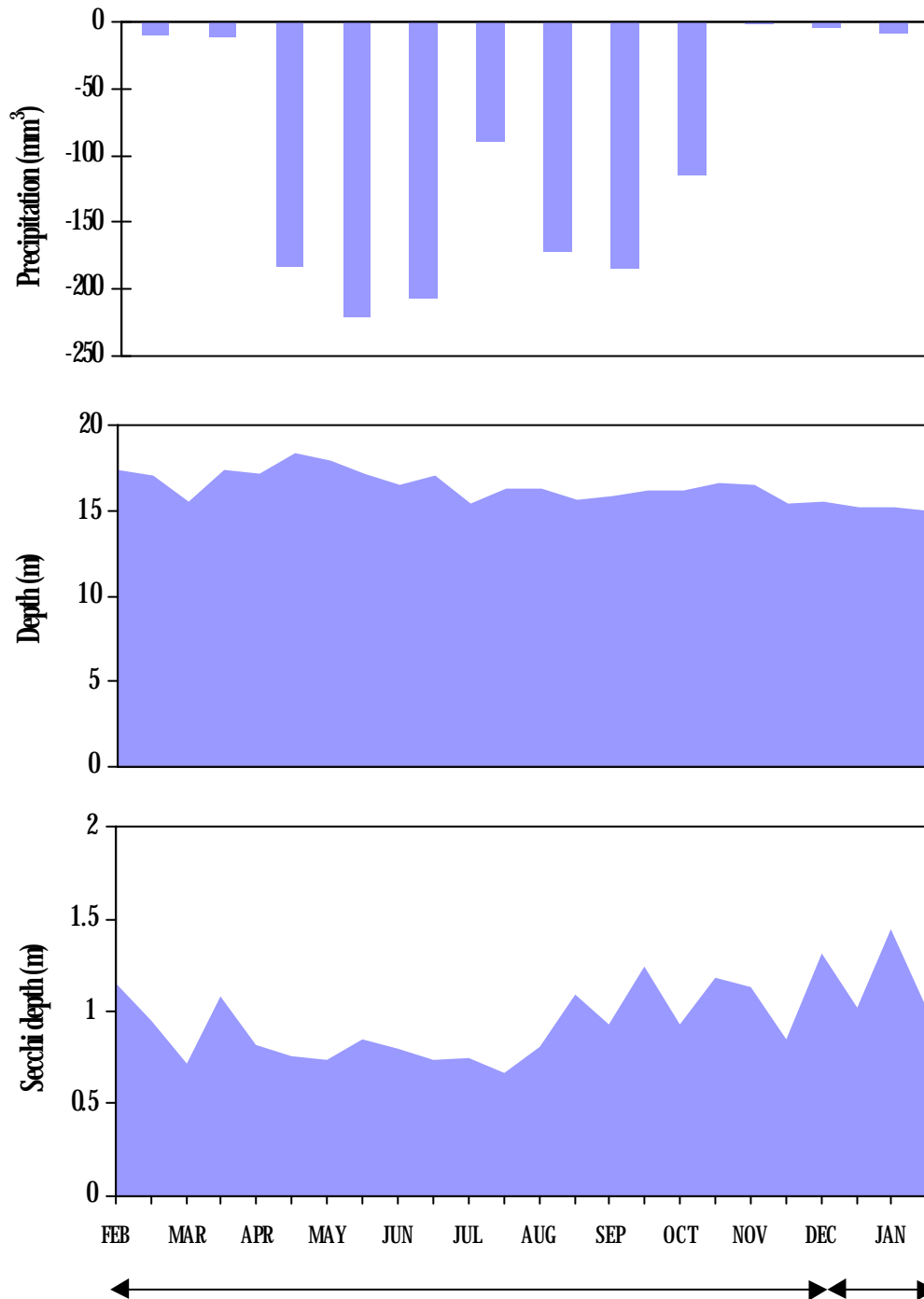
Figure 4.2 Seasonal variation of precipitation (mm^3), water levels (m) and Secchi depth (m) in the first lake of Rama IX lake (February 2000-January 2001)
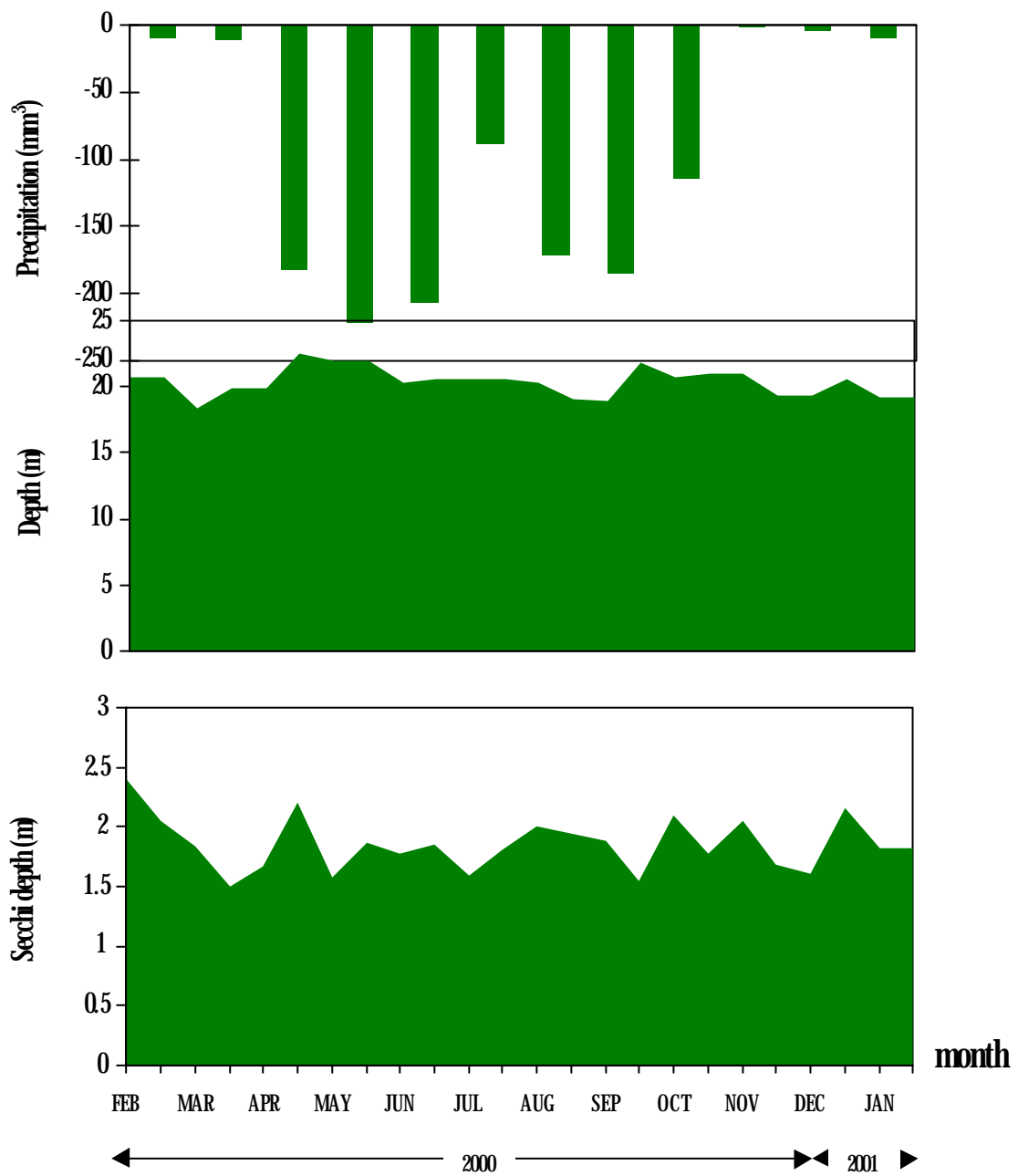
Figure 4.3 Seasonal variation of precipitation (mm³), water levels (m) and Secchi depth (m) in the second lake of Rama IX lake (February 2000-January 2001)

inhibited the penetration of sunlight into the water. The suspended and colloidal matter absorbed and reflexed the light which caused the turbidity in the water. The organic, inorganic and living organisms (size 1-10 micron) appeared in the form of suspension and caused the cloudiness of the water (äÁµÃÕ Ç§ÊÇÑ¹ áÅÐ ·ÇÕÃÃ³ ÊÁÀÙ 2528) and Secchi transparency measurement is associated to a great extent with increased scattering by particulate matter suspensoids (Step nek, 1959; Szczepanski, 1968). This result corresponds to the report of Chaiubol (1998) who studied the relationship between water quality and the distribution of phytoplankton and zooplankton in Ang Kaew reservior, Chiang Mai University, 1997-1998 and found that the turbidity of water negatively correlated with Secchi depth, when the turbidity was high the Secchi depth was low.

In the first lake, the Secchi depth was significantly different from the second lake and there was positive correlation with conductivity, total dissolved solids (P = 0.01) and hardness (P = 0.05) because the water level decreased in the cold season. The low level caused an increase the ions in the water such as Ca^{++}, Mg^{++} and etc. The calcium combined with anion e.g. CO_3 or SO_4 and corverted to $CaCO_3$ or $CaSO_4$ which sank in the sediment to the bottom of the lake (»ÃÐÒ ¾ÃËÁÇ§È• 2539). In the cold season the water was clear and the sunlight could penetrate deeply into the water. In addition, the Secchi depth showed a negative correlation with primary production because the cloudy water blocked the penetration of sunlight into the water depths and decreased the rate of photosynthesis of phytoplankton. This caused a decrease of primary production of the water resources (äÁµÃÕ Ç§ÊÇÑ¹ áÅÐ ·ÇÕÃÃ³ ÊÁÀÙ 2528). In general, Secchi depth revealed a positive correlation with phytoplankton biovolume, primary production and the amount of chloroplyll a of the water resources (Peerapompisal, Somdee, Sonthichai and Rott, 1999). The second lake exceeded the Secchi depth of the first lake because huge amounts of phytoplankton biovolume were present in the first lake with nutrients, such as total phosphorus, ammonia nitrogen etc. The turbidity caused low sunlight penetration into the first lake. The Secchi depth changed with the quantity of phytoplankton and inorganic substances in the water resources (¹Ñ¹·Ò ¤ªÑ¹, 2539) and species-rich lakes tend to have low values for Secchi disk depth (Haberyan, Umaña, Callado and Horn, 1995).

4.2.3 Water temperature

The changes in the water temperature of the water surface were clearly related to

the seasons. In the early stages of this investigation, the temperature showed readings as it was the cold season whereas, the temperature increased in the summer and rainy season. In the first lake, the water temperature ranged from 27.60-32.83°C, the average water temperature was 30.36°C. The maximum water temperature was 32.83°C in August 2000, but the minimum was 27.60°C in February 2000. (Figure 4.4A; Table II-1, Appendix II). For the second lake, the water temperature fluctuated between 27.17 - 32.50°C, the average water temperature was 30.06°C. The highest was 32.10°C in April 2000 and the lowest was 27.17°C in Febuary 2000 (Figure 4.5A; Table II-1, Appendix II).

A study of thermal stratification found that the surface area of both lakes were high and decreased slightly to the bottom of both lakes. This indicates the potential temperature straticification (Figure 4.4 B,C ; 4.5 B,C)

In the first lake, the water temperature did not significantly vary at the first 0-2 metre depths but the temperatures decreased significantly by the 3, 8, 13 metre depths and the bed of the lake. However, the temperature at 13 metre depths and the bed of the lake were not significant different but were lower than the temperature of other levels. For the second lake, the water temperature did not significantly differ between 0-3 metre depths, but there was a difference at 8 metre depth. However, water temperature depths at 13 and 18 metres had no significant differences as neither did the temperature at 18 metre and the bottom of the lake. However, water temperatures of the bottom of both lakes were not much below the water temperatures in temperate lakes. This investigation did not find any thermocline.

The water temperature at the surface area of both lakes did not vary significantly. The water temperature in both lakes meant life was suitable for phytoplankton and aquatic animals. Many fish in tropical lakes, such as in Thailand, live at temperatures between 25-32°C which is the normal temperature in water resources. (äÁµÃÕ¢ÊÊÇ¤ÇÒÃ¯ÔÇÒ³ ÊÁÈÒ¿Õ 2528). The water temperature was lower in the cold season when compared to the other seasons as it was affected by the climate and influenced by Northeast monsoons. Water temperature varied only slightly in the rainy season and the summer season because the locality and latitude of Thailand is in the tropical zone. Corsequently temperatures during the day in rainy season are not different from those in the summer season. This result resembles the report of Chaiubol (1998) who found that the water temperature in the cold season was lower than in the

other seasons, whereas the water temperature in the rainy season was nearly the same as in the summer season.

The thermal stratification revealed that the maximum water temperature was at the water surface. The water temperature decreased slightly to the bottom of both lakes, because the heat from the sunlight affected the water surface much more than the deeper levels. Furthermore, light intensity decreases exponentially with depth (Horne and Goldman, 1994). In the second lake, the water temperature positively correlated with pH because the surface water had higher temperature than other depths. This caused a high ionization of nutrients so the phytoplankton grew well and increased pH value in the water. These findings resemble the research of Chorum (1998) who found that an increase in phytoplankton in Ang Kaew reservoir, Chiang Mai University 1996-1997 resulted in a corresponding rise of photosynthesis. The photosynthesis of phytoplankton used carbondioxide phytoplankton, pH, which meant there was a corresponding rise in the amount of dissolved oxygen in the water. Horne and Goldman (1994) reported that as the water temperature rises, the increase metabolic rates of lakes and river organisms place additional demand on the supply of dissolved oxygen.

4.2.4 Turbidity

In the first lake, the clarity of the water at the water surface ranged from 3.15-8.58 NTU. The average turbidity was 5.66 NTU. The high level of turbidity was in the rainy season and the summer. It was low in the cold season (Figure 4.6A; Table II-1, Appendix II). For the second lake, the turbidity varied between 1.93-3.77 NTU, the average turbidity was 2.64 NTU (Figure 4.7A; Table II-1, Appendix II).

The turbidity of the first lake was higher than the second lake and showed marked difference from the first lake. It did not change over the seasons. Vertical turbidity in the first lake was low at the water surface and increased slightly to the bottom of the lake (Figure 4.6 B, C). The turbidity at the depths of 0, 1, 2, 3 and 8 metres were not significantly different. However, at the depth of 13 metre and the bottom of the lake, turbidity was significantly different. For the second lake, turbidity was low at the water surface and high at the bottom for many months. Sometimes it showed a high reading at the water surface and low in the lower levels and at the bed of the lake. (Figure 4.7 B,C). Turbidity at the depth of 0, 1, 2, 3, 8 and 13 metres was not significantly different, but there was a significant difference when compared to
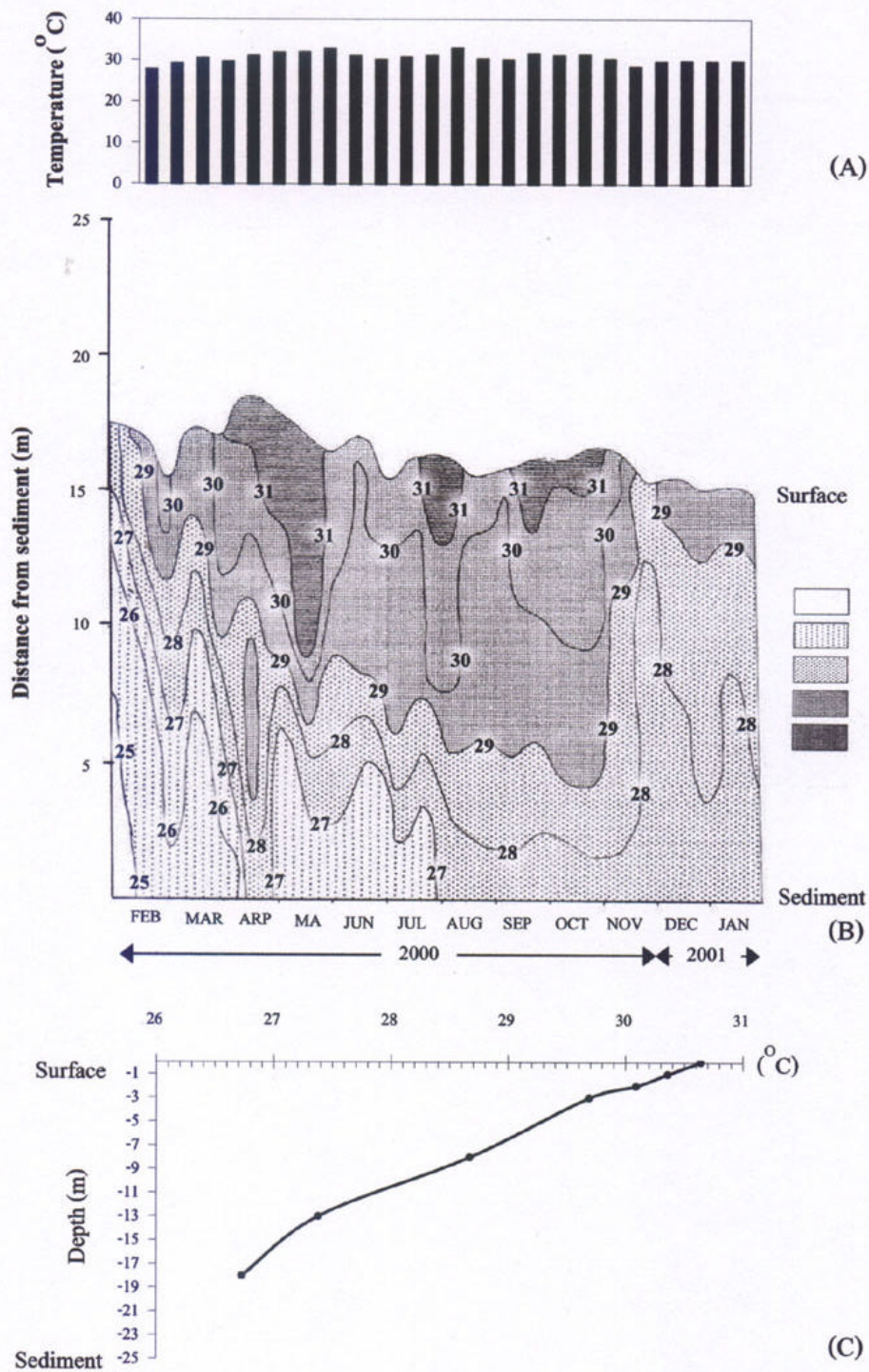
Figure 4.4   Showing the temperature (^{0}C) in the first lake of Rama IX lake (A) the graph of the level of temperature at the water surface (B) the graph of the different water levels of the temperature and (C) the graph of the mean temperature from the water surface to the sediment

Figure 4.5 Showing the temperature (^{0}C) in the second lake of Rama IX lake (A) the graph of the level of temperature at the water surface (B) the graph of the different water levels of the temperature and (C) the graph of the mean temperature from the water surface to the sediment

the turbidity at 18 metres and at the bottom of the lake. Turbidity had a negative correlation with dissolved oxygen in both lakes (P = 0.05) (Table II-2, II-3; Appendix II).

Turbidity from different depths in both lakes was low at the surface and high at the bottom of the lake because the sediment at the bottom of the lake was higher than at the surface. In the deep lake there were subsurface currents which caused sediment in the water body (»ÃĐÁÒ³ ¾ÃËÁÊØ, Ϊ,•2539). In the cold season and the end of the rainy season, there was low turbidity at the surface when compared to the other seasons because in the cold season the rainfall and strong waves decreased which caused the sediment to sink to the bottom of the lake. There was no sediment washing down from the land into the water.

In the first lake, the turbidity was higher than in the second lake and it was significantly different because the first lake had a higher phytoplankton biovolume, chlorophyll a and nutrients such as total phosphorus. These results corresponded to the report of De Casabianca, Laugier and Collart, (1997) who studied the impact of shellfish farming eutrophication on benthic macrophyte communities in the Than Lagoon, France and found that an increase of nutrients (NO_2, NO_3, NH_3, PO_4) and suspended solids made the water increasingly turbid. Turbidity had a negative correlation with Secchi depth, which has been explained already in part 4.2.2. Furthermore, turbidity had a negative correlation with dissolved oxygen in both lakes because the water had high suspended solids and high turbidity. The cloudy water cannot receive the dissolved oxygen when compared to clean water (äÁµÃ̃ Ç§ÊÇÑ Ò¹ÅÐ Ò¡Ç²Ã³ ÊÃÊØ,2528).

In the first lake, turbidity had a positive correlation with nitrite nitrogen as the water had a high turbidity, which decreased the amount of oxygen. So, the nitrite nitrogen could not change into nitrate–nitrogen because oxygen needed for digestion was scarce. Nitrite–nitrogen changes to nitrate–nitrogen by using *Nitrobacter* (Horne and Goldman, 1994). Furthermore, the turbidity in the first lake was higher than the second lake because the rainfall in the rainy season washed down the soil at the surrounding area of the lake into the water. The turbidity in the second lake varied slightly and it did not correlate with the seasons regarding its volume and depth was bigger than that of the first lake. Although in the rainy season rainfall washed down the soil from the land into the water resource, there was no increase in the turbidity of the water.

Figure 4.6 Showing the turbidity (NTU) in the first lake of Rama IX lake (A) the graph of turbidity at the water surface (B) the graph of the different water levels of the turbidity and (C) the graph of the mean turbidity from the water surface to the sediment
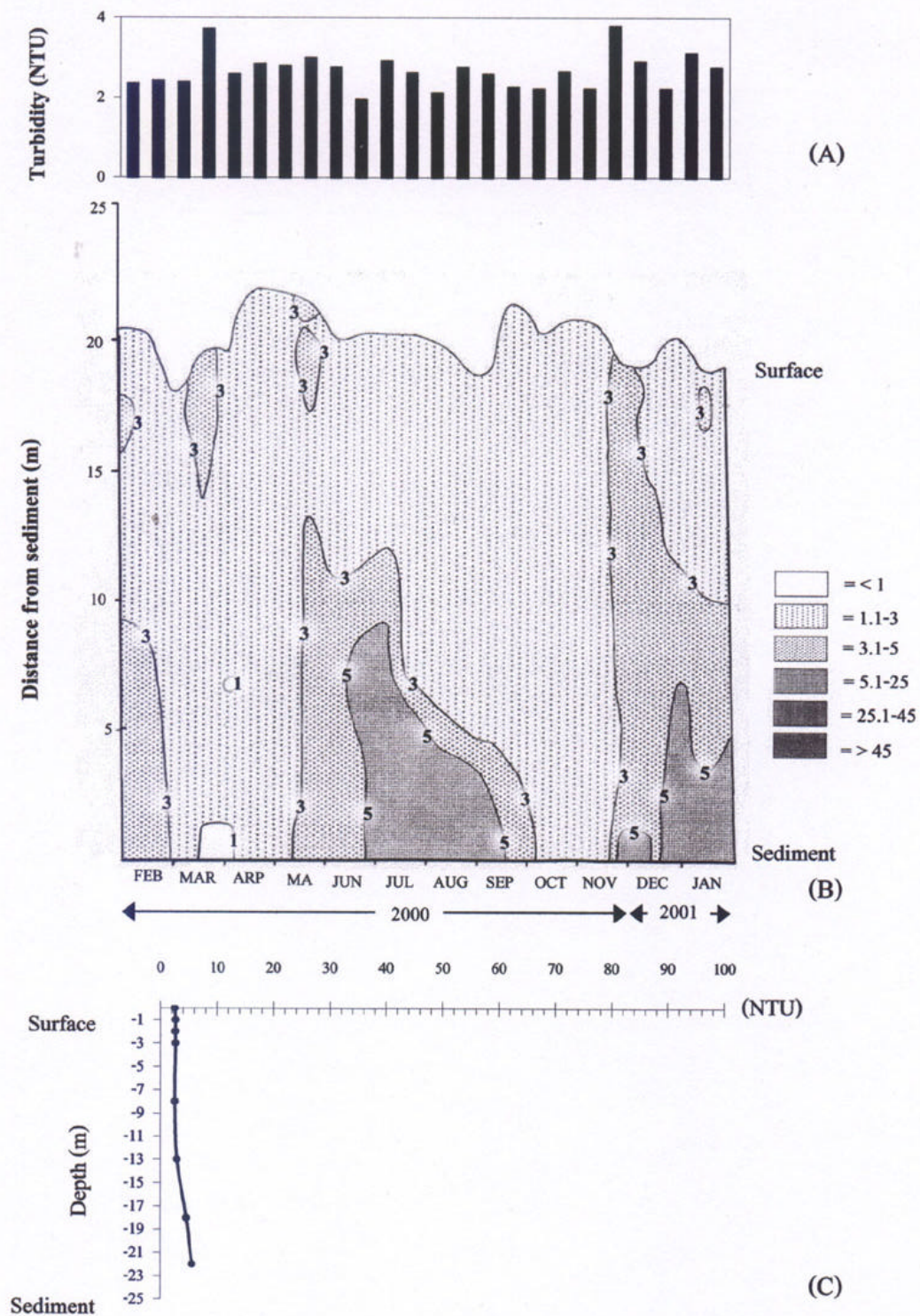
Figure 4.7   Showing the turbidity (NTU) in the second lake of Rama IX lake (A) the graph
of turbidity at the water surface (B) the graph of the different water levels of the
turbidity and (C) the graph of the mean turbidity from the water surface to the
sediment

4.2.5 Conductivity and total dissolved solids

The conductivity at the water surface in the first lake was between 620-870 μ.s. cm^{-1}. The average conductivity was 717.75 μ.s.cm^{-1}. The maximum conductivity was 870 μ.s.cm^{-1} in November 2000 and the minimum was 620 μ.s. cm^{-1} in June 2001. The conductivity was high in the cold season and was slightly lower in the summer and rainy season (Figure 4.8B; Table II-1, Appendix II). The total dissolved solids (TDS) in the first lake varied from 300-430 mg. l^{-1}. The average TDS was 351.38 mg. l^{-1}. The highest TDS was 430 mg. l^{-1} in November 2000 and the lowest was 300 mg. l^{-1} in June 2000 (Figure 4.10A; Table II-1, Appendix II). The TDS was similar to conductivity and this value was half value of the conductivity. For the second lake, the conductivity fluctuated between 1,080-1,360 μ.s.cm^{-1}. The average conductivity was 1,160.50 μ.s.cm^{-1}. The highest conductivity was 1,360 μ.s.cm^{-1} in November 2000 and the lowest was 1,080 μ.s.cm^{-1} in May 2000. This value altered only slightly throughout the investigation (Figure 4.9A; Table II-1, Appendix II). The TDS ranged from 540-670 mg.l^{-1}. The average TDS was 576.25 mg. l^{-1}. The highest level was 670 mg. l^{-1} in November 2000 and January 2001 and the lowest level was 540 mg. l^{-1} in June 2000 (Figure 4.11A; Table II-1, Appendix II).

The conductivity and TDS stratification in the first lake was low at the water surface and varied little with depth. This value was high at the bottom of the lake (Figure 4.8 B,C; 4.10 B, C). The conductivity and TDS at the depths: 0, 1, 2, 3, 8 and 13 metre depths showed little variation, however there was a marked difference at the bottom of the lake. For the second lake, the conductivity and TDS changed little with depth. The conductivity and TDS at the water surface were lower than that at the lower levels in some months but sometimes these values at the water surface were nearly the same as at the lower levels (Figure 4.9B,C ; 4.11B,C). The conductivity and TDS at every depth were fairly uniform. The conductivity and TDS in the second lake was higher than in the first lake and it changed noticeably. In the first lake, the conductivity showed a significant and positive correlation with TDS (P = 0.01) (Table II-2, Appendix II). For the second lake, the conductivity had a significant and positive correlation with TDS and nitrate–nitrogen (P = 0.01) (Table II-3, Appendix II).

Based on the investigation, it was found that the conductivity in both lakes was sometimes especially low in the rainy season and the summer because of rainfall in the rainy season and out of season which increased the water in both lakes. The increase of the water,
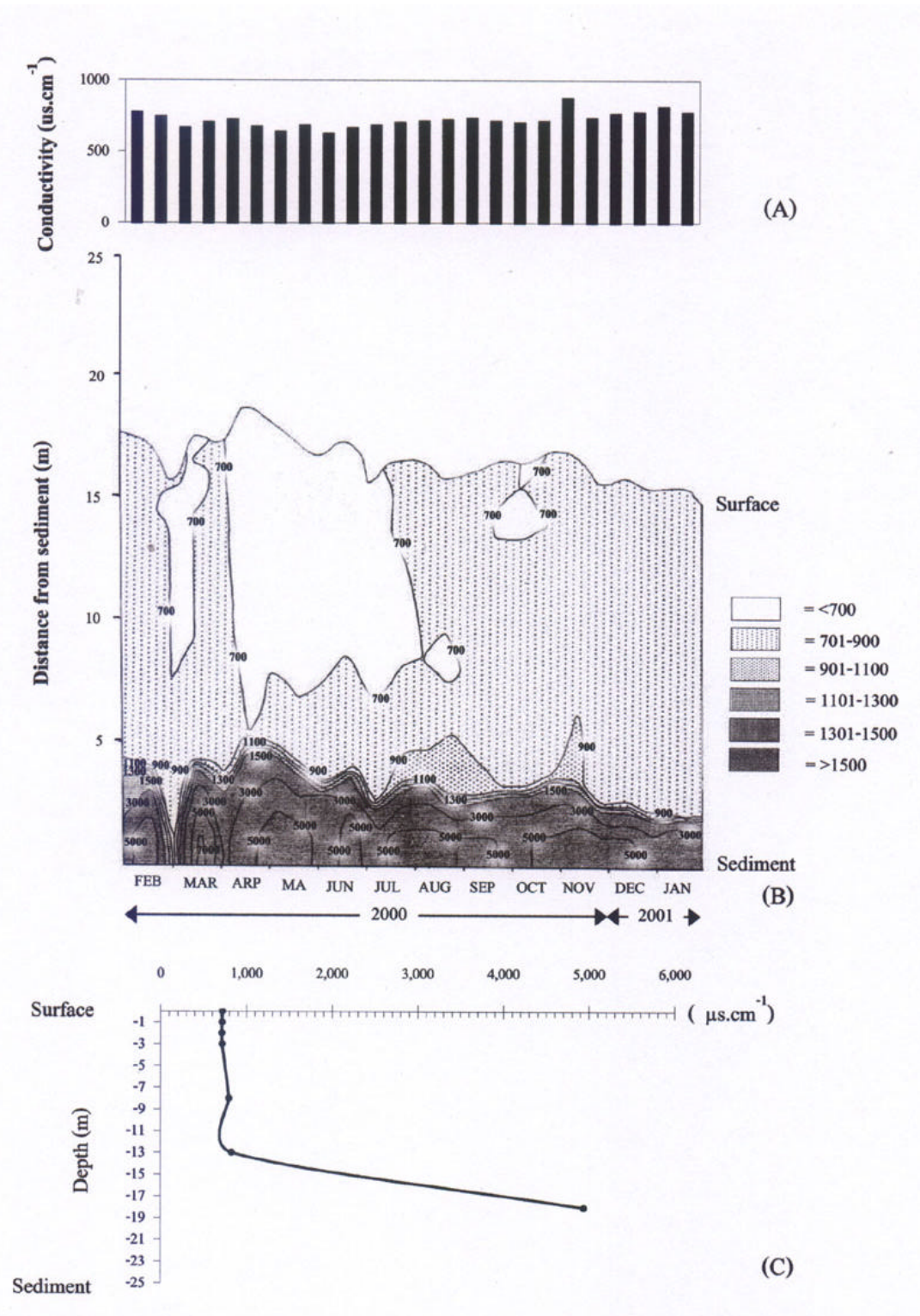
Figure 4.8 Showing the conductivity (μs.cm^{-1}) in the first lake of Rama IX lake (A) the graph of the conductivity at the water surface (B) the graph of the different water levels of the conductivity and (C) the graph of the mean conductivity from the water surface to the sediment
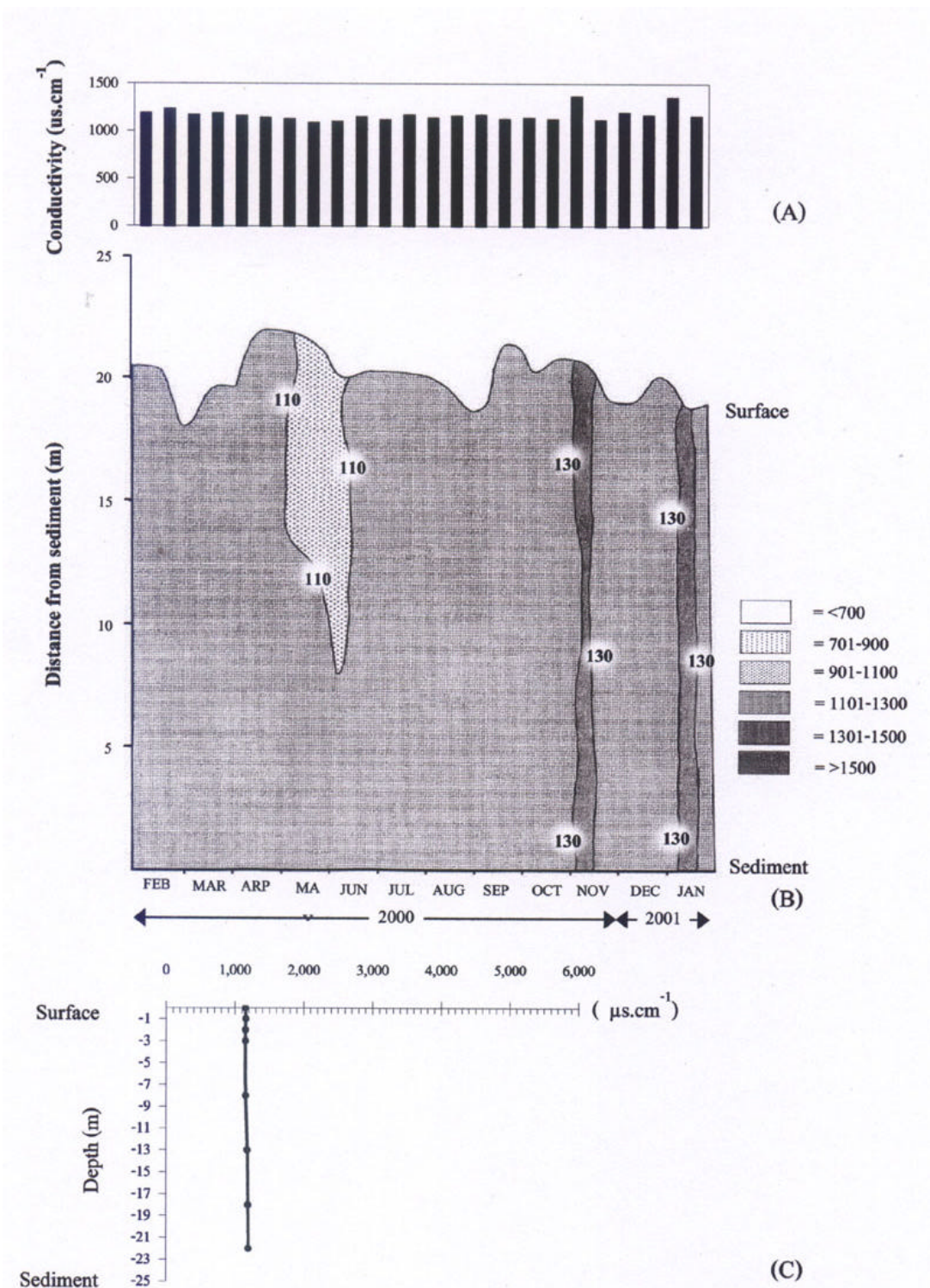
Figure 4.9   Showing the conductivity (s.cm⁻¹) in the second lake of Rama IX lake (A) the graph of the conductivity at the water surface (B) the graph of the different water levels of the conductivity and (C) the graph of the mean conductivity from the water surface to the sediment

Figure 4.10 Showing the TDS (mg.l^{-1}) in the first lake of Rama IX lake (A) the graph of the
TDS at the water surface (B) the graph of the different water levels of the TDS and
(C) the graph of the mean TDS from the water surface to the sediment

Figure 4.11 Showing the TDS (mg.l^{-1}) in the second lake of Rama IX lake (A) the graph of the TDS at the water surface (B) the graph of the different water levels of the TDS and (C) the graph of the mean TDS from the water surface to the sediment

in both lakes caused a dilution of inorganic substances, ions, minerals and etc. in the rainy season. Furthermore, the conductivity had a positive correlation with TDS in both lakes because the total dissolved solids could ionize to ions which can conduct electricity, and their conductivity can be measured (¡ÃÃ³ÇÕÃ•ÊÃ§Ễß̃Ï̃Ñ̃, 2525). For the second lake, the conductivity, and TDS demonstrated a positive correlation with nitrate–nitrogen because the soluble nutrients ionized into ions form which effected high conductivity. These results correspond to the report of Chaiubol (1998) and found that the increase in nutrients increased conductivity, and the growth of phytoplankton at times of high nutrients present in the water.

In the first lake, the conductivity and TDS were high at the bottom of the lake because of the sediment, consisting of many organic and inorganic substances in suspended form at the bottom of the lake. These suspended inorganic substances.

4.3 Chemical parameters of water quality

4.3.1 pH

The pH of the water in the first lake was between 7.68-8.87, the average pH was 8.33. The highest pH was 8.87 in April 2000 and the lowest was 7.68 in September (Figure 4.12A ; Table II-1, Appendix II). The pH of the water showed little variation between the cold and summer seasons, and it was slightly lower in the rainy season. In the second lake, this pH value was between 7.25-7.92. The average pH was 7.61. The maximum of this value was 7.92 in February 2000, and the minimum was 7.25 in March 2000. This value remained nearly the same throughout the year (Figure 4.13A; Table II-1, Appendix II). The pH of the water in the first lake was higher than the second lake and demostrated noticeable differences.

In both lakes, the pH of the water varied with depth and the stratification was clearly visible. The pH value at the water surface was higher than that of the lower levels (Figure 4.12 B,C; 4.13 B,C) but sometimes in the second lake, little change was seen from the surface to lower depths. (Figure 4.13 B,C). In the first lake, pH values at depths of 0, 1, 2 and 3 metres produced similar results, but this altered considerably at 8, 13 metre depths and the lake's bed. However, at 8 metre depth and the ground were not significantly different. In the second lake, the pH of the water showed little variation with depth but in many months the pH at the water

surface was higher than that at the lower levels. The depths of 0, 1, 2 and 3 metres contained similar pH values unlike the values at 8, 13, 18 metre depths and the lake's bed. The pH at 13, 18 metre depths and the bed had not any marked differences. In the first lake, the pH of the water had a positive correlation with dissolved oxygen (P = 0.01) and had a negative correlation with turbidity (P = 0.01) (Table II-2, Appendix II). For the second lake, the pH of the water had a positive correlation with temperature (P = 0.05) (Table II-3, Appendix II).

The pH of the water of both lakes was normal for general water resources which meant the water was livable for living organisms (^{1}Ñ ^{1}Ò ¤ªâÊ^1,2539). This value at the water surface was higher than that at the lower levels because at the water surface photosynthesine of phytoplankton took place more than at the lower levels. So the phytoplankton used high levels of carbondioxide which caused an increase in the pH value in the water. Furthermore, the condition of soil in this area was acidic which caused low pH at the bed of the lake, the acid soil causes acidity in the water too (äÁµÃÕ Ç§ÊÇÑ ìâÅÐ ÕÃÇÃÃ³ ÊÁÐ,2528). The pattern of pH decreased markedly in the hypolimnion. There was little change in pH value throughout the investigation because the inflow–outflow drains of Khlong 5 and Khlong 6 were closed throughout the investigation, which meant there was little contamination from the outside lake. In addition, there was little contamination from people swimming and fishing in the lake on holidays and even then there was little activity. The pH of the water in the first lake had a positive correlation with dissolved oxygen, because many high pH values occur due to intense photosynthetic activity of phytoplankton (Jeffries and Mills, 1994) and the production of photosynthesis from phytoplankton increased the dissolved oxygen in the water (äÁµÃÕ ´Ç§ÊÇÑ ìâÅÐ ÕÃÇÃÃ³ ÊÁÐ,2528). In this investigation a correlation was shown between the increase respectives the pH, dissolved oxygen and biovolume in April 2000 (Figure 4.12A; 4.16A; 4.57A). The result corresponds to the study of Chorum (1998) who found that an increase in photosynthesis due to a large quantity of phytoplankton meant the phytoplankton used a high level of carbondioxide in the water; so, the pH and alkalinity increased too. When the pH value of the water in the reservoirs at Huay Hong Krai Royal Development Study Center, Chiang Mai tended to be alkaline the concentration of phytoplankton was high (Srisuwan, 1993). In addition, the pH of the water showed a negative correlation with turbidity when the cloudy water in the rainy season resulted in low penetration of sunlight into the water. Phytoplankton are able to

Figure 4.12 Showing the pH of the water in the first lake of Rama IX lake (A) the graph of the pH of the water at the water surface (B) the graph of the different water levels of the pH and (C) the graph of the mean pH of the water from the water surface to the sediment

Figure 4.13 Showing the pH of the water in the second lake of Rama IX lake (A) the graph of the pH of the water at the water surface (B) the graph of the different water levels of the pH and (C) the graph of the mean pH of the water from the water surface to the sediment

lower the rate of photosynthesis, so they used less carbondioxide. This caused low pH in the water such as in August and September 2000 (Figure 4.6A, 4.12A). For the second lake, the pH of the water had a positive correlation with temperature. This correlation is explained already in the part 4.2.3 temperature.

4.3.2 Alkalinity

The alkalinity of the water in the first lake varied from 53.30-99.50 mg.l^{-1}. The average alkalinity was 63.52 mg.l^{-1}. The highest value was 99.5 mg.l^{-1} in February 2000, and the lowest was 53.30 in October 2000. This value was the highest in February 2000 and decreased slightly in the summer, and the rainy season it decreased again in the cold season (Figure 4.14A; Table II-1, Appendix II). For the second lake, this value was between 22.40-38.00 mg.l^{-1}. The average alkalinity was 26.10 mg.l^{-1}. The highest value was 38 mg.l^{-1} in February 2000, and the lowest was 22.40 mg.l^{-1} in May 2000. This value was high in February and fluctuated throughtout the investigation (Figure 4.15 A; Table II-1, Appendix II). The alkalinity of the water in the first lake was significantly higher than its was the second lake.

In the first lake, it was low at the water surface and varied little with depth. However, it was high at the lake's bed. There were no noticeable differences between 0, 1, 2, 3, 8 and 13 meter depths, but the alkaline value changed at the bottom of the lake (Figure 41.4B,C) For the second lake, this value was low at the water surface in some months, sometimes this value varied little with depth (Figure 4.15 B,C). The level of alkalinity produced similar results at 0 - 3 and 8 metre depths; however, these contrasted with the levels at 13, 18 meter depths and lake's bed, which showed significant differences between both themselves and the high depths. The alkalinity of the first lake was significantly higher than it was in the second lake.

In the first lake, this value significantly and positively correlated with coliform bacteria (P = 0.01) and significantly negatively correlated with hardness (P = 0.05) (Table II-2, Appendix II). For the second lake, there was a significant and positive correlation with total dissolved solids (P = 0.05) (Table II-3, Appendix II).

The alkalinity is usually indicated by the presence of bicarbonates, carbonates and hydroxides, and less frequently in inland waters by borate, cilicate, phosphates and other base (Wetzel, 1975). The alkalinity of both lakes varied from 10-200 mg.l^{-1} which is categorised as standard in natural reservoirs (^{1}Ñ ^{1}Ò ¤ª â£^{1} ,2539). The alkalinity in both lakes was high in

February 2000 for the first time due to polluted water, drained from Khlong 6 to Khlong 5, passing through Rama IX lake into Khlong Rangsit to decrease water contamination in the previous two months. This caused a decrease in acidity in the lake and increased the alkalinity of the water.

In the first lake, the alkalinity was positively correlated with coliform bacteria because the coliform bacteria contaminated the water resources during the draining of the polluted water. The precipitation of $CaCO_3$ can be induced by many physical and biotic agents such as increasing temperature and bacterial metabolism, but the most common is the photosynthetic utilization of CO_2 by algae and submerged macrophytes. This results in a marked decrease in the total inorganic carbon of the epilimnion (Wetzel, 1975). The decrease of carbondioxide content changed the component of the alkalinity from HCO_3^- to CO_3^- and OH^- (äÁµÃÕ Ç§ÉÇÑ¹ÒÅ¸ ÖÃÄÃ³ ÊÂÈ¡¢2528, 2528). In addition, Weider, Christensor, Weibel and Rocbeck (1968) found that in Ohio state, the increase of bacteria and coliform bacteria correlated with an increase in the amount of soil washed down into the water which in turn increased the turbidity of the water. Furthermore, the alkalinity was negatively correlated with the hardness of the water in the first lake. The investigation showed the decrease of alkalinity in the cold season increased the hardness of the water because the metals such as Ca^{++}, Mg^{++}, Na^{++} etc. increased. In the day, phytoplankton were able to increase the rate of photosynthesis, and increase the pH to 8 or 9. The ions of metals such as $Ca(HCO_3)_2$ were made by the dissociation process. The result was $CaCO_3$ sediment and CO_2 maintained the pH of the water at a level not over 8 (à»ÂÅÑ¹ÕÀÂ¹ ÐÀÇµµ, 2539). When the metals, such as Ca^{++}, combined with CO_3 the sedimentation sank to the hypolimnion, resulting in a decrease in alkalinity at the water surface because the remaining salts stayed at the epilimnion. However, alkalinity and water hardness at the bottom of the lake increased.

In the second lake, the alkalinity was positively correlated with total dissolved solids (TDS), because TDS can ionize to ions in the water. This process showed the degree of mineralization in the water. The increase in TDS showed the increase in inorganic substances. Phytoplankton can use inorganic substances for photosynthesis and consequently increase the alkalinity in the water. This result corresponds to the report of Chaiubol (1998) who studied the relationship between water quality and distribution of phytoplankton and zooplankton in Ang
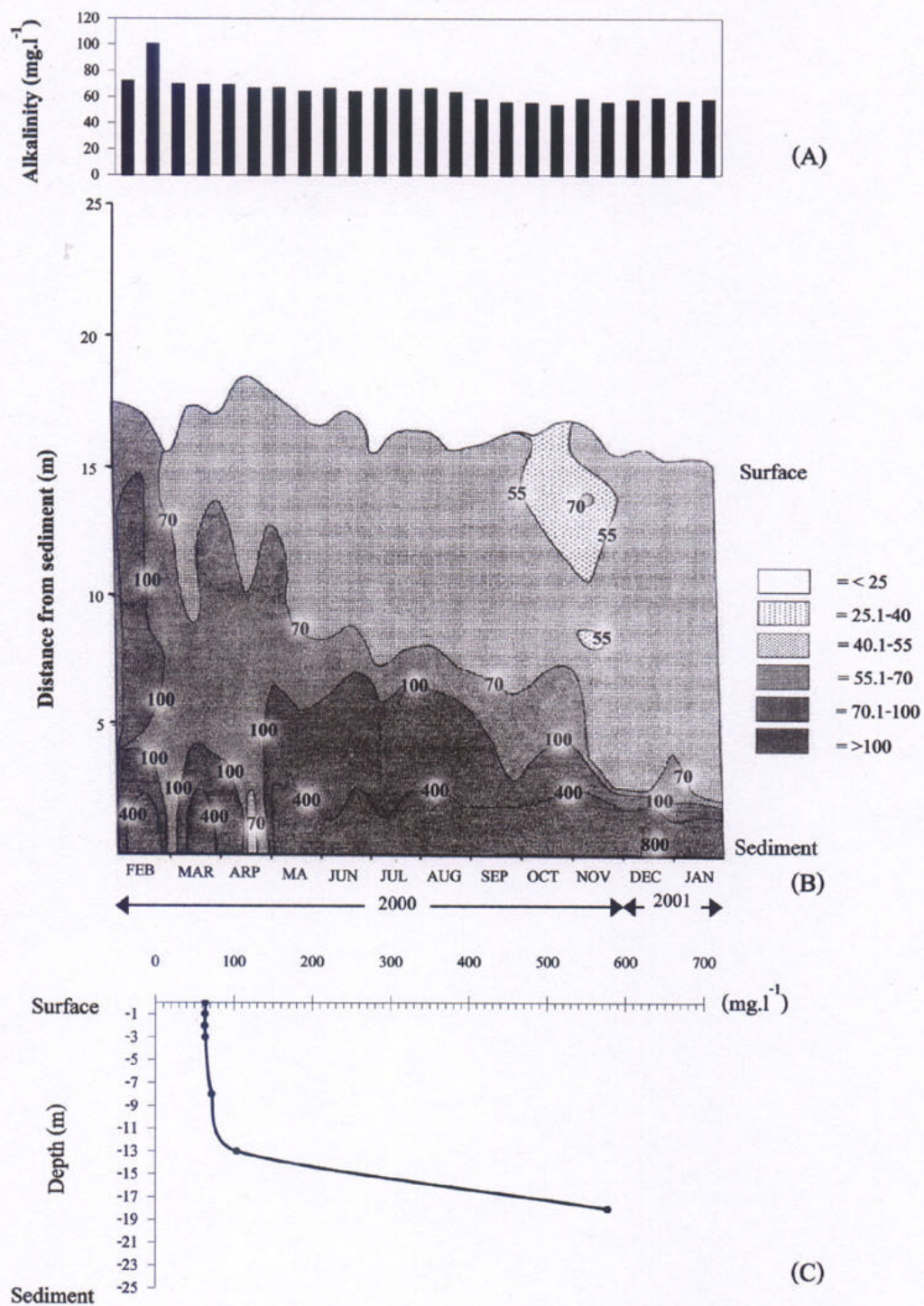
Figure 4.14 Showing the alkalinity (mg.l⁻¹) in the first lake of Rama IX lake (A) the graph of the alkalinity at the water surface (B) the graph of the different water levels of the alkalinity and (C) the graph of the mean alkalinity from the water surface to the sediment
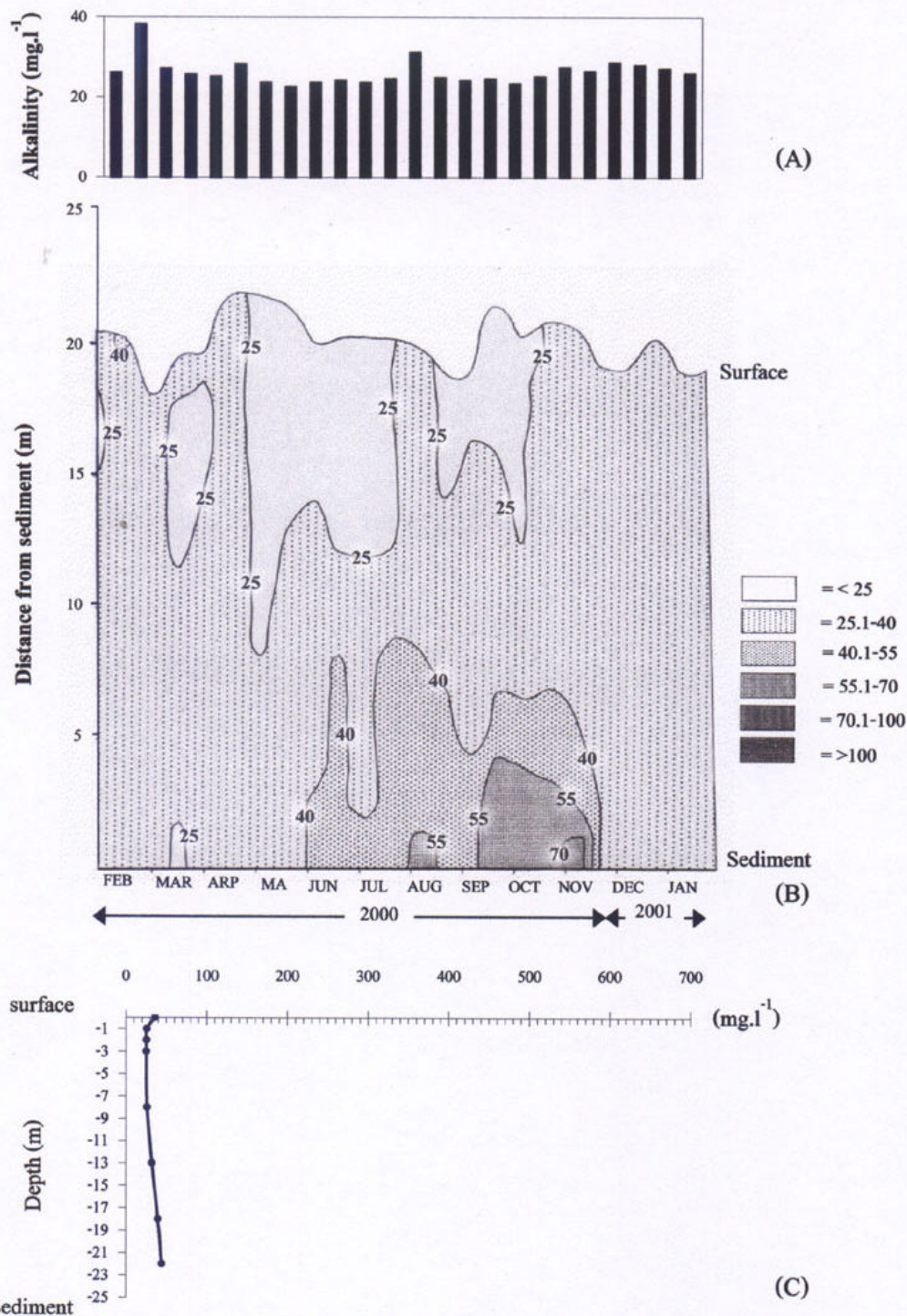
Figure 4.15 Showing the alkalinity (mg.l^{-1}) in the second lake of Rama IX lake(A) the graph of the alkalinity at the water surface (B) the graph of the different water levels of the alkalinity and (C) the graph of the mean alkalinity from the water surface to the sediment

Kaew reservior, Chiang Mai University, 1997-1998 and found that the conductivity and TDS were positively correlated with alkalinity. The soluble nutrients can ionize to ions which increases the conductivity and the rate of photosynthesis of phytoplankton. They use the increase of CO_2 and this in turn causes an increase of alkalinity in the water. For the second lake, the alkalinity showed little change throughout the investigation because this lake had a oligotrophic status which meant there was little change in the nutrients in the water (Wetzel, 1983). In the rainy season, this lake demonstrated high turbidity. The phytoplankton were only able to photosynthesis at a low rate as they used low carbondioxide levels. So, the alkalinity in this season was lower than in other seasons at the water surface.

4.3.3 Dissolved oxygen (DO)

The DO in the first lake at the water surface varied from 4.96-9.70 mg.l^{-1}. The average DO was 7.54 mg.l^{-1}. The highest level was 9.70 mg.l^{-1} in April 2000, and the lowest was 4.96 mg.l^{-1} in October 2000. The DO was high in summer, it decreased slightly in the rainy season and increased a little in the cold season (Figure 4.16A; Table II-1, Appendix II). In the second lake, it swung from 5.60-7.42 mg.l^{-1} The average DO was 6.80 mg.l^{-1}, The highest figure was 7.42 mg.l^{-1} in February 2000, and the lowest was 5.6 mg.l^{-1} in March 2000. This value fluctuated and changed little during the investigation (Figure 4.17A; Table II-1, Appendix II). DO in the first lake was higher than in the second lake and varied significantly. Oxygen levels were found to be high at the water surface and decreased slightly at the low levels to the bed in both lakes. Some months the DO was 0 mg.l^{-1} at the lake's bed. (Figure 4.16B,C; 4.17B,C). In both lakes, DO at the depths of 0, 1, 2 and 3 metre levels did not differ significantly but varied significantly from the 8, 13 metre levels and the lake's bed in the first lake. In the second lake DO at the depths of 0, 1, 2 and 3 metre levels differed significantly from 8, 13, 18 and the ground, but DO at the depth 18 metre and the ground did not differ significantly.

In the first lake, the amount of dissolved oxygen was significant and formed a positive correlation with pH (P = 0.01) (Table II-2, Appendix II). There was a significant difference and negative correlation with turbidity (0.01) in both lakes (Table II-2, II-3; Appendix II).

The dissolved oxygen in both lakes ranged from 5-9 mg.l^{-1} which is found generally in general water resources. This result corresponds with the work of ¹Ñ ¹Ò ¤ªª²Ê̈¹ (̃2539) who

reported that in general the optimum of dissolved oxygen value of 5 mg.l^{-1} is suitable for living organisms in the water; but dissolved oxygen at a low of 3 mg.l^{-1} is dangerous for living organisms in the water.

In the first lake, the dissolved oxygen was high in the summer season, especially in April 2000 and corresponded to the increase of dissolved oxygen because there was high phytoplankton biovolume causing an increase in photosynthesis and resulting in high levels of oxygen into the water. In addition, oxygen from the rainfall out of season increased the amount of oxygen in water resources. These findings resemble the research of Chaiubol (1998) who found that when phytoplankton grew well it produced and released vast amounts of oxygen into the water resources. Wetzel (1975) reported that the resources of dissolved oxygen are the atmosphere and photosynthetic inputs. The amount of oxygen decreased slightly in the rainy season because of the increase in precipition in the rainy season which washed down the soil and the nutrients from the land into the water resources. Furthermore, the sediment and the nutrients released from the lake's bed to the water body caused an increase in trubidity and a depletion of dissolved oxygen in the water. This result resembles the study of Ochumba and Kibaara (1989) who found that the increased turbidity led to decreased oxygen concentration levels at the surface water in Lake Victoria Kenya. In the cold season, the dissolved oxygen increased slightly because the water was cleaner and more transparent than in the rainy season. The clarity of the water effected an increase in the photosynthesis of phytoplankton. When phytoplankton increases the photosynthesis, the dissolved oxygen increases too.

The dissolved oxygen fluctuated between high and low levels in the second lake (Figure 4.17A) as the second lake had oligotrophic status with low phytoplankton biovolume and primary production. So, the dissolved oxygen levels changed little. This finding corresponded to the report of Horne and Goldman (1994) who found that in oligotrophic lakes changes in dissolved oxygen are negligible.

The dissolved oxygen in the first lake was higher than in the second lake because the first lake contained higher phytoplankton biovolume, primary production and chlorophyll a. So, phytoplankton in the first lake were able to produce high levels of dissolved oxygen. In addition, the second lake had higher conductivity and water hardness in the surface water. The second lake showed high amounts of salts at the water surface. Salinity also reduces the
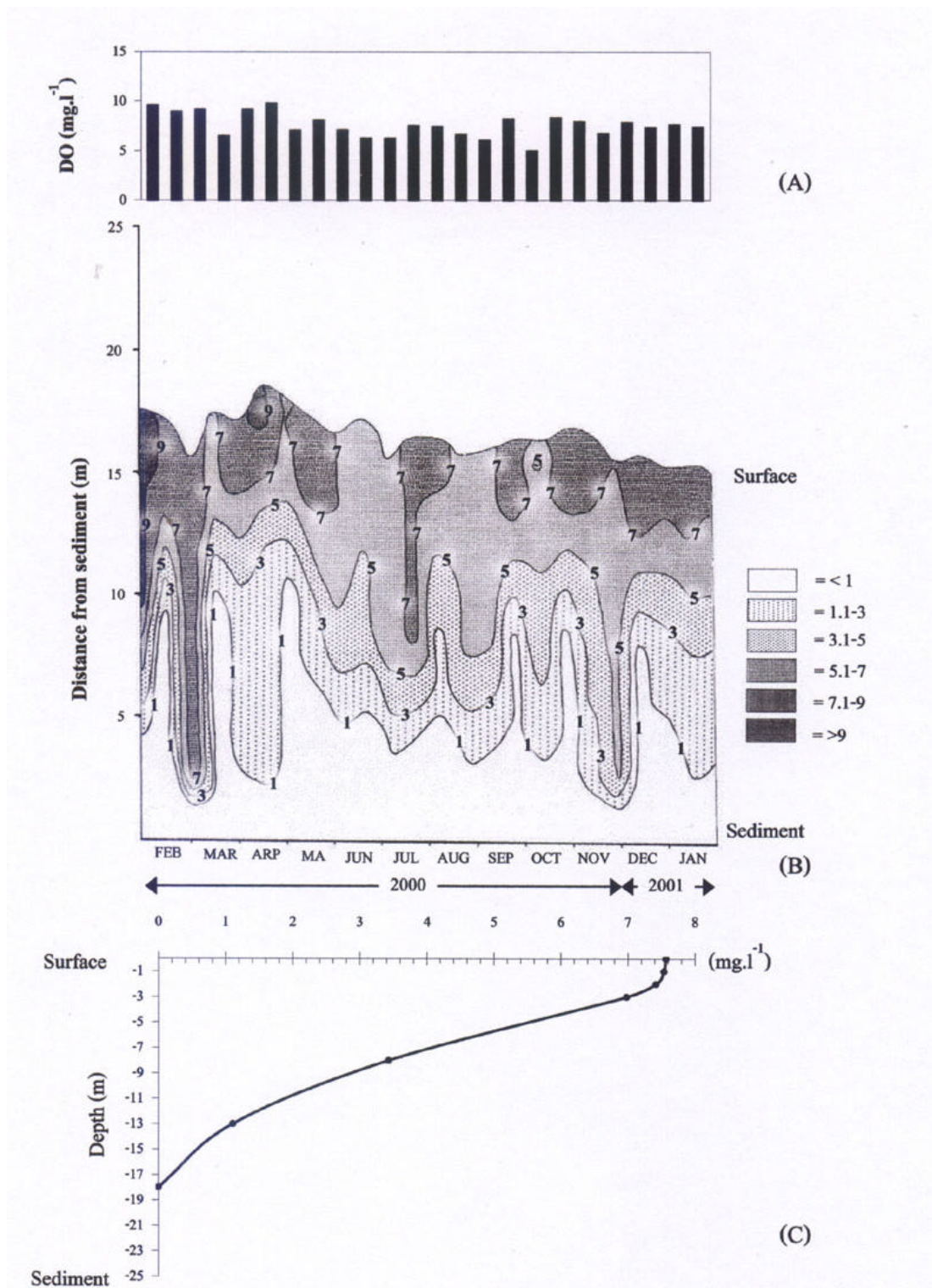
Figure 4.16 Showing the amount of DO (mg.l^{-1}) in the first lake of Rama IX lake (A) the graph of the amount of DO at the water surface (B) the graph of the different water levels of the amount of DO and (C) the graph of the mean DO from the water surface to the sediment
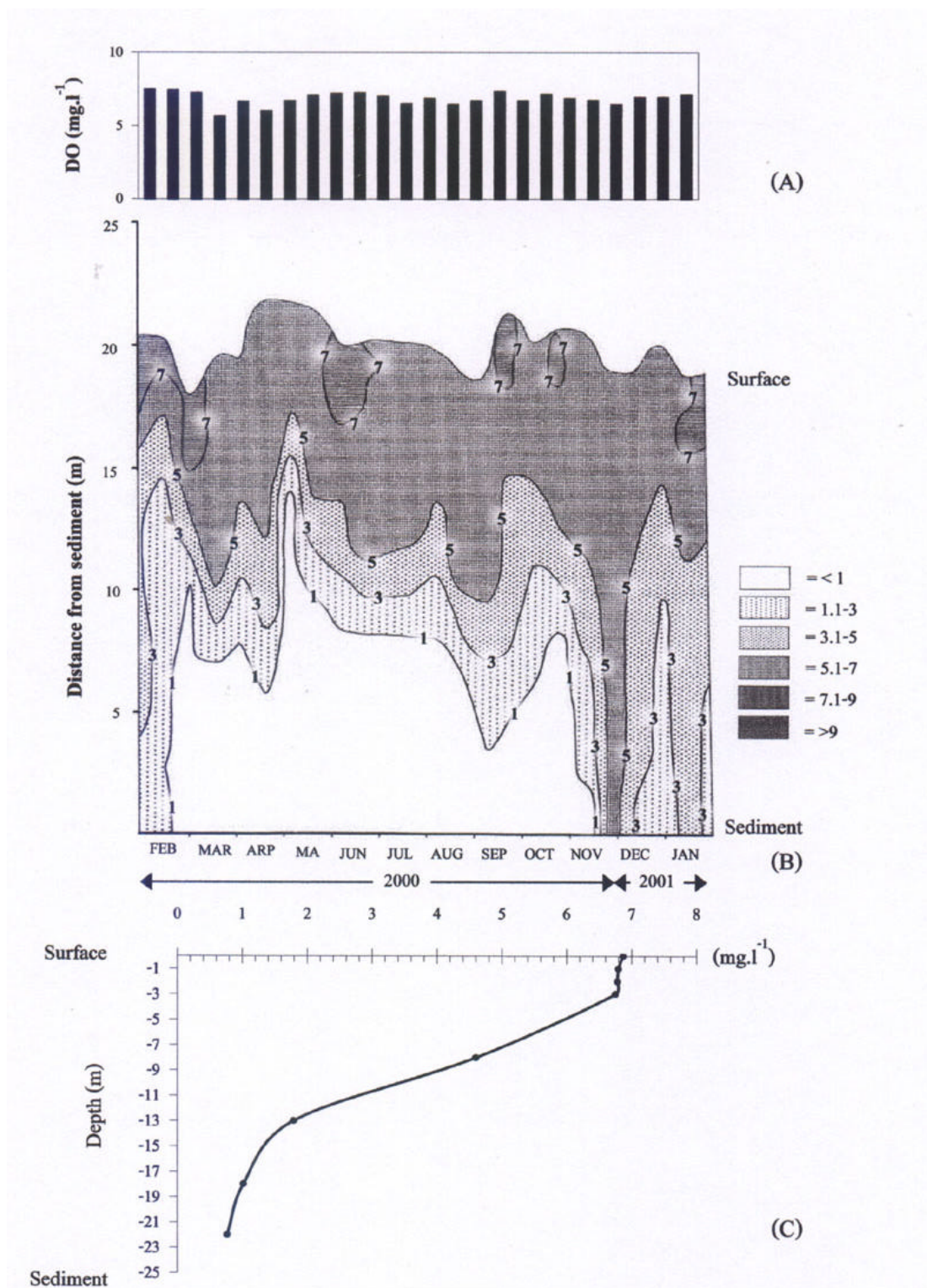
Figure 4.17 Showing the amount of DO (mg.l⁻¹) in the second lake of Rama IX lake (A) the graph of the amount of DO at the water surface (B) the graph of the water levels of the amount of DO and (C) the graph of the mean DO from the water surface to the sediment

solubility of oxygen in water (Horne and Goldman, 1994).

The dissolved oxygen from different depths in both lakes showed a high content at the water surface and decreased slightly in low level depths to the bed (Figure 4.16 B,C ; 4.17B,C) as dissolved oxygen is high in epilimnion and low in the hypolimnion. When oxygen is depleted to a low level, it causes a change in the reduction-oxidations state and the solubility of many metals and some nutrients (Horne and Goldman, 1994). Furthermore, the loss of oxygen from the hypolimnion results from the uptake during oxidation of organic matter, both in the water and especially at the sediment water interface where bacterial decomposition increases greatly (Wetzel, 1973). In a majority of lakes dissolved oxygen is found between 3 to 10 metres (Wetzel, 1973). In addition, oxygen is increasingly depleted as the stratification peroid progresses. The loss of oxygen from the hypolimnion results from the uptake during oxidation of organic matter, both in the water and especially at the sediment water interface where bacterial decomposition increase greatly (Wetzel, 1975).

4.3.4 Biochemical oxygen demand (BOD)

In the first lake, the BOD varied from 0.30-4.20 mg.l^{-1}, the average BOD was 1.53 mg.l^{-1}. The highest level was 4.20 mg.l^{-1} in June 2000 and the lowest was 0.30 mg.l^{-1} in October 2000. The BOD reached its lowest level in the cold season, increased in the summer and reached its peak in the rainy season (Figure 4.18A; Table II-1, Appendix II). The second lake's levels of BOD ranged from 0.16-2.60 mg.l^{-1}, the average BOD was 0.70 mg.l^{-1}. The highest was 2.60 mg.l^{-1} in February 2000 and the lowest was 0.16 mg.l^{-1} in January 2001. The BOD was at its highest in the early stages of this investigation and was the low throughout the rest of the investigation (Figure 4.19 A; Table II-1, Appendix II). The BOD in the first lake was higher than in the second lake and markedly different.

The BOD varied little with depth but sometimes the BOD at the water surface was lower than at the lake's bed in both lakes (Figure 4.18B,C; 4.19B,C). In the first lake at the depths of 0, 1, 2, 3 and 8 metres variations BOD levels were varied significantly from 13 metres and at the bed. In the second lake, BOD was no variations apparent at each depth.

In the first lake, BOD was postively correlated with the water level (P = 0.05) (Table II-2, Appendix II). In the second lake, the BOD had a positive correlation with coliform bacteria (P = 0.01) (Table II-3, Appendix II). The BOD of both lakes was high in the early stages

of this investigation, because the organic substances were contaminated by polluted water which was drained into the lakes during December 1999 and January 2000. The organic substances from polluted water caused high readings of BOD in the water resources findings which agreed with the work of Abel (1989) who found that BOD are generally useful as indicators of the organic loading of water. ÇิเชียรÈ³•¡Õ¹Ð¾Ù¹Õ (2536) reported that the BOD shows the level of contamination or waste water by organic substances. If the water has high levels of BOD, it shows there is a corresponding high level of organic substances in the water. The BOD was high in the summer and reached its peak in the rainy season (especially in June) in the first lake because this lake received precipitation from out of season rain in the summer as well as in the rainy season. The rainfall washed down the sediment and organic substances from the land into the water resource, causing an increase in nutrients. These nutrients were digested by the bacteria which used high amounts of oxygen causing on the increase of BOD (äÁµÃÕ ÇุÊÊÇÑÕ Ô áÅÐ·ÍÇุ²Ã³ ÊÁÈÑ¡ÔìÔ2528). This result corresponded to the study of Peerapompisal, Somdee, Sonthichai and Rott (1998) who studied water quality, distribution and primary productivity of phytoplankton in the reservoir of Mae Kuang Udomtara dam, Chiang Mai 1996-1998 and found that the BOD was high in the summer season but peaked in the rainy season, particularly in September and this finding agreed with the research of Pooarlai (1999) who conducted a analysis of water quality using phytoplankton and coliform bacteria as indicator in Huai Tung Thao reservoir, Chiang Mai province and found that the nitrogen increased in the rainy season, especially in September, with the sediment around the lake washed down into the lake. The nitrogen and the sediment caused an increase in coliform bacteria, and dissolved oxygen was consumed by coliform bacteria for digestion of organic substances.

Furthermore, the BOD positively correlated with the Secchi depth (P = 0.05) in the second lake (Table II-3, Appendix II).

In the second lake, the BOD after February 2000, fluctuated through out the investigation and was lower than in the first lake. As the result, this lake had low nutrients such as nitrate, ammomia and phytoplankton biovolume. So, the bacteria used low amounts of oxygen for digestion. The BOD was low too.

The BOD from different depths in both lakes was low at the water surface and high on the lake's bed because the amount of respiration is roughly proportional to biomass and is

Figure 4.18 Showing the amount of BOD (mg.l^{-1}) in the first lake of Rama IX lake (A) the graph of the amount of BOD at the water surface (B) the graph of the different water levels of the amount of BOD and (C) the graph of the mean BOD from the water surface to the sediment

Figure 4.19 Showing the amount of BOD (mg.l^{-1}) in the second lake of Rama IX lake (A) the graph of the amount of BOD at the water surface (B) the graph of the different water levels of the amount of BOD and (C) the graph of the mean BOD from the water surface to the sediment

particularly high in organically rich sediments where bacteria are abundant. Furthermore, bacterial metabolism is greatest (Home and Goldman 1994 ; Wetzel 1975).

The first lake was positively correlated with the water level because the depth of water was high in the early stages of the investigation and during the rainy season. In the rainy season, the sediment, organic substances and coliform bacteria from the land around the lake washed down into the water caused an increase in the use of dissolved oxygen for digestion of organic substances in the water. This finding agreeed with the study of Geldrich, Best, Kennern and Dosel (1968) who reported that in the rainy season, the bacteria causes higher contamination in the water resources than other seasons. In the second lake, the BOD was positively correlated with Secchi depth and coliform bacteria because there were many organic substances, and coliform bacteria in the early stages of the investigation and in the rainy season. The presence of organic substances and coliform bacteria caused an increase in the cloudiness of the water which decreased the sunlight penetration into the water. The additional coliform bacteria was caused by an increased use in dissolved oxygen in the water.

4.3.5 Hardness

The water hardness at the water surface in the first lake ranged from 174-190 mg. l^{-1}. The average hardness was 182.13 mg.l^{-1}. In the second lake, the figures ranged from 275-290 mg.l^{-1}. The average was 280.73 mg.l^{-1}. This value started in June 2000, and ceased in January 2001. The water hardness in the second lake was higher than the first lake, and there was a significant difference. The water hardness in the first lake was low at the water surface, but it was high on the lake's bed. The water hardness varied little with depth (Figure 4.20 B,C ; Table II-1, Appendix II) as was the case in the second lake (Figure 4.21 B,C; Table II-1, Appendix II). In the first lake, the water hardness had a positive correlation with Secchi depth (P = 0.05) and had a negative correlation with alkalinity and primary production (P = 0.05) (Table II-2, Appendix II) For the second lake, the water hardness had no correlation with the other parameters (Table II-3, Appendix II).

The water hardness at the water surface of both lakes varied little throughout the investigation. It was slightly low in the rainy season because the rainfall decreased the dissolved salts and increased the alkalinity in the water. The water hardness in the second lake at the water surface was higher than in the first lake because in the second lake a larger number of ions of
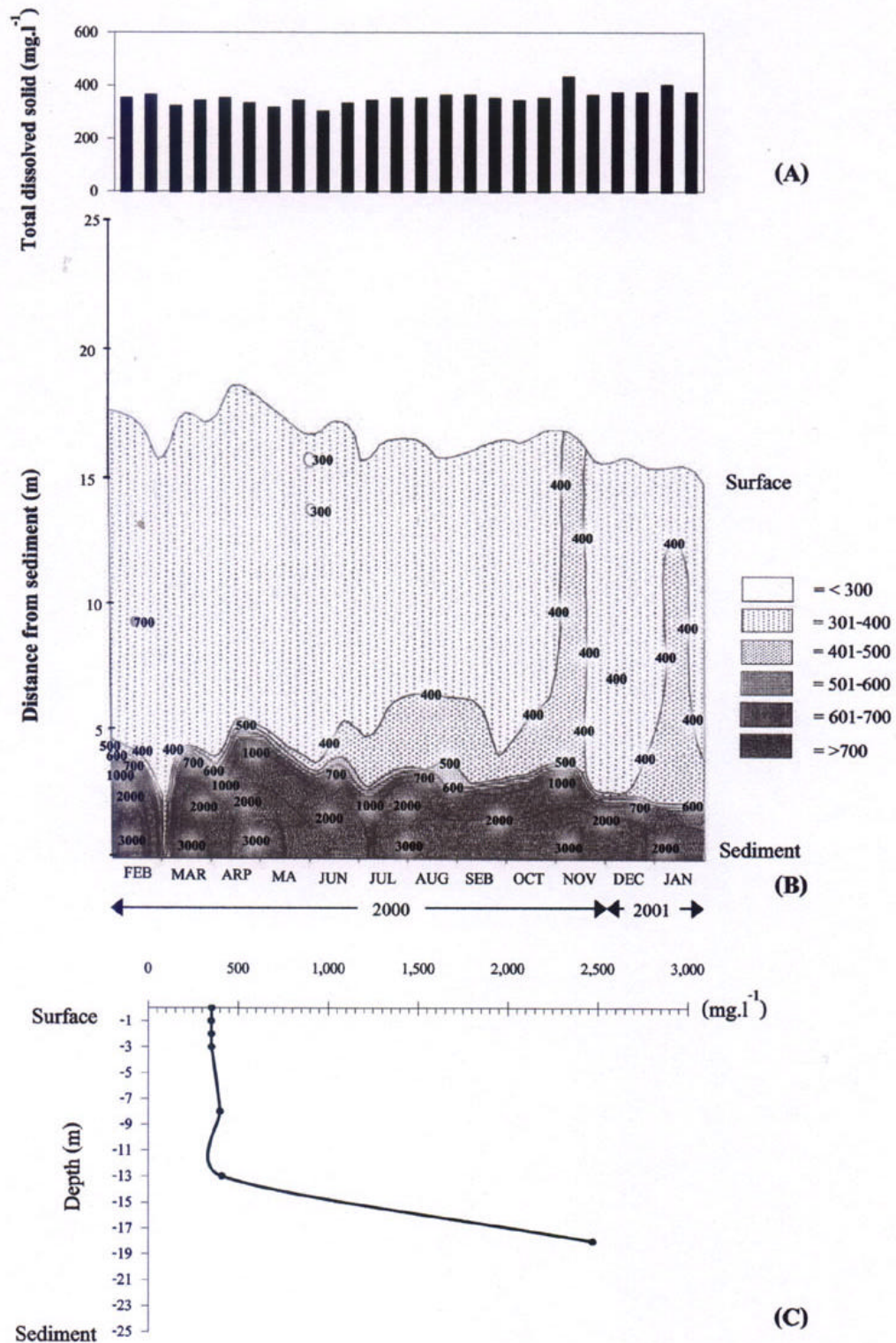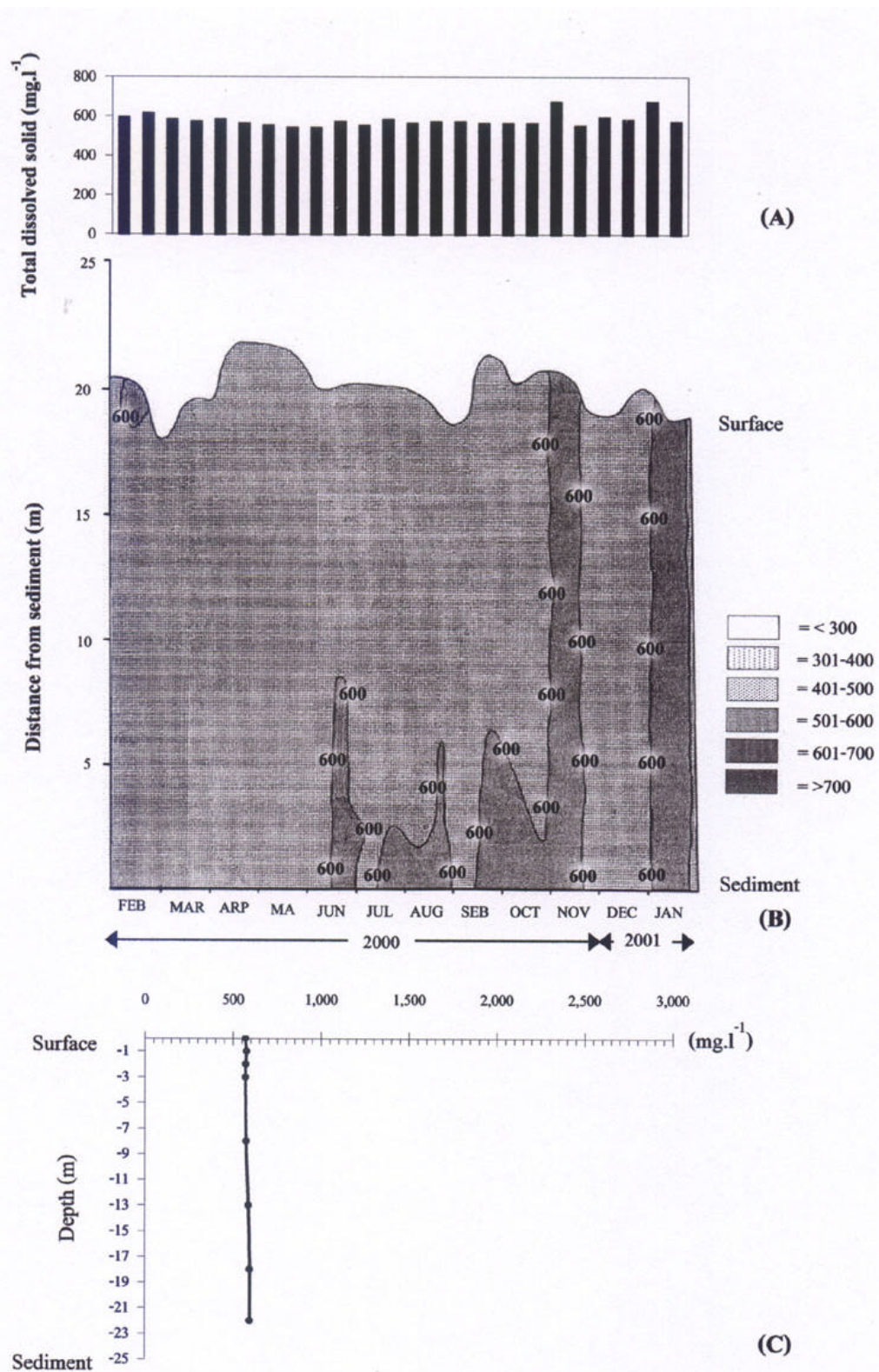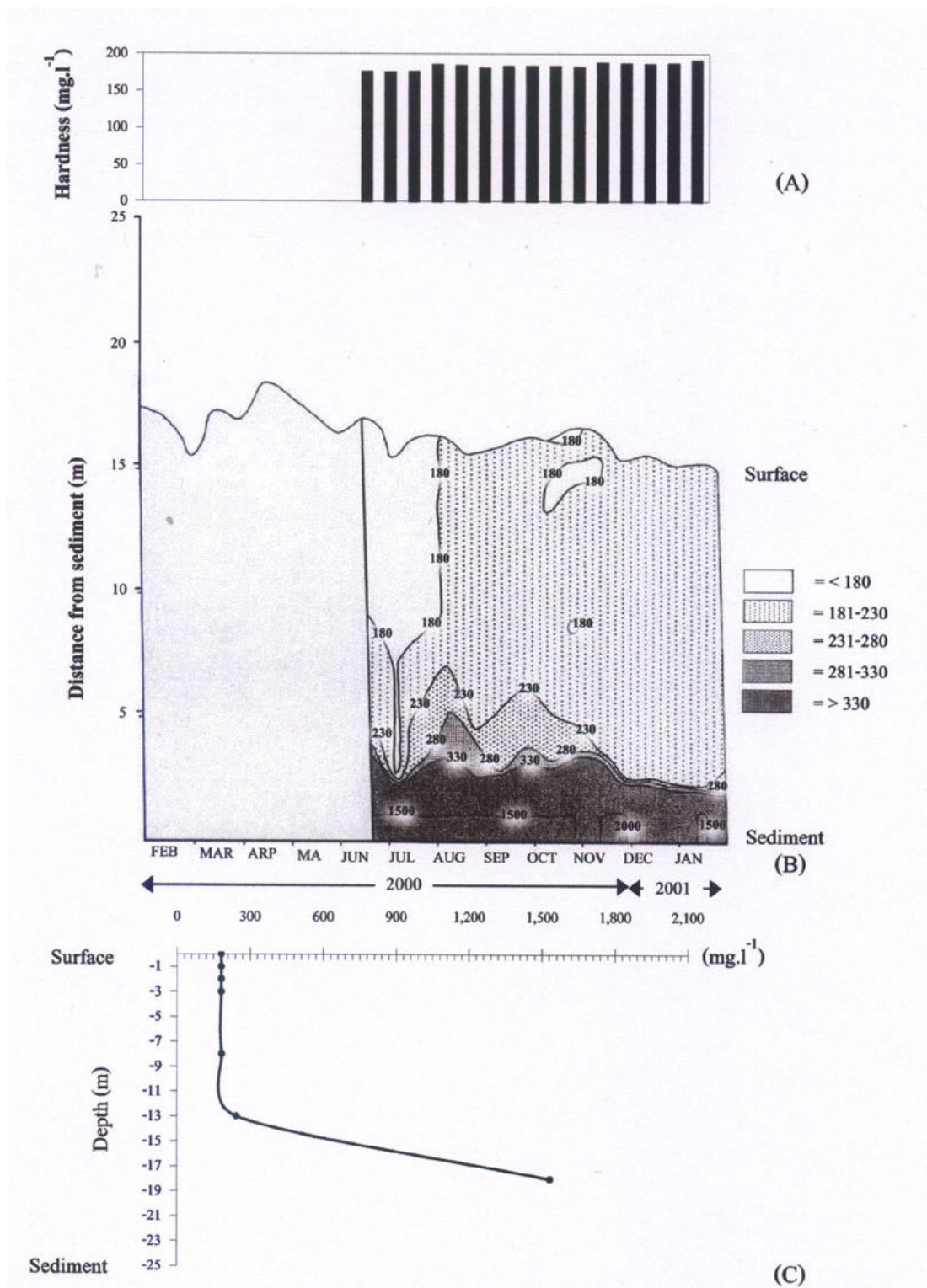
Figure 4.20 Showing the hardness (mg.l^{-1}) in the first lake of Rama IX lake (A) the graph of the hardness at the water surface (B) the graph of the different water levels of the hardness and (C) the graph of the mean hardness from the water surface to the sediment

Figure 4.21 Showing the hardness (mg.l⁻¹) in the second lake of Rama IX lake (A) the graph of the hardness at the water surface (B) the graph of the different water levels of the hardness and (C) the graph of the mean hardness from the water surface to the sediment
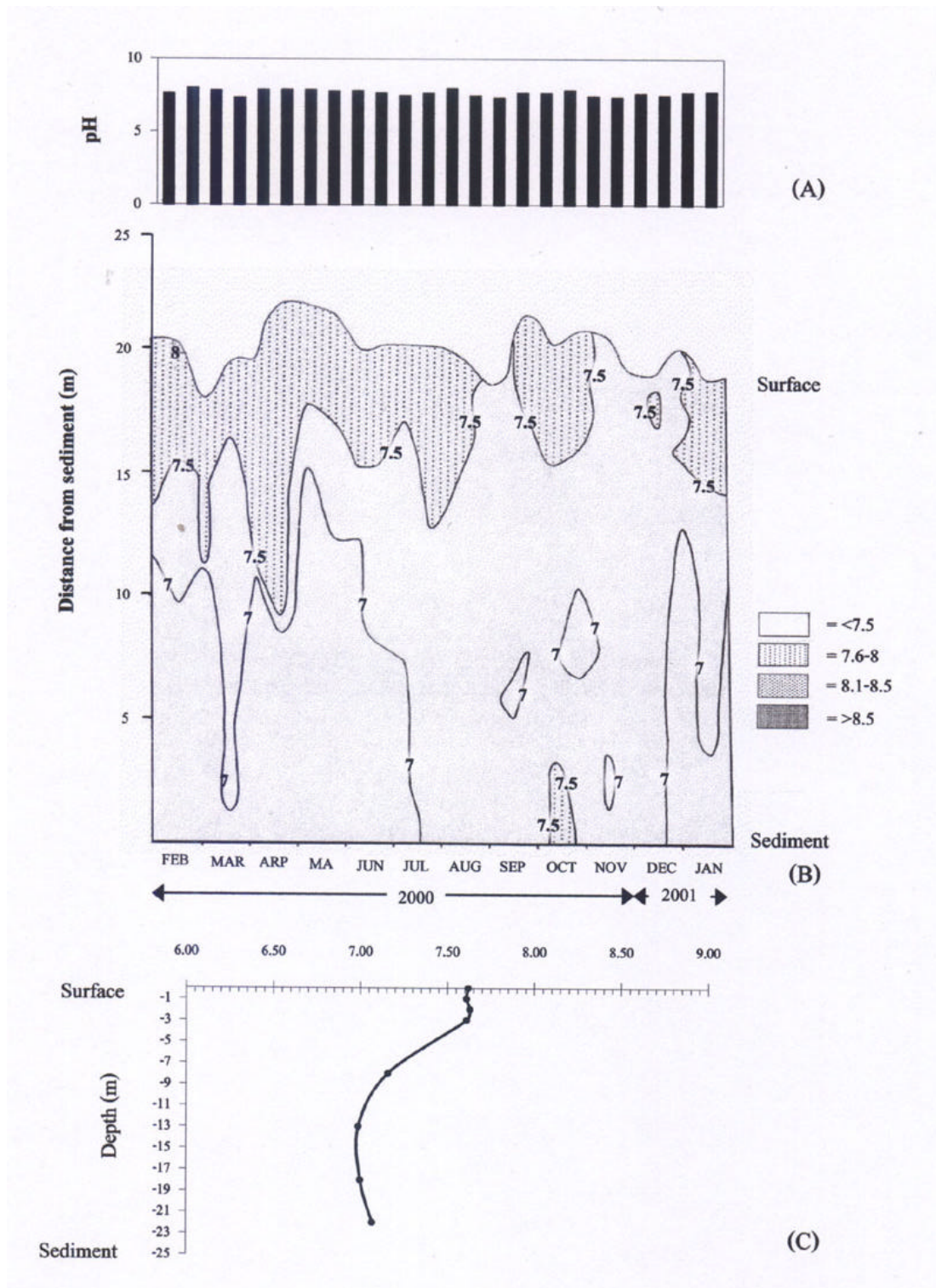
inorganic substances were present with high conductivity and TDS. The water hardness was high in both lakes. It showed low primary production in both lakes. The finding corresponds to the report of Ê¶ÒP Ñ ÃÐÁ§¹ Ð ⁄áË§ª Ùµ(2521) which found that the rate of productivity of water resources will increase when total hardness exceeds 130 ppm of $CaCO_3$, but most total hardness will cause a decrease in productivity in the water resources.

In the first lake, the water hardness had a positive correlation with Secchi depth because the water level decreased in the dry season, especially in January 2001 and the water hardness increased the water clarity in this season. There was decrease in strong waves leading to less sediment from the land being washed into the lake. The ions of metal salts combined with CO_3 and sank to the lake's bed which increased the clarity of the water. Furthermore, phyto-plankton were able to increase the rate of photosynthesis and could use the ions for growth because the minerals such as Ca^{++} are essential for metabolic processes in all living organisms (Horne and Goldman, 1994).

The water hardness was higher at the bed of the first lake than that at the water surface because the ions such as Ca^{++}, Mg^{++} etc. caused water hardness especially Ca^{++} when the Ca^{++} combined with $CO_3^=$ the sediment of $CaCO_3$ increased marl on the lake's bed. Furthermore, Ca^{++} can react with other ions such as $SO_4^=$ to form $CaSO_4$ otherwise called "gypsum" (»ÃÐÀÒ¾ ¾Ã̀ÁÊ Ø̧Ñ̀É,•2539). In the second lake, water hardness only varied slightly with the depth because this lake was big with a high volume of water and strong waves which circulated the total salts from the ground into the body of water.

4.3.6 Nutrients

4.3.6.1 Nitrate-nitrogen

The amount of nitrate-nitrogen in the first lake varied from 0.0006-0.0839 mg.l^{-1}. The average of this value was 0.0204 mg.l^{-1}. The highest value was 0.0839 mg.l^{-1} in September 2000 and the lowest was 0.0006 mg.l^{-1} in December 2000. This value was at its lowest in the cold season and increased slightly in the summer. However, this value was the highest in the rainy season (Figure 4.22 A; Table II-1, Appendix II). For the second lake, this value fluctuated between non-detectable (ND)-0.0393 mg.l^{-1}, the average nitrate nitrogen content was 0.0121 mg.l^{-1}. The highest level was 0.0393 mg.l^{-1} in November 2000 and the lowest was non-detectable in August 2000 (Figure 4.23A; Table II-1, Appendix II).

The amount of nitrate-nitrogen in the first lake was significantly higher than it was in the second lake. The quantity of nitrate-nitrogen in the first lake was not related to the other parameters (Table II-2, Appendix II). In the second lake, nitrate-nitrogen and conductivity were positively related with significant differences (P = 0.05). (Table II-3, Appendix II). The content of nitrate-nitrogen of both lakes did not vary noticeably. The nitrate-nitrogen at the water surface was higher than that at the lower levels, but sometimes this value at the water surface was lower than that at the lower levels (Figure 4.22 B,C; 4.23B,C). In the first lake, the nitrate-nitrogen did not differ significantly between 0-3 metre depths, but there were differences at 8, 13 metre depths and at the bed of the lake. However, the amount of nitrate-nitrogen at 8 and 13 metre depths contained no significant differences. In the second lake, the amount of nitrate-nitrogen did not significantly alter between 1-3 metre depths, but there were clearly apparent differences at the bottom of the lake, 0, 8, 13 and 18 metre depths. However, the amount of nitrate-nitrogen at 0, 8 and 18 metre depths had no significant differences as neither did the nitrate-nitrogen at 13 metre depth and the lake's bed.

The amount of nitrate-nitrogen of both lakes was low throughout the investigation and these values did not exceed 5 mg.l^{-1}, the maximum figure set as the standard of surface water quality in Thailand set by National Environmental Board, 1994. Generally, the average of nitrate-nitrogen is 0.3 mg.l^{-1} in the natural water resources (à»ÂÃÈÑÕ·Á¹ÐÈÇµ, 2539).

In the first lake at the water surface the amount of nitrate-nitrogen reached its highest figure in rainy season especially in September 2000. In addition, the rainfall washed down nitrate-nitrogen from the land around the lake into the lake. The nitrate-nitrogen released from the sediments will enrich the water body. This result corresponded to the report of Horne and Goldman (1994) who found that nitrate ions more easily washed down through soils and are quickly lost from the land. This contrasts with phosphate or ammonium ions, which are retained by the soil. During the fall and winter releases from sediments, precipitation and replenishment from the hypolimnion increase the nitrate and some of the ammonia concentrations. This study also showed that the amount of nitrate-nitrogen in the first lake decreased in the cold season because of the reduction in rainfall which resulted in less nutrients being washed from the land into the water. Furthermore, an amount of nitrate-nitrogen was constantly used by the phyto-
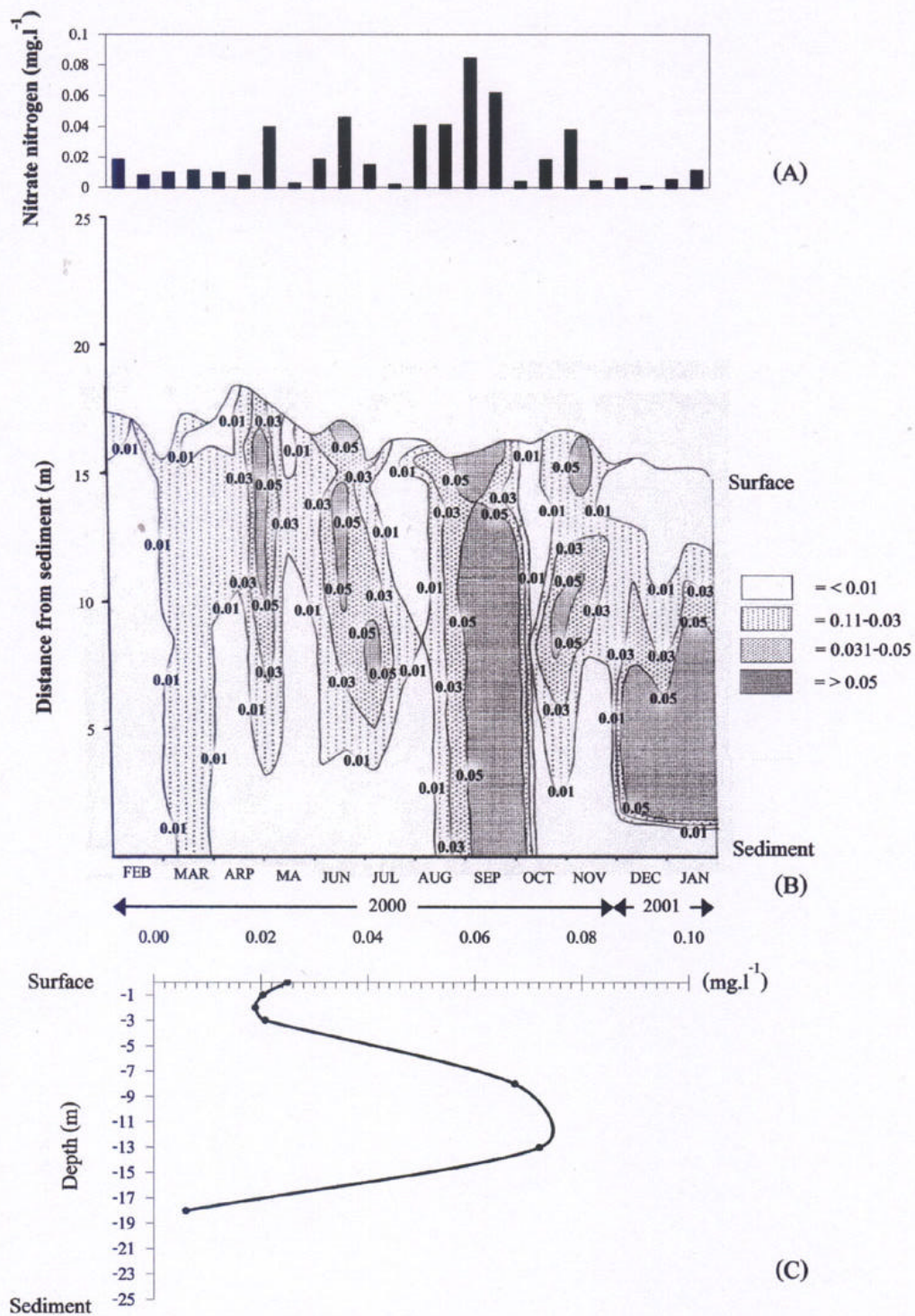
Figure 4.22 Showing the NO_3-N content (mg.l^{-1}) in the first lake of Rama IX lake (A) the graph of the NO_3-N content at the water surface (B) the graph of the different water levels of the NO_3-N content and (C) the graph of the mean NO_3-N content from the water surface to the sediment
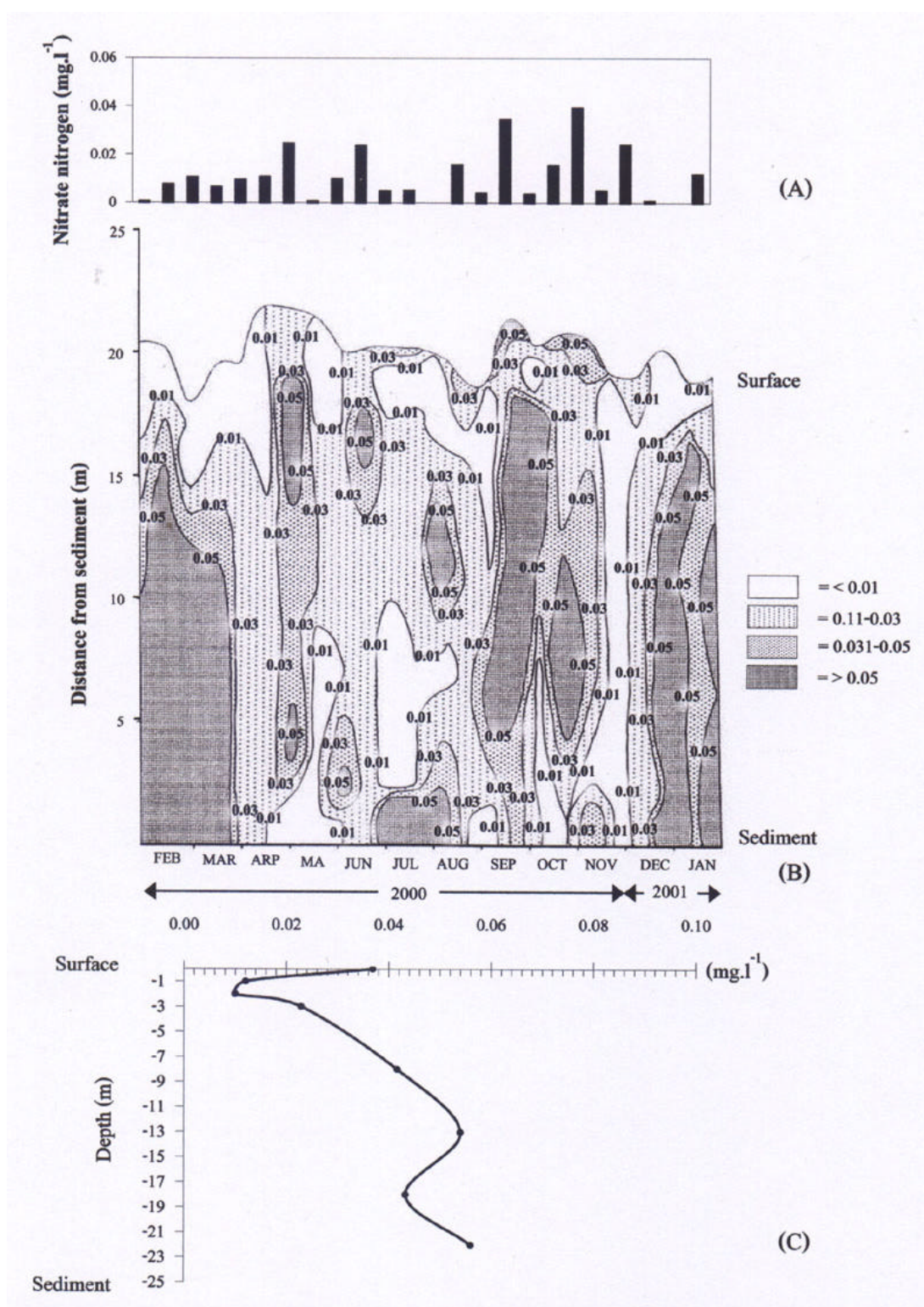
Figure 4.23 Showing the NO_3-N content (mg.l^{-1}) in the second lake of Rama IX lake (A) the graph of the NO_3-N content at the water surface (B) the graph of the different water levels of the NO_3-N content and (C) the graph of the mean NO_3-N content from the water surface to the sediment

plankton. So this value decreased especially in the cold season.

On the contrary, the amount of nitrate-nitrogen in the second lake attained its highest level measured at the water surface in November 2000. The reason for this high level of nutrients was the decrease in water volume in this lake which caused nitrate-nitrogen to gel up. In this month, ionization of nutrients increased due to a higher level of nitrate-nitrogen which in turn caused the rise in the conductivity reading. In August 2000, the amount of nitrate-nitrogen was at its lowest because of the increase in the water volume from continuous precipitation from April to August 2000. Larger water volume caused the decrease in the amount of nitrate-nitrogen at the water surface.

In the first lake, the amount of nitrate-nitrogen at the water surface was higher than in the second lake because this lake was shallower and thus gained more nitrate-nitrogen from the land which was consequently digested by bacteria on the lake's bed. The amount of nitrate-nitrogen in stratification, in the first lake, the amount of nitrate-nitrogen in some months at the water surface was higher than at the bottom of the lake because this lake contained low or zero levels of dissolved oxygen or the lake's bed. So the nitrate-nitrogen on the lake's bed formed ammonia-nitrogen more than other substances. Furthermore, Chuapohak (1982) reported that the amount of ammonia-nitrogen exceeded 0.5-1 $\mu g.l^{-1}$ inhibition using nitrates. Sometimes the amount of nitrate-nitrogen at the water surface was nearly the same as at the bottom of the lake in the early rainy season, from especially August 2000-September 2000 because the rainfall and strong waves mixed up the nutrients in both areas of the water resource.

In the second lake, the amount of nitrate-nitrogen was low at the water surface, but it was high at the hypolimnion in some months because a considerable amount of nitrate-nitrogen was produced from digestion of NH_4 to NO_2 and then to NO_3 done by the bacteria at the bed of the lake. This process used the little remains of dissolved oxygen on the lake's bed and the strong waves circulated dissolved oxygen from the epilimnion to the hypolimnion. Sometimes, the amount of nitrate-nitrogen at the water surface was higher than at the lower depths and the bottom of the lake because of the wind factor. The wind caused water columns and this caused an upwelling of nitrate-nitrogen from the bed to the water body (Boland and Griffiths, 1996).

4.3.6.2 Ammonia-nitrogen

In the first lake, the amount of ammonia-nitrogen varied from 0.0120-0.2300 mg.l^{-1}. The average ammonia nitrogen content was 0.0846 mg.l^{-1}. The highest level ammonia-nitrogen found was 0.2300 mg.l^{-1} in May 2000 and the lowest was 0.0120 mg.l^{-1} in August 2000 (Figure 4.24A ; Table II-1, Appendix II). The second lake, the amount of ammonia-nitrogen was between 0.0119-0.1874 mg.l^{-1}. The average ammonia nitrogen content was 0.0658 mg.l^{-1}.The largest amount ammonia nitrogen was 0.1874 mg.l^{-1} in March 2000 and lowest was 0.0119 mg.l^{-1} in September 2000 (Figure 4.25 A; Table II-1, Appendix II). The quantity of ammonia-nitrogen of both lakes fluctuated throughout the investigation and it was not correlated with the season. The amount of nitrate-nitrogen of both lakes did not significantly differ.

The level of ammonia-nitrogen stratification was low at the water surface but was high at the bottom of the lake. There was clarity variation with depth (Figure 4.24 B,C; 4.25 B,C). In the first lake, the amount of ammonia-nitrogen at the depth of 0-3, 8 and 13 metres were not markedly differents. However, these figures were different from the bottom of the lake. In the second lake, the amount of ammonia-nitrogen did not vary appreciably at 0-3 and 8 metre depths. However, these numbers varied when compared to 13, 18 metre depths and the bottom of the lake.

The amount of ammonia-nitrogen showed no noticeable differences with other parameters in the first lake (Table II-2, Appendix II). In the second lake, the amount of ammonia-nitrogen positively related to primary production (P = 0.05). (Table II-3, Appendix II)

The volume of ammonia nitrogen of both lakes was low throughout the investigation of the water surface. This value did not exceed the standard surface water quality of Thailand which must not exceed 0.5 mg.l^{-1} set by the National Environmental Board in 1994. In addition ammonia in most lakes and streams is generally well below 0.1 mg.l^{-1} and detrimental effects of naturally occuring ammonia are uncommon (Horne and Goldman, 1994).

The amount of ammonia – nitrogen stratification from both lakes (Figure 4.24 B,C ; 4.25 B,C) showed water clarity was higher at the hypolimnion than at the water surface. It showed the ammonia – nitrogen came from digestion by bacteria at the bottom of the lake rather than from contamination from outside the lake. In addition, where reasonably large amounts of organic matter reach the bed of stratified lakes, ammonia-nitrogen tends to accumulate. The
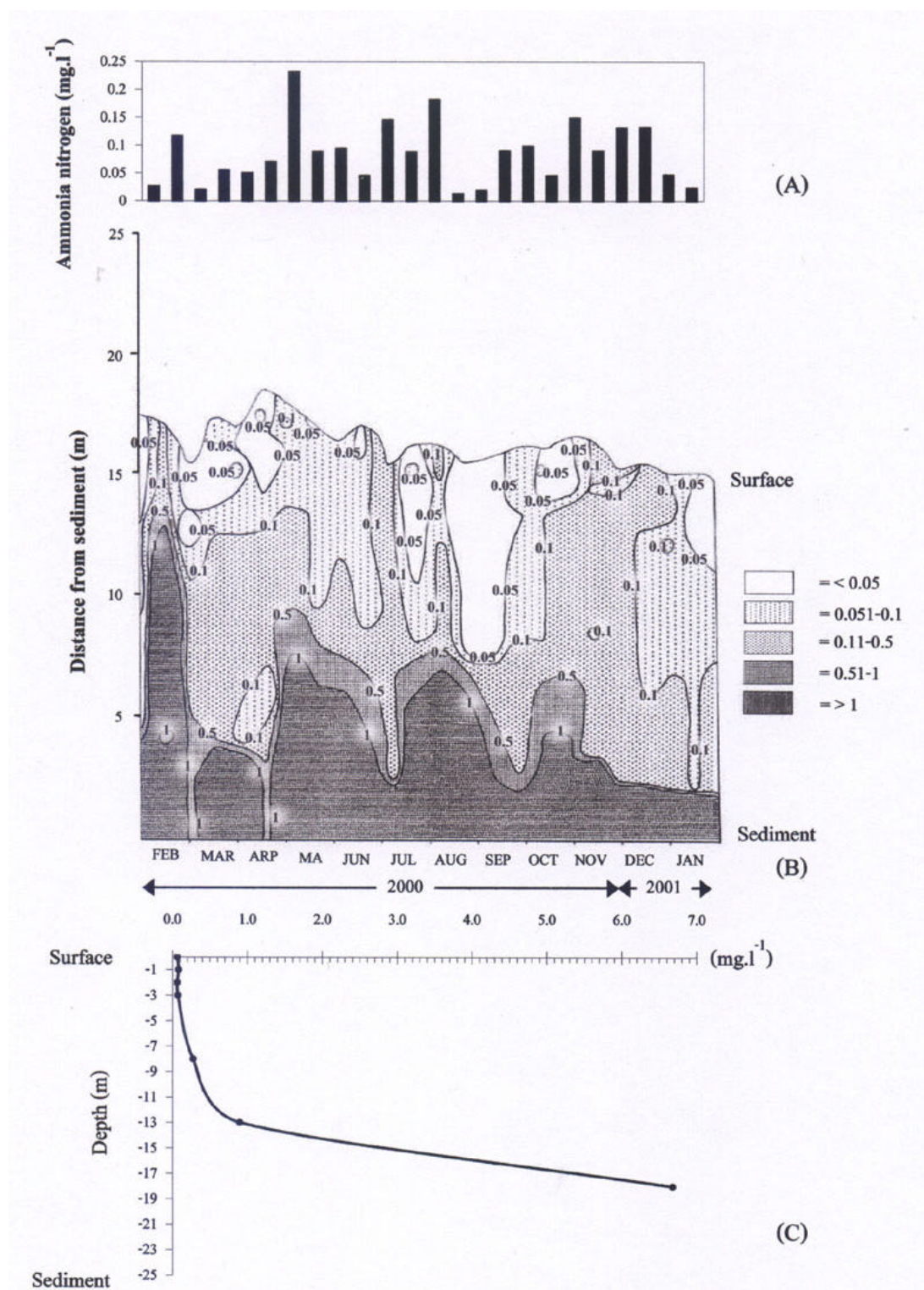
Figure 4.24 Showing the NH$_3$-N content (mg.l^{-1}) in the first lake of Rama IX lake (A) the graph of the NH$_3$-N content at the water surface (B) the graph of the different water levels of the NH$_3$-N content and (C) the graph of the mean NH$_3$-N content from the water surface to the sediment

Figure 4.25 Showing the NH₃-N content (mg.l⁻¹) in the second lake of Rama IX lake (A) the graph of the NH₃-N content at the water surface (B) the graph of the different water levels of the NH₃-N content and (C) the graph of the mean NH₃-N content from the water surface to the sediment

accumulation of ammonia-nitrogen greatly increases when the hypolimnion becomes anoxic (Wetzel, 1975). According to the investigation no dissolved oxygen was found at the bottom of the lake, especially in the first lake. The amount of ammonia-nitrogen increased in both lakes at the water surface in some months because of the bacteria utilizing the amonia-nitrogen at the bed of the lake for growth and they in turn, released amonia-nitrogen from the sediments which enriched the interstitial and overlying water. In addition, the water in both lakes received ammonia-nitrogen from polluted water in the early stages of this investigation and also some ammonia come from the rainfall which washed down the nutrients from the land into the water resources.

In the second lake, the amount of ammonia-nitrogen had a positive correlation with primary production because the phytoplankton received a high level of nutrients. So, the phytoplankton increased the rate of photosynthesis and increased the primary production too. These results agree with the report of Rott, (1984) which said that primary production is influenzed by the inorganic nutrient level.

4.3.6.3 Nitrite-nitrogen

The amount of nitrate-nitrogen in the first lake at the surface ranged from 0-0.0068 mg.l^{-1}. The average nitrate-nitrogen content was 0.0021 mg.l^{-1}. The highest value was 0.0068 mg.l^{-1} in November 2000 and the lowest was 0 mg.l^{-1}. In the second lake, it varied from 0-0.0136 mg.l^{-1}. The average nitrate - nitrogen content was 0.0025 mg.l^{-1}. The highest value was 0.0136 mg.l^{-1} in November 2000 and the lowest was 0 mg.l^{-1} in May and June 2000 (Figure 4.26; Table II-1, Appendix II).

In the first lake, the amount of nitrite-nitrogen had a positive correlation with the turbidity (P = 0.05) (See from Table II-2, Appendix II). In the second lake, the amount of nitrite-nitrogen had no correlation with other parameters. The amount of nitrite-nitrogen in both lakes was low throughout the investigation. This finding agreed with the study of Home and Goldman (1994) who found that nitrite, a partially, reduced form of nitrate, is usually present in very small quantities. Nitrate reductase catalyzes the reaction nitrate-nitrogen to nitrite-nitrogen. Furthermore, only a negligible amount of nitrite-nitrogen was a found it did not exceed 0.1 mg.l^{-1} in the water surface and underground water (¡ÃÃ³ÕÃ•Ê¸ÕÕ·Õ, 2525).

Figure 4.26 Nitrite-nitrogen (mg.l^{-1}) of surface area at the deepest area of Rama IX lake (February 2000-January 2001)

In the first lake, the amount of nitrite – nitrogen had a positive correlation with turbidity because nitrite-nitrogen is one type of suspended solids. When the amount of nitrite-nitrogen was high, the turbidity was high too. (Decasabinca, Laugier and Collart, 1997).

4.3.6.4 Total phosphorus

The amount of total phosphorus in the first lake at the water surface ranged from 0.0035-0.0259 mg.l^{-1}. The average total phosphorus was 0.0148 mg.l^{-1}. The highest level of total phosphorus was 0.0259 mg.l^{-1} in August 2000 and the lowest was 0.0035 mg.l^{-1} in October 2000. This value was at its highest in the rainy season and was at its lowest in the cold season. However, in the other months it was low throughtout the investigation and no variations were apparent (Figure 4.27 A; Table II-1, Appendix II). In the second lake, the amount of total phosphorus fluctuated between 0.0017-0.0335 mg.l^{-1}. The average total phosphorus was 0.0113 mg.l^{-1}. The highest volume of this value was 0.0335 mg.l^{-1} in December 2000 and the lowest was 0.0017 mg.l^{-1} in August 2000. This value reached its peak in the cold season and fell to its lowest in the rainy season. However, the summer showed little change to the rainy season (Figure 4.28 A; Table II-1, Appendix II). The amount of total phosphorus of the first lake was appreciably

higher than it was in the second lake.

The amount of total phosphorus stratification in the first lake was low at the water surface, but it was high on the lake's bed. (Figure 4.27A). The amount of total phosphorus did not significantly vary at the first 0-3, 8 and 13 metre depths, but the quantity was markedly different at the bottom of the lake. In the second lake, the amount of total phosphorus varied little with depth, but sometimes this value at the water surface was lower than that at the lake's bed. However, in this lake no variations were apparent (Figure 4.28A).

In both lakes, the amount of total phosphorus had a positive correlation with SRP (P = 0.05) (Table II-2, II-3; Appendix II). Furthermore, this value was significantly correlated (P = 0.05) to the chlorophyll a in the first lake (Table II-2; Appendix II).

In the first lake the amount of total phosphorus at the water surface was classified as oligotrophic–mesotrophic (total phosphorus 5-10 μg.l^{-1}) except in August 2000 when was mesotrophic-eutrophic (total phosphorus 10-30 μg.l^{-1} following by Lampert and Sommer in 1993 classification (Lampert and Sommer, 1993 quoted in Peerapompisal, 1996). The amount of total phosphorus at the water surface was low. This situation showed the water was unpolluted. This finding agreed with the report of äÁµÃÕ ÇŞÊÇŇ ĜÅĐ ÒĄÇŅÃ³ ÊÁÈÓÒ (2528) which found that the amount of total phosphorus did not exceed 0.6 mg.l^{-1} the figure classified as water pollution. In control and protection of water resources it is considered that the amount of total phosphorus showed not exceed 0.03 mg.l^{-1}, otherwise pollution will occur. According to this investigation, the amount of total phosphorus found was high in the rainy season especially in August 2000 which corresponded to the amount of nitrate–nitrogen from the results, the precipitation was continuously high from April 2000 which resulted in phosphorus being washed down from the sediment or the land into the lake. This was combined with phosphorus released from the sediments which enriched the interstitial and overlying water. This result corresponds to the work of ¹Ñ ¹Ò ¤ªâÊ¹ (2539) who reported that phosphorus was transported back to the water by digestion. In addition, phosphorus was released from the sediments into the water column and also by living organisms in the water, or outside the lake (especially the outflow from the surface water and the precipitation). Furthermore, bacteria are of major importance in the dynamics of phosphorus cycling in the water (Wetzel, 1973). The rate of phosphorus released from the sediments increases markedly and in fact almost doubles if the
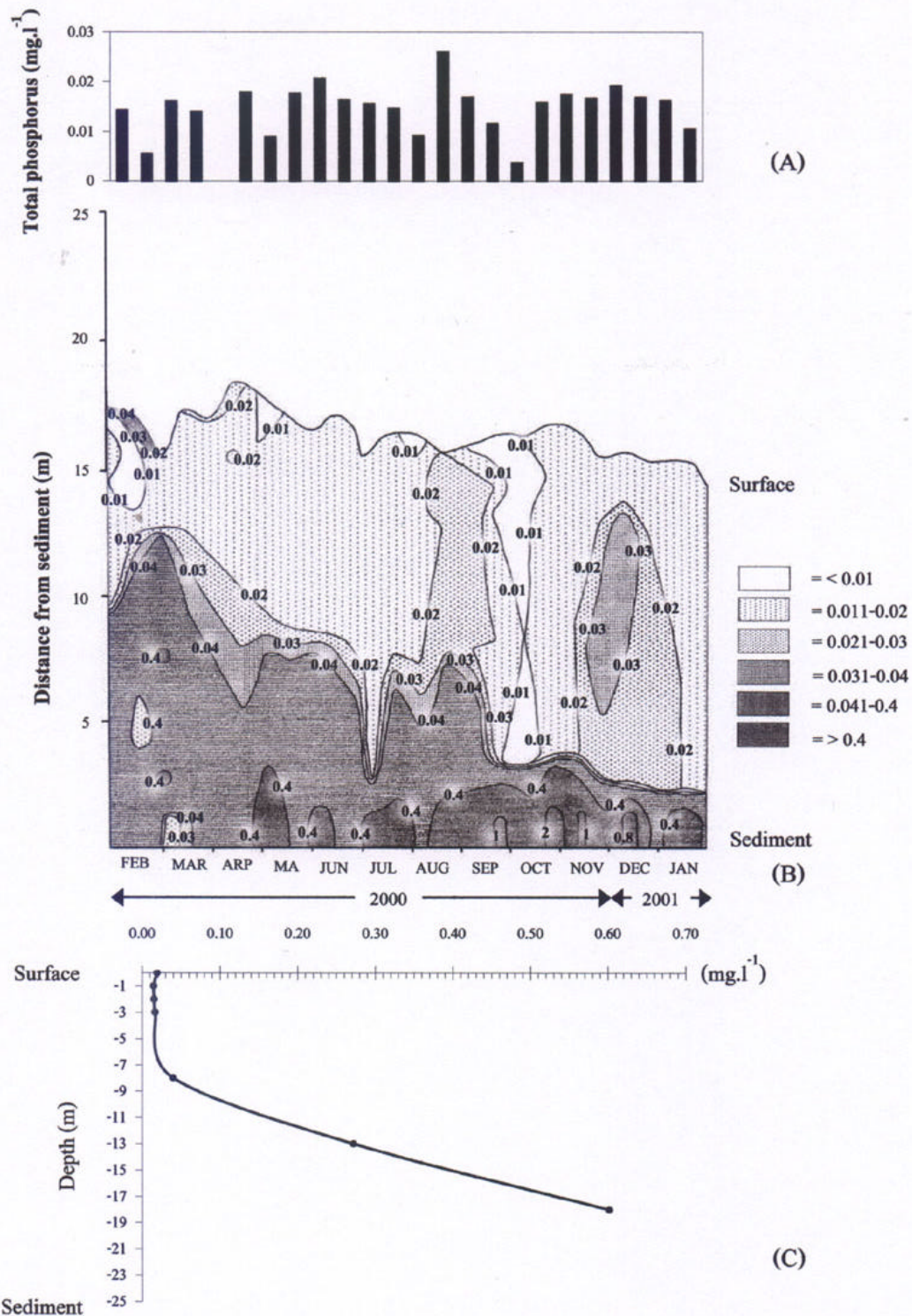
Figure 4.27 Showing the Ptot content (mg.l^{-1}) in the first lake of Rama IX lake (A) the graph of the Ptot content at the water surface (B) the graph of the different water levels of the Ptot content and (C) the graph of the mean Ptot content from the water surface to the sediment
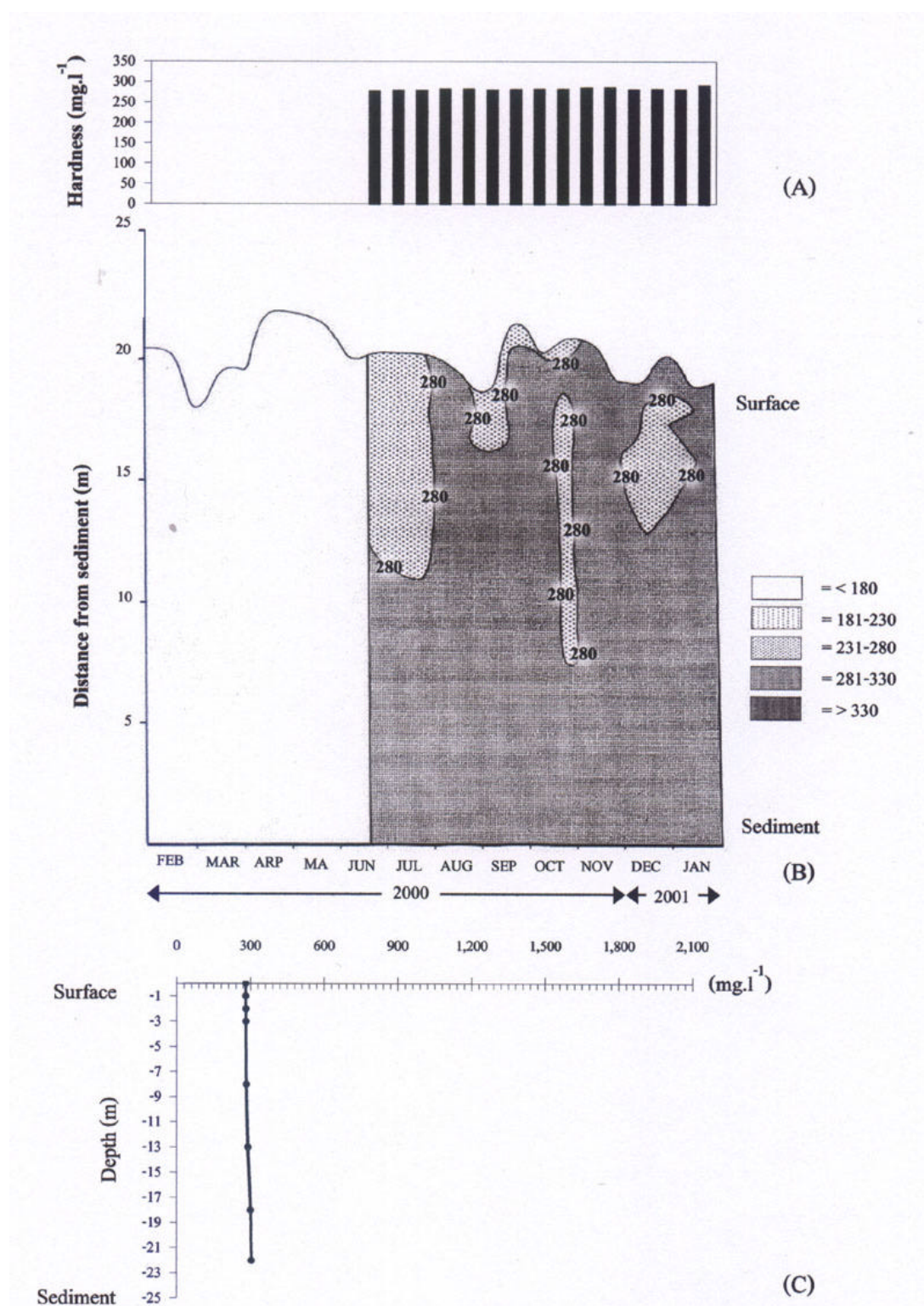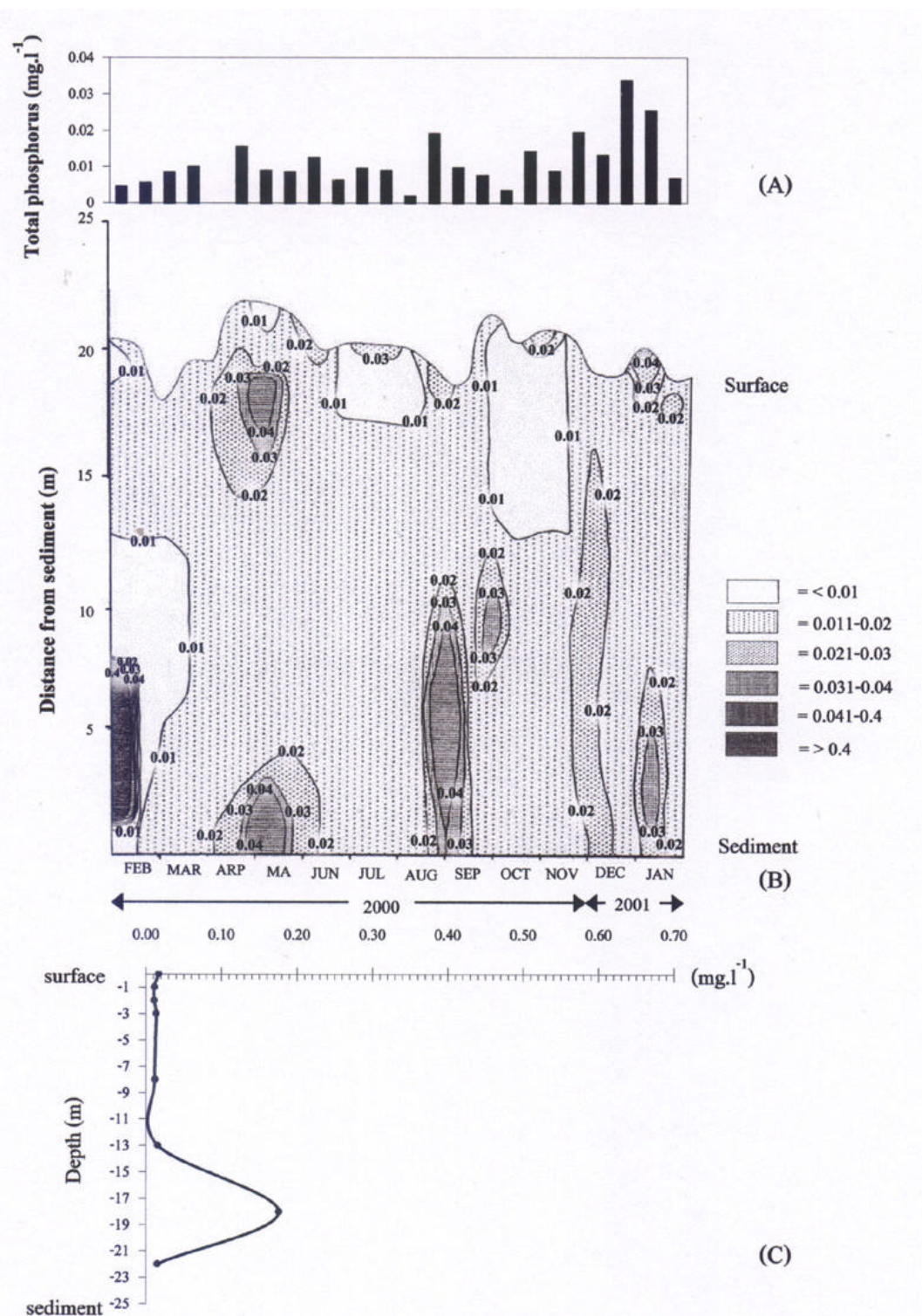
Figure 4.28 Showing the Ptot content (mg.l^{-1}) in the second lake of Rama IX lake (A) the graph of the Ptot content at the water surface (B) the graph of the different water levels of the Ptot content and (C) the graph of the mean Ptot content from the water surface to the sediment

sediments are disturbed by agitation from turbulence or strong currents (Zicker, Berger and Hasler, 1956). However, in the other seasons, the amount of phosphorus demonstrated low variations throughout the investigation and the phosphorous was probably released from the sediments into the water body and from contamination caused by human activity such as swimming, fishing and etc.

In the second lake, the amount of total phosphorus at the surface was categorized as oligotrophic status but was categorized as mesotrophic status in December 2000 and January 2001. This value was 0.0335 and 0.0252 mg.l^{-1} respectively. This classification was conducted by Lampert and Sommer in 1993 (Lampert and Sommer, 1993 quoted in Peerapompisal, 1996). Furthermore, the amount of total phosphorus increased in the rainy season because phosphorus was released from the sediment at the bed of the lake and water was also contaminated from the acitivities of people such as swimming, fishing etc. The stratification of total phosphorus (Figure 4.28B,C) found that this value varied little with depth because of disturbance are by agitation from the waves. In the second lake, the amount of total phosphorus showed no apparent variations throughout the investigation because there was no inflow and outflow of the water. Most of the phosphorus was released from the sediment at the bottom of the lake to the water column. Furthermore, à»ÂÂÈÑÔâ¹ÐÈÇµ (2539) reported that if the lake's morphometry is large then the dissolubility of phosphorus is high. So, most of the phosphorus dissolved in the water and the amount of total phosphorus correlated with the movement of the water (»ÃÐÒ³ ¾ÃÈ ÁÊ Ø ÑÃ•2539).

In the first lake, the amount of total phosphorus at the bottom of the lake was much greater than at the water surface because phosphorus in freshwater is present in sediment particles and forms in living organisms which sink from the surface to the lake's bed by sedimentation (¹Ñ ¹Ò ¤ªâ¹ Ñ Ñ 2539). Furthermore, Wetzel (1971) reported that the most common observations showed a marked increase in phosphorus content in the lower hypolimnion. In natural, low levels of phosphorus at water surface were found ranging from 0.002-0.010 mg.l^{-1} in as oligotrophic lake. Phosphorus combined with Fe, Ca, Al and Na and then sank to the bottom of the lake. Some phosphorus was absorbed by the clay on the bed of the lake (Stumm and Morgan, 1970). In the second lake, the amount of total phosphorus at the water surface was not different from the bottom of the lake because this lake is a big lake with a high

volume of water with strong waves which circulated the phosphorus from the bottom of the lake into the water column.

The amount of total phosphorus in both lakes significantly correlated with SRP because a high amount of total phosphorus was dissolved into SRP in the water. In the first lake, the amount of total phosphorus had a positive correlation with chlorophyll a especially in the rainy season. This finding agreeed with the report of Horne and Goldman (1994) who found that in temperate zones there are many lakes where the amount of total phosphorus is related to the maximum growth of phytoplankton as showed by chlorophyll a.

This investigation found that the amount of total phosphorus had a positive correlation with the amount of chlorophyll a but was not correlated with the phytoplankton biovolume because the various species of phytoplankton were brown with a low chlorophyll a content or perhaps the lack of correlation is an effect of the difficulties in extractions (Peerapompisal, 1996). In additon, some phytoplankton such as dinoflagellate, euglenoid (especially *Trachelomonas* spp. (brown colour) have other pigments (carotenes and xanthophylls present more than chlorophyll a (Peerapompisal, 1996; Round, 1973). Thus chlorophyll a concentration did not parallel the increasing biovolume.

4.3.6.5 Soluble reactive phosphorus (SRP) or Orthophosphate

In the first lake, the amount of SRP was between 0.0006-0.0129 mg.l^{-1}. The average SRP was 0.0043 mg.l^{-1}. The highest SRP value was 0.0129 mg.l^{-1} in July 2000 and the lowest SRP was 0.0006 mg.l^{-1} in May 2000 (Figure 4.29 A; Table II-1, Appendix II). The second lake ranged from 0.0009-0.0113 mg.l^{-1}. The average SRP was 0.0043 mg.l^{-1}. The higest mean SRP was 0.0113 mg.l^{-1} in June and the lowest was 0.0009 mg.l^{-1} in February (Figure 4.30 A; Table II-1, Appendix II). The SRP in each month of both lakes was low and was not significantly different throughout the investigation.

The SRP of stratification was high at the bottom of the lake whereas it was low at the water surface in the first lake (Figure 4.29 B,C). The amount of SRP did not vary appreciably between 0-3, 8 and 13 metre depths. However, the figures were different at the bottom of the lake. In the second lake, the amount of SRP at the ground level was higher than the water surface but in some months varied little with depth. However, the amount of SRP at the bottom of the lake in the second lake was lower than in the first lake (Figure 4.30 B,C). The SRP
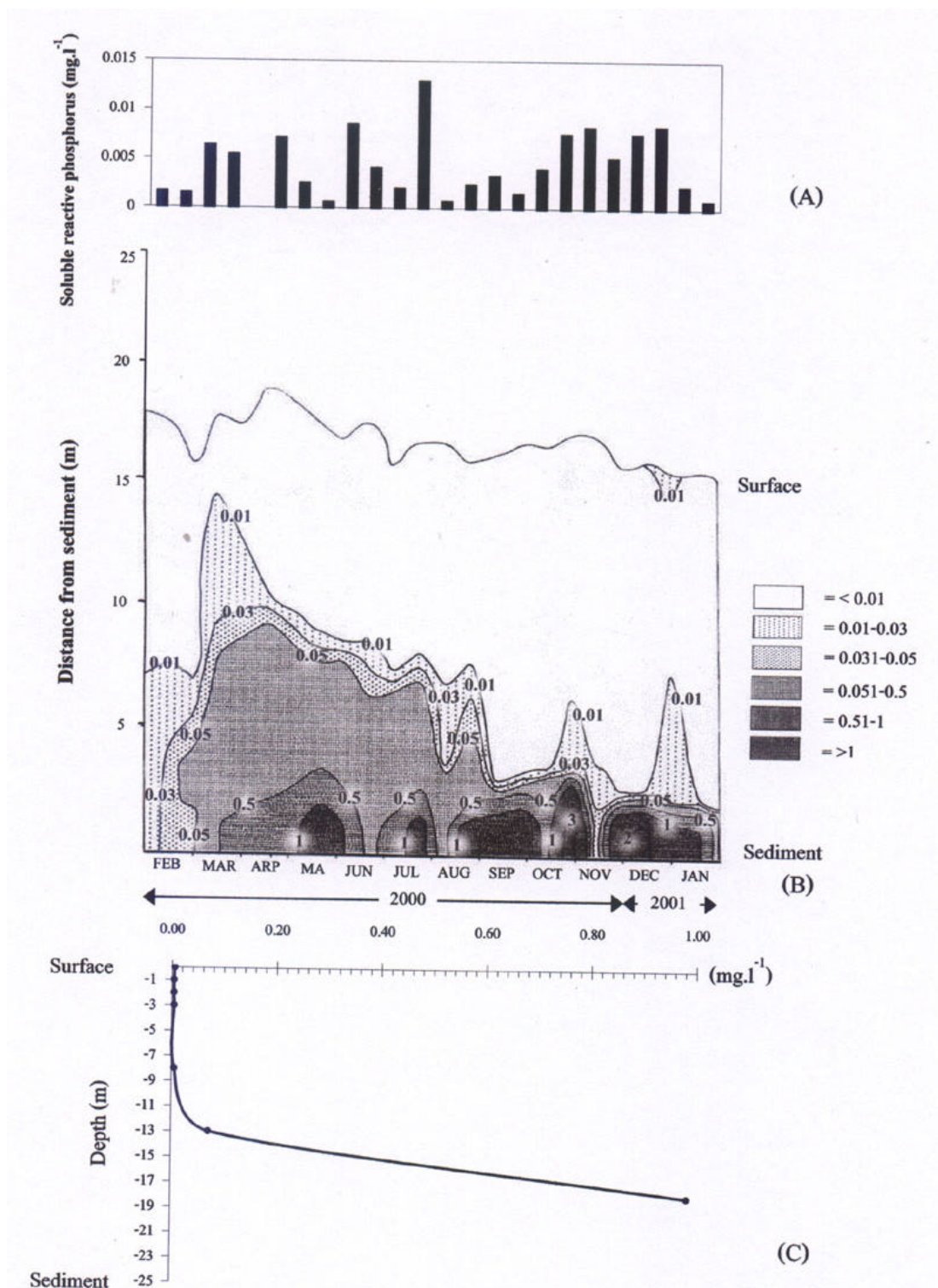
Figure 4.29 Showing the SRP content (mg.l⁻¹) in the first lake of Rama IX lake (A) the graph of the SRP content at the water surface (B) the graph of the different water levels of the SRP content and (C) the graph of the mean SRP content from the water surface to the sediment
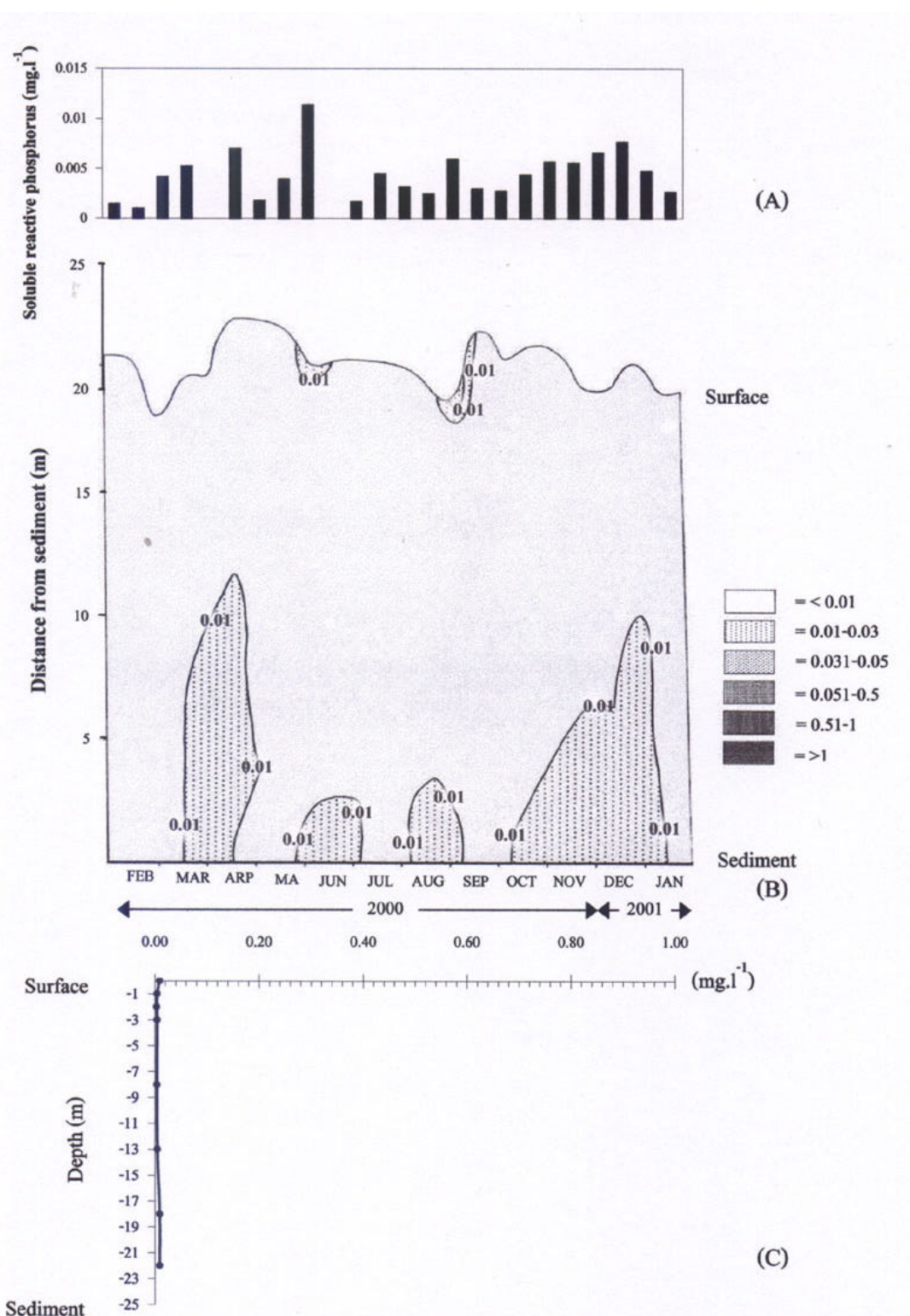
Figure 4.30 Showing the SRP content (mg.l^{-1}) in the second lake of Rama IX lake (A) the graph of the SRP content at the water surface (B) the graph of the different water levels of the SRP content and (C) the graph of the mean SRP content from the water surface to the sediment

of stratification in the second lake did not differ widely between 1-3, 8 and 13 metre depths but at depths of 0, 18 metre depths and the bottom of the lake the SRP was significantly from other depth.

The amount of SRP in both lakes had positive correlation with total phosphorus (P = 0.05) (Table II-2, II-3, Appendix II).

The amount of SRP at the water surface of both lakes was low and there was no variation throughout the investigation because the outflow-inflow water gates in Khlong 5 and Khlong 6 were closed throughout the investigation. So, the polluted water did not flow into the lake. The majority of SRP came from the sediments on the ground and from nutrients washed down by the rain from the land into the lake.

4.4 Biological environment

4.4.1 Primary production

In the first lake, the highest value of gross primary production was $0.97 \, mgO_2.l^{-1}.hr^{-1}$ in April 2000. The lowest value was $0.10 \, mgO_2.l^{-1}.hr^{-1}$ in April 2000. The average G.P. was $0.52 \, mgO_2.l^{-1}.hr^{-1}$. Net primary production (NP) showed the highest value $0.75 \, mgO_2.l^{-1}.hr^{-1}$ in June 2000 and the lowest value was $0.03 \, mgO_2.l^{-1}.hr^{-1}$ in January 2001. The average NP was $0.32 \, mgO_2.l^{-1}.hr^{-1}$. The respiration showed the highest values of respiration was $0.82 \, mgO_2.l^{-1}. \, hr^{-1}$ in April 2000. The lowest value was $0.02 \, mgO_2.l^{-1}.hr^{-1}$ in June 2000. The average respiration was $0.23 \, mgO_2.l^{-1}.hr^{-1}$. (Figure 4.31; Table II-1, Appendix II). The second lake showed a maximum value of gross primary production $0.55 \, mgO_2.l^{-1}.hr^{-1}$ in March 2000 and the minimum value was $0.10 \, mgO_2.l^{-1}.hr^{-1}$ in October 2000 and January 2001. The average of GP was $0.25 \, mgO_2.l^{-1}.hr^{-1}$. The maximum value of net primary production was $0.80 \, mgO_2.l^{-1}.hr^{-1}$ in April 2000 and the minimum values was $0.02 \, mgO_2.l^{-1}.hr^{-1}$ in September 2000. The average NP was $0.15 \, mgO_2.l^{-1}.hr^{-1}$. The respiration was very high in April 2000 with a value of $0.37 \, mgO_2.l^{-1}.hr^{-1}$ and the lowest was $0.03 \, mgO_2.l^{-1}.hr^{-1}$ in September and October 2000. The average respiration was $0.13 \, mgO_2.l^{-1}.hr^{-1}$. (Figure 4.32; Table II-1, Appendix II). In the first lake, the gross primary production, net primary production and the respiration were higher markedly different to the second lake.

In both lakes, the gross primary production, net primary production and respiration were low and fluctuated throughout the investigation. However, in the first lake gross primary production and respiration were high in the summer and low in the cold season. The respiration was very low in the rainy season. The net primary production was high in the rainy season whereas it was low in the cold season. In the second lake, the gross primary production, net primary production and the respiration were very high in the summer. However, the gross primary production was very low in the cold season and the net primary production was very low in the rainy season. The respiration was very low in the rainy season and the cold season (Figure 4.32).

In the first lake, the gross primary production had a negative correlation with the Secchi depth (P = 0.01), conductivity, total dissolved solid and hardness (P = 0.05) (Table II-2, Appendix II). The net primary production significantly varied with the Secchi depth (P = 0.05). However, the net primary production and the respiration had a positive correlation with the gross primary production (P = 0.01) (Table II-2, Appendix II).

In the second lake, the gross primary production had a positive correlation with ammonia–nitrogen (P = 0.05). In addition, the net primary production and the respiration related positively with significant differences to the gross primary production (P = 0.01) (Table II-2, Appendix II).

In both lakes, the gross primary production was low throughout the investigation and were categorized as oligotrophic lakes following by Wetzel in 1983 see Table II-3, Appendix II. The gross primary production increased in the summer season and decreased in the cold season because in the summer the sunlight is stronger than in the other seasons. So, the phytoplankton are able to photosynthesis a lot and this causes an increase in the amount of dissolved oxygen.

In the first lake, the gross primary production negatively related with the Secchi depth because the sunlight's penetration of the water decreases when the water is cloudy. The turbidity inhibits the photosynthesis of phytoplankton. This causes a decrease primary production in the water (äÁµÃÕ Ç§É\Ç³Ñ µÒÅ ·ÒÇÃ³ ÊÁÈÑ¡´Ôì, 2528). Furthermore, the gross primary production had a negative correlation with the conductivity, TDS and the water hardness because when the dissolved salts increased this added to the ion of inorganic substances in the
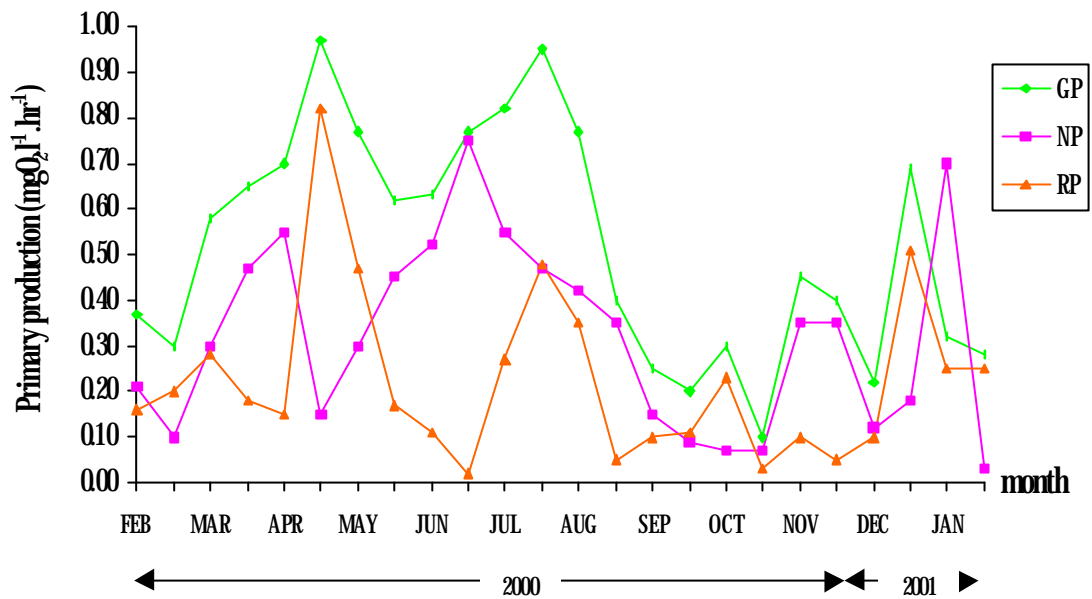
Figure 4.31   Primary production $(mgO_2.l^{-1}.hr^{-1})$ of the first lake of Rama IX lake (February 2000-January 2001)
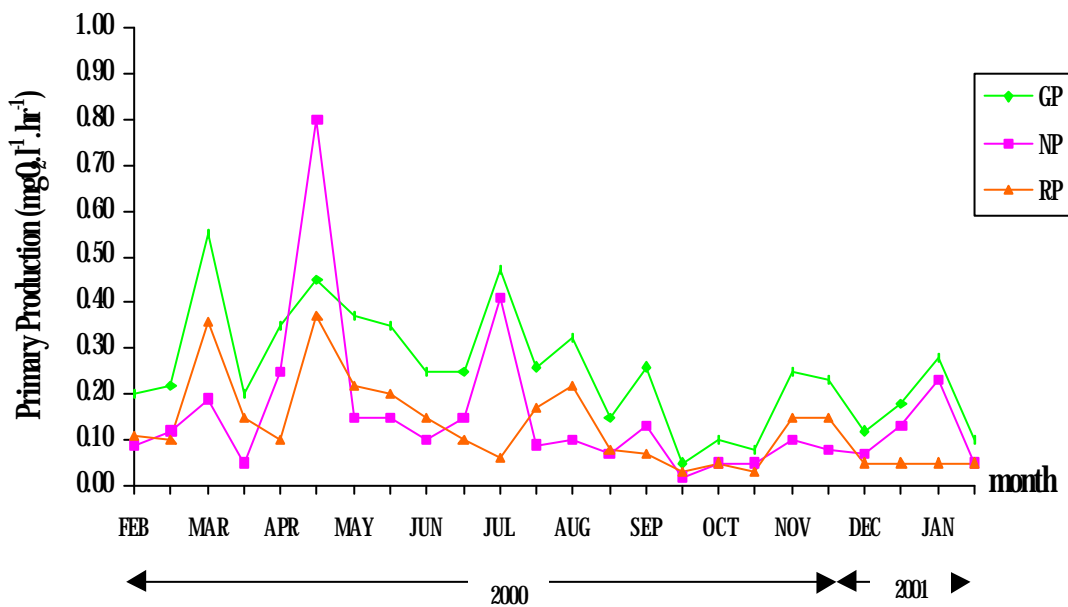
Figure 4.32 Primary production $(mgO_2.l^{-1}.hr^{-1})$ of the second lake of Rama IX lake (February 2000-January 2001)

water. When the water was high the water hardness and the primary production were low. The rate of productivity of water resources will increase when total hardness exceeds 130 ppm of $CaCO_3$, but considerable total hardness will cause a decrease in productivity in the water resourcees as reported by Ê¶ÒP Ñ ÃÐÁ§¹Ò ×áË§ªÒµ,(2521.

The salinity values were 0.4 ppt in the first lake and 0.6 ppt in the second lake. There was salinity in the water. This caused a decrease in dissolved oxygen in the water. This finding agreed with the study of äÁµÃÕ Ç§É·ÇÑ¹ áÅ ÖÒÇ Ã³ ÊÂÒÁ(2528) who reported that the water resources had a high salinity value which caused a decrease in dissolved oxygen. ÊÇÒÒÒ ¡Ò¹ µ Ç¹Ç ÕÑ (2538) reported that the concentration of dissolved salt will decrease the amount of oxygen saturation. The amount of dissolved oxygen will decrease about 5% every $5,000 \, mg.l^{-1}$ with an incrase of chloride.

In the second lake, the salinity, the hardness, conductivity and TDS were higher than in the first lake so the primary productivity was low. The gross primary production showed a positive correlation with ammonia-nitrogen because a rise in the number of nutrients caused an increase in the photosynthesis of phytoplankton so the primary production went up too.

4.4.2 Chlorophyll a

In the first lake, the amount of chlorophyll a at the water surface ranged from $0.1184-20.6608 \, \mu g.l^{-1}$. The average chlorophyll content a was $10.0810 \, \mu g.l^{-1}$. The highest level of chlorophyll a was $20.6608 \, \mu g.l^{-1}$ in July 2000 and the lowest was $0.1184 \, \mu g.l^{-1}$ in February 2000 (Figure 4.33 A; Table II-1, Appendix II). In the second lake, the amount of chlorophyll a varied from non-detec-$12.6096 \, \mu g.l^{-1}$ to a high of $12.6096 \, \mu g.l^{-1}$ in the first part of May 2000 and no chlorophyll a was detected in February, April and the last part of May 2000 (Figure 4.34 A; Table II-1, Appendix II). The amount of chlorophyll a in the first lake was significantly higher than it was in the second lake.

In the first lake, variations of the amount of chlorophyll a with depth are distinct, the amount of chlorophyll a at the water surface was higher than at the lower levels. In some months, the amount of chlorophyll a at the lower levels was higher than at the water surface (Figure 4.33 B,C; Table II-1, Appendix II). The amount of chlorophyll a at the depths 0, 1, 2 and 3 metres were not significantly different, but they varied at the depths of 8, 13 metres and the bottom of the lake. However, at the depth of 13 metres and the lake's bed there was no

significant difference. In the second lake, the amount of chlorophyll a was high at the water surface and it was low at lower depths and the bed. In some months, the amount of chlorophyll a at the lower levels were higher than at the water surface, but sometimes the amount of chlorophyll a varied little with depth (Figure 4.34 B; Table II-1, Appendix II). The amount of chlorophyll a at 0-3 and 8 metre depths did not significantly differ but were appreciably distinct from the figures at 13, 18 metre depths and the ground. However, the amount of chlorophyll a at the depths 13 and 18 metres and the bed were not significantly different.

In the first lake, the amount of chlorophyll a had a positive correlation with the amount of total phosphorus (P = 0.05) (Table II-2, Appendix II). In the second lake, the amount of chlorophyll a positively related with phytoplankton biovolume (P = 0.05) see form Table II-2, Appendix II.

Chlorophyll a is a majority pigment in the cell of phytoplankton. It is important in the photosynthesis of phytoplankton. In addition, chlorophyll a can be used to accurately measure the number of phytoplankton as reported by Hofstraat et al., 1994. According to this investigation, it was clearly found that the amount of chlorophyll a had a positive correlation with phytoplankton biovolume in the second lake. In the first lake, the amount of chlorophyll a had a positive correlation with the amount of total phosphorus because the phosphorus growth limited the nutrients which are related to the growth of phytoplankton. This result corresponds to the studies of Sakamoto, (1966); Vollenwider, (1976) who reported that it is widely accepted that the growth of phytoplankton biomass is related to the particular constituents of the phosphorus. The concentration of chlorophyll a as a measure of phytoplankton biomass has been shown to be related to the total spring phosphorus concentration. Peerapompisal (1996) reported that phytoplankton biovolume showed positive correlations with some of the nutrients, the most significant correlation was with ammonium nitrogen, soluble reactive phosphorus and total phosphorus. Furthermore, Sarvala, Helminen, Saarikari, Salomen and Vuorio (1998) reported that in Lake Pyh j rvi, late summer chlorophyll a showed positive correlation with both total phosphorus in the water.

According to this investigation the amount of chlorophyll a in both lakes was very high in the rainy season but was very low in the cold season. In the rainy season both lakes received an increase in nutrients such as total phosphorus, resulting in a rise in the amount of
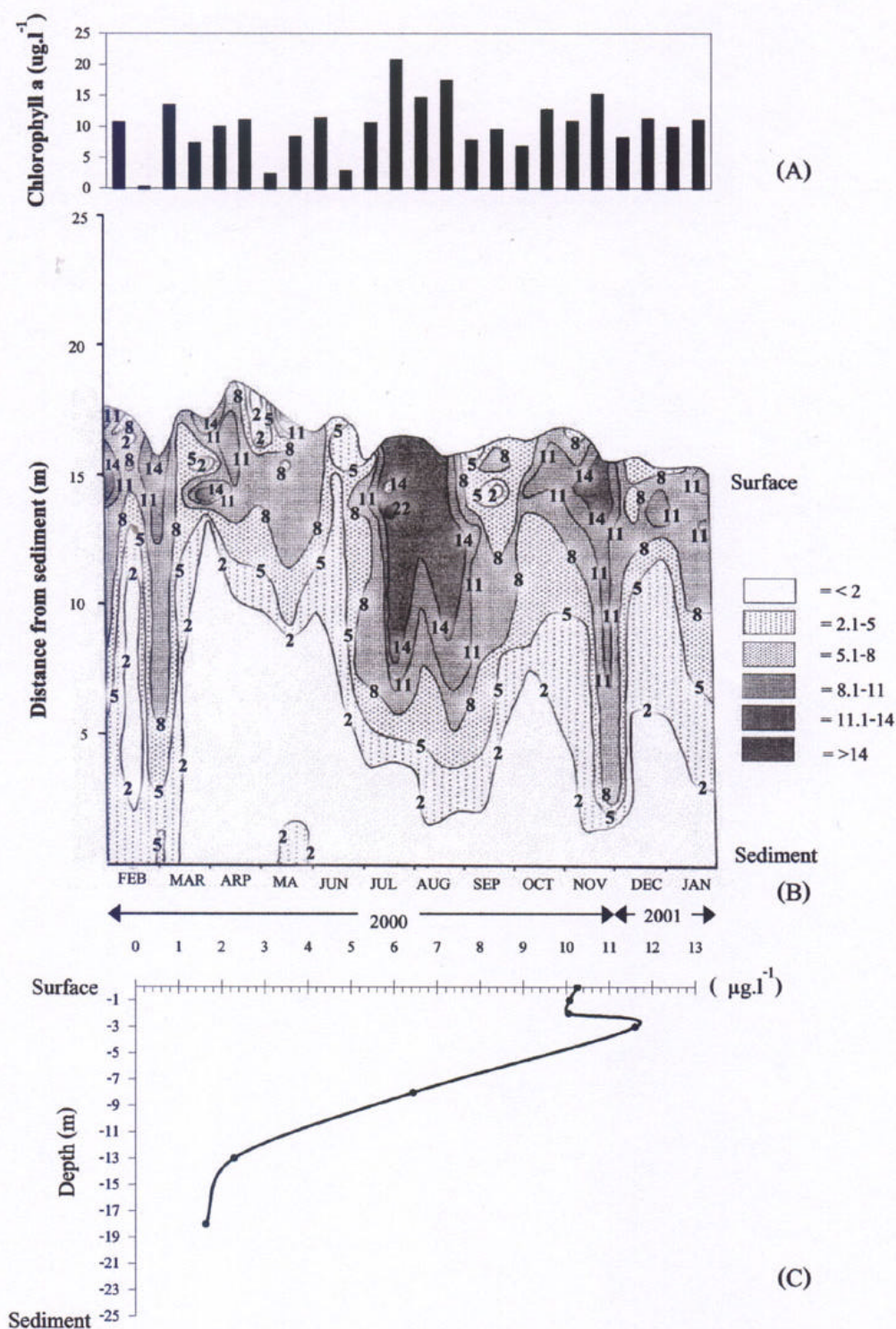
Figure 4.33 Showing the chlorophyll a content (μg.l⁻¹) in the first lake of Rama IX lake (A) the graph of the chlorophyll a content at the water surface (B) the graph of the different water levels of the chlorophyll a content and (C) the graph of the mean chlorophyll a content from the water surface to the sediment

Figure 4.34   Showing the chlorophyll a content ($\mu g.l^{-1}$) in the second lake of Rama IX lake (A) the graph of the chlorophyll a content at the water surface (B) the graph of the different water levels of the chlorophyll a content and (C) the graph of the mean chlorophyll a content from the water surface to the sediment

chlorophyll a. This result resembles the report of Peerapompisal, (1996) who found that in the rainy season of 1992, chlorophyll a reached its maximum in the three reservoirs of Huai Hong Khrai Royal Development Study Centre, Chiang Mai in the rainy season but fell to its minium in the cold part of the dry season (October 1992-February 1993).

The vertical distribution of chlorophyll a and phytoplankton of both lakes was high at the water surface and it was low on the bed because sunlight can penetrate intensively only at surface. In some months, the amount of chlorophyll a at the water surface was lower than that at the lake's bed, but sometimes the amount of chlorophyll a at the surface and the other depths did not vary in the warm part of the summer season, the temperature was high and the sunlight was very strong. The high temperature and strong sunlight made *Cylindrospermopsis raciborskii* the dominant speciecs of phytoplankton. It has gas vacuoles which enable it to move to the lower levels or to the bottom of the lake as reported by Walsby, 1992. Furthermore, the group of dinoflagellate can move vertically to avoid light by using the flagellate.

4.4.3 Coliform bacteria

In the first lake coliform bacteria ranged from 4-460 MPN.100 ml^{-1}. The average of coliform bacteria was 113.75 MPN.100 ml^{-1}. The highest level of coliform bacteria was 460 MPN.100 ml^{-1} in February 2000 and September 2000 and the lowest was 4 MPN.100 ml^{-1} in November 2000. The second lake, coliform bacteria varied from 4-240 MPN.100 ml^{-1}. The average coliform bacteria was 45.17 MPN.100 ml^{-1}. The highest figure of coliform bacteria was 240 MPN.100 ml^{-1} in February and September 2000 and the lowest was 4 MPN.100 ml^{-1} in August and October 2000 (Figure 4.35; Table II-1, Appendix II). The number of coliform bacteria in the first lake were higher than in the second lake and were noticeably different.

In the first lake, coliform bacteria had positive correlation with alkalinity (P = 0.01) but these was negative correlation with phytoplankton biovolume (P = 0.05) (Table II-2, Appendix II). In the second lake, coliform bacteria had positive correlation with BOD (P = 0.01) (Table II-2, Appendix II).

In both lakes, coliform bacteria were low throughout the investigation. They did not exceed of 5,000 MPN.100 ml^{-1} the surface water quality standards of Thailand and could be placed in the second category set by National Environmental Board, 1994.
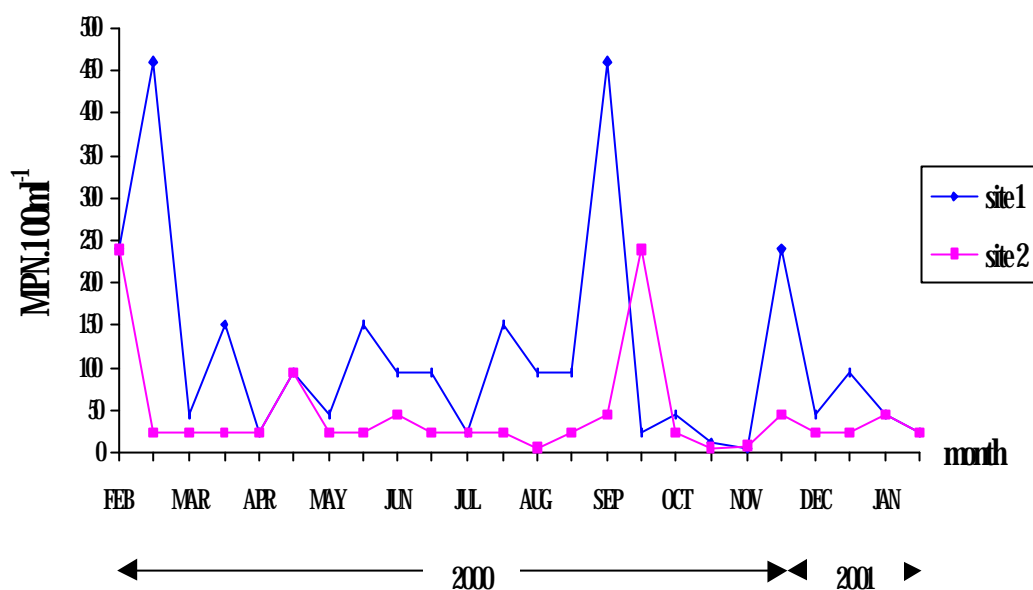
Figure 4.35 The number of coliform bacteria (MPN.100 ml^{-1}) of the first lake and the second lake of Rama IX lake (February 2000-January 2001)

Coliform bacteria were high in the rainy season and in the first stages of the investigation, but they were low in the cold season because in the early part of this investigation coliform bacteria and polluted water were drained from Khlong 6 to Khlong 5 and passed through Rama IX lake. Furthermore, there was contamination from the land, and human activities which affected the water. The digestion of inorganic substances by bacteria decreases in the summer and in the cold season because the temperature is more extreme and unsuitable for the growth of coliform bacteria (Alexander, 1967).

In the first lake, coliform bacteria had a negative correlation with phytoplankton biovolume because the coliform bacteria and phytoplankton absorbed more nutrients during the early part of the investigation and the rainy season. The absorption of the great amount of nutrients caused an increase in the growth of both living organisms. When the turbidity was high in the water, sunlight could not penetrate deeply into the water which subsequently caused low photosynthesis of phytoplankton and decreased the number of phytoplankton. This decrease combined with the increase in bacteria in the water caused an increase in the use of dissolved oxygen. Hawher and Linten (1974) reported that when the number of bacteria increased in

freshwater, it was related to an increase in organic and inorganic substances in the water resources especially when the water flows through agricultural and industrial areas with intestinal bacterial originating from man or animals.

4.4.4 Phytoplankton

4.4.4.1 Species composition

A study of the biodiversity of phytoplankton was conducted in order to monitor water quality in Rama IX lake, Pathumthani province, Thailand from February 2000 to January 2001. Phytoplankton were found in both lakes and was classified into 6 divisions, 12 orders, 28 families, 62 genera and 95 species of phytoplankton. The first lake was classified into 6 divisions, 12 orders, 26 families, 58 genus and 86 species. The second lake was classified into 6 divisions, 12 orders, 23 families, 48 genus and 59 species see from Table 4.1.

Following Rott's 1981 classifications, this investigation found that the total phytoplankton consisted of 9 groups in the first lake. The Chlorophyceae was the most abundant species with 30 species approximately 34% of the total phytoplankton. There were 17 species of Cyanophyceae of the total phytoplankton about 19%. There were 21 species of Euglenophyceae as 24% at the total phytoplankton. Diatomophyceae were found 9 species adding up to around 0% of the total phytoplankton. Four species of Dinophyceae and Cryptophyceae were present calculated at 4% of the total phytoplankton. Zygnemaphyceae had 3 species calculated at 3% of the total phytoplankton and Chrysophyceae and Xanthophyceae had 1 species each calculated at 1% of the total phytoplankton (Figure 4.36).

In the second lake, this investigation found the total phytoplankton could be divided into 8 groups. The Chlorophyceae was the most common species with 21 species found calculated at 33% of the total. Euglenophyceae had 11 species present estimated at 17%. Twelve species of Cyanophyceae of were found around 19% of the total. Cryptophyceae and Dinophyceae had 4 species each calculated at 6% of the total. Zygnemaphyceae had 2 species present calculated at 13% of the total and Chrysophyceae had 1 species calculated at 2% of the total (Figure 4.37).

In the first lake, phytoplankton comprised 86 species. The majority group of phytoplankton was Cyanophyceae, Euglenophyceae and Dinophyceae respectively. The dominant species was *Cylindrospermopsis raciborskii, Peridiniopsis cunningtonii* and

Table 4.1 List of the species of phytoplankton survey in Rama IX lake
(February 2000-January 2001)

Phytoplankton species	Lake 1	Lake 2
Cyanophyceae		
Anabaena sp.	✓	✓
Anabaena aphanizomenoides Forti	✓	✓
Aphanizomenon sp.	✓	✓
Aphanothece nidulans Richter	✓	✓
Aphanothece smithii Komﾠｰkovﾠ-Legnerovﾠ et Cronberg	✓	✓
Aphanocapsa elachista W. et. G.S. West	✓	-
Aphanocapsa nubilum Komﾠｰrek et Kling	✓	✓
Coelomoron pusillum (VanGoor) Komﾠｰrek	✓	-
Cylindrospermopsis raciborskii (Wolosz.) Seenayya & Subba	✓	✓
Cylindrospermopsis phillippinensis	✓	✓
(Taylor.) Ka.		
Gomphosphaeria natans Komﾠｰreket Hindﾠ k	✓	-
Merismopedia punctata Meyen	✓	✓
Microcystis aeruginosa Kﾠｰtzing	✓	-
Oscillatoria limosa Ag. ex. Gomont	✓	✓
Planktolyngbya limnetica Lemmermann	✓	✓
Planktolyngbya sp.	✓	-
Spirulina platensis (Nords) Geitler	✓	✓
Cryptophyceae		
Chroomonas sp.	✓	✓
Cryptomonas sp.	✓	✓
Rhodomonas sp.1	✓	✓
Rhodomonas sp.2	✓	✓
Dinophyceae		
Ceratium furcoides (Levander) Langhans	✓	✓

Table 4.1 (cont.)

Phytoplankton species	Lake 1	Lake 2
Peridiniopsis cunningtonii **Lemmermann**		
Peridinium sp. 1	✓	✓
Peridinium sp. 2	✓	✓
Diatomophyceae		
Achnanthes minutissima **Kützing var.** *minutissima*	✓	✓
Amphora sp.	-	✓
Anomoeoneis vitrea **(Grunow) Ross**	✓	✓
Aulacoseira granulata **(Ehrenberg) Ralfs**	✓	✓
Cocconeis placentula **Ehrenberg**	✓	✓
Cyclotella sp.	✓	-
Cymbella sp	-	✓
Eunotia sp.	✓	-
Fragilaria ulna var. *acus* **(Kützing) Lange-Bertalot**	✓	✓
Gyrosigma macrum **(W.Smith) Griffith & Henfrey**	-	✓
Gyrosigma sp.	✓	-
Nitzschia sp.	✓	✓
Chrysophyceae		
Uroglenopsis americana **(Calkins) Lemmermann**	✓	✓
Chlorophyceae	✓	✓
Acanthosphaera sp.	✓	✓
Actinastrum gracillimum **G.M.Smith**	✓	-
Ankistrodesmus falcatus **(Corda) Ralfs**	✓	✓
Botryococcus braunii **Kützing**	✓	✓
Carteria sp.	✓	✓
Chlamydomonas sp.1		
Chlamydomonas sp.2	✓	✓
Chlorogonium sp.	✓	✓
Chlorella vulgaris **Beijerinck**	✓	✓

Table 4.1 (cont.)

Phytoplankton species	Lake 1	Lake 2
Coelastrum microporum **Naegeli**	✓	-
Coelastrum pseudomicroporum **Korshikov**	✓	-
Coelastrum sphaericum **Naegeli**	✓	✓
Crucigeniella crucifera **(Wolle) Kom rek**	✓	✓
Dictyosphaerium tetrachotonum **Printz**	✓	✓
Dictyosphaerium pulchellum **Wood**	✓	-
Eudorina elegans **Ehrenberg**	✓	-
Eutetramorus globosus **Walton**	✓	-
Monoraphidium arcuatum **(Korshikov) Hind k**	✓	✓
Monoraphidium contortum **(Thuret) Kom kov -Legnerov**	✓	✓
Monoraphidium griffithii **(Berkeley) Kom kov -Legnerov**	✓	✓
Monoraphidium irregulare **(G.M. Smith) Kom kov -Legnerov**	✓	✓
Oocystis **sp.**	-	✓
Pandorina morum **(O.F.M ller) Bory**	✓	-
Pediastrum simplex **Meyen**	✓	✓
Planktonema lauterbornii **Schmidle**	✓	✓
Radiococcus planktonicus **J.W.G. Lund**	✓	-
Scenedesmus acuminatus **(Lagerh.) Choda. var.** *acuminatus*	✓	-
Scenedesmus armatus **(Chod.) G. M.Smith**	✓	-
Scenedesmus opoliensis **P. Richter**	✓	-
Spirogyra **sp.**	-	✓
Tetraedron minimum **(A.Braun) Hansgirg**	✓	✓
Tetrastrum staurogeniaeforme **(Schr der) Lemmermann**	✓	✓
Zygnemaphyceae		
Cosmarium bioculatum **Brébisson ex. Ralfs**	✓	✓
Staurodesmus phimus **var.** *semulunaris* **(Schmidie) Teil**	✓	-
Staurastrum perundulatum **Gionlel**	✓	✓

Table 4.1 (cont.)

Phytoplankton species	Lake 1	Lake 2
Xanthophyceae		
Isthmochloron gracile (Reinsch) Hansgirg	✓	-
Euglenophyceae		
Euglena charkowiensis Swir.	✓	✓
Euglena proxima P.A. Dangeard	✓	✓
Euglena minima France	✓	-
Phacus longicauda (Ehrenberg) Dujardin	✓	-
Lepocinclis sp.	✓	✓
Phacus pyrum (Ehrenberg) F. Stein	✓	-
Phacus ranula Pochmann (Ehrenberg) Dujardin	✓	-
Trachelomonas bernardinensis W. Vischer	✓	✓
Trachelomonas curta Da Cunha	✓	-
Trachelomonas dubia (Swir.) Deflandre	✓	-
Trachelomonas dybowskii Drezepolski	✓	✓
Trachelomonas hispida (Perty) Stein	✓	-
Trachelomonas intermedia Dangeard	✓	✓
Trachelomonas minima Drez.	✓	-
Trachelomona mucosa Swirenko	✓	✓
Trachelomonas oblonga Lemmermann	✓	✓
Trachelomonas similis Stokes	✓	-
Trachelomonas volvocina Ehrenberg	✓	✓
Trachelomonas volvocinopsis Swirenko	✓	✓
Strombomonas fluviatilis (Lemm.) Deflandre	✓	✓
Strombomonas verrucosa var. *borystheniensis* (Roll) Deflandre	✓	-

Chlorophyceae
Cyanophyceae
Euglenophyceae
Diatomophyceae
Zygnemaphyceae
Dinophyceae
Cryptophyceae
Chrysophyceae
Xanthophyceae
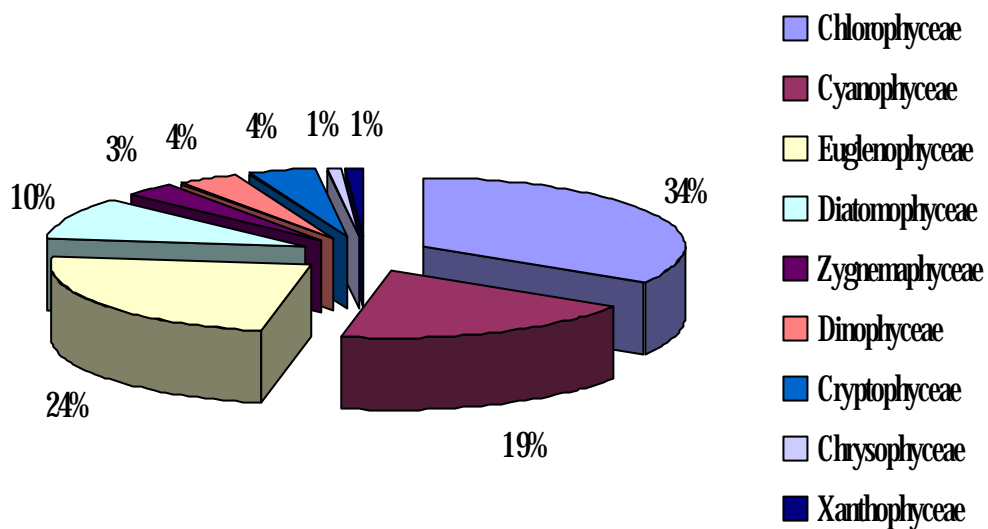
Figure 4.36 The percentage of each group of phytoplankton in the first lake of Rama IX lake (February 2000-January 2001)

Chlorophyceae
Cyanophyceae
Euglenophyceae
Diatomophyceae
Zygnemaphyceae
Dinophyceae
Cryptophyceae
Chrysophyceae
Xanthophyceae
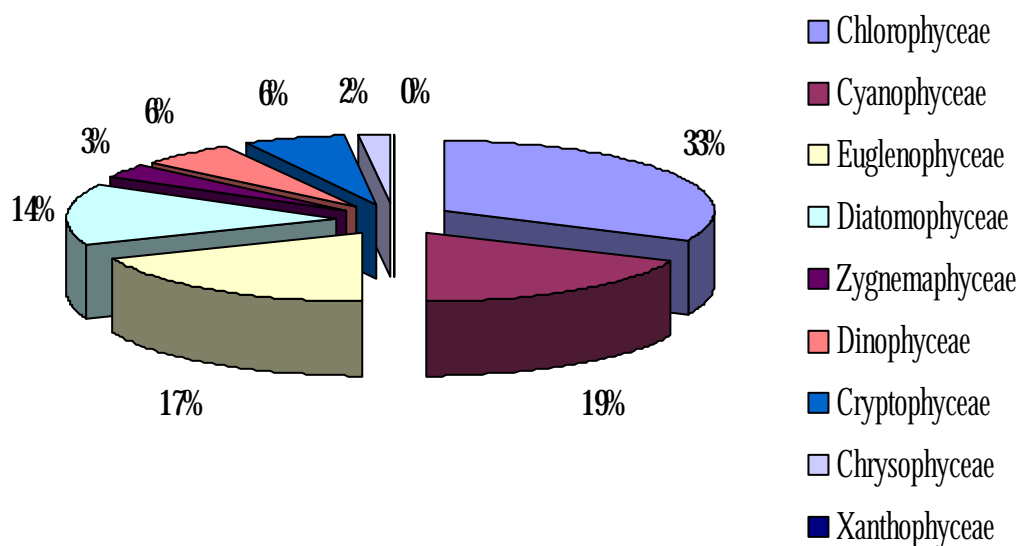
Figure 4.37 The percentage of each group of phytoplankton in the second lake of Rama IX lake (February 2000-January 2001)

Trachelomonas volvocina respectively.

In the second lake, phytoplankton comprised 59 species. The biggest group of phytoplankton was Cyanophyceae, Euglenophyceae and Dinophyceae respectively. The dominant species was *Cylindrospermopis raciborskii*, *Trachelomonas volvocina*, *Peridinium* sp.1 respectively.

The number of species of phytoplankton in the second lake was less than those in the first lake because in the second lake the nutrients were lower than in the first lake resulting in lower phytoplankton biovolume when compared to the numbers in the study of Peerapompisal (1996) who found 127 species of phytoplankton in Huai Hong Khrai Royal Development Study Centre with the water quality in the lake mesotrophic-eutrophic. Pooarlai (1999) found 170 species of phytoplankton in Huai Tung Thao reservoir, Chaig Mai province. The water quality in this lake was mesotrophic. Chorum (1998) found 64 species of phytoplankton with mesotrophic water quality. In addition, Wannasai (1999) found that the total phytoplankton consisted of 84 species with the water quality oligotrophic-mesotrophic.

The morphology of all phytoplankton species are illustrated by photographs and SEM graphs in Figure 4.38-4.50 and in category 4.4.4.2 there are a description of the morphological features of phytoplankton in Rama IX lake.

4.4.4.2 Identification of phytoplankton in this investigation

Key to families

1. prokaryotic cell...Cyanophyceae
1. eukaryotic cell...2
    2. cell without gullet, without eyespot...3
        3. cell without flegella 4
            4. semicells in front veiw, with process or without process or without valves..............
               ....Zygnemaphyceae
            4. unicellar, two valves, with possession of silicous cell walls (frustules) ....
               ....Diatomophyceae
        3. cell with flagellate or without flagellate 4
            4. cell solitary, with 2 flagella 5

5. one flagellum in sulcus and one flagellum in girdle or cingulum.....................
....Dinophyceae

5. flagella unequal in length, in subapical or lateral ....Cryptophyceae

4. cell colony or filament or unicellar, without flagella or with flagella 5

5. with chrysolaminarin..6

6. pigments contained in chloroplast in which yellow, brown or golden-brown.....
....Chrysophyceae

6. pigment contained in chloroplast in which carotenoid (diadinoxanthin,
heteroxanthin)..Xanthophyceae

5. with paramylon, ...Chlorophyceae

2. cell with a gullet, a red eyespot..Euglenophyceae

Key to genera

Cyanophyceae

1. trichomes

2. straight or slightly cure...3

3. 1 heterocyst intercalary...4

4. almost spherical...*Anabaena*

4. long cylindrical ....*Aphanizomenon*

3. 1 or 2 heterocyst or without heterocyst...4

4. 1 or 2 heterocyst at the end of trichome..............................*Cylindrospermopsis*

4. without heterocyst ....*Oscillatoria*

2. straight or spiral or regularly coiled...3

3. straight or spirals, firm sheath...*Planktolyngbya*

3. regulary coiled without sheath...*Spirulina*

1. colonies

2. colonies spherical or irregular...3

3. colonies macroscopic to microscopic...4

4. cell spherical, oval, clustered together, with red granule... ....*Microcystis*

4. cell spherical or cylindrical often in pairs, without red granule.............*Aphanocapsa*

3. colonies microscopis, sometimes compose of two colonies..................................4

    4. cell slightly elongate..*Coelomoron*

    4. cell heart shape..*Gomphosphaeria*

2. colonies tubular, flat or oval to irregular..3

3. colonies tubular flat, cell spherical...*Merismopedia*

3. colonies oval to irregular, cell widely oval to cylindrical, with rounded ends.............

....*Aphanothece*

Cryptophyceae

1. cells blue – green in colour..*Chroomonas*

1. cells variously coloured but never blue – green...2

    2. cells oval or pear shaped, with a single red chloroplast containing a large, centrally

    positioned pyrenoid...*Rhodomonas*

    2. cells oval or broadly rounded, with 1 or 2 red, olive – green or yellowish – green

    chloroplasts containing 1-4 pyrynoids if present.....................................*Cryptomonas*

Dinophyceae

1. cell with a long, anterior horn and 2 or 3 posterior horns ....*Ceratium*

1. cell shape almost compact or ovoid, sometimes with small projections at apex and

    antaapex..2

    2. epitheca plates with 3 intercalary plates..*Peridinium*

    2. epitheca with only one intercalary plates...*Peridiniopsis*

Chrysophyceae

1. cell ovoid or egg – shaped, seperated and evenly spaced within a colonial envelope ;

    without scales in the wall ; flagella 2, of unequal length; chloroplast pale yellow

    ....*Uroglenopsis*

Diatomophyceae

1. cell solitary, raphe or pseudoraphae in one valve

    2. cell cylindrical or cyclic or elliptic or cured 3

3. cell cylindrical or cyclic...4

    4. cell cylindrical, in some species the pole with spines or teeth ....*Aulacoseira*

    4. cell cyclic, value with an intramarginal zone of costae encircling.............*Cyclotella*

3. cell elliptic or cured..4

    4. cell elliptic 1 plastid or many plastids..5

      5. margins bent or rectangular or naviculate in girdle veiw, valve without – rim, two
      or many plastids ....*Achnanthes*

      5. raphe in hypovalve, pseudoraphe in epivalve, with central and polar nodules in
      the hypovalve, 1 plastid...*Cocconeis*

    4. cell cured..5

      5. cell cured, margin smooth...6

        6. the dorsal margin convex than the ventral, single H – shaped chloroplast
        ....*Cymbella*

        6. the ventral margin of cured frustule, cell usually with concave margin
        ....*Amphora*

      5. cell cured, wavy or undulate late on one margin as seen in valve view, transversly
      striate...*Eunotia*

2. cell sigmoid or elongate – boat shaped..3

    3. cell sigmoid, central pores of raphe not turned 4

      4. cell with a boardly sigmoid value, to large plate – like chloroplast lying one
      along each side of girdle...*Gyrosigma*

      4. cell narrowly sigmoid with acute apices; or two plastids arranged for and the end
      of the cell...*Nitzschia*

    3. cell elongate boat, central pores of raphe turned............................*Anomoeoneis*

1. cell joined to form ribbin like colonies, pseudoraphe both valve...........................*Fragilaria*

Chlorophyceae

1.   unicellular genera

1.   with flagella...2

2. 2 flagella, cell elongate or ovoid to ellipsoid. 3

   3. cells elongate fusiform and narrowly pointed the apical without an external sheath, without eyespot..*Chlorogonium*

   3. cells ovoid to ellipsoid, with 1 apical papillae, with a narrow mucilaginous sheath, with epe spot...*Chlamydomonas*

2. 2 flagella, elliptic or cordiform...*Cateria*

1. without flagella 2

2. cell spherical, without lobed 3

   3. with spine long then abrupthy narrowed to a fine bristle, chloroplast plate like or lobe ....*Acanthosphaera*

   3. without spine, chloroplast a parietal cup or merely a plate.........................*Chlorella*

2. cell flat, polyhedric, variously lobed to from dichotomous or trichotomous spine – tipped processes..*Tetraedron*

2. Gelatinous colonial genera

1. colony composed of more 2, compactly arranged in mucilage.....................................2

2. composed of 4 cells...3

   3. colony spherical, with radiating fibrils...*Radiococcus*

   3. colony clear globe of mucilage, without radiating fibril, cells near or at the periphery..*Eutetramorus*

2. composed of muliple cells...3

   3. colony composed of cell oval or spherical.. 4

      4. without attached by fine, branching strands...

         5. cells oval, rectangular or trapezoidal the outer walls entire; arrange in 4's form quadrate plates or in multiples of 4 ....*Cruciginiella*

         5. cells elliptic or lemon shape, 4-16 generations of mother cell walls enclosing daughter cells ....*Oocystis*

      4. with attached by fine, branhring strands ....*Dictyosphaerium*

   3. coenobium composed of cell oval or sphaerical..4

      4. cell without adjoned by interconnecting...5

         5. cell oval, tendency to occur in tiers..*Eudorina*

        5. cell spherical or oval, cells crowded, somewhat pyriform..................*Pandorina*

       4. cell adjoined by interconnecting, protuberances of mucilaginous cell sheaths

       ....*Coelastrum*

1. colony composed of 2, compactly arranged in semiopaque mucilage.............*Botryococcus*

3. **Nongelatinous colonial genera**

1. with spine...2

   2. cell triangular or ovoid, forming quadrangular plates and bearing 1 or more

     spines..*Tetrastrum*

   2. cell oval or fusiform, wall smooth or with 1 or 2 cured spine; cell adjoined along their

     longitudinal walls in a linear series.......................................*Scenedesmus*

1. without spine...2

   2. coenobia elongate or disc 3

     3. usually elongated cells radiating in all directions from a common

       centre..*Actinastrum*

      3. disc or star shape, flat, cell closely adpressed with intercellular spaces.........*Pediastrum*

   2. colonies of bundles or fan shaped groups of cell often only untied

     equatorially ....*Ankistrodesmus*

4. **Filamentous or spindle shape genera**

1. filamentous genera..2

   2. with a gelationus sheath, composed of cylindrical cells arranged in a row with equidistant

     interventing space...*Planktonema*

   2. without a gelatinous sheath, with long cylindrical, chloroplast definitely spiralled or

     ribbon...*Spirogyra*

1. spindle shape or straight cured or spirally twisted or abruptly narrowing to acute apices

     ....*Monoraphidium*

Zygnemaphyceae

1. semicells without arms 2

   2. angles of cell with single spine, face of semicells without warts or protuberances

     ....*Staurodesmus*

2. angles of cell without spine, angles of cell not continued into processes, mostly rounded
....*Cosmarium*

1. semicells with 2 extended arms at their apices as seen in front view, narrowly elliptic or
fusiform when seen from the top...*Staurastrum*

Xanthophyceae

1. cell solitary, rectangular and margin concave, the angle projected into narrow, twice
furcated processes ....*Isthmochloron*

Euglenophyceae

1. movement euglenoid..2

    2. with lorica...3

        3. cells enclosed in a buff or brown – coloured lorica regulary
        ornamented..*Trachelomonas*

        3. cells enclosed in lorica, irregularly ornamented, wall usually rough.......................
        ....*Strombomonas*

    2. without lorica, contractile body movement violent.......................................*Euglena*

1. rigid movement not euglenoid...2

    2. cells flattened dorsiventrally, usually spirally twised in at least part of the cell,
    paramylon bodies variable in number..*Phacus*

    2. cells broadly ovoid, pear-shaped or ellipsoidal, usually with a short tail, paramylon
    bodies 2 and large...*Lepocinclis*

4.4.4.3 Description of morphological features of phytoplankton in Rama IX lake
Cynophyceae

1. *Anabaena* sp. (Plate 1a, 1b; Figure 4.38A)

Trichomes straight or bent, with almost rounded end cells, 60-325 μm. long. Cells barrel or beadlike shaped, diameter 2-4 μm. Heterocyst almost spherical, 2.5-3.75 μm broad, with a smooth hyaline outer wall, heterocysts intercalary.

Habitats : Lake 1 and 2 (In this investigation)

Distribution : -

2. *Anabaena aphanizomenoides* Forti (Plate 1a, 1b; Figure 4.38C)

Trichomes single, straight or bent slightly curved 250-300 long, without mucilaginous sheaths, at the ends attenuated and rounded, but without markedly elongated cells. Cells shortly barrel–shaped or cylindrical, 2-3 μm broad, 3-4 long with gas vacuole. Heterocyst spherical or ellipsoidal, diameter 2-3 μm, with smooth colourless wall. Some filament could be found akinetes spherical to ellipsoidal.

Habitats : Lake 1 and 2

In water of tropical lake (Hind k and Moustaka, 1988)

Distribution : Sri Lanka (Rott, 1983); Greece (Hind k and Moustaka, 1988);

Hungary (Vor s and G de, 1993); Thailand (Chorum, 1997; Chiang

Mai University, 2001); British Isles (John, Whitton and Brook, 2002)

3. *Aphanizomenon* sp. (Plate 1a, 1b; Figure 4.38D)

Trichomes solitary or slighty curved, 65-275 μm long, without mucilaginous sheaths. Cell elongate or cylindrical, 2.5-3.75 μm broad, 6.25-7.5 long at the ends attenuated. Heterocyst intercalary, long cylindrical, 2-3 μm broad and 5-6 μm long. Akinetes not observed.

Habitats : Lake 1 and 2

Lake (water bloom) (Hind k and Moustaka, 1988)

Distribution : -

4. *Aphanothece nidulans* Richter (Plate 2a, 2b; Figure 4.39F)

Colonies microscopic, spherical, oval to irregular, yellow-geen, 30-50 μm in diameter or more, cells irregularly arranged in mucilaginous envelop, distant from each other or densely clustered. Cells cylindrical to spherical, 1-2 μm broad, 2-3 μm long, without gas vesicles.

Habitats : Lake 1 and 2

Fresh water, not polluted, clear water bodies, cold–water aquaria

(Kom rek and Anagnostidis, 1999)

Distribution : Greece (Hind k and Moustaka, 1988); South America (Tesolin and

Tell, 1996); Africa, Asia, Brazil, Europe, India, Sri Lanka, (Kom rek

and Anagnostidis, 1999)

5. *Aphanothece smithii* Komárková-Legnerová et Cronberg (Plate 3a, 3b; Figure 4.40C)

Colonies microscopic, oval to irregular, sometimes elongate, free floating, usually not very densely distributed cell; colonial mucilage colourless. Cell oval to cylindrical, pale blue-green, 2-3 μm broad and 3-4 μm long.

Habitats   :   Lake 1 and 2

Freshwater, planktonic in mesotrophic and slightly eutrophic usually large water bodies (lakes, reservoirs, ponds) (Komárek and Anagnostidis, 1999)

Distribution   :   Canada, Temperate zone, Scandinavia (Komárek and Anagnostidies, 1999)

6. *Aphanocapsa elachista* W. et G.S. West (Plate 3a, 3b; Figure 4.40B)

Colonies spherical or irregular 50-100 μm diameter; with cells arranged single or in pairs in hyaline mucilaginous envelopes, after division in twos. Cells spherical, 1-2 μm diameter, cell contents homogenous, without gas vescicles.

Habitats   :   Lake 1 (In this investigation)

Planktonic in eutrophic waters (Komárek and Anagnostidis, 1999; Jonn, Whitton and Brook 2002)

Distribution   :   Greece (Hindák and Moustaka, 1988); Africa (Romo, Bécares and Compere, 1995 quoted in Komárek and Anagnostidis, 1999);

In tropical countries, rare in warm regions of the temperate zone, Europe (Komárek and Anagnostidis, 1999), British Isles (John, Whitton and Brook, 2002)

7. *Aphanocapsa nubilum* Komárek et King (Plate 1a , 1b; Figure 4.38G)

Colonies small, microscopic, irregularly spherical, multicellular, 12-14 μm diameter, mucilage colourless. Cells spherical, irregularly distributed, 2 μm diameter, without gas vescicles.

Habitats   :   Lake 1 and 2

Planktonic in clear lake, ponds and swamps (Komárek and

Anagnostidis, 1999)

Distribution   :   Cosmopolitan; Europe : rarely found in lakes (Kom rek and
                     Anagnostidis, 1999)

8. *Coelomoron pusillum* (Van Goor) Kom rek (Plate 1a, 1b; Figure 4.38E)

Colonies microscopic, spherical or irregularly oval, sometimes composed of two colonies, 18-20 μm. in diameter, aggregated; only with 16 cells. Mucilaginous envelopes colourless. Cells oval, plae blue green, 2-3 μm. broad, 3-4 μm. long, without gas vesicle.

Habitats   :   Lake 1
                 Planktonic in eutrophic waters (Kom rek and Anagnostidis, 1999)

Distribution   :   Europe and North Amereica, the whole tropical region (Kom rek and
                     Anagnostidis, 1999)

9. *Cylindrospermopsis raciborskii* (Wolosz.) Seenayya & Subba (Plate 2a, 2b; Figure 4.39A)

Trichomes solitary, straight or slightly curved, not / or slightly constricted at the cross walls of cells. Cells cylindrical 1.5-3 μm. long, with gas vescides, sometimes indistinct. In many filaments only one heterocyst could be found, rarely two, one at each end of the filament. Heterocyst long conical to long ovoid, 2-3 μm. broad, 5-13 μm. long. Akinetes long cylindrical to ellipsoidal, 3-5 μm. broad, 4-15 μm. long, in pairs or three in number, jointed to heterocyst.

Habital   :   Lake 1 and 2
                Planktonic in freshwater (ÅÑ Ò ÇŞÈĄ̃Ñ •2542)

Distribution   :   Austria, Brazil, Burma, Czechoslovakia, Greece, Hungary, India,
                     Indonesia, Sri Lanka, USA, USSR, (Horecka and Kom rek, 1979);
                     Cuba (Kom rek, 1984; Nicaragua (Ruiz and Pum, 1987); West
                     Slovakia (Hind k, 1988); East Africa (Kom rek and Kling, 1991);
                     Thailand (Srisuwan, 1994; Pooarlai, 1999; Peerapompisal, Pekthong,
                     Waiyaka and Promkutkaew, 2000); Tropical, rare in temperate
                     (Peerapompisal, 1996).

10. *Cylindrospermopsis phillippinensis* (Tayler) Ka. (Plate 5a, 5b; Figure 4.42A)

      Trichomes circularis, coiling of filaments, Cell cylindrical, 2-3 μm. broad, 60-80 μm. long, cell contents homogenous, with gas vesicles. Heterocyst, terminal, long conical to long ovoid, 3-5 μm. broad and 7-8 μm. long.

Habitat	:	Lake 1 and 2
Distribution	:	Indonesia, Phillippines (Horecka and Kom rek, 1979); Cuba (Kom rek, 1984); Nicaragua (Ruiz and Pum, 1987); Thailand (Srisuwan, 1994; Pekthong, 1996; Pooarlai, 1999); Tropical, rare in temperate (Peerapompisal, 1996).

11. *Gomphosphaeria natans* Kom rek et Hind k (Plate 1a, 1b; Figure 4.38F)

      Colonies irregularly spherical, mucilagenous sheaths, 30 μm. diameter. Cells oval or slightly spherical, with grey–blue or olive-green, with sparsely distributed granules, 2.5 μm. broad, 3.4 μm. long.

Habitat	:	Lake 1
		Planktonic in oligotrophic or mesotrophic lake (Kom rek and Anagnostidis, 1999)
Distribution	:	Astria, Canada, France, Northern USA, Sound Argentina, South Slovakia (Kom rek and Anagnostidis, 1999)

12. *Merismopedia punctata* Meyen (Plate 2a, 2b; Figure 4.39E)

      Colonies, flat, tubular, rectangular; 2-16 cells, cells close together or in some distance form one another. Mucilage distinct, hyaline, colourless. Cells spherical or oval before division, with grey to pale blue green, 2-2.5 μm. diameter

Habitat	:	Lake 1 and 2
		Planktonic in mesotrophic freshwater (Kom rek and Anagnostidis, 1999; John, Whitton and Brook, 2002)

Distribution	:	Europe (Huber-Pestalozzi, 1938 quoted in Desikachary, 1959);

USA (Smith, 1950; Whitford and Schumacher, 1969); India
(Disikachary, 1959); North Tchad (Compere, 1970 quoted in
Peerapompisal, 1996) Nigeria (Compere, 1980); Ecuador (Rott, 1981);
Sri Lanka (Rott, 1983); Cuba (Komrek, 1989); Nicaragua (Ruiz and
Pum, 1987); Austria, Hungary, Slovkia, (Hindk, 1992); Ethiopia
(Kebede and Belay, 1994); Sri Lanka (Rott and Lenzenweger, 1994);
Thailand (Chaiubol, 1998; Pooarlai, 1999)

13. *Microcystis aeruginosa* Ktzing (Plate 3a, 3b; Figure 4.40E)

Colonies spherical, oval to irregular, mucilage colourless, with cell loosely to densely arranged in hayaline mucilaginous envelopes. Cells spherical to broadly oval, 2-5 μm. in diameter, with gas vesicles, cell contents homogenous.

Habitat : Lake 1

Fresh and brackish waters, planktonic in eutrophic (lakes, reservoirs, fishpond) (Komrek and Anagnostidis, 1999); In central of the lake (Hirano, 1975)

Distribution : Thailand (Hirano, 1975; Wannasai, 1998; Mahakhant, et al. 1998; Peerapompisal, Sonthichai, Somdee, Mulsin and Rott, 1999); Sri Lanka (Rott, 1983); Greece (Hindk and Moustaka, 1988); France (Aleya, 1992); Japan (Lee, Tsuzuki; Takeuchi, Yokoyama and Karube, 1994); Taiwan (Liu and Tseng, 1996); Rassia (Korneva and Mineeva, 1996; Holopainen, Huttunen, Letanskaya and Protopopova, 1996); Korea (Ha, Cho, Kim and Joo, 1999); British Isles (John, Whitton and Brook, 2002)

14. *Oscillatoria limosa* Ag. ex Gomont (Plate 2a, 2b; Figure 4.39B)

Trichomes solitary, straight, dull blue-green, brown or olive-green, not constricted at the croos-walls. Cells cylindrical, cell usually broader than long, 6-13 μm. board, 2-5 μm. long, end-cell flatly rounded with slightly thickened membrane.

Habitat	:	Lake 1 and 2
		In a standing fresh and salt water. (Desikachary, 1959)
Distribution	:	India (Turner, 1892 quoted in Desikachary, 1959); Malaya (Huber-Pestalozzi, 1938 quoted in Desikachary, 1959); Europe, South Africa, India, Burma, Malaya, Borneo, Thailand, China and Japan (Yamagishi and Hirano, 1973); Austria (Rott, 1981); Thailand (Udomlak, 2000); British Isles (John, Whitton and Brook, 2002)

15. *Planktolyngbya limnetica* Lemmermann (Plate 1a, 1b; Figure 4.38B)

Filaments solitary, straight, not constricted at the cross wall of cells, sheath thin or narrow, colourless. Cells shorts to long cylindrical, 1-2 μm. broad, 1-3 μm. long, as long as broad, end cells not attenuated, rounded; cell contents pale blue-green to grey, without a granule at the cross wall.

Habitat	:	Lake 1 and 2
		Reservoir, lake, ponds (Desikachary, 1959)
Distribution	:	Europe, Java, New Zeland, Antarctic, Africa, North America (Huber – Pestalozzi, 1938); Burma (Skuja, 1949, 1953 quoted in Desikachary, 1959); Thailand (Hirano, 1975; Peerapompisal, 1996; Pooarlai, 1999) Nigeria (Compere, 1980); Sri Lanka (Rott, 1983); Venezuela (Vilarrubia, 1995).

16. *Planktolyngbya* sp. (Plate 1a, 1b; Figure 4.38H)

Trichomes typically inside a firm sheath, regularly twisted, regulary twisted, colourless compact spirals, short filament, 60-70 μm. long. Cells cylindrical, 1-2 μm. in diameter. Identification is not possible from fixed samples. Not very frequent species.

Habitat	:	Lake 1
		Freshwater (Desikahary, 1959)
Distribution	:	-

17. *Spirulina platensis* (Nords) Geitler   (Plate 2a, 2b; Figure 4.39C)

Trichomes regularly coiled, without cross walls, without mucilaginous envelops, very slightly attenuated towards the apex, breadth of coiling 50 μm. Cells cylindrical, with gas vesicles, 4-5 μm in diameter.

Habitat   :   Lake 1 and 2

                          Pond, Lake (Hirano, 1967)

Distribution   :   Thailand, India and Central Africa (Hirano, 1967) Thailand (Pooarlai,

                          1999; Peerapompisal, 2001) Tokyo (Lee, Tsuzuki, Takeuchi,

                          Yokoyama and Karube, 1994)

Cryptophyceae

1. *Chroomonas* sp. (Plate 9a, 9b; Figure 4.46F)

Cells oval or slipper shaped, without a gullet, usually bilobed anteriorly with the flagella some what lateral; chloroplast 3, blue-green or bluish, parietae plates, with pyrenoid, 5-9 μm. broad, and 7-17.5 μm long. Identification is not possible from fixed samples.

Habitat   :   Lake 1 and 2

                          Freshwater (Prescott, 1970)

Distribution   :   -

2. *Cryptomonas* sp. (Plate 9a, 9b; Figure 4.46G)

Cells oval, with 1 or 2 parietal, olive-green or yellowish-green chloroplasts which are often red containing 1-4 pyrenoids if present; flagella 2, attached on the apical end; contractile vacuoles 1-3, with gullet, 12.5-20 μm. broad, 22.5-37.5 μm long. Identification is not possible from fixed samples.

Habitat   :   Lake 1 and 2

                          Lake, habitats rich in organic materials (Whitford and Schumacher,

                          1969)

Distribution   :   -

3. *Rhodomonas* sp. 1   (Plate 9a, 9b; Figure 4.46H)

Cells oval or pear shaped, with a single red chloroplast containing a large, centrally positioned pyrenoid, with a longitudinal furrow bordered by trichocysts, 4-7 μm broad, 10-14.5 μm long. Identification is not possible from fixed samples.

Habitat   :   Lake 1 and 2

Freshwater (Prescott, 1970)

Distribution   :   -

4. *Rhodomonas* sp. 2   (Plate 9a, 9b; Figure 4.46I)

Cells oval, with a single red chloroplast containing a large, centrally positioned pyrenoid, with a longitudinal furrow bordered by trichocysts, 4-7 μm broad, 10-14.5 μm long. Identification is not possible from fixed samples.

Habitat   :   Lake 1 and 2

Freshwater (Prescott, 1970)

Distribution   :   -

Dinophyceae

1. *Ceratium furcoides* (Levander) Langhans (Plate 3a-3b and 12a; Figure 4.40A, 4.19D)

Cells narrowly spindle-shaped, strongly dorsiventrally flattened, epitheca formed into a narrow horn; a long horn forms from just above the cingulum, hypotheca broad and short, drawn out into 2 (occasionally 1 or 3) posterior horns, with usually 20 or 3, rarely 1; with four apical plates not reaching apex of epitheca; chloroplasts numerous and oval shape.

Habital   :   Lake 1 and 2

In oligotrophic and eutrophic lakes and reservoirs, a summer species (Popovsk and Pfiester, 1999; Whitton and Brook, 2002)

Distribution   :   Europe (Huber-Pestalozzi, 1968; Popovsk and Pfiester, 1999; Whitton and Brook, 2002)

2. *Peridiniopsis cunningtonii* Lemmermann. (Plate 13a; Figure 4.50C, D)

Cells oval and extremely flattened dorsiventrally, The epitheca is conical; the hypotheca rounded with 2-6 spines. The epicone has only six preequatorial plates. The cingulum spirals slightly to the left. The sulcus barely extends into the epitheca; it widens along the hypotheca where it does not reach the antapex. Hypothecal plates bear is spicules. The plate are delicate reticulated. Chloroplasts are present; cell 17.5-22.5 μm broad, 25-30 μm long and 17.5-20 μm thick.

Habitat   :   Lake 1 and 2

                      Lakes and ponds (Popovsky and Pfiester, 1990)

Distribution   :   Africa, Asia and Europe (Lefevre, 1928) quoted in Peerapompisal

                      1996); Sri Lanka (Rott, 1983); Asia and Central Europe (Popovsky

                      and Pfiester, 1990); Thailand (Peerapompisal, 1996); Cosmopolitan

                      (Popovsky and Pfiester, 1990; John, Whitton and Brook, 2002)

3. *Peridinium* sp.1 (Plate 13a; Figure 4.50A)

Cells spherical and slightly flattened dorsiventrally. The cingulum is wide, relatively deep and spirales to left. The sulcus extends slightly into the epicone, it widens slightly along the hypocone where it reaches the antapex. The apical pore is shifted to the left; the plate pattern is asymmetric. Cell 17.50-20 μm broad 20-25 μm long and 12.5-15 μm thick.

Habit :   Lake 1 and 2

                      Small-big standing waters, from oligotrophic to eutrophic

Distribution :   -

4. *Peridinium* sp.2 (Plate 13a; Figure 4.50B)

Cells covered with obvious theca consisting of cellulosic plates; cell shape almost compact or ovoid, sometimes with small projections at apex and antapex; cell 20-23 μm broad, 27.5-34 μm long and 17.5-20 μm thick.

Habit :   Lake 1 and 2

                      Plankton in lakes (John, Whitton and Brook, 2002)

Distribution :   -

Diatomophyceae

1. *Achnanthes minutissima* Kützing (Plate 13a; Figure 4.50F)

Cells linear-lanceolate to linear-elliptical or linear in valve view, with true raphes and one pseudoraphae; apices bluntly rounded or slightly tapering not protracted; girdle veiw markedly bent. Cells narrow in both views, often with reflexed apices when seen in girdle veiw; between central raphe endings small and knob-like; cells rarely moving, sometimes attached by mucilage stalks secreted from one end of the raphid valve, 2.5-4 μm. broad, 5-25 μm. long and striae 30-32 in 10 μm.

Habitat : Lake 1 and 2

Freshwater (Edmondson, 1963); Acidic lakes (Stokes and Yung, n.d.) ; Marine (Round, Crawford and Mann, 1990)

Distribution : Canada (Stokes and Yung, n.d. quoted in Smol, Battarbee, Davis and Merilinem, 1986); Finland (Tolonen, Linkkonen and Patil, 1986); Cosmopolitan (Krammer and Lange – Bertarot, 1991); Sweden (Anderson, 1994; Kelly and Whitton, 1995); England and Scotland (Kelly, Penny and Whitton, 1995); Thailand (Waiyaka, 1998; Peerapompisal, Pekthong, Waiyaka and Promkutkaew, 2000); Spain (Sabater, 2000); Cosmopolitan (ÅÑÒ Ç§ÈÃ̪Ñ,•2542)

2. *Amphora* sp. (Plate 4a, 4b; Figure 4.41L)

Cells with variously dorsiventral valves, often biconvex in girdle view. The raphe presents two cured lines near the ventral margin of the valve, the two cures meeting over the central nodule which lies next to the ventral margin of the all. Cells contain a single chloroplast : chloroplast usually H shaped, lapping around the cell with the central pyrenoid against one side of the girdle. Cells small, 9 μm. borad, 20 μm. long in girdle veiw. Identification is not possible from fix samples. Not very frequent species.

Habitat : Lake 2 (In this imustigation)

Freshwater, cells attached to the substratum (Cox, 1996)

Distribution : -

3. *Anomoeoneis vitrea* (Grunow) Ross (Plate 13a; Figure 4.50E)

Cells solitary, usually lying in valve veiw. Valves are elongates boat-shaped in valve view with narrowly rounded apices. Cells have a single, highly lobed plastid with its centre close to one side of the girdle, deeply invaginated beneath the raphes slits and centrally along the midline of the girdle. A large more or less spherical, pyrenoid lies at the centre of the plastid. Raphe central, with hooked in the same direction. Cells generally small, 5-6.25 μm. broad, 20-27.5 μm. long, and striae 38 in 10 μm.

Habitat   :   Lake 1 and 2

Freshwater, in water of high conductivity and acidic water (Round, Crawford and Mann, 1990)

Distribution   :   -

4. *Aulacoseira granulata* (Ehrenberg) Ralfs (Plate 6a, 6b, 12a ; Figure 4.43D, 4.49B)

Frustules without intercalary bands; cells arranged in filaments of cylindrical cells in girdle view. The valves are either flat or convex in which instance there are teeth at the poles which aid in adjoining the cells. In some there is a sulcus or ringlike incision around midregion, the girdle being smooth. The wall is punetate, coarsely or faintly. In this species the spines have two "roots" that straddle a row of pores on the mantles; valves 5-7.5 μm. broads and 16-18 μm. long. Chloroplast discoid.

Habitat   :   Lake 1 and 2

Freshwater (Round, Crawford, Mann, 1990); Planktic in mesotrophic to eutrophic waters (ÅÑÒ Ç§ÈÃļÑ •2542)

Distribution   :   USA (Prescott, 1970); Europe (Krammer and Lange-Bertalot, 1991); Netherlands. (Brink, Katwijk and Velde, 1994); England (Cox, 1996); Finland (Karjalainen, Holopainen and Huttunen, 1996); Russia (Laugaste and Pork, 1996; Laugaste, Jastremskij and Ott, 1996) South America (Tesolin and Tell, 1996); Thailand (Cha-umphol, 1996; Kraibut, 1996; Chaiubol, 1998; Chorum, 1998; Pooarlai, 1999, Wannasai, 1999) Cosmopolitan (ÅÑÒ Ç§ÈÃļÑ •2542)

5. *Cocconeis placentula* Ehrenberg (Plate 12a; Figure 4.49A)

Cells are broadly ovoid-elliptic in valve veiw, heterovalvar. The epivalve shows an axial pseudoraphe and is convex whereas the hypovalve is concave, or flat and shows a raphe; with a central and polar nodules. The valves have prominent transverse striae but the pattern differs on the 2 valves. In many there is a clear marginal band foremed by a interruption of the striae on the valve which has the raphe. Chloroplast, which is flat and c-shaped. Cells solitary, $10.2\mu m$, broad, $16.2\mu m$ long and striae 15 in $10\mu m$.

Habitat   :   Lake 1 and 2

                               Fresh water to marine, living on the plants, rocks, etc. (Round, Crawford and Mann, 1990)

Distribution   :   USA (Prescott, 1951); Phillippines (Hirano, 1967); Cosmopolitan (Hirano, 1967); England (Kelly and Whitton, 1995); England and Scotland, (Kelly, Penny and Whitton, 1995); South America (Tesolin & Tell, 1996); Rassia (Bondarenko, Guselnikova, Logacheva and Fomazkina, 1996); Thailand (Waiyaka, 1998; Peerapompisal, Pekthong, Waiyaga and Promkutkaew, 2000); Spain (Sabater, 2000)

6. *Cyclotella* sp. (Plate 5a, 5b; Figure 4.42C)

Cells short, drum-shaped, free-living or forming filaments, chains or rarely clusters united by mucilage. Valve with an intramarginal zone of costae encircling, the cells smooth or finely punctate within the marginal circle of costae. Plastids numerous, discoid. Cells 17.5–25 μm diameter in valve veiw. Identification from fixed material is not possible. Unfrequent species.

Habitat   :   Lake 1

                               Fresh water (Round, Crawford and Mann, 1990; Cox, 1996)

Distribution   :   -

7. *Cymbella* sp. (Plate 4a, 4b; Figure 4.41K)

Cells with dorsiventral valves, the dorsal margin more convex than the ventral, the latter may be straight or concave; apices bluntly rounded. Single H-shaped chloroplast with a central lenticular pyrenoids towards the dorsal margin. Cells may be solitary or attached to the

substratum by mucilages stalks. Cells with small narrow valves, 5 μm. broad, 22.5 μm. long in valve veiw. Identification is not possible from fix samples. Not very frequent species.

Habitat   :   Lake 2

                          Freshwater (Prescott, 1962; Cox, 1996)

Distribution   :   -

8. *Eunotia* sp. (Plate 5a, 5b; Figure 4.42D)

Cells bent or cured in the apical regions; wavy or undulate on one margin as seen in valve view. The face of the valves is transversely striate. The polar nodules are conspicious and from them to the ventral (concave) margin a short raphe extends. Two elongate chloroplasts lying on the ventral side of the cell and extending onto the valve faces. Cells may attach to a surface or each other by apical mucilage pads, rectangular in girdle veiw with 7.5-9.5 μm. broad, 22.5 μm. long. Identification is not possible from fix samples. Not very frequent species.

Habitat   :   Lake 1

                          Freshwater (Prescott, 1962; Cox, 1996)

Distribution   :   -

9. *Fragilaria ulna* var. *acus* (K   tzing) Lange - Bertalot (Plate 6a, 6b; Figure 4.43E)

Cell oblong or swollen at centre in girdle veiw; if expansed then cells are only liked in their central portions. Cells joined to from ribbon-like colonies. The pseudoraphe is broad and distinct and occurs in both valves. Two plate–like plastids. Cells in nature seen in girdle view, with 2.5-5 μm. brood and striae 13 in 10 μm.

Habitat   :   Lake 1 and 2

                          Freshwater (Krammer and Lange–Bertalot, 1991)

Distribution   :   Cosmopolitan (Krammer and Lange–Bertalot, 1991); South America

                          (Tesolin and Tell, 1996) Thailand (Noinumsai, 2000)

10. *Gyrosigma macrum* (W. Smith) Griffith & Henfrey (Plate 6a, 6b; Figure 4.43F)

Cells are sigmoid in valve view, as is the narrow and long axial field which is enlarged in the midregion. The ends of the raphe at the central area a bend or are hooked in opposite

directions. The valve is marked by intersecting longitudinal and transverse straie. In girdle veiw the frustules are lanceolate. Two-plate-like chloroplasts, sometimes with lobed margins lie along each side of the girdle. Cells solitary, with 7.5-10 μm. broad, 182.5-200 μm. long and striae 26-28 in 10 μm.

Habitat	:	Lake 2
		Planktonic in freshwater, brackish water to marine (Huber-Pestalozzi, 1983; Krammer and Lange–Bertalot, 1991).
Distribution	:	Cosmopolitan (Huber-Pestalozzi, 1983; Krammer and Longe–Bertalot, 1991)

11. *Gyrosigma* sp. (Plate 5a, 5b; Figure 4.42K)

Cells with a broadly sigmoid valve; two large plate–like chloroplast lying one along each side of the girdle, extending slightly under the valve face. Cell solitary, with 12.5-15 μm. broad and 51-55 μm. long. Identification is not possible from fix samples. Not very frequent species.

Habitat	:	Lake 1
		Freshwater and brackish water to marine (Round, Crawford and Mann, 1990)
Distribution	:	-

12. *Nitzschia* sp. (Plate 4a, 4b; Figure 4.41J)

Cells narrowly sigmoid with acute apices, sometimes sigmoid in valve or girdle view. Two plastids arranged fore and the end of the cell, with a plate under each valve face, linked by a narrow isthmus near one pole. Cells solitary, with 2.5 μm. broad, 40-55 μm. long. Identification from fixed material is not possible. Unfrequent species.

Habitat	:	Lake 1 and 2
		Freshwater to marine usually epipelic or planktonic.
Distribution	:	-

Chrysophyceae

1. *Uroglenopsis americana* (Calkins) Lemmermann. (Plate 3a, 3b; Figure 4.40D)

Cells ovoid or egg-shaped, the hundreds of cells in a colony, not interconnected by stalks, with 35 μm in diameter. The cells have flagella of unequal length, with 2.5 μm broad and 3.75 μm long. Chloroplast plate-like yellow-brown color.

Habitat : Lake 1 and 2

Planktonic in lakes (Prescott, 1970); Slightly deep lakes, hardness water (ÅÑÒÇSÈÄþÑ,•2542)

Distribution : Cosmopolitan (Whiftford and Schumacher, 1969); USA (Prescott, 1962 and 1970)

Chlorophyceae

1. *Acanthosphaera* sp. (Plate 4a, 4b; Figure 4.41I)

Cells spherical, spine long and slender, with a distinct basal section thickned, then abruptly narrowed to a fine bristle. Cells with 7.5-17.5 μm diameter. Chloroplast plate-like or lobe. Identification is not possible from fix sample. Not very frequent species.

Habitat : Lake 1 and 2

Freshwater (Prescott, 1970)

Distribution : -

2. *Actinastrum gracillimum* G.M. Smith (Plate 5a, 5b; Figure 4.42F)

Colonies composed of 4-16 truncate-fusiform, without mucilaginous sheaths. Cells cylindrical, with very slightly narrowed to abruptly truncate poles, forming colonies of individuals with the long axes of the cells radiating in all planes from a common center; cells 2.5 μm broad and 20-25 μm long. Chloroplast plate-like, lie around the cell.

Habitat : Lake 1

Planktonic in lake (Prescott, 1962)

Distribution : USA (Presscott, 1962)

3. *Ankistrodesmus falcatus* (Corda) Ralfs (Plate 5a, 5b; Figure 4.42E)

Colonies composed of 2-32 individuals, without mucilaginous sheaths. Cells needle-like to somewhat spindle-shaped; chloroplast 1, a parietal plate without pyrenoids; cell 1.25-2 μm. broad and 38-50 μm. long.

Habitat   :   Lake 1 and 2

Acid water and High Temperature (Prescott, 1962); In fish-farm ponds where nutrient level are high. (John, Whitton and Brook, 2002)

Distribution   :   USA (Prescott, 1962); Cosmopolitan, Burma (Hirano, 1967); Thailand (Hirano, 1967; Chaiubol, 1998); Cambodia (Yamagishi and Hirano, 1975); British Isles (John, Whitton and Brook, 2002)

4. *Botryococcus braunii* Kützing (Plate 5a, 5b; Figure 4.42H)

Colonies composed of 2 cells. Colonial mucilage much folded and extended into tough, foamy strands, often forming colonial complexes by inter connecting strands of mucilage. Cells ellipsoid, radiately arranged at the periphery of irregularly shaped, usually dark-colored masses of mucilage. Chloroplast thin or dense parietal net with 1 pyrenoid. Diameter of colonies often 25 - 30 μm.

Habitat   :   Lake 1 and 2

Freshwater (Prescott, 1962)

Distribution   :   USA (Smith, 1950; Whiford and Schumacher 1969; Prescott, 1970); North Tchad (Compere, 1967, Compere, 1970 quoted in Peerapompisal, 1996); Bangladesh (Islam, 1973); Central America (Kuzel-Hellmich, e.d. quoted in Peerapompisal, 1996); Thailand (Hirano, 1975; Yamagishi and Kanetsuna, 1987; Peerapompisal, 1996); Ecuador (Rott, 1981); Sri Lanka (Rott, 1983); Austria (Deisinger, 1984); Ethiopia (Kebede and Belay, 1994); Venezuela (Vilarrubia, 1995); Cosmoporitan (Peerapompisal, 1996); France (Tadonliki, Ngando, Amblard, Sargas and Devaux, 2000); British Isles (John, Whitton and Brook, 2002)

5. *Cateria* sp. (Plate 5a - 5b, Figure 4.42G)

Cells elliptic or cordiform in front veiw, with a definite cell wall; furnished with 4 long flagella. Chloropast parietal, cup-shaped. Cell 7.5-10 μm. broad and 12.5-20 μm. long.

Habitat : Lake 1 and 2

      Freshwater (Prescott, 1970)

Distribution : -

6. *Chlamydomonas* sp. 1 (Plate 4a, 4b; Figure 4.41C)

Cells narrowly ovoid to ellipsoid , with 1 apical papillae, from which the 2 flagella arise; often with a narrow mucilaginous sheath. Chlorophast a dense, padded body occupying the entrie cell, with pyrenoid; eye spot usually evidence. Cells 2.5-5 μm. broad and 7.5-12.5 μm. long. Identification is not possible from fix sample. Not very frequent species.

Habitat : Lake 1 and 2

      Freshwater (Prescott, 1970)

Distribution : -

7. *Chlamydomas* sp. 2 (Plate 4a, 4b; Figure 4.41D)

Cells broadly oviod to ellipsoid, with 1 apical papillae, from which the 2 flagella arise; often with a narrow mucilaginous sheath; eye spot usually evidence Chloroplast a dense, padded body occupying the entrie all, with one to several pyrenoid, anteriar contractile vacuole. Cells 5-10 μm. broad and 10-15 μm. long. Identification is not possible from fix sample. Not very frequent species.

Habitat : Lake 1 and 2

      Freshwater (Prescott, 1970)

Distribution : -

8. *Chlorogonium* sp. (Plate 4a, 4b; Figure 4.41A)

Cells elongate fusiform and narrowly pointed the apical without an external sheath. Cells composed of 2 flagella. Cells 1-2 μm. broad and 10-17.5 μm. long. Identification is not possible from fixed samples. Not very frequent species.

Habitat   :   Lake 1 and 2

Freshwater (Prescott, 1970)

Distribution   :   -

9. *Chlorella vulgaris* Beijerinck   (Plate 4a, 4b; Figure 4.41B)

Cells spherical, scattered among other algae; chloroplast a parietal cup without a pyrenoid; cell 2.5-5 μm. in diameter.

Habitat   :   Lake 1 and 2

In lakes, especially where there is concentration of organic matter (Prescott, 1962)

Distribution   :   USA (Prescott, 1962; Whitford and Schumacher, 1969); Probably cosmopolitan (Jonh, Whitton and Brook, 2002)

10. *Coelastrum microporum* Naegeli   (Plate 4a, 4b; Figure 4.41F)

Coenobium spherical, composed of 8-64 sheated globose cells. Cells joined without connecting projections; small intercellular spaces; cells 12.5-17.5 μm. in diameter including the sheath.

Habitat   :   Lake 1

Planktonic in the lake (Prescott, 1962).

Distribution   :   USA (Smith, 1950; Whitford and Schumacher, 1969; Prescott, 1970); Bangladesh (Islam, 1973); Japan (Yamagishi and Hirano, 1973); Peru (Hegewald, Aldave and Schnepf, 1978); Nigeria (Compere, 1980); Ecuador (Rott, 1981); Sri Lanka (Rott, 1983); Austria (Deisinger, 1984); Thailand (Yamagishi and Kanetsuna; 1987; Peerapompisal, 1996); Nicaragua (Ruiz and Pum, 1987); France (Aleya, 1992); Probably cosmopolitan (John, Whitton and Brook, 2002)

11. *Coelastrum pseudomicroporum* Korshikov (Plate 8a, 8b; Figure 4.45A)

Coenobium spherical, composed of 8-32 cells. Cell slightly ovate, at the top narrowly rounded with a thickened cell wall. Each cell is connected with 5-6 neighbouring cells,

intercellular spaces very small and usually triangular. Chloroplast parietal with pyrenoid. Cells 5 μm. broad, 7.5 μm. long and colony 3.5 μm. in diameter.

Habitat : Lake 1

        Planktonic in eutrophic, sea, (Huber – Pestalozzi, 1983)

Distribution : Europe (Huber-Pestalozzi, 1983; British Isles (John, Whitton and

        Brook, 2002)

12. *Coelastrum sphaericum* Naegeli (Plate 7a, 7b; Figure 4.44A)

   Coenobium spherical, composed of 4-64 conical cells, the narrow end directed outward, enclosed in delicate gelatinous sheath, the sheath at free ends thicker than in other parts; cell 7.5 μm. in diaimeter.

Habitat : Lake 1 and 2

        Planktonic in Freshwater (Pescott, 1962)

Distribution : USA (Prescott, 1962; Whitford and Schumancher, 1969); Thailand

        (Yamagishi and Kametsuna, 1987; Wannasai, 1998); Probably

        cosmopolitan (John, Whitton and Brook, 2002)

13. *Crucigeniella crucifera* (Wolle) Komárek (Plate 8a, 8b; Figure 4.45B)

   Colony consisting of 4-sided cells arranged about a central square opening, outer side concave inner side straight or slightly convex, with blunt apices, internal space small and rectangular; sometimes coenobia joined to form syncoenobia of 16 or more cells; cells 2-2.5 μm. broad and 3-5 μm. long.

Habitat : Lake 1 and 2

        Planktonic in Freshwater (Whitford and Schumancher, 1969)

Distribution : USA (Prescott, 1962; Whitford and Schumancher, 1969) Thailand

        (Pooanlai, 1998); Probably cosmopolitan (John, Whitton and Brook,

        2002)

14. *Dictyosphaerium tetrachotonum* Printz (Plate 7a, 7b; Figure 4.44D)

Colony ovoid, composed of 4-64 oblong-ovate cells, with cup-like chloroplast. Mother cells much widened before division. Daughter cells oblong, arranged parallel, inclosed in mucilage, with pyrenoid. Cells 1.5-2 μm. broad and 2-2.5 μm. long.

Habitat   :   Lake 1 and 2

Distribution   :   Europe (Huber-Pestalozzi, 1983) Sri Lanka, (Rott, 1983); Cuba
                            (Kom   rek 1983); Thailand (Yamagishi and Kanetsuna, 1987);
                            Probably cosmopolitan (John, Whitton and Brook, 2002).

15. *Dictyosphaerium pulchellum* Wood (Plate 7a, 7b; Figure 4.44F)

Colony spaerical, composed of 4-32 sperical cells, with cup-like chloroplast. Cells arranged in series of 4 on dichotomously branched threads, inclosed in mucilage; cells 5 μm. in diameter.

Habitat   :   Lake 1
                            Plankton in acid bog lakes (Taylor, 1935 quoted in Prescott, 1951);
                            Generally distributed in many soft water as well as semi-hard water
                            lakes. (Prescott, 1962)

Distribution   :   USA (Prescott, 1962 , 1970; Whitford and Schumancher, 1969);
                            Nicaragua (Ruiz and Pum, 1987); Netherlands (Brink, Katwijk and
                            Velde, 1994); Scotland (Jomes, Yong, Hartley and Watts, 1996);
                            Probably cosmopolitan (John, Whitton and Brook, 2002)

16. *Eudorina elegans* Ehrenberg (Plate 7a, 7b; Figure 4.44B)

Coenobial ovate, composed of 16-32 sphaerical cells or slightly pear-shaped evenly disposed within a glatinous envelope, or arranged in transverse series, the crowded toward the interior; Chloroplast cup-shaped; eye spot anterior; Cells 5-7.5 μm. in diameter; colonies up to 200 μm. in diameter.

Habitat   :   Lake 1
                            Common in euplankton of hard water lake (Prescott, 1962)

Distribution   :   USA (Prescott, 1962, 1970; Whitford and Schumancher, 1969); Japan (Yamagishi and hirano, 1973) Cosmoporitan (Yamagishi and Hirano, 1973), Thailand (Hirano, 1975); Africa (Kebede and Belay, 1994); Argentina (Pizzolon, Santinelli, Marinone and Marque, 1995); Cosmopolitan (John, Whitton and Brook, 2002)

17. *Eutetramorus globosus* Walton   (Plate 8a, 8b; Figure 4.45C)

Colonies a clear globe of mucilage, composed of 4 spherical cells, arranged at or near the periphery and the sheath is homomogenous, without radiating fibrils. Cells, 5 μm in diameter.

Habitat   :   Lake 1

Distribution   :   USA (Prescott, 1970)

18. *Monoraphidium arcuatum* (Korshikov) Hindâk   (Plate 6a, 6b; Figure 4.43A)

Cells spindle shaped, sometimes slightly curved, attenuated into long processes, usually 5 time longer than broad. Chloroplast concave, without pyrenoid. Cells 2-3 μm broad and 18-32 μm long.

Habitat   :   Lake 1 and 2

                  Planktonic in the water (Huber-Pestalozzi, 1983)

Distribution   :   Nîgeria (Compere, 1970); Egypt, England, Cuba, Russia, Czechoslovakia, Cosmopolitan (Huber-Pestalozzi, 1983); Russia (Bondarenko, Guselnikova, Logacheva and Fomazkina, 1996)

19. *Monoraphidium contortum* (Thuret) Komârkovâ-Legnerovâ   (Plate 4a, 4b; Figure 4.41E)

Cells spindle, narrow, spirally twisted, with acute apices, 1-2 μm broad and 7-40 μm. long.

Habitat   :   Lake 1 and 2

                  Planktonic in eutrophic (Huber-Pestalozzi, 1983)

Distribution   :   Austria (Deisinger, 1984, Cosmopolitan (Huber-Pestalozzi, 1983); Nicaragua (Ruiz and Pum, 1987); Thailand (Peerapompisal, 1996); Probably cosmopolitan (John, Whitton and Brook, 2002)

20. *Monoraphidium griffithii* (Berkeley) Komärkovä-Legnerovä (Plate 5a, 5b; Figure 4.42B)

Cells straight, spindle-shaped, with acute apices usually about 12 times longer than broad, 1.5-2.5 μm. broad and 35-50 μm. long.

Habitat   :   Lake 1 and 2

Planktonic in mesotrophic and eutrophic (Huber-Pestalozzi, 1983)

Distribution   :   Cosmopolitan (Huber-Pestalozzi, 1983); Spain (Romo & Tongeren, 1995); Probably cosmopolitan (John, Whitton and Brook, 2002)

21. *Monoraphidium irregulare* (G.M.Smith) Komärkovä-Legnerovä (Plate 6a, 6b; Figure 4.43C)

Cells spindle–shaped, narrow, spirally twisted long usually more than 10 times longer than broad, gradually narrowing to pointed apices cell 1.25 μm. broad and 12.5-16.7 μm. long.

Habitat   :   Lake 1 and 2

Planktonic in oligotrophic and mesotrophic (Huber-Pestalozzi, 1983)

Distribution   :   Europe (Huber-Pestalozzi, 1983); Probably cosmopolitan (John, Whitton and Brook, 2002)

22. *Ooccystis* sp. (Plate 4a, 4b; Figure 4.41G)

Cells crowded in groups of 4-16, inclosed by the old mother cell wall; ellipsoid or ovate cells with thickened cell walls on the poles. Chloroplast parietal plate; cell 2.5-5 μm. broad, and 5-10 μm. long. Identification is not possible from fix sample.

Habitat   :   Lake 2

Distribution   :   -

23. *Pandorina morum* (O.F. Müller) Bory (Plate 7a, 7b; Figure 4.44C)

Coenobia usually distinctly ovate, composed of 8-16 cells compactly arranged and inclosed by a common gelationous envelope; Flagella 2, arising from the anterior end of cell and diverging widely after emerging from the colonial envelope. Chloroplast a prietal cup with pyrenoid; eyespot anterior and lateral. Cells, 10-15 μm. broad, 12.5-17.5 μm. long and colony 220 μm. in diameter.

Habitat	:	Lake 1
		Common in plankton of both hard water and soft water lake but more frequent among dense growths of algae in shallows, especially in water rich in nitrogenous matter. (Prescott, 1962)
Distribution	:	USA (Prescott, 1962, 1970); Cosmopolitan (John, Whitton and Brook, 2002)

24. *Pediastrum simplex* Meyen   (Plate 7a, 7b; Figure 4.44E)

Coenobia entire, composed of 16-32-64 smooth-walled cells; inner cells 5 or 6 side; peripheral cells with the outer free wall extended to form a single tapering, horn-like process with concave margins, chloropast a parietal reticulum, covering the wall with a pyrenoid, cells $25\,\mu m$. diameter, $35\,\mu m$. long and colony $80\,\mu m$. in diameter.

Habitat	:	Lake 1 and 2
		Common in the plankton of number of lakes. (Prescott, 1962)
Distribution	:	USA (Prescott, 1962); Thailand (Hirano, 1975); Sri Lanka (Rott, 1983) Widespread (John, Whitton and Brook, 2002)

25. *Planktonema lauterbornii* Schmidle   (Plate 6a, 6b; Figure 4.43B)

Filament simple, composed of cylindrical cells arranged in a row with equidistant interventing space, inside a gelatinous sheath; cell 2.5-$3\,\mu m$. broad and 9-$15\,\mu m$. long.

Habitat	:	Lake 1 and 2
		Freshwater (Yamagishi and Hirano, 1973)
Distribution	:	USA (Whitford and Schumacher, 1969); Europe, China and Japan (Yamagishi and Hirano, 1973)

26. *Radiococcus planktonicus* J.W.G.Lund (Plate 2a, 2b; Figure 4.39G)

Coenobia of 4-64 cells and cells grouped in tetrads, more rarely the mucilage including fine, radiating fibrils; single-celled or as 2 or 8 cells groups, cells spherical, $2.5\,\mu m$. in diameter.

Habitat	:	Lake 1
		Freshwater (Whitford and Schumacher, 1969)

Distribution   :   USA (Whitford and Schumadcher, 1969; Prescott, 1970); Europe
                     (Huber-Pestalozzi, 1983); Probably cosmopolitan (John, Whitton and
                     Brook, 2002).

27. *Scenedesmus acuminatus* (Lagerh.) Choda. var *acuminatus* (Plate 8a, 8b; Figure 4.45D)

Coenobia composed of 2-4 celled arranged in a single, with cells in one row or very slightly alternating; Cells spindle-shaped. For one type the cells are either straight in the whole colony or the marginal cells are curved; cells 2.5-3 μm broad and 15-18 μm long. Chloroplast with a distinct pyrenoid.

Habitat   :   Lake 1
                Planktonic in freshwater (Prescott, 1962)
Distribution   :   USA (Prescott, 1962); Cosmopolitan (Yamagishi and Hirano, 1973;
                     Huber – Pestalozzi, 1983); Cuba (Kom   rek, 1983); Sri Lanka (Rott,
                     1983); Netherlands (Brink, Katwijk and Velde, 1994)

28. *Seenedesmus armatus* (Chod.) G.M. Smith   (Plate 8a, 8b; Figure 4.45E)

Coenobia composed of 2-8 cells arranged in a single, partially alternating series, oblong-ellipsoid but with ends broadly rounded; with a median, longitudinal ridge; terminal cell with short spine at each pole, cell 5 μm broad and 10 μm long.

Habitat   :   Lake 1
                Planktonic in lake and pond (Prescott, 1962)
Distribution   :   USA (Prescott, 1962); Europe and Japan (Yamagishi and Hirano,
                     1973); South India (Hegewald, Hind   k and Schinepf, 1990)

29. *Scenedesmus opoliensis* P. Richter   (Plate 5a, 5b; Figure 4.42J)

Coenobia composed of 2-4-8 naviculoid cell arranged in a single series, with free walls of outer cells convex, the lateral adjoined walls in contact along 1/3–2/3 of their length; outer cell with a long spine at each pole (inner cells with a spine at one pole only, or sometime without spines); cells 5-7.5 μm broad and 7.5-15 μm long. Chloroplast with pyrenoid.

Habitat   :   Lake 1
                Planktonic in freshwater (Prescott, 1962)

Distribution　　:　　USA (Prescott, 1962; Hirano, 1967); Africa, Europe, Thailand
(Hirano, 1967); Cosmopolitan, Japan (Yamagishi and Hirano, 1973);
Cuba (Kom　rek, 1983); Sri Lanka (Rott, 1983); South India
(Hegewald, Hind　k & Schnepf, 1990)

30. *Spirogyra* sp.　　(Plate 2a, 2b; Figure 4.39D)

　　　　Filament long and unbranched, with long cylinadrical cells, 30 μm. broad and 200 μm.
long, with plane end walls; chloroplast definitely spiralled or ribbon. Identification not possible
from fix sample. Not very frequent species.

Habitat　　　:　　Lake 2
　　　　　　　　In rainy season, freshwater (Prescott, 1962; Whitford and Schumacher,
　　　　　　　　1969)
Distribution　　:　　-

31. *Tetraedron minimum* (A. Braun) Hansgirg　　(Plate 8a, 8b; Figure 4.45F)

　　　　Cells small, flat, tetragonal, the angles rounded, lobate ends and the margin concave;
cell 5-7.5 μm. in diameter. Chloroplast parietal with a central or slightly excentrical pyrenoid;
walls thick and smooth, wrinkled or warty.

Habitat　　　:　　Lake 1 and 2
　　　　　　　　Euplankton of many lakes and ponds (Prescott, 1951)
Distribution　　:　　USA (Prescott, 1962, 1970; Whitford and Schumacher, 1969);
　　　　　　　　Cosmopolitan, Japan (Yamagishi and Hirano, 1973) Bangladesh
　　　　　　　　(Islam, 1973); Central America (Kusel-Fetzmann, 1973); Peru
　　　　　　　　(Hegwald Aldave and Schnepf, 1978); Nigeria (Compere, 1980);
　　　　　　　　Ecuador, (Rott, 1981); Cuba (Kom　rek, 1983); Sri Lanka (Rott, 1983);
　　　　　　　　Austria (Deisinger, 1984); Nicaragua (Ruiz and Pum, 1987); Ethiopia
　　　　　　　　(Kebede and Belay, 1994); Netherlands (Brink, Katwijk and Velde,
　　　　　　　　1994); Thailand (Peerapompisal, 1996); Probably cosmopolitan and in
　　　　　　　　the British Isles (John, Whitton and Brook, 2002)

32. *Tetrastrum staurogeniaeforme* (Schröder) Lemmermann (Plate 4a, 4b; Figure 4.41 H)

A colony of 4 trianglular cells, cruciately arranged about a small rectangular space, lateral margins of the cells straight and adjoined, the outer free walls convex an furnished with as many as 6 fine hair-like setae; chloroplast one, parietal discs at the outer sides of cells, with pyrenoid; cells 2.5-3.75 µm broad, 3.75-5 µm long and colony 7-15 µm in diameter with out setae.

Habitat	:	Lake 1 and 2
		Planktonic in lake (Prescott, 1962)
Distribution	:	USA (Prescott, 1962; Whitford and Schumacher, 1969); Cuba
		(Komárek, 1983)

Zygnemaphyceae

1. *Cosmarium bioculatum* Brébisson ex. Ralfs (Plate 8a, 8b, 12a; Figure. 4.45H and 4.49 E)

Cells small, sinus deep, narrow towards inside, widening outwards, semicells transverse oblong-elliptical with a somewhat flatly rounded base and apex; wall smooth with punctate; cells 7.5-8 µm broad, 10-15 µm long, 2.5-3.75 µm thick.

Habitat	:	Lake 1 and 2
		In moderate acid oligo-mesotrophic water in lakes, pond, pH 5-8.5
		(9); In small nutrient-poor lake (John, Whitton and Brook, 2002)
Distribution	:	Southeast Asia (Hirano, 1967); Thailand (Hirano, 1975); Cosmopolitan
		(Croasdale and Flint, 1988; John, Whitton and Brook, 2002); Europe
		(Lenzenweger, 1999)

2. *Staurodesmus phimus* var. *semulunaris* (Schmidie) Teil (Plate 8a, 8b, 12a; Figure. 4.45I, 4.49F)

Semicells crescent shaped (often lunate); sinus open, acute; typically isthmus rater broad, apex concave; terminal spines divergent and spines of moderate length and end views conspicuously narrow; cells 7.5-10 µm broad, 5-7.5 µm long without process; 17.5-20 µm broad, 15-17.5 long with process, isthmus 6 µm.

Habitat　　　　:　　　Lake 1

　　　　　　　　　　　　Planktonic in lake (Croasdale, Flint and Racine, 1994)

Distribution　　:　　　Europe, Azores, U.S.A (Telling, 1967); Europe (Lenzenweger, 1997).

3. *Staurastrum perundulatum* Gionlel (Plate 12a; Figure 4.49C)

Semicells with a median protuberance, apical margin slightly concave, apical angles produced to form a long nodulated diverging process tipped with four spines; ventral view oblong-elliptic with a protuberance in the middle of each side; cells 5-7.5 μm. broad and 7.5-10 μm. long, without processes, 20-22.5 μm. broad, 225.5-25 long with process.

Habitat　　　　:　　　Lake 1 and 2

　　　　　　　　　　　　Freshwater (Yamagishi and Kanetsuna, 1987)

Distribution　　:　　　Thailand (Yamagishi and Kanetsuna, 1987); Europe (Lenzonweger, 1997).

Xanthophyceae

1. *Isthmochloron gracile* (Reinsch) Hansgirg (Plate 8a, 8b; Figure 4.45G)

Cells solitary, rectangular and the margin concave, the angle projected into narrow, twice furcated processes which are tipped with 3 short spines; cell 10-30 μm. in diameter.

Habitat　　　　:　　　Lake 1

　　　　　　　　　　　　Planktonic in pond (Whitford and Schumacher, 1969)

Distribution　　:　　　USA (Whitford and Schumacher, 1969); China, Europe, India, Japan, North America, (Yamagishi and Hirano, 1973); Thailand (Peerapompisal, 1996)

Euglenophyceae

1. *Euglena charkowiensis* Swir.　　(Plate 10a, 10b; Figure 4.47A)

Cell elongate and slightly twisted, anterior end broadly rounded and posterior end becoming a fairly long tail; chloroplast disc-sphaed; paramylon rod-shaped; cell 12.5-17.5 μm. broad, 110 μm. long without tail and 127.5-137.5 μm. long with tail.

Habitat   :   Lake 1 and 2

Freshwater (Yamagishi and Hirano, 1973)

Distribution   :   Europe (Huber-Pestalozzi, 1955; Hirano, 1967); Malaya (Hirano,

1967); Russia, Japan (Yamagishi and Hirano, 1973); Thailand (Hirano,

1975)

2. *Euglena proxima* Dangeard   (Plate 10a, 10b; Figure 4.47C)

Cell fusiform, narrowed posteriorly to a blunt tip; periplast spirally striated, anterior narrowly rounded; chloroplast numerous, irregularly shaped disc without pyrenoids; paramylon bodies numerous small rods scattered throughout the cell; flagellum about 1.5 times cell length; cells 12.5-22.5 μm. broad, 27-89.50 μm. long without tail and 30-92.5 long with tail.

Habitat   :   Lake 1 and 2

Planktonic in lake (Prescott, 1962); Plankton in moderately polluted

water (John, Whitton and Brook, 2002)

Distribution   :   Europe (Huber-Pestalozzi, 1955); USA (Prescott, 1962; Whitford and

Schumacher, 1969); Thailand (Hirano, 1975); Probably cosmopolitan

(John, Whitton and Brook, 2002)

3. *Euglena minima* France   (Plate 10a, 10b; Figure 4.47F)

Cell fusifrom to somewhat pyriform, produced posteriorly into a short, blunt often curved tip; membrane smooth; flagellum   the length of the cell; chloroplast plate-like with pyrenoid, paramylon bodies many small rods; cells 10 μm. broad and 20 μm. long without tail and 25 μm. long with tail.

Habitat   :   Lake 1

Planktonic in Lake (Prescott, 1962)

Distribution   :   Europe (Huber-Pestalozzi, 1955); USA (Prescott, 1962)

4. *Phacus longicauda* (Ehrenberg) Dujardin   (Plate 10a, 10b; Figure 4.47B)

Cell broadly ovoid to pyriform tapering gradually posteriorly to form a long, straight, sharply pointed caudus and its length equal to the length of a cell body; anteriorly broadly

rounded; periplast longitudinally striated ; flagellum shorter than the cell in length; paramylon-body 2 and variable in size; cells 37.5-45 μm broad and 52.5-73 μm long without tail and 52.5-120 μm long with tail.

Habitat	:	Lake 1
		Euplankton in lake (Prescott, 1962); Plankton in clean to moderately polluted water (John, Whitton and Brook, 2002)
Distribution	:	USA (Prescott, 1962; Whitford and Schumacher 1969); Europe (Huber-Pestalozzi, 1955); Thailand (Hirano, 1975; Peerapompisal, 1996); Nigeria (Compere, 1980); Austria (Deisinger, 1984); Netherlands (Brink, Katwijk and Velde, 1994); Probably cosmopolitan (John, Whitton and Brook, 2002)

5. *Lepocinclis* sp. (Plate 5a, 5b; Figure 4.42 I)

Cell round, oval or fusiform in front veiw, round in end view; fixed in shape when swimming; with a firm and usually spirally striated periplast; paramylum in the form of 2 (or 4) lateral rings folded along the periplast; posteriorly extended into and abruptly pointed tail-piece (rarely gradually tapering); cell 10-12.5 μm broad and 13-20 μm long without tail and 23-30 μm long with tail.

Habitat	:	Lake 1 and 2
		Euplankton in freshwater which is rich in organic acids and nitrogenous substances (Prescott, 1962; John, Whitton and Brook, 2002)
Distribution	:	-

6. *Phacus pyrum* (Ehrenberg) F. Stein (Plate 10a, 10b; Figure 4.47 D)

Cell ovoid, narrowed gradually posteriorly to long straight, finely pointed caudus; broadly rounded anteriorly, but with 2 papillae between which the flagellum emerges; pellicle faintly spirally ribbed; paramylon bodies 2 ring-like plates, laterally situated; chloroplasts small, numerous, disc-shaped; cells 6-12.5 μm broad and 17.50-25 μm long without tail and 24-32.5 μm long with tail.

Habitat	:	Lake 1
		Euplankton in freshwater (Prescott, 1962); Plankton in clean to moderately polluted water (John, Whitton and Brook, 2002)
Distribution	:	USA (Prescott, 1962); Europe (Huber-Pestalozzi, 1955); Probably cosmopolitan (John, Whitton and Brook, 2002)

7. *Phacus ranula* Pochmann (Ehrenberg) Dujardin (Plate 10a, 10b; Figure 4.47E)

Cell long elliptic, posterior projected into a long robust and sharp tail; broadly rounded anteriorly, but with 2 papillae between which the flagellum emerges; periplast longitudinally striated; chloroplast numerous ring like–plate; flagellum equal the cell in length; cells 30-40 μm. broad, 50-65 μm. long without tail and 71-86 μm. long with tail.

Habitat	:	Lake 1
		Freshwater (Hirano, 1967)
Distribution	:	Europe (Huber-Pestalozzi, 1955; Java and Indo-China (Hirano, 1967); Thailand (Hirano, 1967, 1975)

8. *Trachelomonas bernardinensis* W. Vischer   (Plate 11a, 11b; Figure 4.48C)

Corica ellipsoid and narrowed posteriorly into a short conical projection; collar cylindric and circled with a spiny margin ; wall densely punctate; lorica 5-12.5 μm. broad and 25-28 μm. long.

Habitat	:	Lake 1 and 2
		Freshwater (Yamagishi and Hirano, 1973)
Distribution	:	Europe (Huber-Pestalozzi, 1955); Japan (Yamagishi and Hirano, 1973)

9. *Trachelomonas curta* Da Cunha   (Plate 9a, 9b; Figure 4.46A)

Lorica compressed globose, broad longer than length in lateral view;   apical pore surrounded by a ring-like thickening : wall smooth; lorica 13 μm. broad and 11 μm. long.

Habitat	:	Lake 1
		Occurs in swamps, lakes and village pond; indicator of moderately polluted water (John, Whitton and Brook, 2002)

Distribution : Europe, Venezuela, Australia (Huber-Pestalozzi, 1955); Japan (Yamagishi and Hirano, 1973); Probably cosmopolitan (John, Whitton and Brook, 2002)

10. *Trachelomonas dubia* (Swir.) Deflandre   (Plate 11a, 11b; Figure 4.48G)
Lorica ellipsoid, broadly rounded posteriorly, truncate at the anteriar end and abruptly narrowed to from a short cylindrical neck; wall smooth, thickned at the base of the collar; lorica 10 μm. broad and 25 μm. long.

Habitat : Lake 1
Euplanktonic in Freshwater (Prescott, 1962)

Distribution : USA (Prescott, 1962); Europe (Huber-Pestalozzi, 1955; Japan and Java (Yamagishi and Hirano, 1973); Thailand (Peerapornpisal, 1996); Probably cosmopolitan (John, Whitton and Brook, 2002)

11. *Trachelomonas dybowskii* Drezepolski   (Plate 9a, 9b; Figure 4.46D)
Lorica ellipsoid, with short collar; wall smooth; lorica 12.5-15 μm. broad and 16-17.5 μm. long.

Habitat : Lake 1 and 2
Freshwater (Huber-Pestalozzi, 1955)

Distribution : Europe, Australia (Huber-Pestalozzi, 1955)

12. *Trachelomonas hispida* (Perty) Stein   (Plate 11a, 11b; Figure 4.48B)
Lorica ellipsoidal, ends more or less rounded or narrowed anteriorly;   reddish brown; with denticulations on both ends, other part of body densely punctate; lorica 11-18.75 μm. broad and 20-25 μm. long.

Habitat : Lake 1
Freshwater (Prescott, 1962); Plankton in swamps, pond ditches; indicator of clean to moderately polluted water (John, Whitton and Brook, 2002)

Distribution : USA (Prescott, 1951; Whitford and Schumacher, 1969); Europe (Huber-Pestalozzi, 1955); Thailand (Hirano, 1975; Peerapompisal, 1996); Bangladesh (Islam and Muniruzzaman, 1981); Sri Lanka (Rott, 1983); Austria (Deisinger, 1984); Probably cosmopolitan (John, Whitton and Brook, 2002)

13. *Trachelomonas intermedia* Dangeard   (Plate 9a, 9b; Figure 4.46E)

Lorica globose to ovoid; surrounded by a ring like thickening; without a collar; wall brown punctate; lorica 20-22.5 μm. and 22.5-35 μm. long.

Habitat : Lake 1 and 2
Freshwater (Prescott, 1962); Plankton in lakes ponds and ditches (John, Whitton and Brook, 2002)

Distribution : USA (Prescott, 1962); Europe (Huber-Pestalozzi, 1955); North Tchad (Compere, 1970 quoted in Peerapompisal, 1996); Congo, Venezuela, Manchuria, Burma and Japan (Yamagishi and Hirano, 1973); Thailand (Peerapompisal, 1996); Widespread (John, Whitton, Brook, 2002)

14. *Trachelomonas minima* Drez.   (Plate 11a, 11b; Figure 4.48E)

Lorica ovate; with short collar; wall brown punctate and roughed thickening; lorica 10-12 μm. in diameter.

Habitat : Lake 1
Distribution : Europe (Huber-Pestalozzi, 1955)

15. *Trachelomonas mucosa* Swirenko (Plate 11a, 11b; Figure 4.48F)

Lorica ovoid, with distinct collar; wall reddish-brown smooth and thickened at the margin of lorica; lorica 12.5-17.5 μm. broad and 17.5-27.5 μm. long.

Habitat : Lake 1 and 2
Distribution : Europe (Huber-Pestalozzi, 1955); Thailand (Chorum, 1998)

16. *Trachelomonas oblonga* Lemmermann   (Plate 11a, 11b; Figure 4.48D)

Lorica ellipsoidal, wall yellow–brown to reddish-brown, smooth, broadly rounded both posteriorly and anteriorly; with or without a ring like thickening; flagellum about twice lorica length; lorica 12.5-15 μm. broad and 20-22.5 μm. long.

Habitat   :   Lake 1 and 2

Planktonic in field ponds, puddles and ditches, indicator of clean to moderately polluted water (John, Whitton and Brook, 2002)

Distribution   :   Europe (Huber-Pestalozzi, 1955); France, Australia, Argentina and Japan (Yamagishi and Hirano, 1973); Wide spread (John, Whitton and Brook, 2002)

17. *Trachelomonas similis* Stokes   (Plate 11a, 11b; Figure 4.48A)

Lorica ovoid or oblong-ellipsoid; flagellum aperture in a curved collar; wall with scattered punctate; chloroplasts numerous in each cell; lorica 15 μm. broad and 25 μm. long.

Habitat   :   Lake 1

Freshwater (Prescott, 1962); In ponds lakes, brackish-water; indicator of clean to moderately polluted water (John, Whitton and Brook, 2002)

Distribution   :   USA (Prescott, 1962); Europe (Huber-Pestalozzi, 1955); Thailand (Wannasai, 1999); Probably cosmopolitant (John, Whitton and Brook, 2002)

18. *Trachelomonas volvocina* Ehrenberg   (Plate 9a, 9b; Figure 4.46B)

Lorica globose, flagellum aperture without a collar; wall yellowish or reddish-brown, sometimes colourless, smooth; chloroplast many ovoid discs; pigment-spot usually evident in the lower apical end; test 7.5-15 μm. in diameter.

Habitat   :   Lake 1 and 2

Generally distributed; common in ponds and ditches (Prescott, 1962); In lakes, ponds and peat bogs; indicator of middly or neavily polluted water (John, Whitton and Brook, 2002)

Distribution : USA (Smith, 1950; Prescott, 1951; Whitford and Schumacher, 1969); Europe (Huber-Pestalozzi, 1955); Cosmopolitan (Hirano, 1967; John, Whitton and Brook, 2002) Japan (Yamagishi and Hirano, 1973); Nigeria (Compere, 1980); Ecuador (Rott, 1981); Banglagesh (Islam and Muniruzzaman, 1981); Sri Lanka (Rott, 1983); Austria (Deisinger, 1984); Venezuela (Vilarrubia, 1995); Russia (Gontcharow, 1996); Thailand (Peerapompisal, 1996)

19. *Trachelomonas volvocinopsis* Swirenko   (Plate 9a, 9b; Figure 4.46C)

Lorica globose; wall yellow to green smooth; apical pore with a ring-like thickening; Chloroplast plate shaped, without pyrenoids; lorica 8-20 μm. in diameter.

Habitat : Lake 1 and 2

In lake, ponds; indicator of midly to mode rately water polluted (John, Whitton and Brook, 2002)

Distribution : Europe (Huber-Pestalozzi, 1955); North Tchad (Compere, 1970); quoted in Peerapompisal, 1996) Netherlands (Brink, Katwijk and Velde, 1994); Thailand (Peerapompisal, 1996). Widespeed (John, Whitton and Brook, 2002)

20. *Strombomonas fluviatilis* (Lemm.) Deflandre (Plate 11a, 11b; Figure 4.48 I)

Lorica long ovoid to fusiform; posteriorly into tapering, short, acute caudus; wall brown sometime colorless, rough, lolica with neck which is containous with body ; lorica 17.5-20 μm. broad and 32.5 μm. long.

Habitat : Lake 1 and 2

Distribution : Europe (Huber-Pestalozzi, 1955); Thailand (Hirano, 1967)

21. *Strombomonas verrucosa* var *borystheniensis* (Roll) Deflandre (Plate 11a, 11b; Figure 4.48H)

Lorica broadly ovoid; posteriorly broadly rounded wall brown rough; lorica 22.5 μm. broad and 32.5 μm. long.

Habitat   :   Lake 1

Distribution   :   Europe (Huber-Pestalozzi, 1955)

4.4.4.4 Dominant species

Cylindrospermopsis raciborskii was found to be the dominant species and was the highest phytoplankton biovolume throughout the investigation. This phytoplankton is one type of filamentous blue green algae, cosmopolitan in tropical zones and the summer in temperate (Rott, 1987). Peerapompisal (1996) reported that the genus *Cylindrospermopsis* is known to be commonly distributed throughout all the tropical countries. The very common *C. raciborskii* has a pantropical distribution, but occasionally occurs in the summer season in warmer temperate areas. The less common *C. phillippinensis* is known from several localities in very distant tropical regions (Kom̆rek and Kling, 1991). This investigation of both lakes found that nutrients such as nitrogen and phosphorus were low throughout the investigation. Assessment of the water quality indicated that both lakes were oligotrophic.

However, in the first lake, the amount of total phosphorus was 0.02 mg.l^{-1} in June and in August 2000. In the second lake, the amount of total phosphorus was 0.03 mg.l^{-1} in December 2000 and it was 0.02 mg.l^{-1} in January 2001. Assessment of the water quality indicated that it was mesotrophic according to the classifications of Lampert and Sommer, 1993 quoted in Peerapompisal, 1996 (Table 5, Appendix II).

Furthermore, this investigation found that both lakes consisted of high water hardness. The dominant species of phytoplankton of both lakes was *Cylindrospermopsis raciborskii* throughout the investigation. This phytoplankton can adapt and survive in low nutrient conditions. There are many survival reasons :

(1) *Cylindrospermopsis raciborskii* can adapt because it regulates its position in the water column varying its depths. It has gas vacuoles which help its buoyancy in water starved cell. Carbohydrate is produced during the day in photosynthesis hence an increase in weight. This results in it sinking and after consuming all the carbohydrate overnight it floats to the surface in the morning (Horne and Goldman, 1994).

(2) *C. raciborskii* is able to fix nitrogen from the air and convert it into nitrate, nitrogen fixation by a heterocyst formation also protects it from the occasional depletion of this
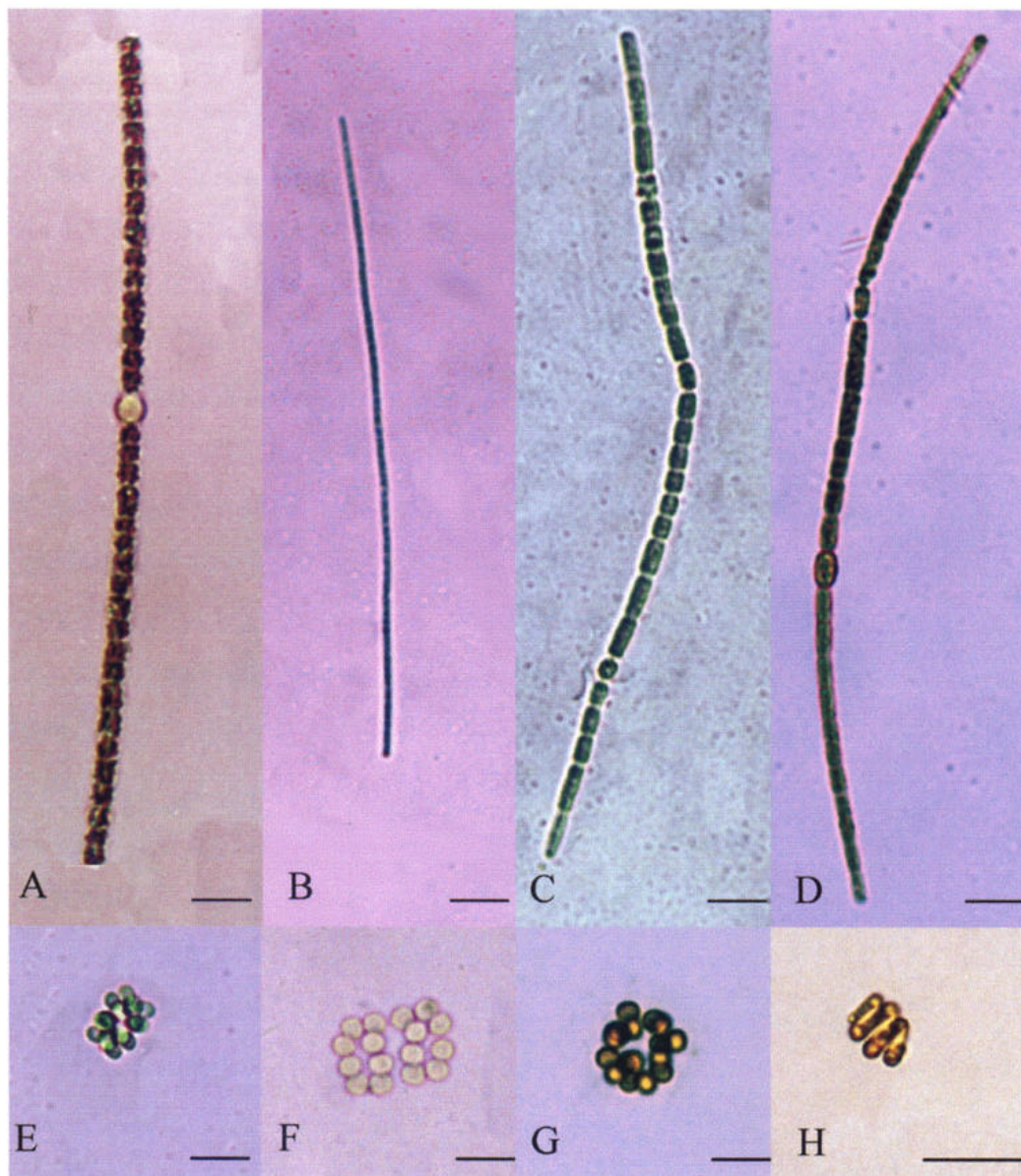
Plate 1a

Figure 4.38a Micrograph of phytoplankton found in Rama IX lake

(A-H) Cyanophyceae: (A) *Anabaena* sp., (B) *Planktolyngbya limnetica* Lemmermann, (C) *Anabaena aphanizomenoides* Forti, (D) *Aphanizomenon* sp., (E) *Coelomoron pusillum* (Van Goor) Komárek, (F) *Gomphosphaeria natans* Komárek et Hindák, (G) *Aphanocapsa nubilum* Komárek et Kling, (H) *Planktolyngbya* sp.

Scale bar = 10 μm
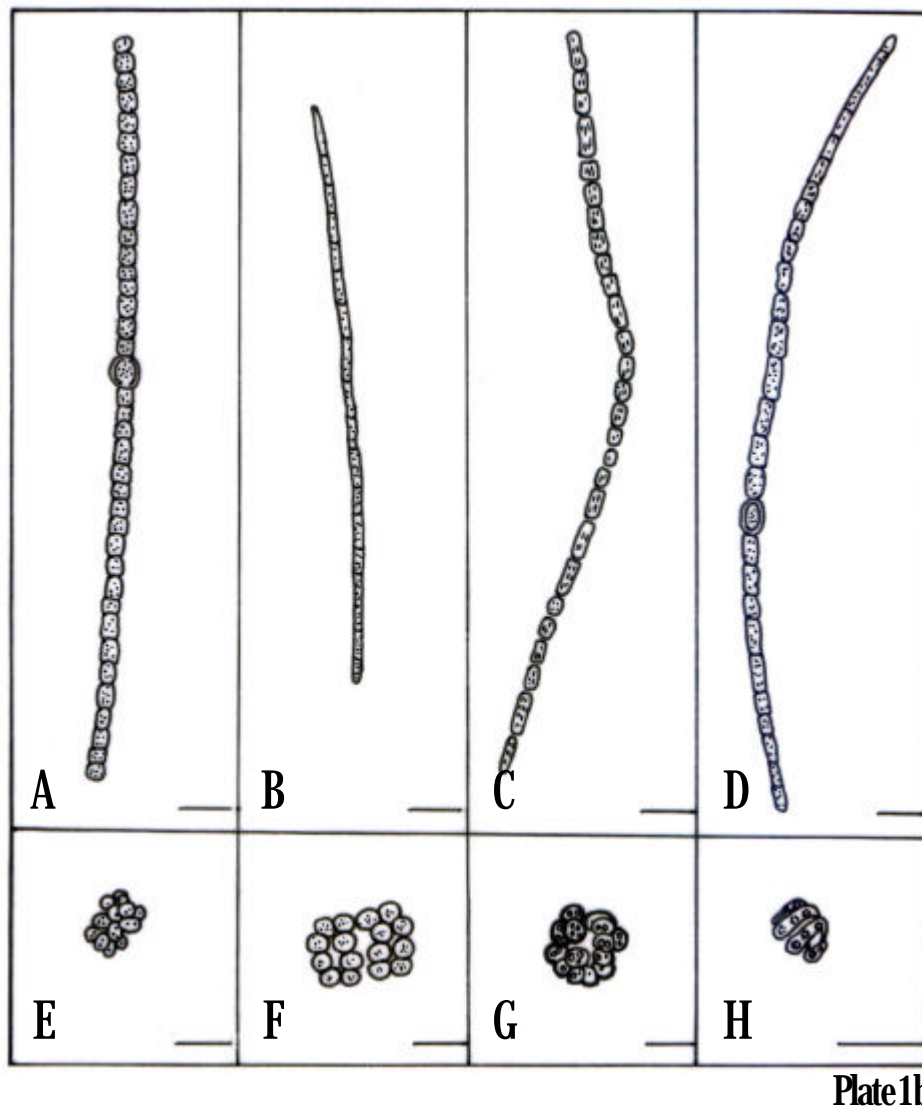
Plate 1b

Figure 4.38b   Illustration of phytoplankton found in Rama IX lake
(A-H) Cyanophyceae: (A) *Anabaena* sp., (B) *Planktolyngbya limnetica*
Lemmermann, (C) *Anabaena aphanizomenoides* Forti, (D) *Aphanizomenon* sp.,
(E) *Coelomoron pusillum* (Van Goor) Komárek, (F) *Gomphosphaeria natans*
Komárek et Hindák, (G) *Aphanocapsa nubilum* Komárek et Kling, (H)
Planktolyngbya sp.
Scale bar = 10 m
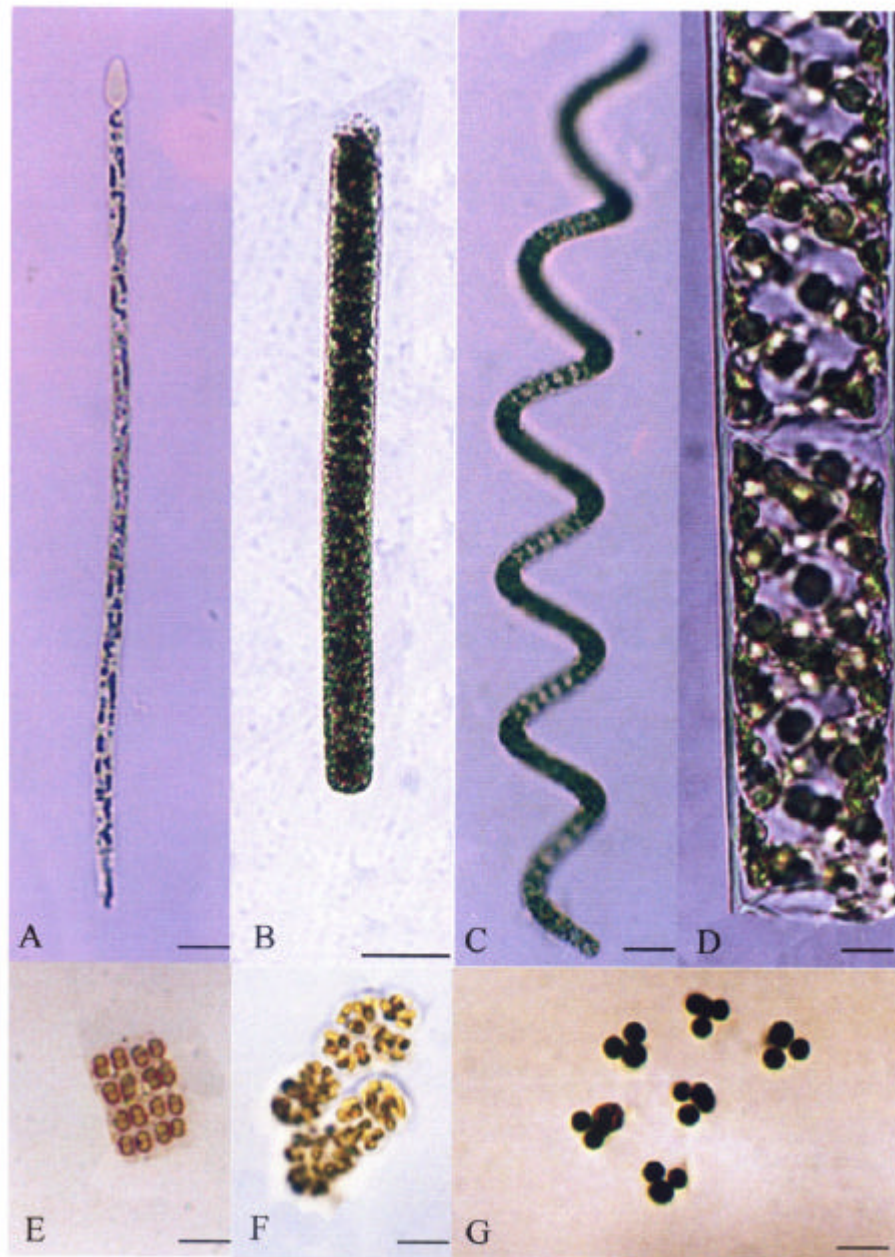
Plate 2a

Figure 4.39a **Micrograph of phytoplankton found in Rama IX lake**
(A-B) Cyanophyceae: (A) *Cylindrospermopsis raciborskii* (Wolosz.) Seenayya & Subba, (B) *Oscillatoria limosa* Ag. ex. Gomont, (C) *Spirulina platensis* (Nords) Geitler, (D) Chlorophyceae: *Spirogyra* sp., (E-F) Cyanophyceae: (E) *Merismopedia punctata* Meyen, (F) *Aphanothece nidulans* Richter, (G) Chlorophyceae: *Radiococcus planktonicus* J.W.G. Lund
Scale bar = 10 m
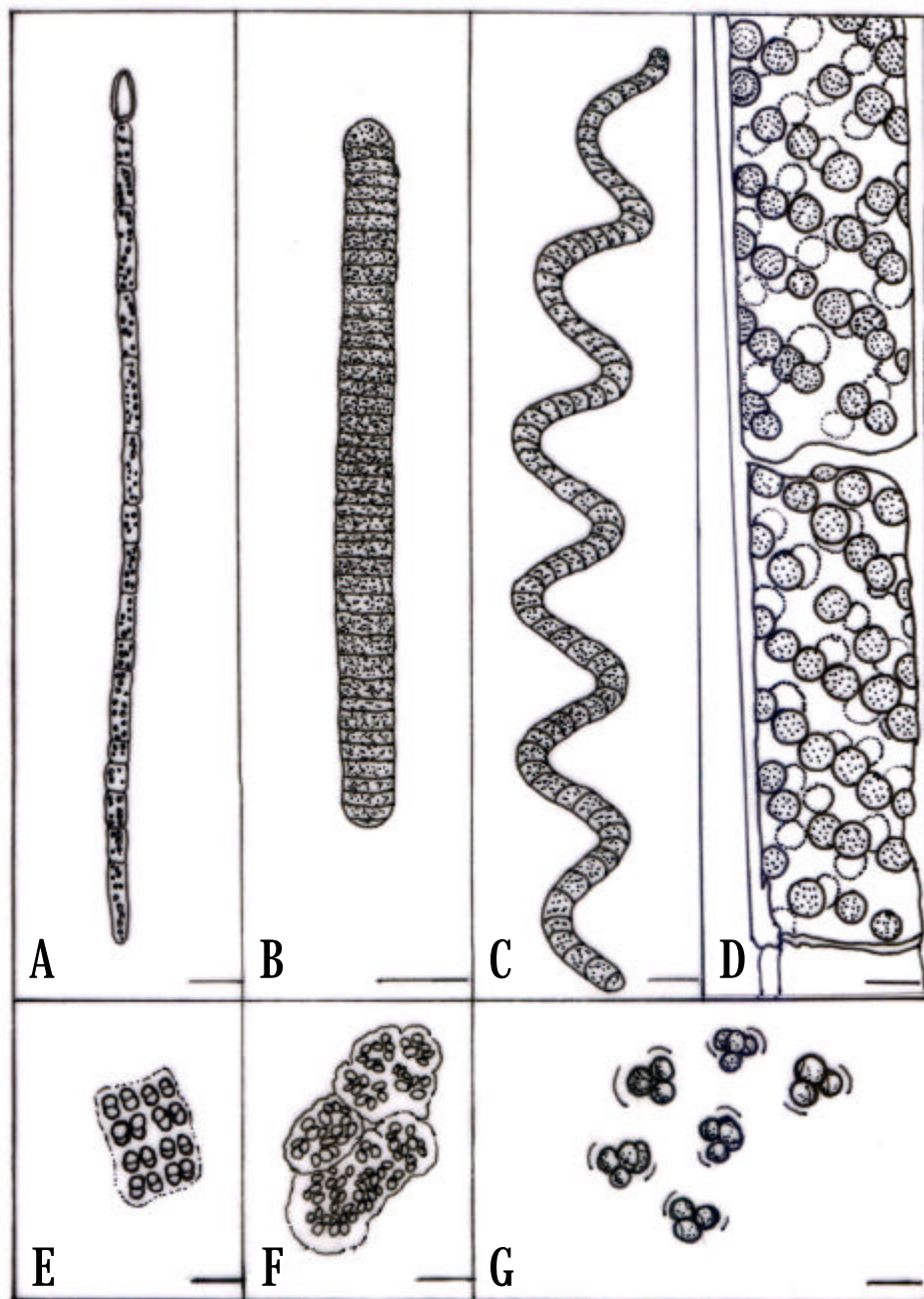
Plate 2b

Figure 4.39b Illustration of phytoplankton found in Rama IX lake

(A-B) Cyanophyceae: (A) *Cylindrospermopsis raciborskii* (Wolosz.) Seenayya & Subba, (B) *Oscillatoria limosa* Ag. ex. Gomont, (C) *Spirulina platensis* (Nords) Geitler, (D) Chlorophyceae: *Spirogyra* sp., (E-F) Cyanophyceae: (E) *Merismopedia punctata* Meyen, (F) *Aphanothece nidulans* Richter, (G) Chlorophyceae: *Radiococcus planktonicus* J.W.G. Lund

Scale bar = 10 m
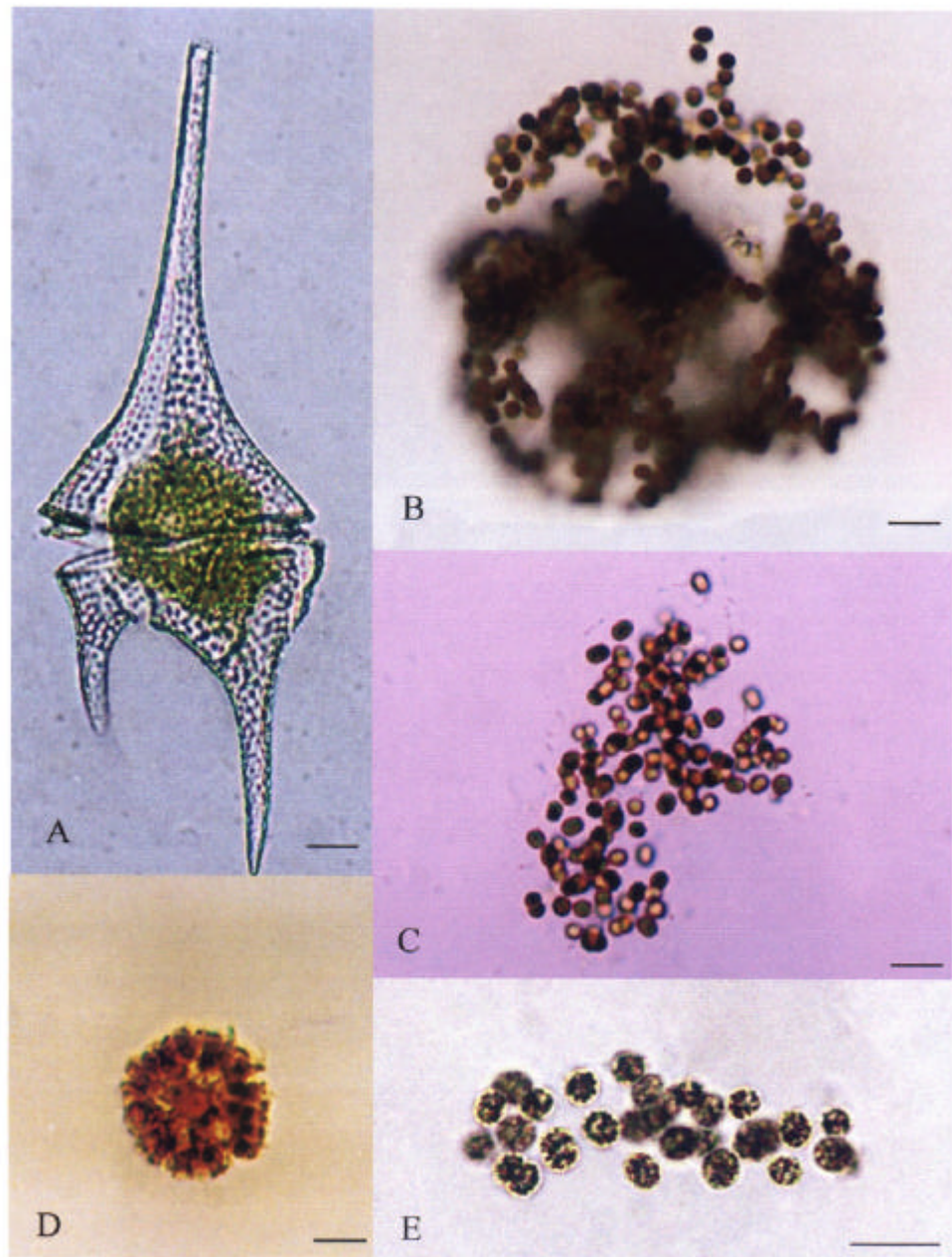
Plate 3a

Figure 4.40a Micrograph of phytoplankton found in Rama IX lake

(A) Dinophyceae: *Ceratium furcoides* (Levander) Langhans, (B-C) Cyanophyceae: (B) *Aphanocapsa elachista* W. et. G.S. West, (C) *Aphanothece smithii* Komárková-Legnerová et Cronberg, (D) Chrysophyceae: *Uroglenopsis americana* (Calkins) Lemmermann, (E) Cyanophyceae: *Microcystis aeruginosa* Kützing

Scale bar = 10 µm
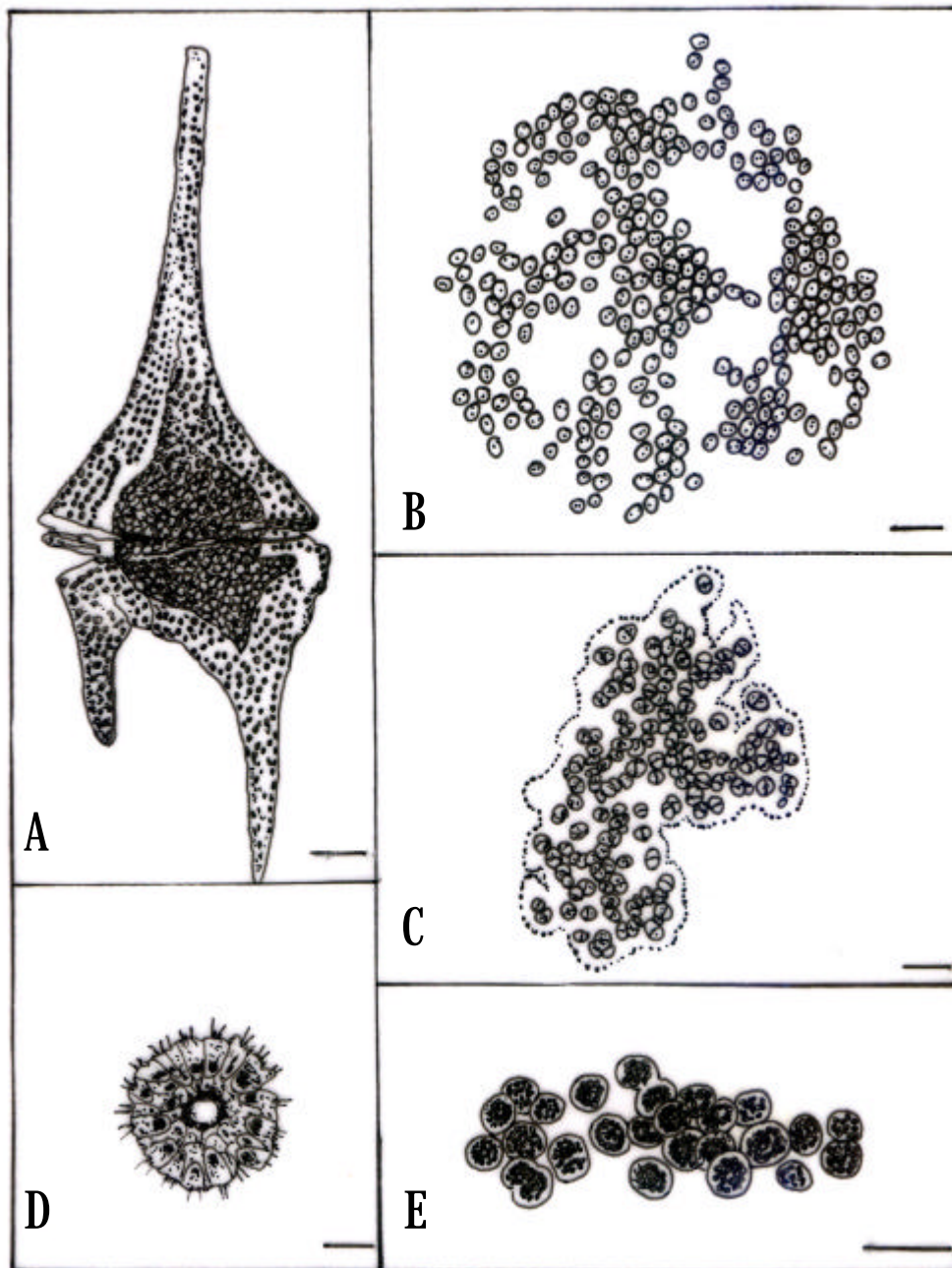
Figure 4.40b Illustration of phytoplankton found in Rama IX lake

(A) Dinophyceae: *Ceratium furcoides* (Levander) Langhans, (B-C) Cyanophyceae: (B) *Aphanocapsa elachista* W. et. G.S. West, (C) *Aphanothece smithii* Komárková-Legnerová et Cronberg, (D) Chrysophyceae: *Uroglenopsis americana* (Calkins) Lemmermann, (E) Cyanophyceae: *Microcystis aeruginosa* Kützing

Scale bar = 10 μm
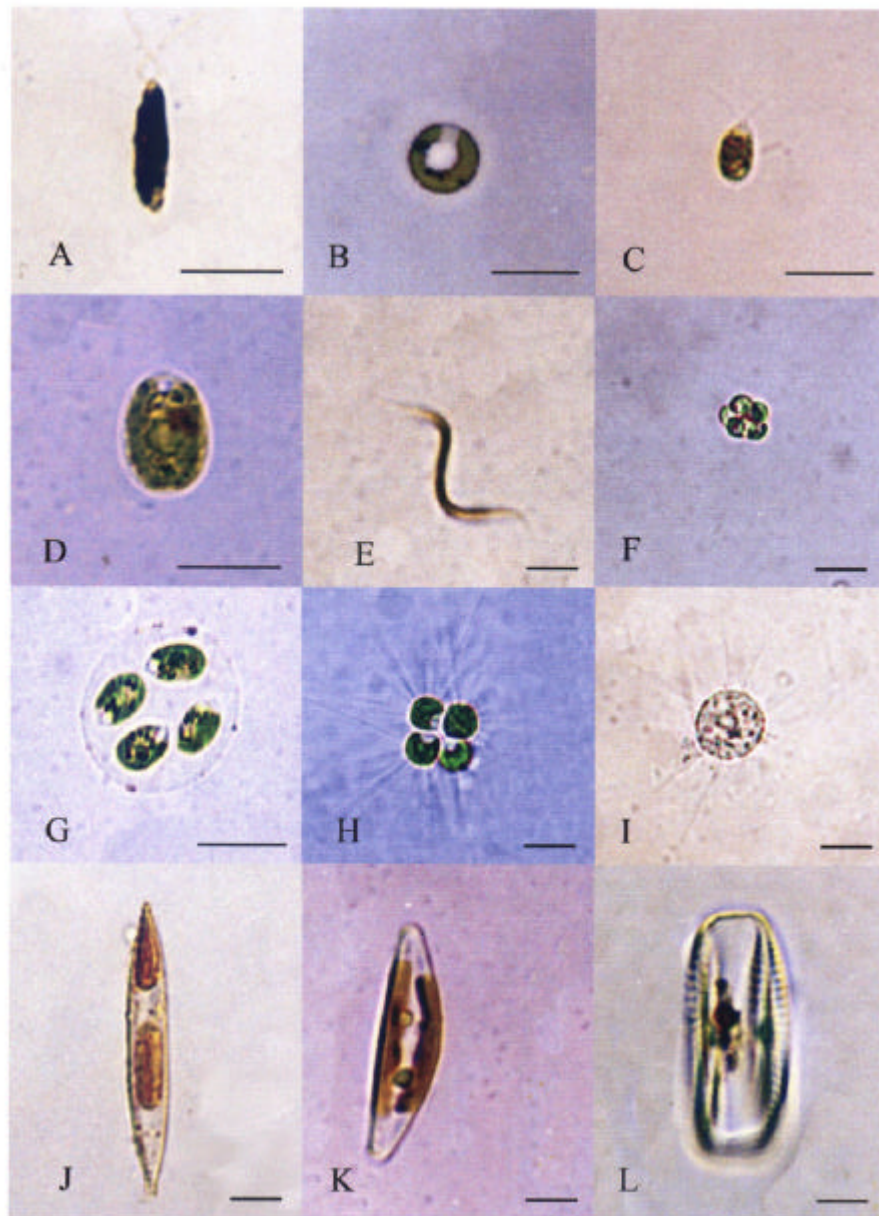
Plate 4a

Figure 4.41a **Micrograph of phytoplankton found in Rama IX lake**

(A-I) **Chlorophyceae:** (A) *Chlorogonium* **sp.,** (B) *Chlorella vulgaris* **Beijerinck,** (C) *Chlamydomonas* **sp.1,** (D) *Chlamydomonas* **sp.2,** (E) *Monoraphidium contortum* **(Thuret) Kom rkov -Legnerov ,** (F) *Coelastrum microporum* **Naegeli,** (G) *Oocystis* **sp.,** (H) *Tetrastrum staurogeniaeforme* **(Schr der) Lemmermann,** (I) *Acanthosphaera* **sp., (J-L) Diatophyceae:** (J) *Nitzschia* **sp.,** (K) *Cymbella* **sp.,** (L) *Amphora* **sp.**

Scale bar = 10 **m**
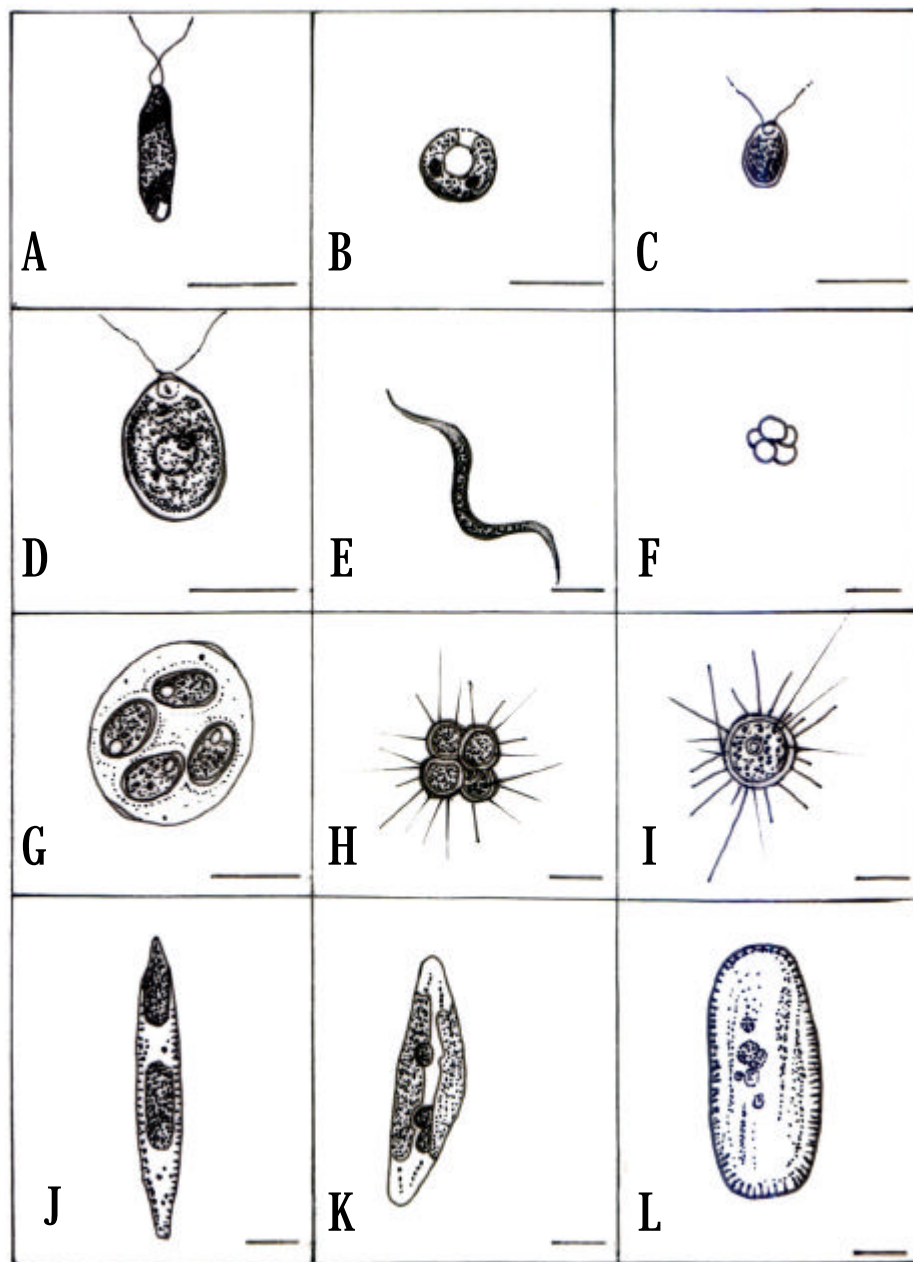
Plate 4b

Figure 4.41 b Illustration of phytoplankton found in Rama IX lake

(A-I) **Chlorophyceae: (A)** *Chlorogonium* **sp., (B)** *Chlorella vulgaris* **Beijerinck, (C)** *Chlamydomonas* **sp.1, (D)** *Chlamydomonas* **sp.2, (E)** *Monoraphidium contortum* **(Thuret) Kom rkov -Legnerov , (F)** *Coelastrum microporum* **Naegeli, (G)** *Oocystis* **sp., (H)** *Tetrastrum staurogeniaeforme* **(Schr der) Lemmermann, (I)** *Acanthosphaera* **sp., (J-L) Diatophyceae: (J)** *Nitzschia* **sp., (K)** *Cymbella* **sp., (L)** *Amphora* **sp.**

Scale bar = 10 m
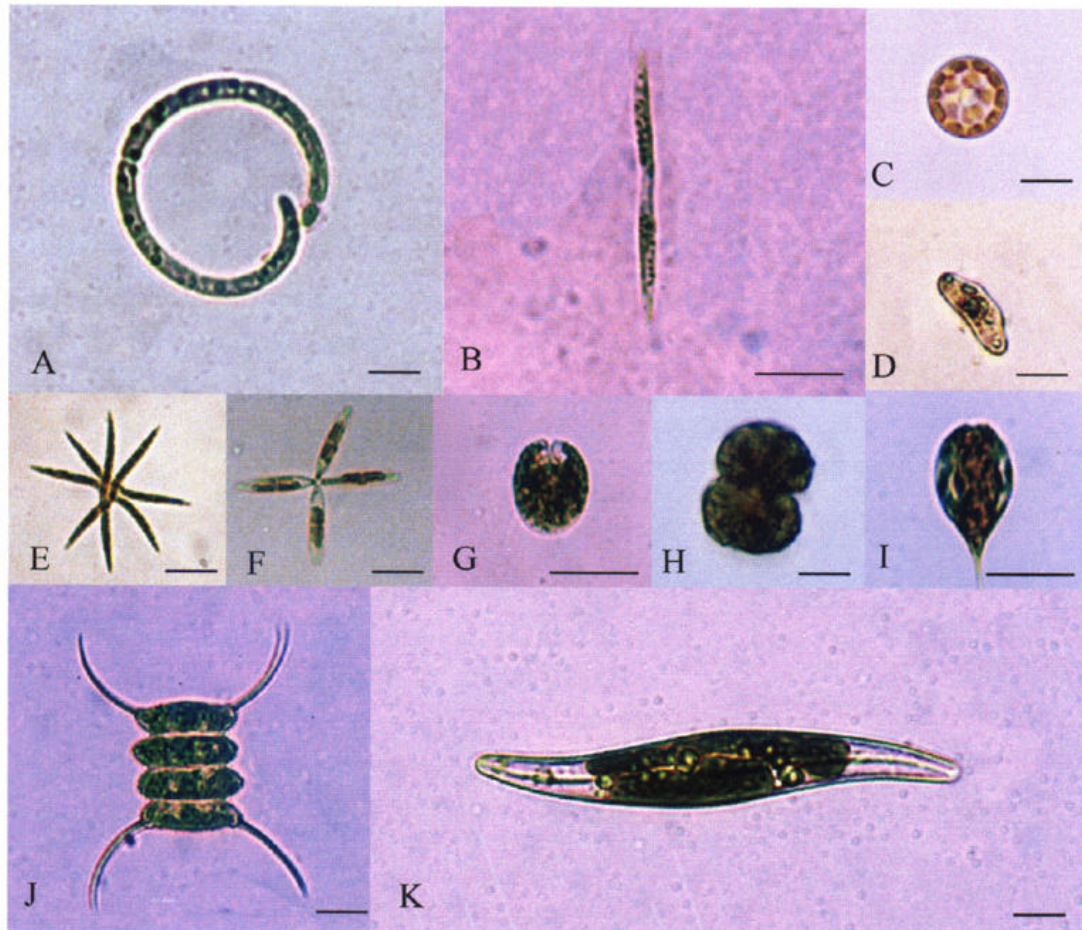
Plate 5a

Figure 4.42a Micrograph of phytoplankton found in Rama IX lake

(A) Cyanophyceae: *Cylindrospermopsis philippinensis* (Taylor) Ka., (B) Chlorophyceae: *Monoraphidium griffithii* (Berkeley) Kom rkov Legnerov , (C-D) Diatomophyceae: (C) *Cyclotella* sp., (D) *Eunotia* sp., (E-H) Chlorophyceae: (E) *Ankistrodesmus falcatus* (Corda) Ralfs, (F) *Actinastrum gracillimum* G.M. Smith, (G) *Cateria* sp., (H) *Botryococcus braunii* K tzing, (I) Euglenophyceae: *Lepocinclis* sp, (J) Chlorophyceae: *Scenedesmus opoliensis* P. Richter, (K) Diatomophyceae: *Gyrosigma* sp.

Scale bar = 10 m
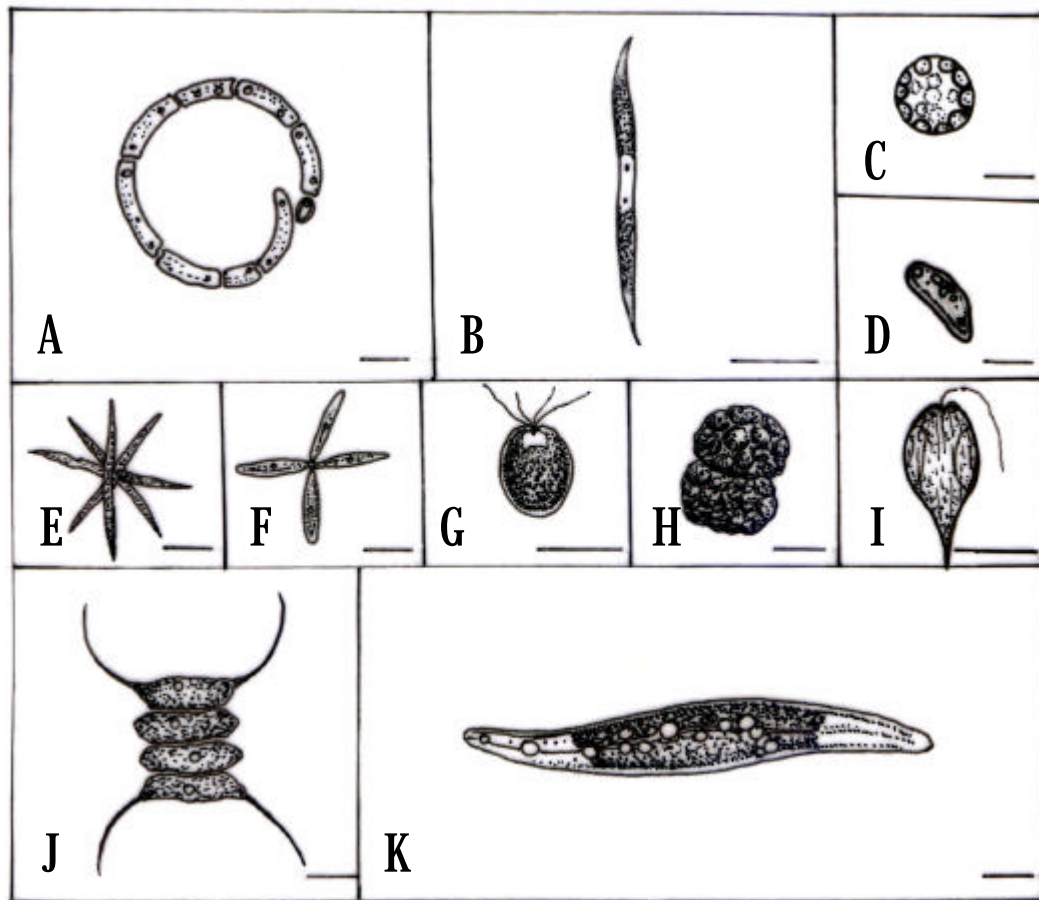
Plate 5b

Figure 4.42b Illustration of phytoplankton found in Rama IX lake

(A) Cyanophyceae: *Cylindrospermopsis philippinensis* (Taylor) Ka., (B) Chlorophyceae: *Monoraphidium griffithii* (Berkeley) Kom rkov Legnerov , (C-D) Diatomophyceae: (C) *Cyclotella* sp., (D) *Eunotia* sp., (E-H) Chlorophyceae: (E) *Ankistrodesmus falcatus* (Corda) Ralfs, (F) *Actinastrum gracillimum* G.M. Smith, (G) *Cateria* sp., (H) *Botryococcus braunii* K tzing, (I) Euglenophyceae: *Lepocinclis* sp, (J) Chlorophyceae: *Scenedesmus opoliensis* P. Richter, (K) Diatomophyceae: *Gyrosigma* sp.

Scale bar = 10 m
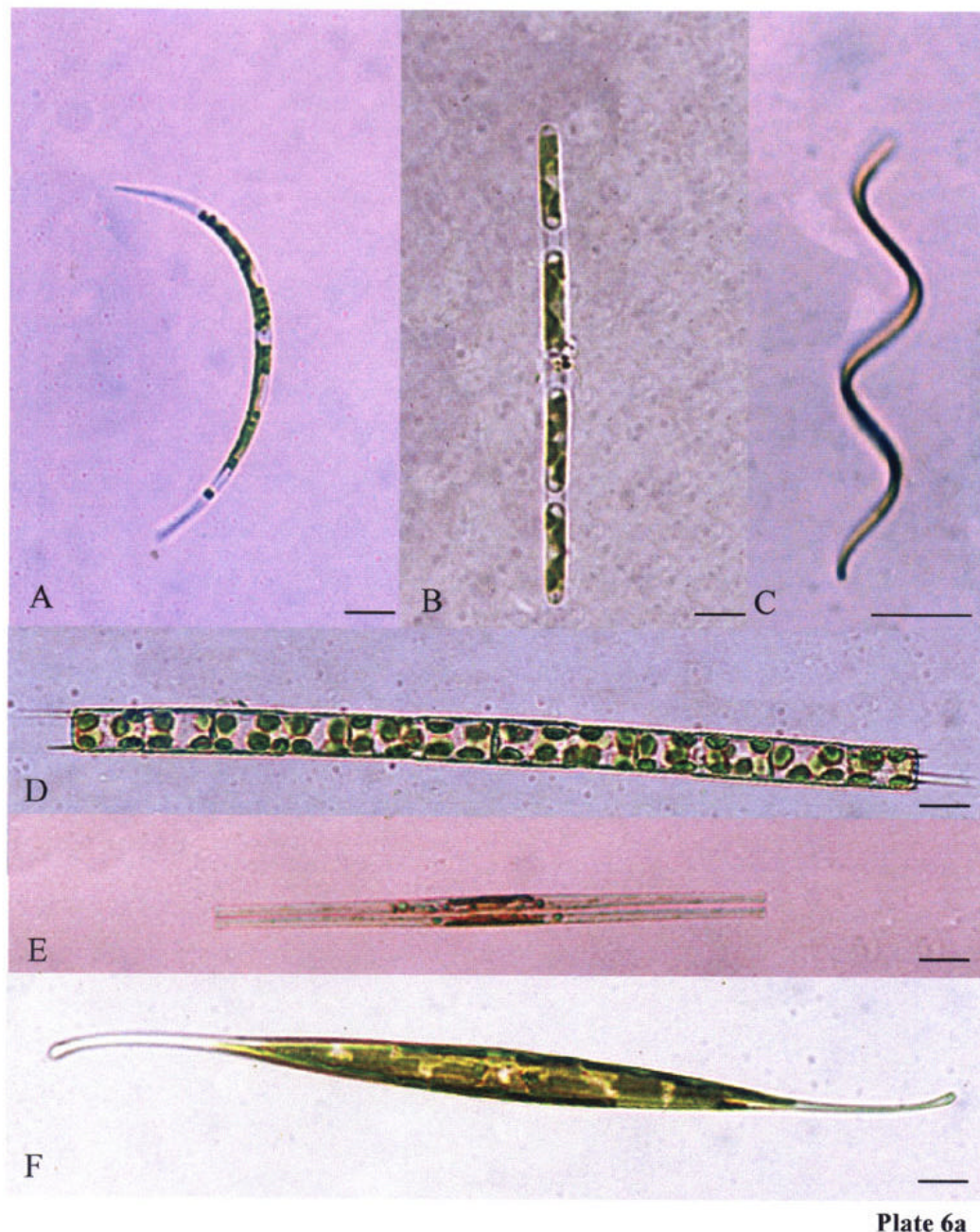
Plate 6a

Figure 4.43a Micrograph of phytoplankton found in Rama IX lake

(A-C) Chlorophyceae: (A) *Monoraphidium arcuatum* (Korschikov) Hindàk
(B) *Planktonema lauterbornii* Schmidle, (C) *M. irregulare* (G.M. Smith)
Komàrkovà-Legnerovà, (D-F) Diatomophyceae: (D) *Aulacoseira granulata*
(Ehrenberg) Ralfs, (E) *Fragilaria ulna* var. *acus* (Kützing) Lange-Bertalot,
(F) *Gyrosigma macrum* (W. Smith) Griffith Henfrey
Scale bar = 10 µm
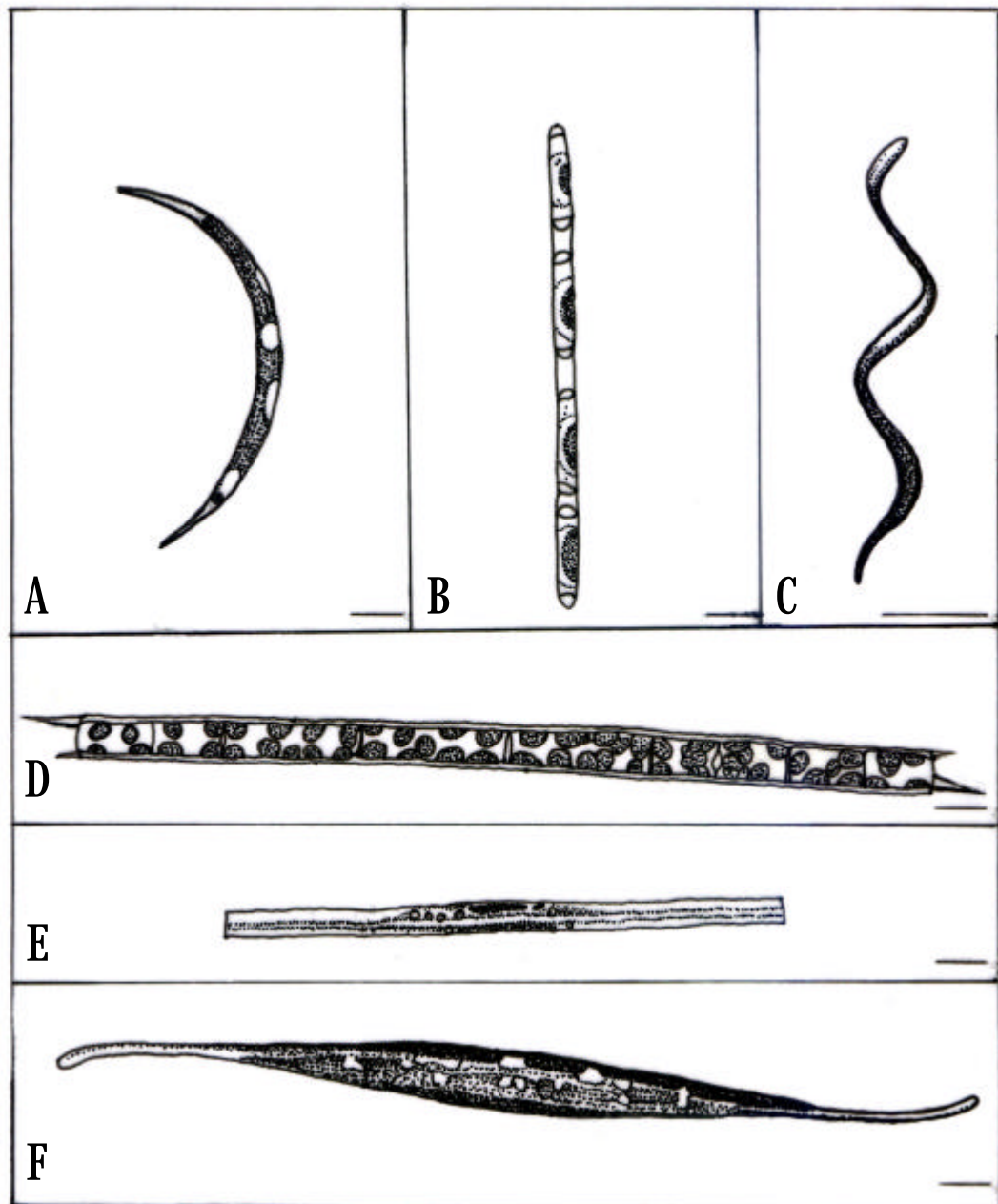
Plate 6b

Figure 4.43b Illustration of phytoplankton found in Rama IX lake

(A-C) Chlorophyceae: (A) *Monoraphidium arcuatum* (Korschikov) Hindàk

(B) *Planktonema lauterbornii* Schmidle, (C) *M. irregulare* (G.M. Smith)

Komàrkovà-Legnerovà, (D-F) Diatomophyceae: (D) *Aulacoseira granulata*

(Ehrenberg) Ralfs, (E) *Fragilaria ulna* var. *acus* (Kützing) Lange-Bertalot,

(F) *Gyrosigma macrum* (W. Smith) Griffith Henfrey

Scale bar = 10 µm
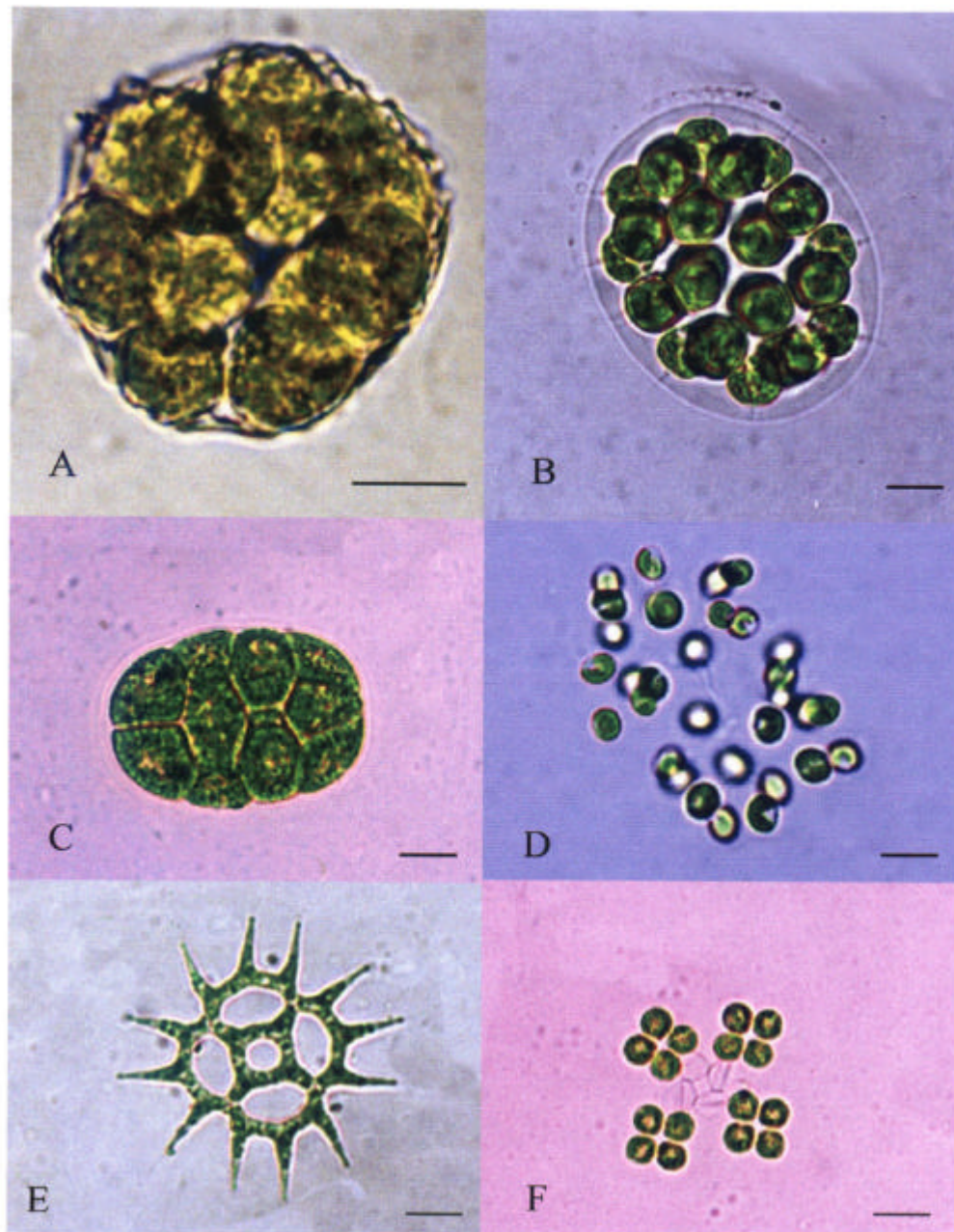
Plate 7a

Figure 4.44a Micrograph of phytoplankton found in Rama IX lake

(A-F) **Chlorophyceae:** (A) *Coelastrum sphaericum* Naegeli, (B) *Eudorina elegans* Ehrenberg, (C) *Pandorina morum* (O. F. Müller) Bory, (D) *Dictyosphaerium tetrachotonum* Printz, (E) *Pediastrum simplex* Meyen, (F) *D. pulchellum* Wood

Scale bar = 10 µm
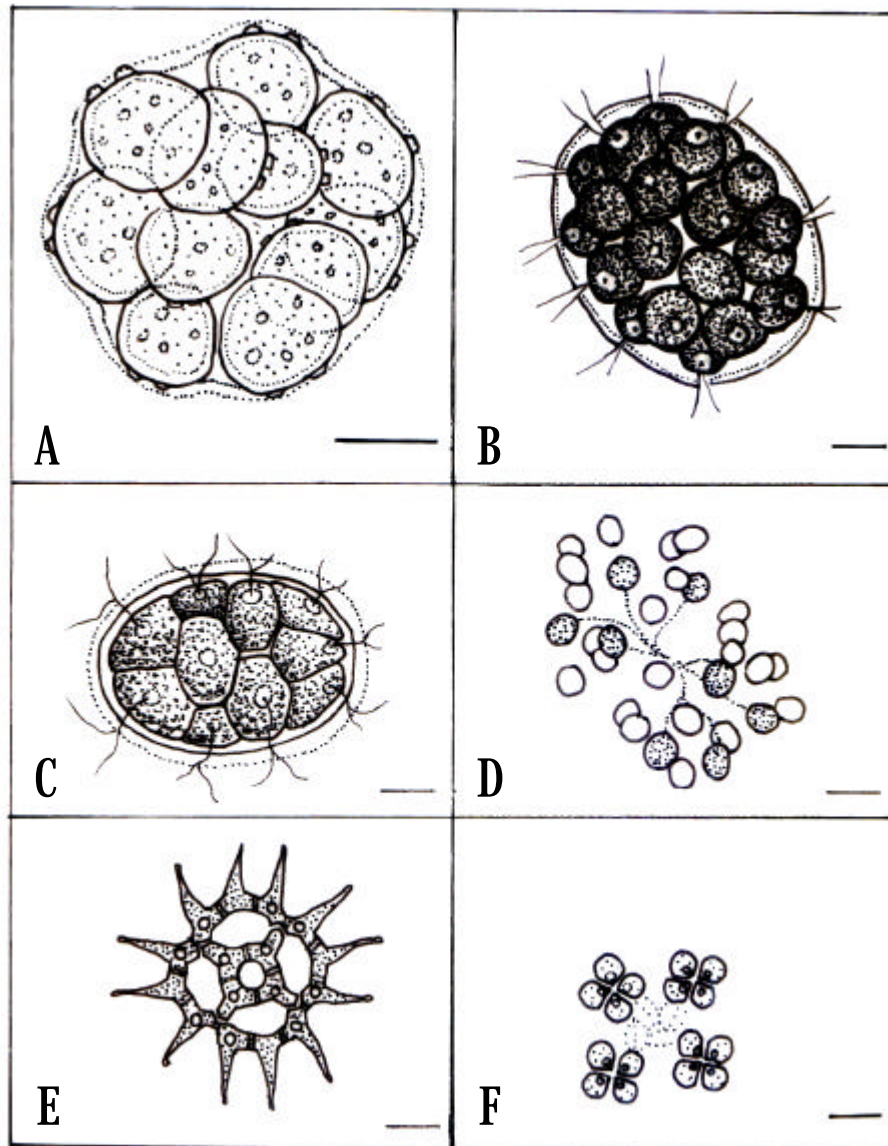
Plate 7b

Figure 4.44b Illustration of phytoplankton found in Rama IX lake

(A-F) **Chlorophyceae:** (A) *Coelastrum sphaericum* Naegeli, (B) *Eudorina elegans* Ehrenberg, (C) *Pandorina morum* (O. F. Müller) Bory, (D) *Dictyosphaerium tetrachotonum* Printz, (E) *Pediastrum simplex* Meyen, (F) *D. pulchellum* Wood

Scale bar = 10 µm
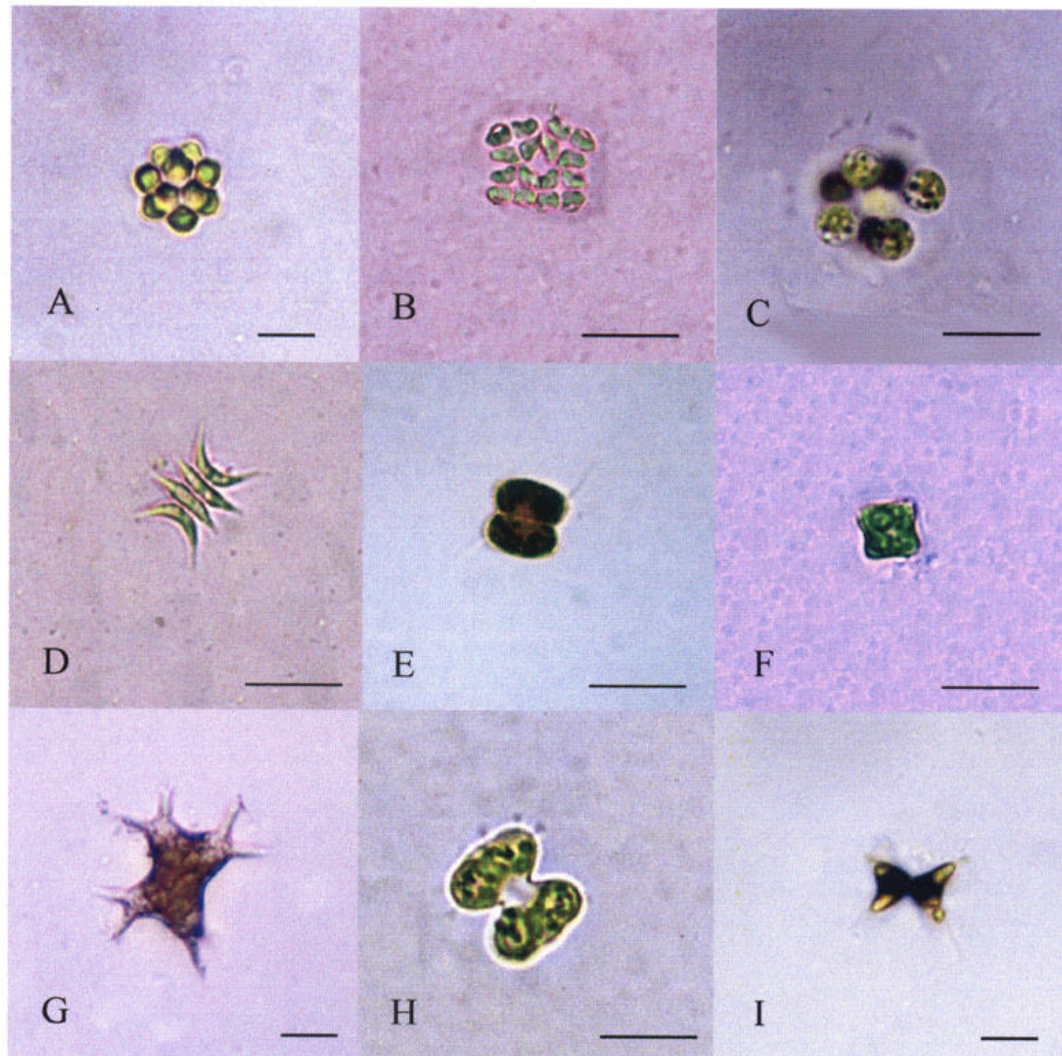
Plate8a

Figure 4.45a **Micrograph of phytoplankton found in Rama IX lake**

(A-F) Chlorophyceae: (A) *Coelastrum pseudomicroporum* **Korshikov, (B)** *Cruciginella crucifera* **(Wolle) Kom rek, (C)** *Eutetramorus globosus* **Walton, (D)** *Scenedesmus acuminatus* **(Lagerh.) Choda.** var. *acuminatus,* **(E)** *S. armatus* **(Chod.) G. M. Smith, (F)** *Tetraedron minimum* **(A. Braun) Hansgirg, (G) Xanthophyceae :** *Isthmochloron gracile* **(Reinsch) Hansgirg, (H-I) Zygnemaphyceae: (H)** *Cosmarium bioculatum* **Br bisson ex. Ralfs, (I)** *Staurodesmus phimus* var. *semulunaris* **(Schmidie) Teil.**

Scale bar=10 m

Plate 8b
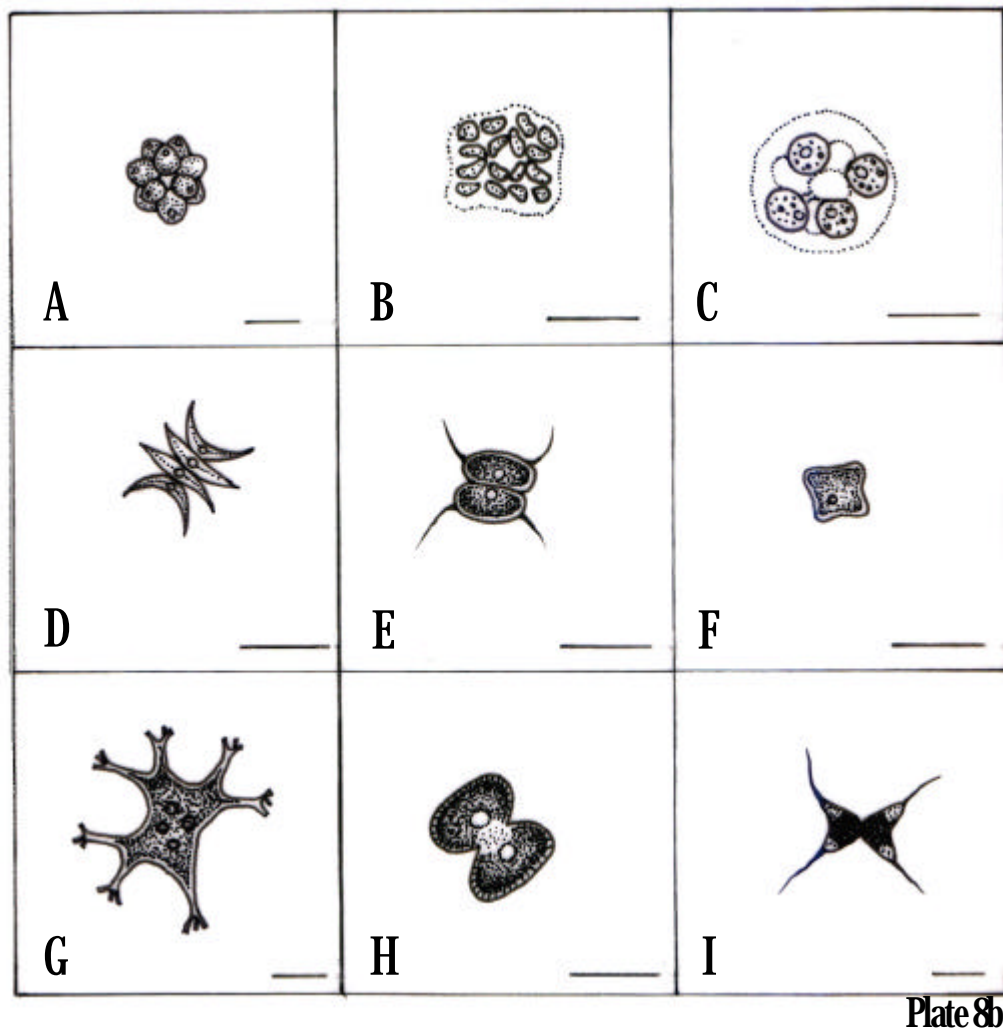
Figure 4.45b Illustration of phytoplankton found in Rama IX lake

(A-F) Chlorophyceae: (A) *Coelastrum pseudomicroporum* Korshikov, (B) *Cruciginella crucifera* (Wolle) Komárek, (C) *Eutetramorus globosus* Walton, (D) *Scenedesmus acuminatus* (Lagerh.) Choda. var. *acuminatus*, (E) *S. armatus* (Chod.) G. M. Smith, (F) *Tetraedron minimum* (A. Braun) Hansgirg, (G) Xanthophyceae :*Isthmochloron gracile* (Reinsch) Hansgirg, (H-I) Zygnemaphyceae: (H) *Cosmarium bioculatum* Brébisson ex. Ralfs, (I) *Staurodesmus phimus* var. *semulunaris* (Schmidie) Teil.

Scale bar = 10 μm
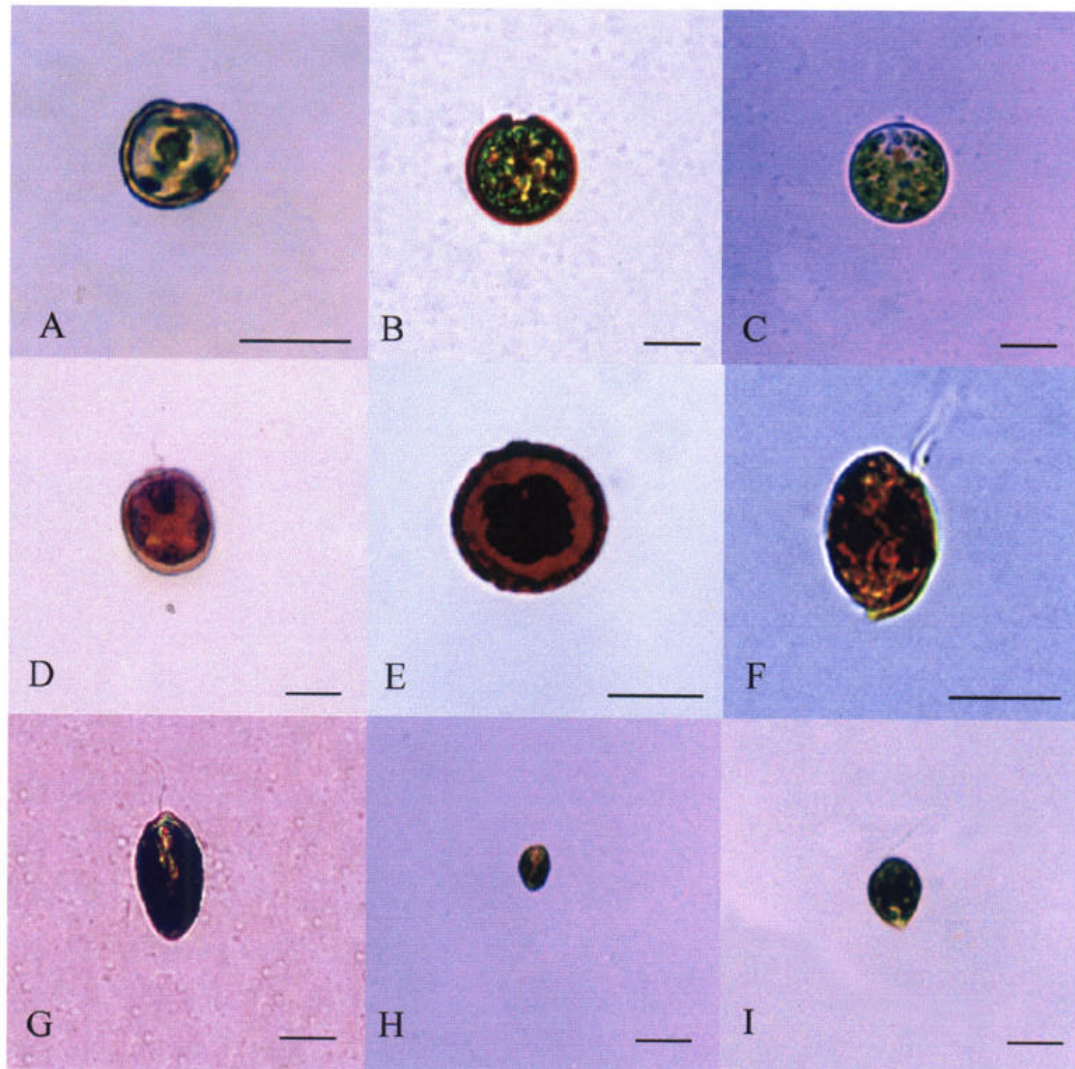
Plate 9a

Figure 4.46a   Micrograph of phytoplankton found in Rama IX lake
(A-E) Euglenophyceae: (A) *Trachelomonas curta* **Da Cunha, (B)** *T. volvocina*
Ehrenberg, (C) *T. volvocinopsis* **Swirenko, (D)** *T. dybowskii* **Drezepolski, (E)**
T. intermedia **Dangeard, (F-I) Cryptophyceae: (F)** *Chroomonas* **sp., (G)**
Cryptomonas **sp., (H)** *Rhodomonas* **sp.1, (I)** *Rhodomonas* **sp.2**
Scale bar = 10   m
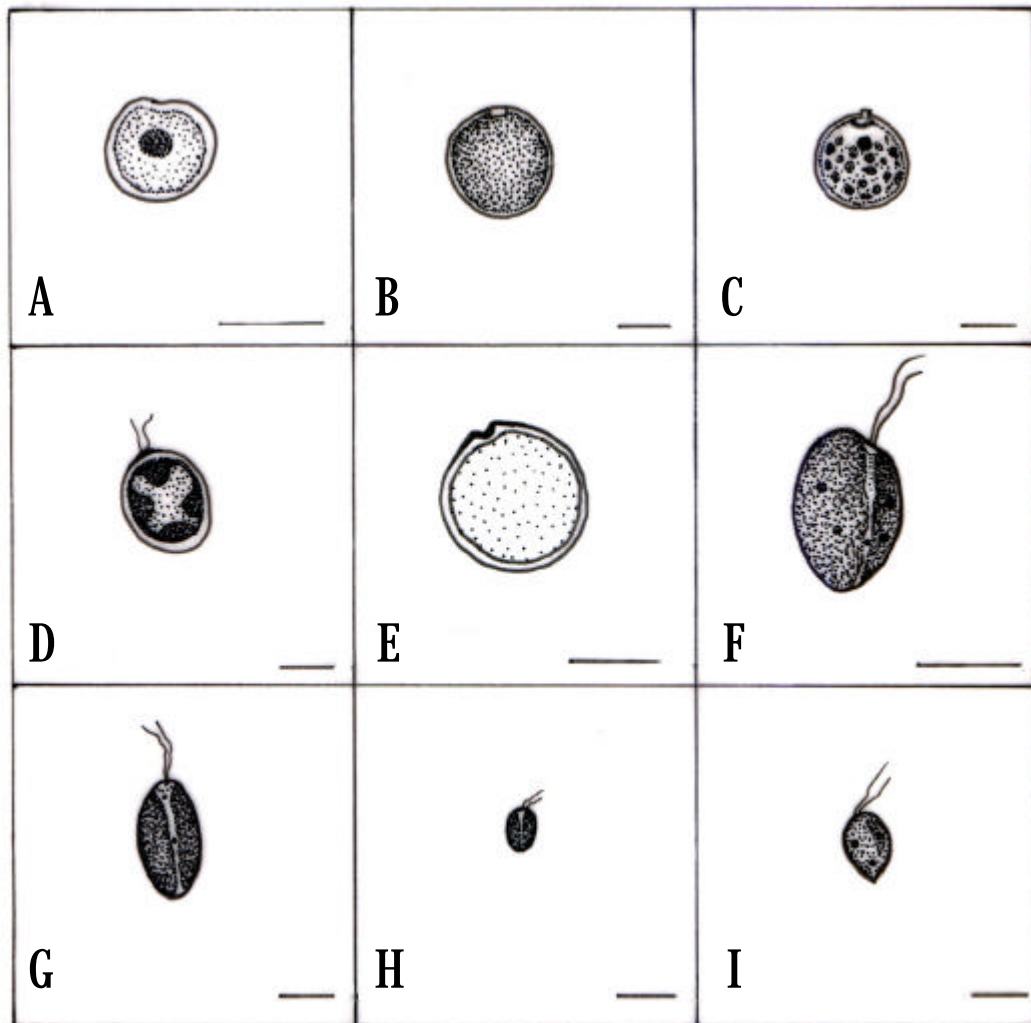
Plate 9b

Figure 4.46b   Illustration of phytoplankton found in Rama IX lake

(A-E) Euglenophyceae: (A) *Trachelomonas curta* **Da Cunha, (B)** *T. volvocina* **Ehrenberg, (C)** *T. volvocinopsis* **Swirenko, (D)** *T. dybowskii* **Drezepolski, (E)** *T. intermedia* **Dangeard, (F-I) Cryptophyceae: (F)** *Chroomonas* **sp., (G)** *Cryptomonas* **sp., (H)** *Rhodomonas* **sp.1, (I)** *Rhodomonas* **sp.2**

Scale bar = 10   m
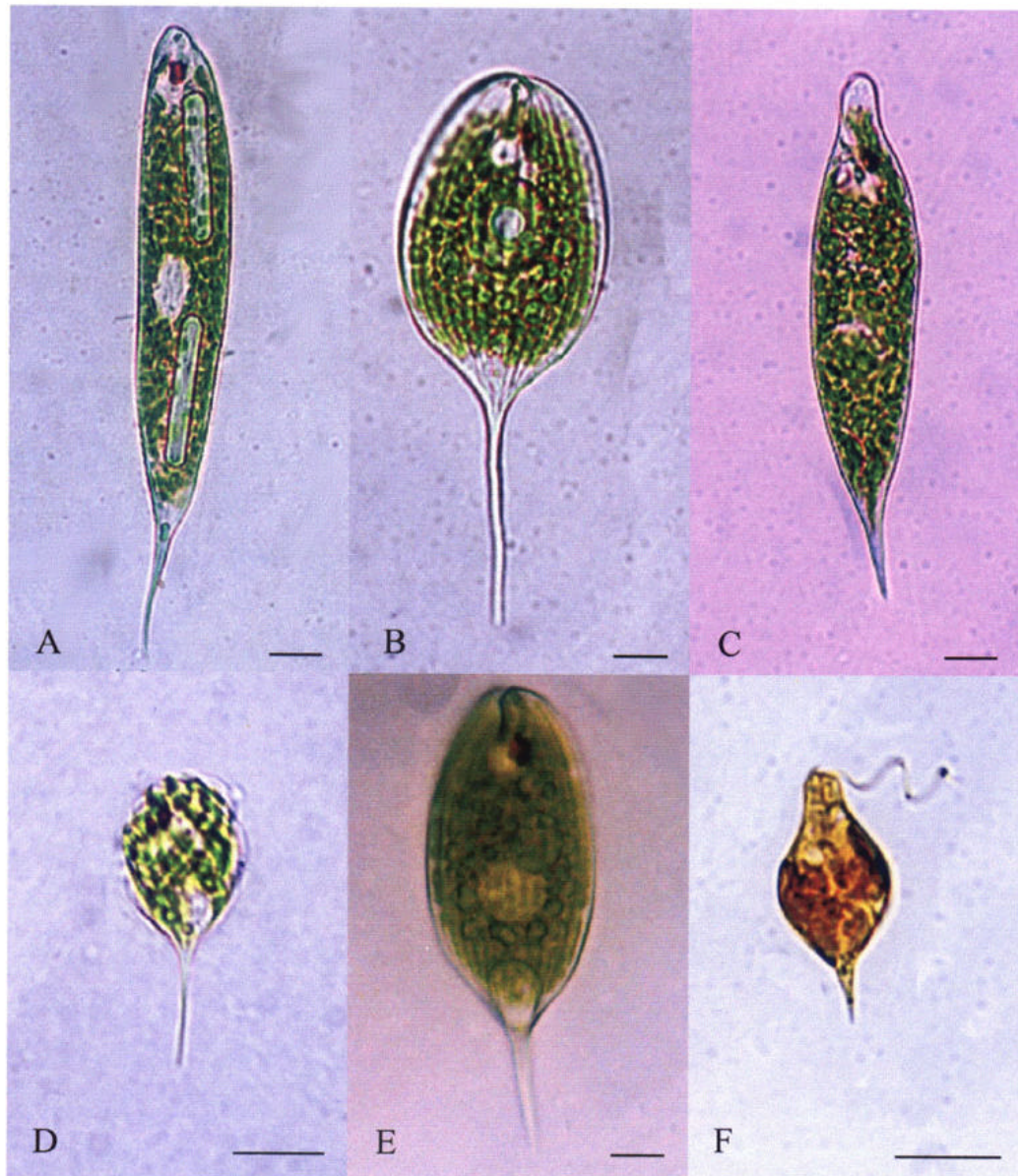
Plate 10a

Figure 4.47a Micrograph of phytoplankton found in Rama IX lake

(A-F) **Euglenophyceae: (A)** *Euglena charkowiensis* **Swir., (B)** *Phacus longicauda* **(Ehrenberg) Dujardin, (C)** *E. proxima* **Dangeard, (D)** *P. pyrum* **(Ehrenberg) F. Stein, (E)** *P. ranula* **Pochmann (Ehrenberg) Dujardin, (F)** *E. minima* **France**

Scale bar = 10 m
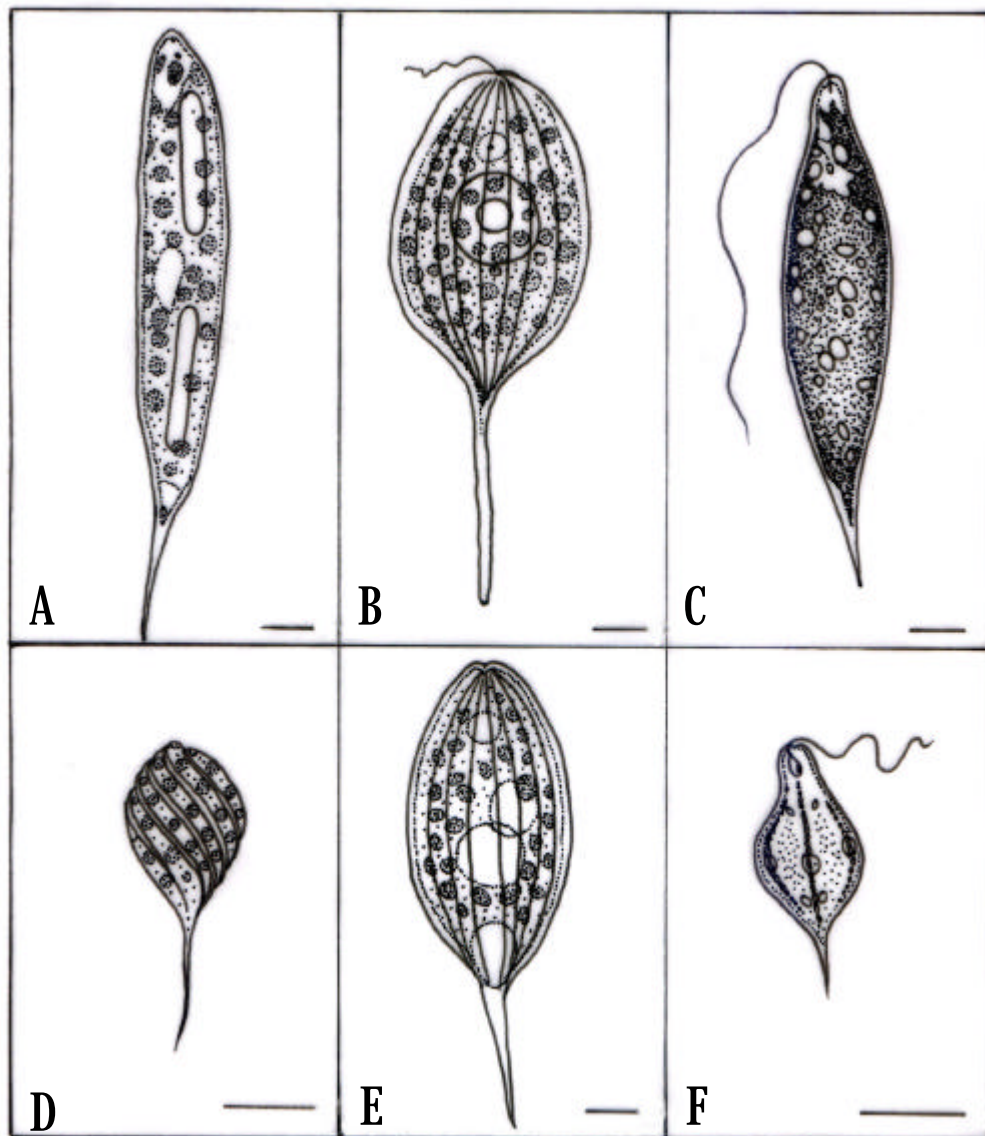
Plate 10b

Figure 4.47b **Illustration of phytoplankton found in Rama IX lake**

(A-F) **Euglenophyceae: (A)** *Euglena charkowiensis* **Swir., (B)** *Phacus longicauda* **(Ehrenberg) Dujardin, (C)** *E. proxima* **Dangeard, (D)** *P. pyrum* **(Ehrenberg) F. Stein, (E)** *P. ranula* **Pochmann (Ehrenberg) Dujardin, (F)** *E. minima* **France**

Scale bar = 10 m
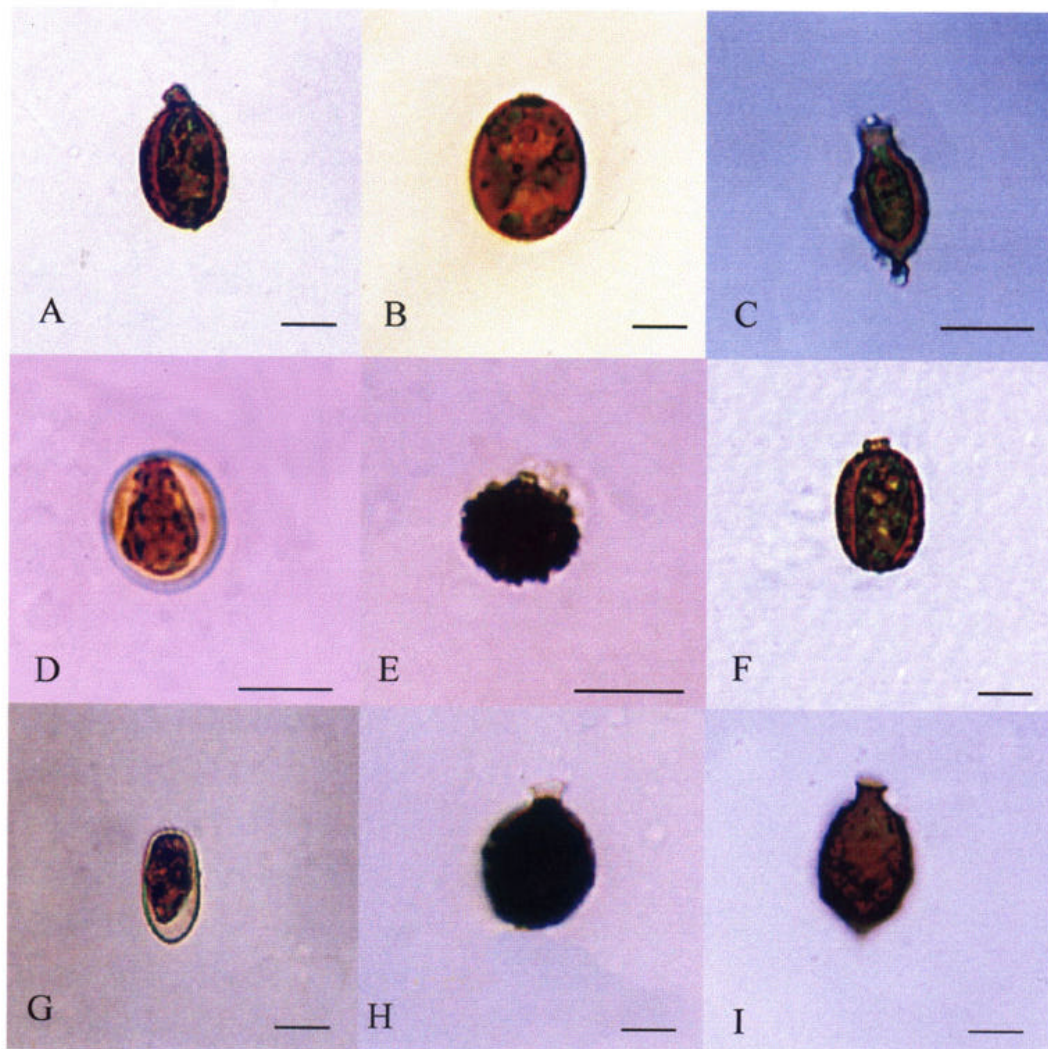
Plate 11a

Figure 4.48a Micrograph of phytoplankton found in Rama IX lake

(A-I) Euglenophyceae: (A) *Trachelomonas similis* Stokes, (B) *T. hispida* (Perty) Stein, (C) *T. bernardinensis* W. Vischer, (D) *T. oblonga* Lemmermann, (E) *T. minima* Drez., (F) *T. mucosa* Swirenko, (G) *T. dubia* (Swir.) Deflandre, (H) *Strombomonas verrucosa* var. *borystheniensis* (Roll) Deflanddre, (I) *S. fluviatilis* (Lemmermann) Deflandre

Scale bar = 10 m
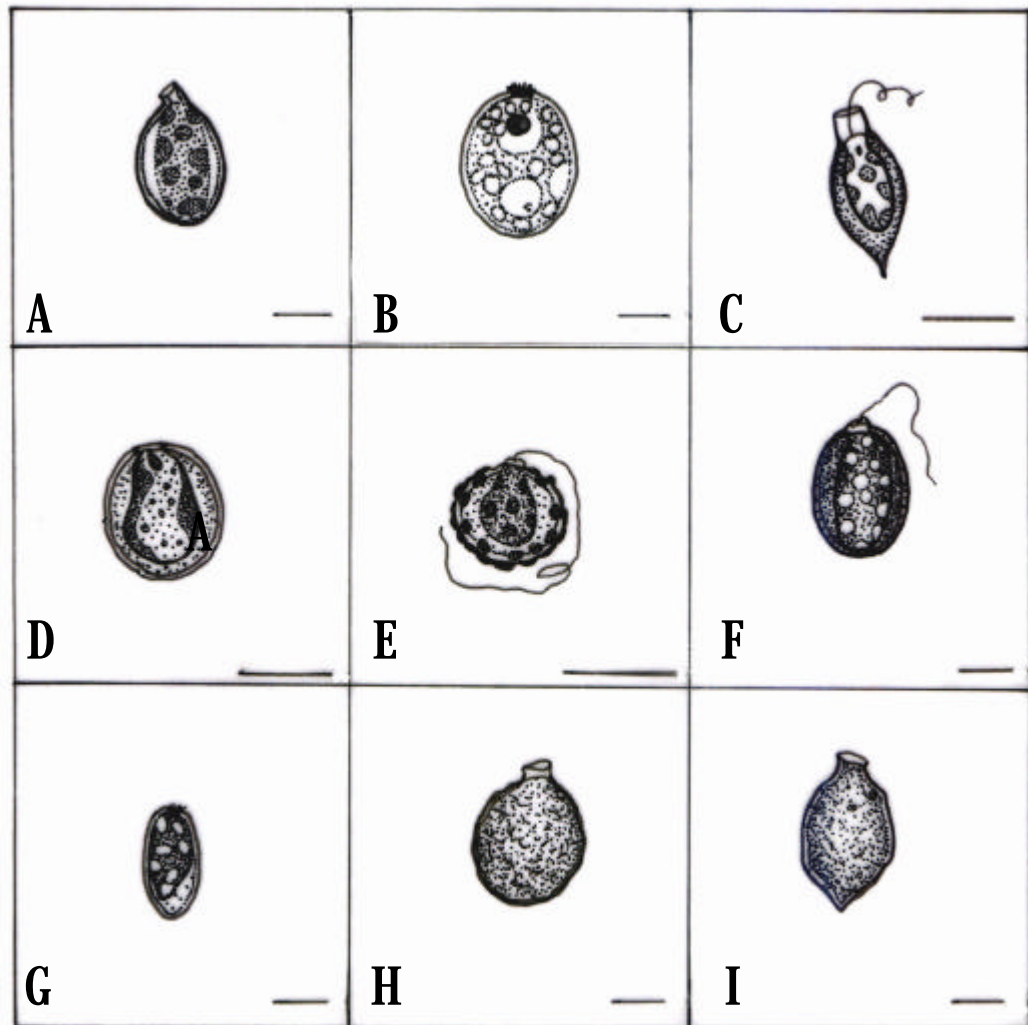
Plate11b

Figure 4.48b Illustration of phytoplankton found in Rama IX lake

(A-I) **Euglenophyceae: (A)** *Trachelomonas similis* **Stokes, (B)** *T. hispida* **(Perty) Stein, (C)** *T. bernardinensis* **W. Vischer, (D)** *T. oblonga* **Lemmermann, (E)** *T. minima* **Drez., (F)** *T. mucosa* **Swirenko, (G)** *T. dubia* **(Swir.) Deflandre, (H)** *Strombomonas verrucosa* var. *borystheniensis* **(Roll) Deflanddre, (I)** *S. fluviatilis* **(Lemmermann) Deflandre**

Scale bar = 10   m
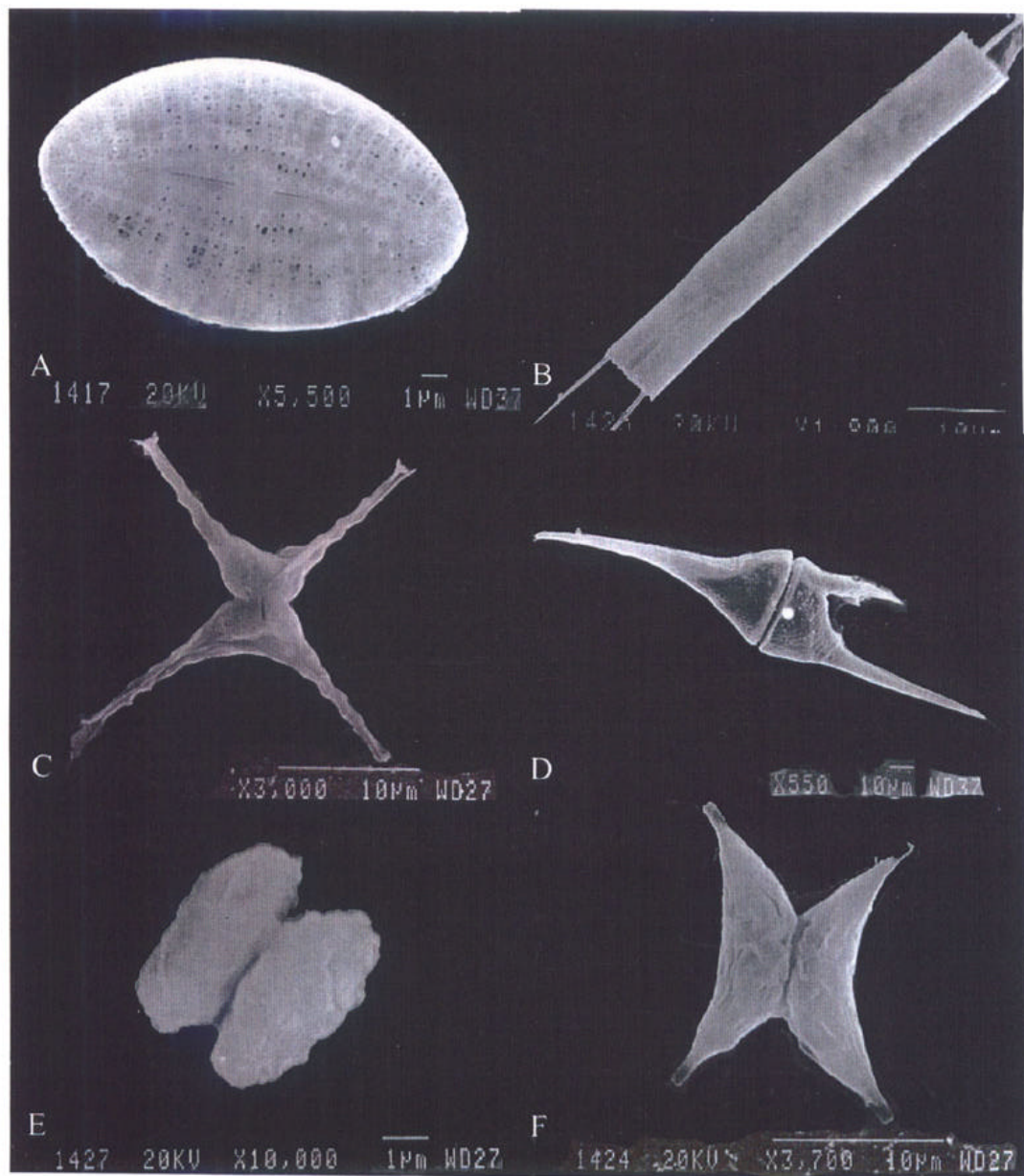
Plate 12a

Figure 4.49a Micrograph of phytoplankton found in Rama IX lake

(A-C) Diatomophyceae: (A) *Cocconeis placentula* Ehrenberg, (B) *Aulacoseira granulata* (Ehrenberg) Ralf, (C) Zygnemaphyceae: *Staurastrum perundulatum* Gionlel, (D) Dinophyceae: *Ceratium furcoides* (Levander) Langhans, (E-F) Zygnemaphyceae: (E) *Cosmarium bioculatum* Brebissorn ex. Ralfs, (F) *Staurodesmus phimus* var. *semulunaris* (Schmidie) Teil

SEM-micrographs

Scale bar A and E = 1 mm, B, C, D and F = 10 mm
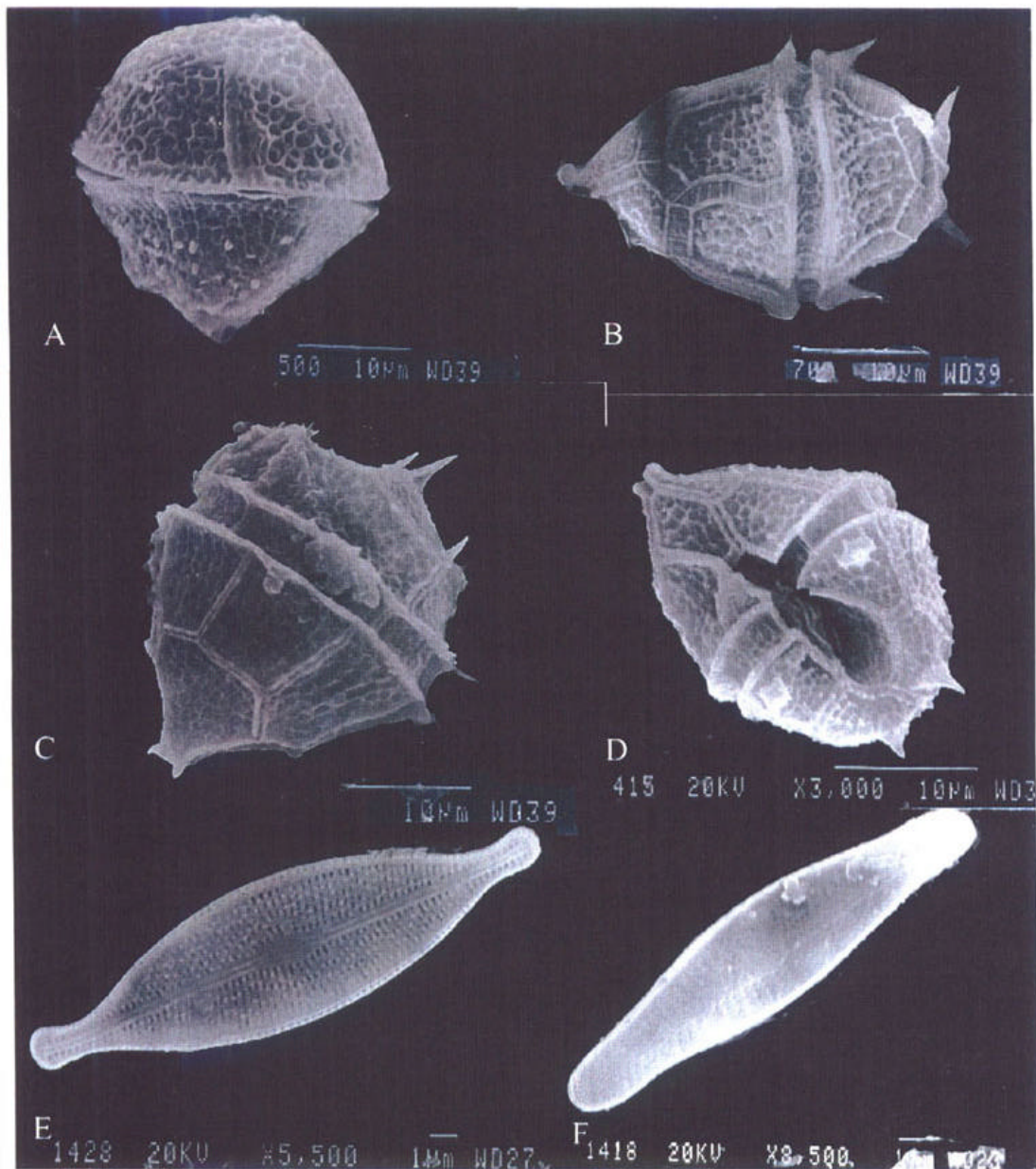
Plate 13a

Figure 4.50a Micrograph of phytoplankton found in Rama IX lake

(A-D) **Dinophyceae: (A)** *Peridinium* sp.1, **(B)** *Peridinium* sp.2, **(C)** *Peridiniopsis cunningtonii* **Lemmermann,** dorsal view   **(D)** ventral view, **(E-F) Diatomophyceae: (E)** *Anomoeoneis vitrea* **(Grunow) Ross., (F)** *Achnanthes minutissima* **Kutzing var.** *minutissima*

SEM-micrographs

Scale bar (A-D) = 10 mm, (E-F) = 1 mm

nutrient (Peerapompisal, 1996).

(3) This phytoplankton has the ability to store phosphorus in cells as polyphosphate bodies and can use it for growth (Horne and Goldman, 1994). Finally, this phytoplankton can move from the hypolimnion to the epilimnion for translocating phosphorus. So, it can adapt in the epilimnion which has low levels of phosphorus (Head, Jones and Bailey – Watts, 1999).

According to the investigation, this phytoplankton can spread to the lower depths and the lake's bed due to the reasons mentioned above. In addition, this phytoplankton has migration capacity in the water column to escape light and translocate nutrients from lake's bed to the surface. (Head, Jones and Bailey – Watts, 1999).

This phytoplankton was found to have positive correlation with total biovolume (P = 0.01) in both lakes because *Cylindrospermopsis raciborskii* was the dominant phytoplankton and was found every month throughout the investigation of both lakes.

In the second lake, this phytoplankton had positive correlation with chlorophyll a (P = 0.05) because chlorophyll a is a majority of pigment in a cell and is essential in photosynthesis of phytoplankton. When phytoplankton increases, chlorophyll a will increase too. However, this investigation's statistics revealed no correlation between this phytoplankton and the other parameters because in the investigation there was little change in the nutrients. The lake's water was mixed with the inflow-outflow drain from Khlong 5 and Khlong 6 and they were closed throughout the investigations which meant there was little contaimination from outside the lakes. So, nitrogen and phosphorus were low. This result corresponds to the report of Wetzel (1983) who also found that the water quality did not change much. It was of a reasonably good standard and consistent throughout the study. Consequently, the factors affecting the growth of the algae became less prominent.

Based on this investigation, the isoline graph of nitrate – nitrogen of the first lake showed a trend of reduction in the end of January 2001 (Figure 4.22B,C) and decreased in the beginning of January 2001 in the second lake (Figure 4.23B, C) whereas phytoplankton were very high at this time (Figure 4.57 B, C ; 4.58 B, C).

This result resembles the report of Srisuwan (1993) and Peerapompisal (1996) who found that *Cylindrospermopsis raciborskii* had negative correlation with nitrate-nitrogen in

the reservoirs in the Huai Hong Khrai Royal Development Study Centre, Chiang Mai province. Although, the amount of nitrate-nitrogen decreased this did not result in a decrease of this phytoplankton.

Furthermore, toxin was recently found produced by heterocystous *Cylindrospermopsis raciborskii* (Woloszynska) Seenayya and Subba Raju. This organism was retrospectively implicated (Hawkins, Rumegar, Jackson and Falconer, 1985) as the causative agent in a incident of poisoning of people in 1979, where a large cyanobacterial bloom on Solomon Dam, Palm existed. In the United States *C. raciborskii* was not commonly found until about 10 years ago when it was discovered to be a regular component of waterblooms in Florida (Champman and Schelske, 1997).

In south-east Asia water blooms of cyanobacteria are also frequently observed in fresh water lakes and reservoirs. However, until recently, only the heptapeptide hepatatoxic microcystins were known to occur in some Thailand water blooms (Mahakhant, et al. 1998). During studies of testing for toxic cyanobacteria in Asia, a strain of *C. raciborskii* (CY-Thai) was isolated from a fish pond in Bangkok. It was examined for its taxonomy based upon morphology an 16S RNA gene sequence. It was also examined for production of the hepatotoxic cyanotoxin called cylindrespermopsin and dexoycylindrospermopsin (Carmicheal, et al., 2001). Shaw, Seawright, Island, in Northern Queensland, Australia which were associated with causing hepatoenteropathy in 148 native people (Bourke, Hawes, Neilson and Stallman, 1983; Byth, 1980). The toxin was later identified as a tricyclic hydroxymethyluracil given the general name cylindrospermopsin (Otaui, Moore and Runnergar, 1992). Hawhins, Runnegar, Jackson and Falconer (1985) reported that cylindrospermopsin is a cyclic guanine alkaloid which is a hepatotoxin. This toxin which is a protein synthesis inhibitor, also causes damage to the kidneys, spleen, intestine, heart and thymus (Codd, 2001). Cylindrosprmopsin is now known to also be produced by the cynobacteria *Umezakia natans* (Harada et al., 1994) and *Aphanizomenon ovalisporum* (Banker, et al., 1997; Shaw, et al., 1999). More and Lam (2000) also propose that an interim guideline for cylindrospermopsin in drinking water should be 1 $\mu g.l^{-1}$. These studies, and the increasing occurrence of *C. raciborskii* point out the need for proper monitoring and control of cylindrospermopsin its producer organism, and other cyanotoxins in the world's water supplies (Carmichoel, et al., 2001).

There has not been a report in Thailand about blooming of *C. raciborskii* which acutely effects living organisms in the water resources. In this study, the researcher found no living organism affected by this toxin; however, during the investigation the researchers asked the public who went swimming in the lakes, especially in the first lake if they experienced any itching, rash or irritation on their skin.

However, the authorities should be cautious and ensure and there is no increase in nutrients, especially phosphorus, in the water resources. This phosphorus occurs from wastewater from domestic sources and fertilizer which in turn cause an increase in the nutrients in the water resources.

4.4.4.5 Phytoplankton biovolume

The biovolume of the total phytoplankton was calculated from the abundance and volume approximation for each species following Rott (1981) see from table 4.2

The study of phytoplankton biovolume in the first lake found that the Cyanophyceae had the most phytoplankton at 69.80%, compared to 20.47% for Dinophyceae, 7.14% for Euglenophyceae, 0.95% for Diatomophyceae 0.71% for Cryptophyceae, 0.70% for Chlorophyceae, 0.15% for Zygnemaphyceae and 0.08% for Chrysophyceae (Figure 4.51). In the second lake, the phytoplankton biovolume Cyanophyceae contained with 59.52% of total biovolume. Dinophyceae at 20.53% Euglenophyceae of 14.68%, Diatomophyceae at 2.73%, Zygnemaphyceae at 1.19%, Cryptophyceae 0.63%, Chlorophyceae at 0.47% and Chrysophyceae of 0.25% respectively (Figure 4.52).

The phytoplankton biovolume in lake group fluctuated throughout the investigation. In the first lake, the change of phytoplankton biovolume was at its highest in January 2001 (Cyanophyceae) and at its lowest in March 2000 (Cyanophyceae). The second group was Dinophyceae, third was Euglenophyceae, Diatomophyceae, Chlorophyceae, Cryptophyceae, Zygnemaphyceae and Chrysophyceae followed respectively (Figure 4.53). In the second lake, the change of phytoplankton biovolume flauctuated throughout this study. This value was at its highest in January, 2001 (Cyanophyceae) and at its lowest was in March, 2000 (Cyanophyceae). Following was Dinophyceae, Euglenophyceae, Diatomophyceae, Zygnema-phyceae, Cryptophyceae, Chlorophyceae and Chrysophyceae respectively. (Figure 4.54).

Tabel 4.2 Phytoplankton species relevant size data and details for methodological conversion of counts to biovolume

(n = number of measurements, CE = calculated by cell, CO = calculated by colony)

Phytoplankton species	Length (μm)		Width and Dimeter (μm)		Thickness (μm)	Volume (μm^3)	n	Geometric Shape	Shape
	Cell	Filament	Cell	Colony					
Cyanophyceae									
Anabaena sp.	-	183.7	2.88	-	2.88	1,198	10	Cylinder	Filament
Anabaena aphanizomenoides Forti	-	267	2.5	-	2.5	1,312	3	Cylinder	Filament
Aphanizomenon sp.	-	203	2.75	-	2.75	1,207	5	Cylinder	Filament
Aphanothece nidulans Richter	1.75	-	1.3	-	1.3	204 CO	5	Ellipsoid	Colony(102 cells)
Aphanothece smithii Komárková-Legnerová et Cronberg	3.75	-	2.5	-	2.5	1512 CO	2	Ellipsoid	Colony(126 cells)
Aphanocapsa elachista W.et. G.S. West	-	-	1.3	-	-	250 CO	1	Sphere	Colony(250 cells)
Aphanocapsa nubilum Komárek et Kling	-	-	2	-	-	56 CO	2	Sphere	Colony(14 cells)
Coelomoron pusillum (Van Goor) Komárek	3.75	-	2.5	-	2.5	192 CO	3	Ellipsoid	Colony(16 cells)
Cylindrospermopsis raciborskii (Wolosz.) Seenayya & Subba	-	71.3	2.5	-	-	350	35	Cylinder	Filament
Cylindrospermopsis philippinensis (Taylor) Ka.	-	68.7	2.3	-	-	298	35	Cylinder	Filament

Tabel 4.2 (cont.)

Phytoplankton species	Length (µm)		Width and Dimeter (µm)		Thickness (µm)	Volume (μm^3)	n	Geometric Shape	Shape
	Cell	Filament	Cell	Colony					
Gomphosphaeria natans Komárek et Hindák	3.4	-	2.5	-	2.5	176^{CO}	3	Ellipsoid	Colony(16 cells)
Merismopedia punctata Meyen	-	-	2.5	-	-	8^{CE}	3	Sphere	Colony(16 cells)
Microcystis aeruginosa Kützing.	-	-	2	-	-	100^{CO}	10	Sphere	Colony(25 cells)
Oscillatoria limosa Ag.ex. Gomont	-	231.25	8.25	-	-	12,371	10	Cylinder	Filament
Planktolyngbya limnetica Lemmermann	3	-	1	-	-	40	20	Cylinder	Filament
Planktolyngbya sp.	-	66	2	-	-	207	10	Cylinder	Filament
Spirulina platensis (Nords) Geitler	-	50	5	-	-	982	3	Cylinder	Filament
Cryptophyceae									
Chroomonas sp.	11.7	-	5.7	-	4.5	157	5	Elliptic-Ellipsold	Cell
Cryptomonas sp.	12.4	-	6.3	-	4.78	196	10	Elliptic-Ellipsold	Cell
Rhodomonas sp.1	9	-	4	-	3	17	10	1/2Ellipsold+1/2Cone	Cell
Rhodomonas sp.2	11.6	-	5.7	-	4.75	59	3	1/2Ellipsoid+1/2Cone	Cell

Tabel 4.2 (cont.)

Phytoplankton species	Length (μm)		Width and Dimeter (μm)		Thickness (μm)	Volume (μm^3)	n	Geometric Shape	Shape
	Cell	Filament	Cell	Colony					
Dinophyceae									
Ceratium furcoides (Levander) Langhans	80.5	-	45	-	20	24,491	10	Cone+1/2Ellipitc-Con +Cylinder	Cell
Peridiniopsis cunningtonii Lemmermann	25	-	22.5	-	18	5,306	20	Elliptic-Ellipsold	Cell
Peridinium sp. 1	21	-	17.5	-	12.5	2,407	20	Elliptic-Ellipsold	Cell
Peridinium sp. 2	30	-	22	-	17.5	6,052	20	Elliptic-Ellipsold	Cell
Diatomophyceae									
Achnanthes minutissima Kützing var. *minutissima*	13.8	-	3.1	-	-	21	2	2 pyramid	Cell
Amphora sp.	20	-	9	-	-	849	1	Cylinder	Cell
Anomoeoneis vitrea (Grunow) Ross	22	-	4.75	-	-	52	10	2 pyramid	Cell
Aulacoseira granulata (Ehrenberg) Ralfs	-	67.2	6.3	-	-	2,081	22	Cylinder	Filament
Cocconeis placentula Ehrenberg	16.2	-	10.2	-	-	883	1	Ellipsoid	Cell
Cyclotella sp.	-	-	20.83	-	-	4,736	3	Sphere	Cell
Cymbella sp	5	-	22.5	-	-	147	1	1/2Ellipsoid	Cell

Tabel 4.2 (cont.)

Phytoplankton species	Length (µm)		Width and Dimeter (µm)		Thickness (µm)	Volume (µm³)	n	Geometric Shape	Shape
	Cell	Filament	Cell	Colony					
Eunotia sp.	7.5	-	22.5	-	5.63	249	2	1/2Elliptic-Ellipsoid	Cell
Fragilaria ulna var.*acus* (Kützing) Lange-Bertalot	149.75	-	3.13	-	1.5	703	10	Parallelepiped	Cell
Gyrosigma macrum (W.Smith)Griffith & Henfrey	191.25	-	10	-	7.5	7,516	3	2Elliptic-Cone	Cell
Gyrosigma sp.	52.75	-	14	-	11	4,257	5	2Elliptic-Cone	Cell
Nitzschia sp.	49	-	2.5	-	-	61	10	2Pyramid	Cell
Chrysophyceae									
Uroglenopsis americana (Calkins) Lemmermann	3.75	-	2.5	-	-	1572^co	3	Ellipsoid	Colony (128 Cells)
Chlorophyceae									
Acanthosphaera sp.	-	-	11	-	-	697	5	Sphere	Cell
Actinastrum gracillimum G.M.Smith	25	-	2.5	-	1.88	472^co	2	4Parallelepiped	Colony(4cells)
Ankistrodesmus falcatus (Corda) Ralfs	21.25	-	1.88	-	-	320^co	10	2Cone	Colony (8 cells)
Botryococcus braunii Kützing	25.3	-	17.8	-	12	6,190	35	2Ellipsoid	Colony
Carteria sp.	15.25	-	9.25	-	9.25	684	10	Ellipsoid	Cell
Chlamydomonas sp.1	10.37	-	3.77	-	3.77	77	10	Ellipsoid	Cell

Tabel 4.2 (cont.)

Phytoplankton species	Length (µm)		Width and Dimeter (µm)		Thickness (µm)	Volume (µm^3)	n	Geometric Shape	Shape
	Cell	Filament	Cell	Colony					
Chlamydomonas sp.2	12	-	7	-	7	308	5	Ellipsoid	Cell
Chlorogonium sp.	13.33	-	1.5	-	1.5	16	3	Ellipsoid	Cell
Chlorella vulgaris Beijerinck	-	-	3.75	-	-	28	3	Sphere	Cell
Coelastrum microporum Naegeli	-		13.21	-	-	1208[CO]	5	Sphere	Colony (15cells)
Coelastrum pseudomicroporum Korshikov	7.5	-	5	-	-	392[CO]	2	Ellipsoid	Colony (4cells)
Coelastrum sphaericum Naegeli	-	-	7.5	-	-	1768[CO]	3	Sphere	Colony (8cells)
Crucigeniella crucifera (Wolle) Komárek	5	-	2.6	-	2	56[CO]	3	Elliptic-Ellipsoid	Colony (4cells)
Dictyosphaerium tetrachotonum Printz	2.5	-	2	-	2	20[CE]	10	Ellipsoid	Colony (16cells)
Dictyosphaerium pulchellum Wood	-	-	5	-	-	264[CE]	2	Sphere	Colony (16 cells)
Eudorina elegans Ehrenberg	-	-	7.5	-	-	7,074[CO]	3	Ellipsoid	Colony (32 cells)
Eutetramorus globosus Walton	-	-	5	-	2	262[CO]	2	Sphere	Colony (4cells)
Monoraphidium arcuatum (Korshikov) Hindák	31.5	-	2	-	2	66	10	2Cone	Cell
Monoraphidium contortum (Thuret) Komárková-Legnerová	8	-	2	-	2	17	10	2Cone	Cell

Tabel 4.2   (cont.)

Phytoplankton species	Length (µm)		Width and Dimeter (µm)		Thickness (µm)	Volume (μm^3)	n	Geometric Shape	Shape
	Cell	Filament	Cell	Colony					
Monoraphidium griffithii (Berkeley) Komárková-Legnerová	21	-	2.1	-	-	49	3	2Cone	Cell
Monoraphidium irregulare (G.M. Smith) Komárková-Legnerová	14.7	-	1.25	-	-	36	3	6Cone	Cell
Oocystis sp.	8	-	3.75	-	-	236	5	4Ellipsoid	Colony
Pandorina morum (O.F.Müller) Bory	10.83	-	7.92	-	-	5,696	6	Ellipsoid	Colony(16cells)
Pediastrum simplex Meyen	13	-	7	-	3	912	5	Trapezoid+Tringular parallelepiped	Colony(8cells)
Planktonema lauterbornii Schmidle	-	99.5	2.5	-	-	489	5	Cylinder	Filament
Radiococcus planktonicus J.W.G. Lund	-	-	2.5	-	-	3070[co]	1	Sphere	Colony(24cells)
Scenedesmus acuminatus (Lagerh.) Choda var. *acurminatus*	15	-	2.5	-	2.5	98	5	2Cone	Colony(4cells)
Scenedesmus armatus (Chod) G. M.Smith	10	-	5	-	-	262	1	Ellipsoid	Cell (2 cell)
Scenedesmus opoliensis P.Richter	10	-	7.29	-	7.29	1,114	3	Ellipsoid	Cell (4 cells)

Tabel 4.2 (cont.)

Phytoplankton species	Length (μm)		Width and Dimeter (μm)		Thickness (μm)	Volume (μm^3)	n	Geometric Shape	Shape
	Cell	Filament	Cell	Colony					
Spirogyra sp.	200	-	30	-	-	141,480	1	Cylinder	Filament
Tetraedron minimum (A.Braun)Hansgirg	7	-	6	-	-	147	10	Parallelepiped	Cell
Tetrastrum staurogeniaeforme (Schröder) Lemmermann	4.38	-	3.13	-	-	90	2	Ellipsoid	Colony(4cells)
Zygnemaphyceae									
Cosmarium bioculatum Brébisson ex. Ralfs.	7.5	-	5	-	3.75	147	20	2Elliptic-Ellipsoid	Cell
Staurodesmus phimus var.*semulunaris* (Schmidie) Teil	16	-	4.25	-	-	303	2	2Ellipsoid	Cell
Staurastrum perundulatum Gionlel	7.5	-	5	-	3	274	20	2Parallelepiped +4Truncated Cone	Cell
Xanthophyceae									
Isthmochloron gracile (Reinsch) Hansgirg	33	-	30	-	2	343	3	2 Trapezoid+ 12Parallelepiped +4 Trangular Parallelepiped	Cell

Tabel 4.2 (cont.)

Phytoplankton species	Length (μm)		Width and Dimeter (μm)		Thickness (μm)	Volume (μm³)	n	Geometric Shape	Shape
	Cell	Filament	Cell	Colony					
Euglenophyceae									
Euglena charkowiensis Swir.	127.5	-	14.17	-	-	2,094	3	1/2Ellipsoid+1/2Cone	Cell
Euglena proxima P.A. Dangeard	49.25	-	15.5	-	-	945	10	1/2Ellipsoid+1/2Cone	Cell
Euglena minima France	25	-	10	-	-	169	3	1/2Ellipsoid+1/2Cone	Cell
Phacus longicauda (Ehrenberg) Dujardin	52.5	-	37.5	-	-	5,816	10	1/2Ellipsoid+1/2Cone	Cell
Lepocinclis sp.	23.75	-	10.83	-	-	187	3	1/2Ellipsoid+1/2Cone	Cell
Phacus pyrum (Ehrenbeg) F.Stein	24.81	-	7.83	-	-	128	10	1/2Ellipsoid+1/2Cone	Cell
Phacus ranula Pochmann (Ehrenberg) Dujardin	71.50	-	40	-	10	14,986	3	Elliptic-Ellipsoid	Cell
Trachelomonas bernardinensis W. Vischer	26.15	-	12.13	-	-	2,016	10	Ellipsoid	Cell
Trachelomonas curta Da Cunha	11	-	13	-	-	974	1	Ellipsoid	Cell
Trachelomonas dubia (Swir.) Deflandre	25	-	10	-	10	1,308	5	Ellipsoid	Cell
Trachelomonas dybowskii Drezepolski	17.28	-	13.41	-	-	1,628	5	Ellipsoid	Cell
Trachelomonas hispida (Perty) Stein	20	-	11	-	11	1,267	10	Ellipsoid	Cell
Trachelomonas intermedia Dangeard	35	-	20	-	20	7,330	5	Ellipsoid	Cell

Tabel 4.2 (cont.)

Phytoplankton species	Length (μm)		Width and Dimeter (μm)		Thickness (μm)	Volume (μm^3)	n	Geometric Shape	Shape
	Cell	Filament	Cell	Colony					
Trachelomonas minima Drez.	-	-	11	-	-	697	3	Sphere	Cell
Trachelomona mucosa Swirenko	22.75	-	14.25	-	-	2,421	10	Ellipsoid	Cell
Trachelomonas oblonga Lemmermann	22.5	-	15	-	-	2,653	3	Ellipsoid	Cell
Trachelomonas similis Stokes	25	-	15	-	-	2,947	3	Ellipsoid	Cell
Trachelomonas volvocina Ehrenberg	-	-	12	-	-	904	15	Sphere	Cell
Trachelomonas volvocinopsis Swirenko	-	-	15	-	-	1,767	15	Sphere	Cell
Strombomonas fluviatilis (Lemm.) Deflandre	32.5	-	18.75	-	-	5,987	2	Ellipsoid	Cell
Strombomonas verrucosa var.*borystheniensis*	32.5	-	22.5	-	-	8,621	2	Ellipsoid	Cell

(Roll) Deflandre
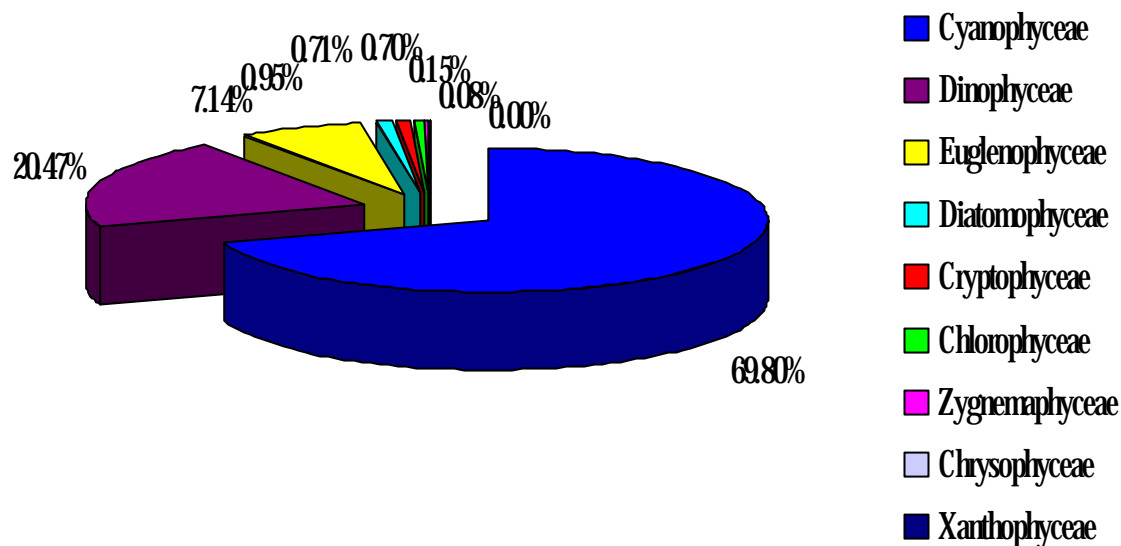
Figure 4.51   Each group of phytoplankton biovolume expressed in percentage terms in the
first lake of Rama IX lake (February 2000-January 2001)
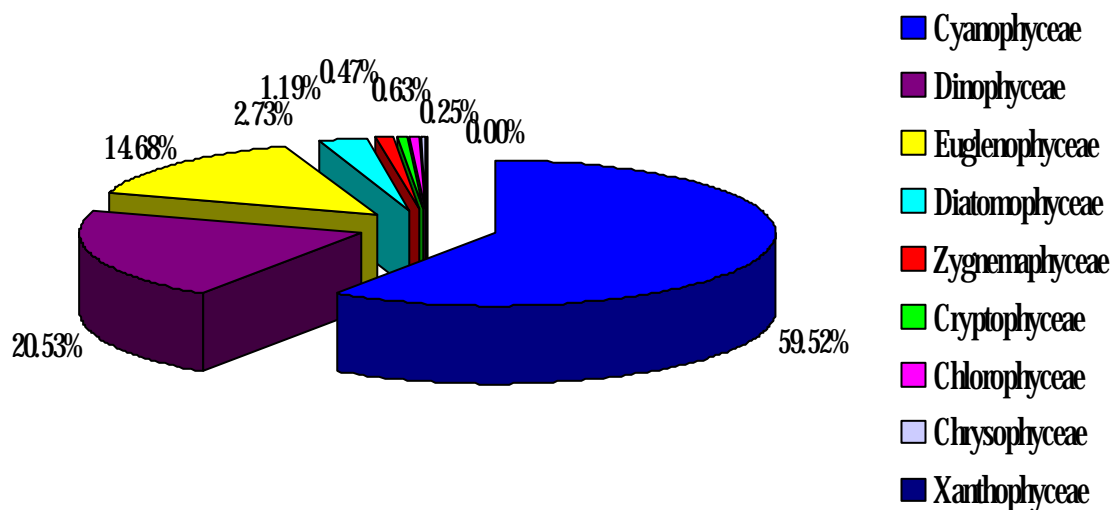
Figure 4.52   Each group of phytoplankton biovolume expressed in percentage terms in the
second lake of Rama IX lake (February 2000-January 2001)

The dominant group of phytoplankton in both lakes was Cyanophyceae, Dinophyceae, and Euglenophyceae respectivety. However, the Cyanophyceae fluctuated throughout the investigation. The dominant species of phytoplankton in both lakes was *Cylindrospermopsis raciborskii* which had the highest phytoplankton biovolume. In the first lake, this species was followed by *Peridiniopsis cunningtonii, Trachelomonas volvocina, Peridinium* sp.1, *Ceratium furcoides, Peridinium* sp.2, *T. mucosa, Fragilaria ulna* etc. respectively (Figure 4.55). This group of phytoplankton represents about 10 percent of the total species of phytoplankton. In the second lake, *T. volvocina* was the second most dominant species followed by *Peridinium* sp. 1, *Peridiniopsis cunningtonii, Ceratium furcoides, Anomoeoneis vitrea, T. mucosa, Staurastrum perundulatum* etc. respectively. This group of phytoplankton represents about 10 percent of the total species of phytoplankton (Figure 4.56). When *C. raciborskii* and *T. volvocina* increased *Peridinium* sp.1, *Peridiniopsis cunningtonii, Ceratium furcoides, Anomoeoneis vitrea* tended to decrease, although there were not a statistical correlation. These species of phytoplankton can indicate water quality.

In the first lake, phytoplankton biovolume at the surface ranged from 967.24-11,084.16 $mm^3.m^{-3}$. The average phytoplankton biovolume was 4,451.55 $mm^3.m^{-3}$. The highest value was 11,804.16 $mm^3.m^{-3}$ in January 2001 and the lowest was 967.24 $mm^3.m^{-3}$ in November 2000 (Figure 4.57). In the second lake, phytoplankton biovolume at the surface varied from 137.34-1,426.98 $mm^3.m^{-3}$. The average phytoplankton biovolume was 494.65 $mm^3.m^{-3}$. The Highest value was 1426.98 $mm^3.m^{-3}$ in January 2001 and the lowest was 137.34 $mm^3.m^{-3}$ in November 2000 (Figure 4.58). The phytoplankton biovolume of the first lake was significantly higher than in the second lake.

In the first lake, the percentage of phytoplankton biovolume stratification showed that when the water level was at 0 metre depth phytoplankton biovolume was 20% of the total compared to 25% at the depth at 1 metre, which was the depth with the most phytoplankton biovolume of the total. There were 2 other high phytoplankton biovolumes at 2 metre depth (22%) and 3 metre depth (20%). The percentage of phytoplankton biovolume was low at 8 and 13 metre depths and were 8% and 4% respectively of the total; however, the ground level contained a very low percentage of 1% (Figure 4.59). In the second lake, the phytoplankton biovolume at the 0 metre depth was about 22% it was higher than in the lower depths for
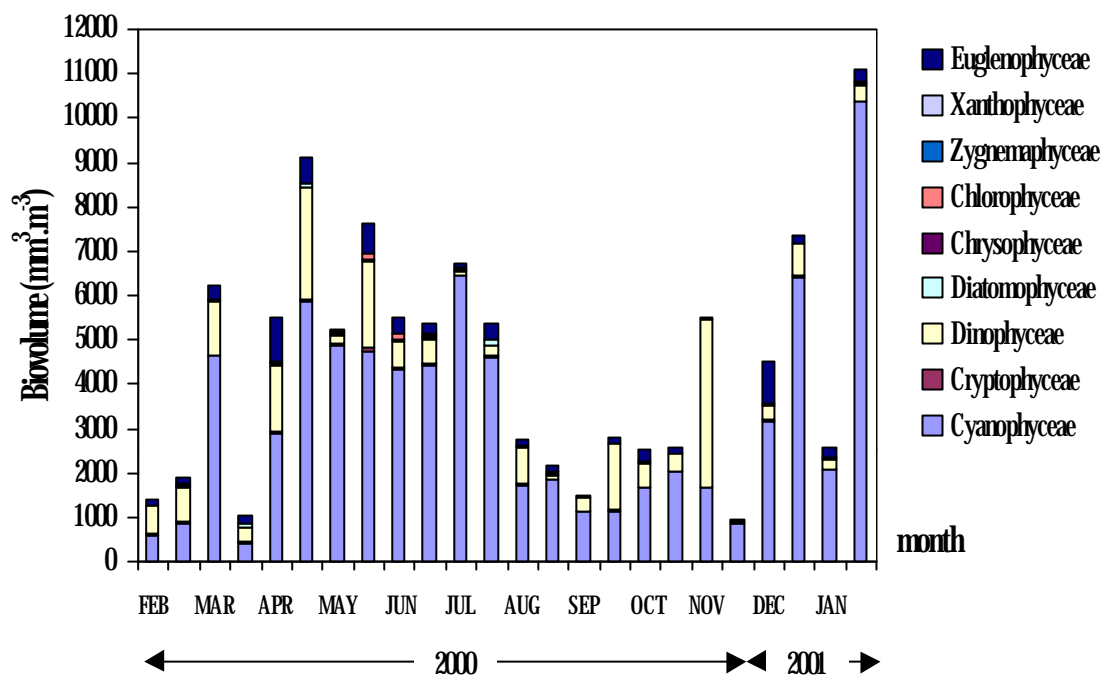
Figure 4.53 Changes in total biovolume of each group of phytoplankton in the first lake of Rama IX lake (February 2000-January 2001)
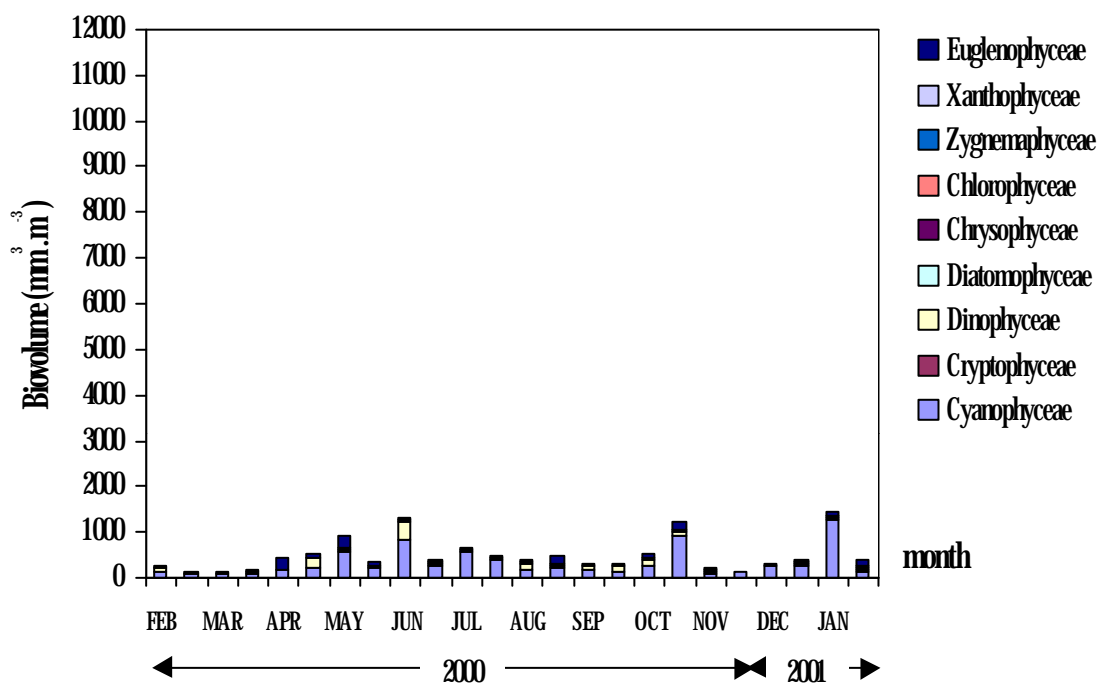
Figure 4.54 Changes in total biovolume of each group of phytoplankton in the second lake of Rama IX lake (February 2000-January 2001)
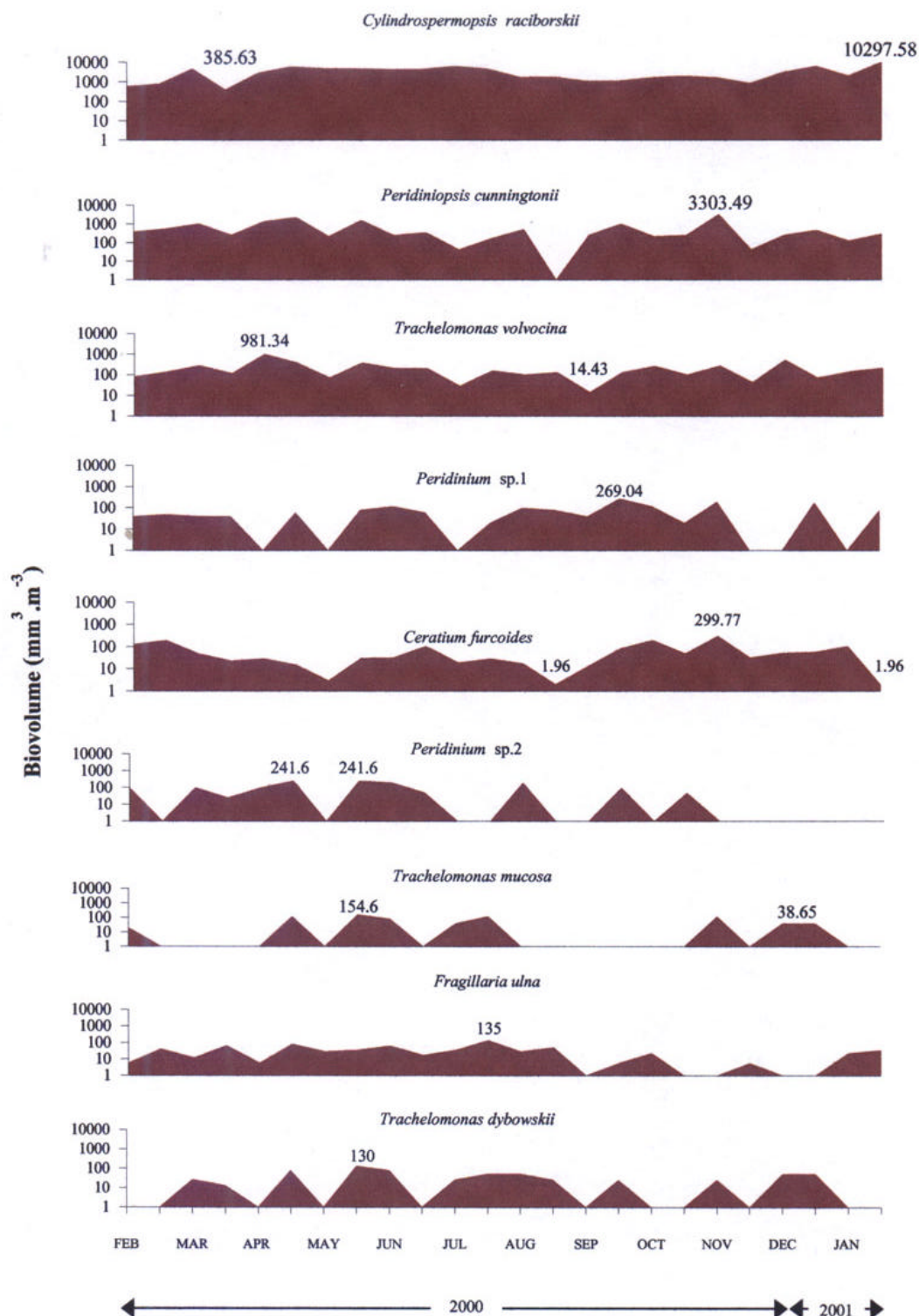
Figure 4.55 Comparison of the biovolume (mm³.m⁻³) of the dominant species using 10% of the total species of phytoplankton in the first lake of Rama IX lake (February 2000-January 2001)
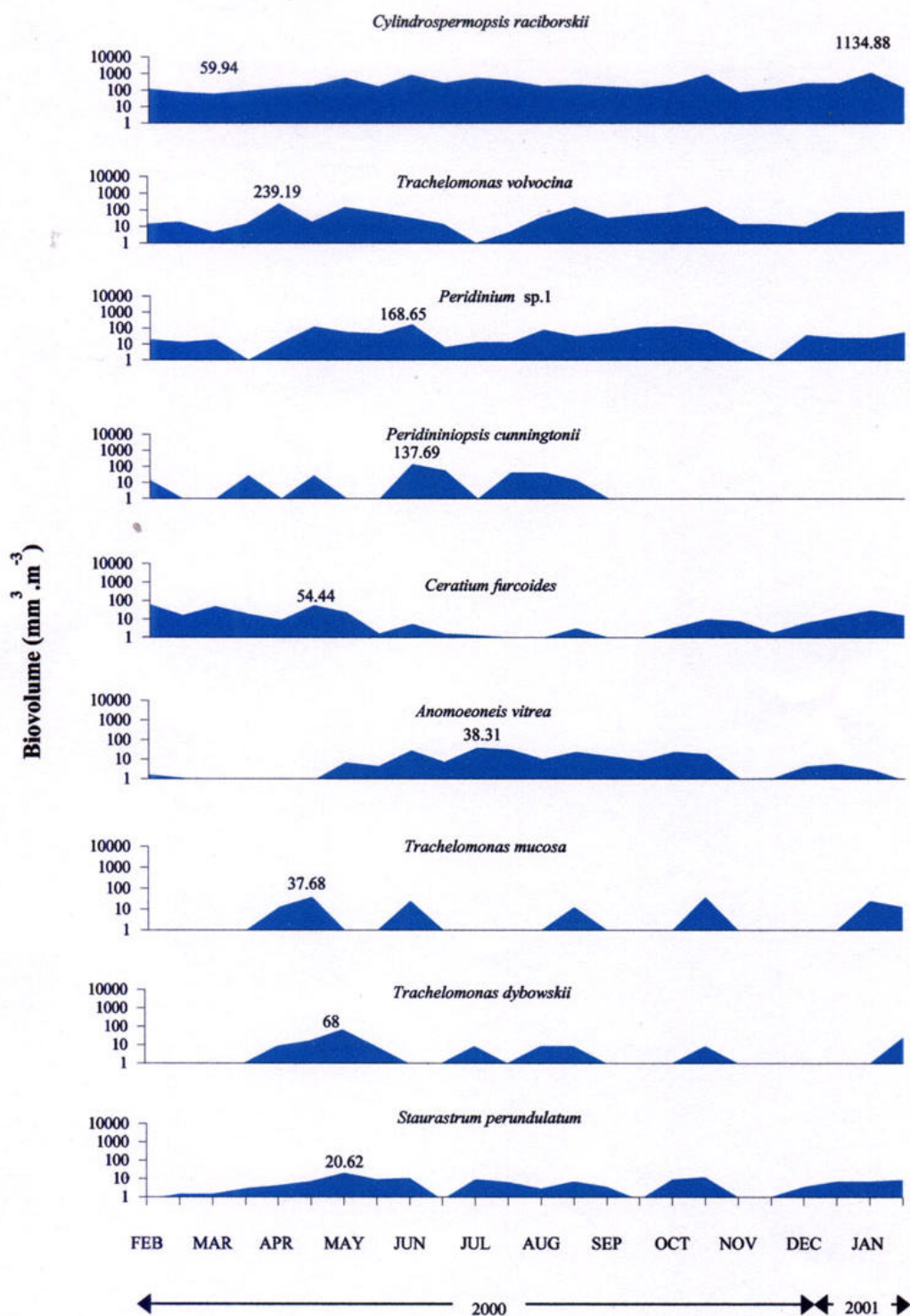
Figure 4.56 Comparison of the biovolume (mm³.m⁻³) of the dominant species using 10% of the total species of phytoplankton in the second lake of Rama IX lake (February 2000-January 2001)
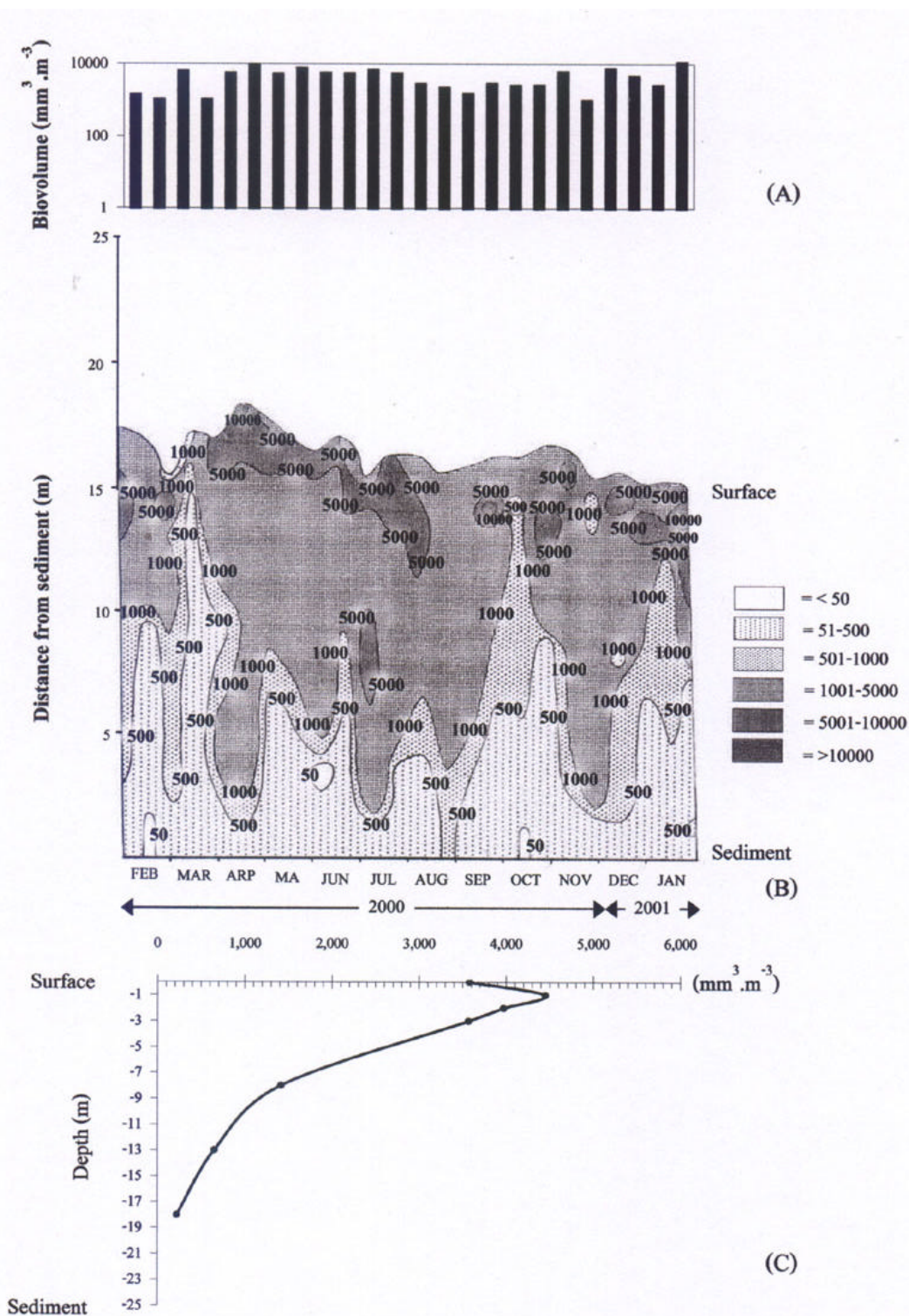
Figure 4.57 Showing the biovolume (mm³.m⁻³) in the first lake of Rama IX lake (A) the graph of the biovolume at the water surface (B) the graph of the different water levels of the biovolume and (C) the graph of the mean biovolume from the water surface to the sediment
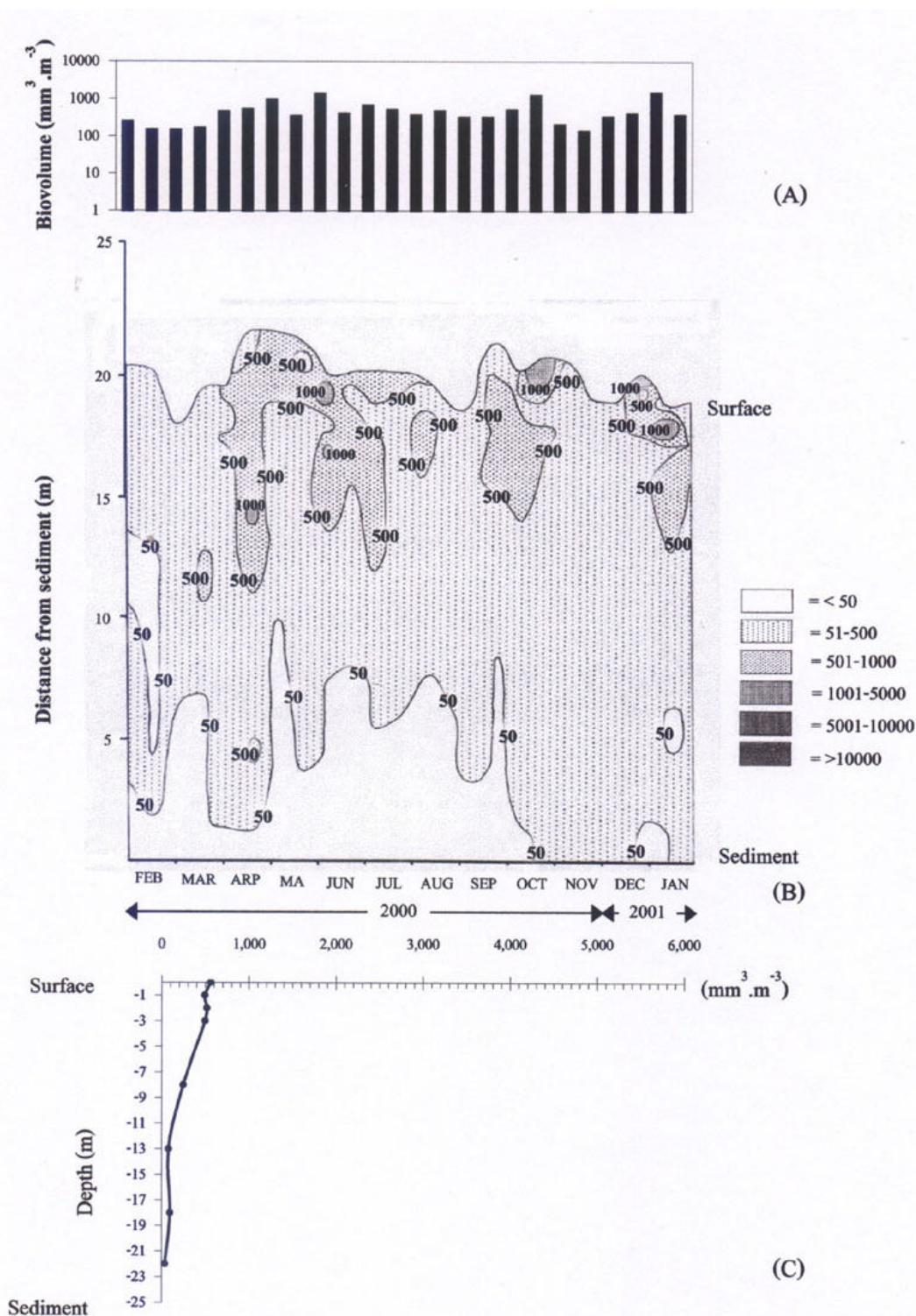
Figure 4.58   Showing the biovolume ($mm^3.m^{-3}$) in the second lake of Rama IX lake (A) the
graph of the biovolume at the water surface (B) the graph of the different water
levels of the biovolume and (C) the graph of the mean biovolume from the water
surface to the sediment

example each depth at 1, 2 and 3 metres it was 20%. The phytoplankton biovolume at the depth of 8 metre was 10%. The percentage of phytoplankton biovolume was low at 13 and 18 metre depths (3% and 4%). However, at the lake's bed there was a very small percentage, about 1% (Figure 4.60)

In both lakes, the phytoplankton biovolume stratification was high at the water surface and slightly lower at lower depths (Figure 4.57; 4.58). In the first lake, the phytoplankton biovolume at the depths 0-3 metres did not substantially differ; however, they were markedly different to the biovolume at 8, 13 metre depths and the bed of the lake. In the second lake, the phytoplankton biovolume did not significantly vary between 0-3 metre depths. However, these figures were different to 8, 13, 18 metre depths and the lake's bed. The biovolume at 13, 18 metre depths and the lake's bed had no significant differences.

In the second lake, phytoplankton biovolume had positive correlation with chlorophyll a (P = 0.05) see Table II-3; Appendix II.

In both lakes, phytoplankton biovolume at the water surface was most abundant in January 2001 because the rainfall had ceased with no sediment running off from the land into the water. This caused a decrease in nutrients from the land into the lake. The turbidity decreased and the sunlight increased and could penetrate into the water. So, phytoplankton were able to increase photosynthesis. Although, the nutrients especially nitrogen and phosphorus, decreased *C. raciborskii* was the dominant species in both lakes and this phytoplankton can fix nitrogen from the air and covert it into nitrate. So, it can grow in water with low levels of nitrate–nitrogen. The phytoplankton biovolume of stratification in both lakes in the surface water tended to be higher than at the lower depths and the bed because the sunlight was able to penetrate into the surface water. So, the phytoplankton grew well and increased the phytoplankton biovolume. In the second lake, phytoplankton biovolume had a positive correlation with chlorophyll a because chlorophyll a is a majority pigment in the cell of phytoplankton which is essential in photosynthesis. When phytoplankton biovolume increases, chlorophyll a will increase too.

According to the investigation, the correlation between dissolved nutrients, and other parameters is related to the dominant species, in the first lake, SRP had positive correlation with *Trachelomonas volvocina*. (P = 0.05) because with the growth of euglenoids all species had a most positive correlation with the nutrients as reported by Wetzel (1983). Sommer
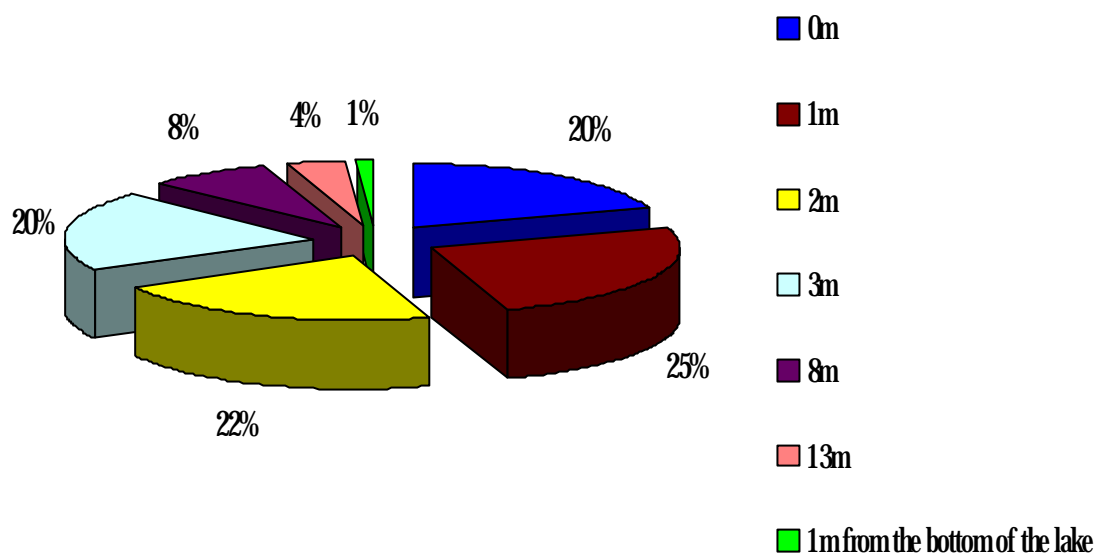
Figure 4.59 The percentage of total biovolume of phytoplankton various depths in the first lake of Rama IX lake (February 2000-January 2001)
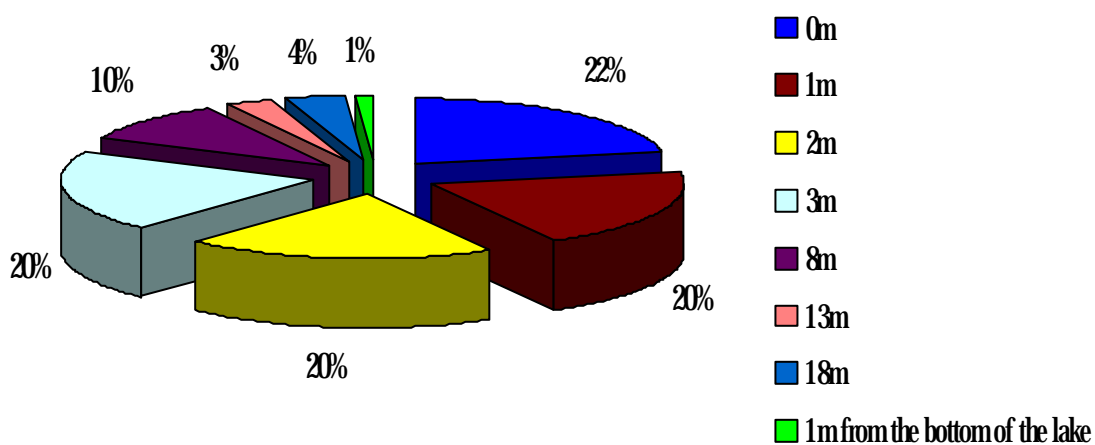
Figure 4.60 The percentage of total biovolume of phytoplankton various depths in the second lake of Rama IX lake (February 2000-January 2001)

(1989) reported that the euglenoids need to use high amounts of phosphorus for growth. In the second lake, SRP had a positive correlation with *Perdiniopsis cunningtonii* (P = 0.01). because this plankton can use SRP for growth. In the water resources which have high phosphorus blue green algae such as *Microcystis, Oscillatoria, Anabaena* and dinoflagellates such as *Peridinium, Ceratium* can be found as reported by Presscott, 1962. In addition, when the water in Ang Kaew reservoir, Chiang Mai increased SRP and ammonia-nitrogen, the dominant species found were *Peridinium inconspicuum, Coelastrum reticulatum, Aulacoseira granulata, Phacus meson* and *Phacus pleuronectus* (Chorum, 1998).

In the second lake, *Peridinium* sp. 1 had a negative correlation with total dissolved solid because the amount total dissolved solid increased which meant an increase in ions such as calcium, magnesium, sodium, potassium etc., nitrogen and phosphorus compound etc. When these TDS increased the *Peridinium* sp.1 grew less. This result may indicate an oligotrophic status of this lake although this phytoplankton did not have the largest phytoplankton biovolume and Rigler and Dillon (1974) reported that nineteen reservoirs in temperate regions when phosphorus increased, the amount of chlorophyll a increased in parallel too.

Based on the investigation, the amount of chlorophyll a in the first lake had a positive correlation with total phosphorus, but there was no statistical correlation between chlorophyll a and phytoplankton biovolume because the dominant species of phytoplankton such as *Peridiniopsis cunningtonii, Trachelomonas volvocina, Peridinium* sp.1 etc. have other pigments such as peridinin, dinoxanthin etc. more than chlorophyll a (¡Ò-¨¹ÀÒª¹•ÅêÓªâ¹-Á¹µ,•2527; Peerapompisal, 1996; Round 1973). Thus, chlorophyll a concentration did not correlate into an increase in biovolume. In the second lake, chlorophyll a had a correlation with phytoplankton biovolume, but there was no statistical correlation between chlorophyll a and total phosphorus because the water quality did not change much. It was rather good and consistent throught the study. Consequently, the factors affecting the growth of the algae became less prominent which agreed with the work of Wetzel, 1983.

4.4.4.6 The categorization of water quality in Rama IX lake

Consideration of the trophic level of both lakes followed Wetzel, (1983) classifications which used different trophic categories according to the chemical, physical and

biological properties of the water and the dominant group of phytoplankton. The amount of chlorophyll a and followed Lorriane and Vollenweider, 1981 classifications (Table IV-2, Appendix IX). The dominant species were classified according to Reynoids, 1980 quoted in Harper, 1992 and the total phosphorus, chlorophyll a, phytoplankton biovolume were measured according to Lampert and Sommer, 1993 quoted in Peerapompisal, 1996; classifications (Table IV-6, Appendix IX). Assessment of the water quality indicated that the first lake was mesotrophic. The second lake was oligotrophic to mesotrophic.

Consideration of the water quality of both lakes was classified using the surface water quality standards of Thailand set by National Environmental Board in 1994. Some parameters used in decision making were color, odor, taste, water temperature, pH, dissolved oxygen, BOD, nitrate-nitrogen, ammonia-nitrogen and total coliform bacterias. The water in both lakes could be placed as being in the second category, but the water from both lakes was relatively clean enough for household consumption after being properly treated. According to the investigation, consideration of the trophic level of both lakes especially phosphorus and nitrogen followed the classificon of Reynoids, 1980 quoted in Happer, 1992; Lampert and Sommer, 1993 quoted in Peerapompisal, 1996; Lorriane and Vollenweider, 1981 and Wetzel, 1983. The water in both lakes was low and the trophic levels did not exceed the standard set by the National Environmental Board in 1994. The water quality of the first lake was found to be mesotrophic at the water surface using the trophic status, color, turbidity and primary production as parameters. However, when the amount of chlorophyll a and phytoplankton biovolume were the parameters, the first lake was considered mesotrophic to eutrophic status. In the second lake, consideration of the water quality at the water surface using the parameters of trophic status, color, turbidity, primary production, chlorophyll a and phytoplankton biovolume revealed the lake was oligotrophic to mesotrophic, as the water in some months could be classified as mesotrophic.

Table 4.3 Comparison of the physical, chemical and biological parameters in the first lake of the Rama IX lakes from 1995 to 2001.

Parameters	ÇÂÐÈÉÑ ÍÔÍÄÇ©Ñ¹ áÅÐ ã¨ÃÂ¨¬Ã Õ¢Ç©Ñ¡ÇÉ (2538-2540)			ÃÑ¨ÅÃÂ¢ÕÒÈÒ áÅÐ ÍÁÍ¡É ¡ÔÔÔ¨ÕÕ§¤• (2540-2541)	The present researcher
	1995	1996	1997	(2540-2541)	(2000-2001)
Conductivity (μs.cm⁻¹)	843-205,000	385-1,123	1,135-1,620	1,500	620-870
PH	3.1-7.2	6.6-7.7	6-7.8	6.6-7.2	7.68-8.87
Alkalinity (mg.l⁻¹)	0-76.6	19.5-68.1	5-43	9-10	53.30-99.50
Total hardness (mg.l⁻¹)	138.1-4,850	122.1-337.8	317.3-411.0	368-385	174-190
NH₃-N (mg.l⁻¹)	-	-	-	0.2	0.0120-0.23
NO₃-N (mg.l⁻¹)	-	-	-	1.5-1.8	0.0006-0.0839
Total phophorus (mg.l⁻¹)	-	-	-	0.6-0.8	0.0035-0.0259
E.coli (MPN. Mg.l⁻¹)	-	-	-	<3	-
Coliform bacteria (MPN.100mg.l⁻¹)	-	-	-	-	4-460

Table 4.4 Comparison of the physical, chemical and biological parameters in the second lake
of Rama IX lakes from 1995 to 2001 (ND = non detectable)

Parameters	ÇÑÈ¡ÒÍÔ¹·ÃÕ áÅÐ ã¨ÒÃ¨Ò ¢Ñ¹¸ì (¾.È.2538-2540)			ÃÒÁÒà¸ÕºÅ áÅÐ ÍèÍÂ ¡ÙÅÒ§Ò¤ (2540-2541)	The present researcher (2000-2001)
	1995	1996	1997		
Conductivity (µs.cm¹)	433-14,090	1,156-1,563	1,345-1,914	1,600	1,110-1,360
pH	3.3-7.5	6-8.1	6.6-7.6	7.1-7.3	7.25-7.92
Alkalinity (mg.l¹)	0.7-6.6	10-33.5	6-24.5	20-21	22.40-38.00
Total hardness (mg.l¹)	140.6-2,208	210-7.436.9	325.3-432.4	356-369	275-290
NH_3-N (mg.l¹)	-	-	-	0.1-0.2	0.0119-0.1874
NO_3-N (mg.l¹)	-	-	-	1.7-2.0	ND-0.0393
Total phophorus (mg.l¹)	-	-	-	0.3-0.6	0.0017-0.0335
E.coli (MPN. mg.l¹)	-	-	-	<3	-
Coliform bacteria (MPN.100mg.l¹)	-	-	-	-	4-240

According to Tables 4.3-4.4, the water quality in 2000-2001 in both lakes was better than in 1995-1998 because the conductivity, total hardness and the amount of total phosphorus, ammonia–nitrogen and nitrate–nitrogen decreased whilst alkalinity and pH increased. Furthemore, the acidity of the water in the lakes decreased because rainfall and water from outside the lakes were drained into the lake diluting the acidity of the lake in 1995. This gradually improved the water quality and the water from these lakes can now be used for agricultural and household consumption. However, the water hardness and the conductivity was high in both lakes throughout the investigation, especially in the first lake. They both showed high levels of total salts but low levels of nutrients in both lakes.

In addition, the water management authorities should ensure that no wastewater and no disposal of rubbish are released into the lake to protect the water quality for future public benefit.

4.4.4.7 The correlation between water quality and phytoplankton

According to the investigation in the first lake the phytoplankton biovolume decreased in the rainy season because the rainfall washed the sediments and organic matter from the land into the lake. This event caused an increase in the turbidity in the water which decreased the sunlight penetration into the water. So, it resulted in the decrease in photosyn-thesis of phytoplankton causing the phytoplankton biovolume, primary productivity and dissolved oxygen to fall.

This result corresponds to the report of Stepanek, (1959); Szczepanski, (1968) who found that the reduction of Secchi transparency measurement is associated to a great extent with increased scattering by particulate matter suspensoids. Furthermore, ÅÑÒ ÇŞÈÃłÑ (2538) reported that the seasons were essential for the quantities of phytoplankton in the river and streams, especially in tropical regions. The rainfall washes soil or sediment into rivers. This condition causes an increase in turbidity and decreases Secchi depth and photosynthesis of phytoplankton. So, the phytoplankton decrease in the rainy season. The phytoplankton biovolume was at its highest in the cold season, especially in January 2001, and was quite high in April and July 2000. Because the small amount of rain caused the water to possess greater clarity and the sunlight could penetrate further into the water. The rainfall also caused an increase in the amount of carbondioxide in the water resources, especially in April and July 2000. The condition of having sunlight and carbondioxide caused the phytoplankton to increase the rate of photosynthesis and it meant more dissolved oxygen was produced. So, the pH and alkalinity increased too. This result resembles the report of äÁµÃÕ ÇŞÉÇÑ¸Å¡Å·ÕÃ³ ÊÅÈ (2528) and Wetzel (1975) who found that the precipitation can induce photosynthetic utilization of carbondioxide by algae and submerged macrophyte. The result is a marked decrease in the total inorganic carbon of the epilimnion. The decrease of the carbondioxide content causes changes in the component of alkaline from HCO_3^- to $CO_3^=$ and to OH^- respectively. The changes cause an increase in the pH and alkalinity in the water. Furthermore, Shirota (1966) found that the quantities of phytoplankton in the cold season were higher than in the rainy season because the water was clearer. The sunlight can penetrate far into the water and increase the rate of photosynthesis in phytoplankton.

The alkalinity had a negative correlation with the water hardness because the water level decreased in the cold season. The decrease in water level and increase in the metals such as Ca^{++}, Mg^{++}, etc. In turn the water hardness and conductivity in the water increased. In addition, during the day time, phytoplankton were able to increase the rate of photosynthesis and increase the use of carbondioxide content in the water. The photosynthesis caused an increase in the pH level to 8 or 9 in the water, but in the cold season the alkalinity at the surface decreased. The ionization of $Ca(HCO_3)_2$ was caused by the dissociation, as shown in the following equation $Ca(HCO_3)_2 \longrightarrow CaCO_3 + CO_2 + H_2O$. The result was $CaCO_3$ sediment on the bed of the lake and CO_2 maintained the pH of the water at a level not over 8 (à»ÂÂÈ¡ÑÂ¡Â¹ ÐÈÇµ, 2539; Swingle, 1969). When the ions such as Ca^{++} combined with CO_3 sedimentation sank to the hypolimnion. The alkalinity at the water surface decreased, but alkalinity and hardness at the bottom of the lake increased. This, combined with the water level, decreased in the cold season. It caused an increase in total hardness and conductivity in the water. Although the carbondioxide was used by algae and submerged macrophyte the alkalinity decreased because the remaining salts stayed at the epilimnion.

The conductivity had positive correlation with total dissolved solids because the total dissolved solids could ionize to ion which can conduct electricity and their conductivity can be measured (¡ÃÃ³ÔÃ•ÊÑ¹ÉÚ, 2525). The BOD of both lakes was high in the early stages of this investigation because the organic substances were contaminated by polluted water which was drained into the lake during December 1999-January 2000. This caused high readings of BOD in the water resources, findings which agreed with the work of ¢ÒÂÅ¡Ñ³Ì• ¡Õ¹Ð¼ÙÕ Ô (2536), if the water has high BOD it indicates there is a high level of organic substances in the water. However, the BOD was highest in the rainy season. The rainfall washed down the sediment and organic substances from the land into the water resources. This action caused an increase in the quantities of bacteria in the water. The nutrients were digested by bacteria which used high amounts of oxygen causing an increase of BOD. This finding agreed with the research of Pooarlai, (1999) who found that nitrogen increased in the rainy season with the sediment around the lake washed down into the lake. The sediment washed down caused an increase in coliform bacteria and dissolved oxygen was consumed by coliform bacteria for digestion of organic substances.

In the first lake, the nutrients at the water surface were low throughout the study. Although, in some months the nutrients were plentiful they did not exceed the surface water quality standards of Thailand. In the first lake, the amount of nutrients were a little higher than in the second lake.

In the first lake, nitrate-nitrogen and ammonia-nitrogen had no statistical correlation with other parameters. The amount of nitrite-nitrogen had positive correlation with the turbidity because in the rainy season, the rainfall washed down the sediment from the land into the lake. This condition caused turbidity and the decrease in the amount of dissolved oxygen in the first lake. The amount of total phosphorus was low throughout the study in the first lake. The amount of total phosphorus had a positive correlation with the amount of SRP and chlorophyll a because the large amount of total phosphorus in the water could dissolve and turn into high level of SRP. The amount of total phosphorus increased in the rainy season, especially form July to August 2000. Phosphorus caused an increase in chlorophyll a. This result resembles the report of Home and Goldman (1994) who found that in most lake studies there is a direct relationship between the concentration of the growth-limiting nutrients and the maximum crop of phytoplankton. In the temperate zone, there are many lakes where the amount of total phosphorus is statistically well-related to the maximum phytoplankton abundance as shown by chlorophyll a.

In the second lake, Secchi depth had a negative correlation with the turbidity and positive correlation with BOD, as in the first lake. The turbidity in this lake was low throughout this study but noticeably the turbidity increased slightly, not due to sediment as in the first lake, but due to an increase in phytoplankton, in April, July 2000 and January 2001. The second lake receives water form the first lake. Its capacity is therefore higher. The higher capacity of water causes greater water clarity than in the first lake. The water temperature had a positive correlation with pH because the water temperature at the water surface was high causing an increase in the ionization of organics, inorganics, nutrients such as nitrate-nitrogen. This resulted an increase in the TDS value in this lake. The TDS could ionize to ion which can conduct electricity and their conductivity can be measured (¡ÃÃ³ÕÃ• ÊÕÃÕ•, 2525). In addition, äÁµÃÕ ÇŞÉÇÑ ¢ÅÐ ¨ÕÇÃÃ³ ÊÁÊÕ 2528) reported that conductivity increases when the water temperature increases because the temperature affects the ionization of

components. The nutrients can ionize to ions which increases the conductivity and the rate of photosynthesis of phytoplankton. They use the increase of carbondioxide and this in turn causes an increase in pH, alkalinity and dissolved oxygen in the water. The finding corresponds to the report of Chorum (1998) who found that when phytoplankton increases, the rate of photosynthesis and carbondioxide used increases. This in turn increases the pH, alkalinity and dissolved oxygen in this lake. The amount of total phosphorus had a positive correlation with SRP because total phosphorus could dissolve into SRP. When the nutrients increase, the phytoplankton grows well. This condition causes an increase in phytoplankton biovolume with a corresponding incrase in the amount of chlorophyll a. The result resembles the study of Hofstraat et.al. (1994) who found that chlorophyll standard beads serve this purpose well and can be used to calibrate all relevant parameters for phytoplankton studies. The coliform bacteria had a positive correlation with BOD because the organic substances increased which caused an increase in the amount of coliform bacteria which in turn meant an increase in the use of oxygen.

The second lake was oligotrophic. The water quality changed little throughout the investigation resulting in a low correlation between the growth of phytoplankton with the parameters affecting the growth of phytoplankton. The finding corresponds to the study of Wetzel, (1983) who also found that the water quality did not change much. It was rather good and consistant throughout the study. Consequently the factors affecting the growth of the algae become less prominent. In both lakes, the water hardness was high, especially in the second lake where the water hardness at the surface was higher than the water hardness in the first lake. In both lakes, water hardness exceeded the water quality standard of water supply which standardize water hardness as between 50-80 mg.l^{-1} (¡ÃÁÍ¹ÒÂÑ,2539).

4.4.4.8 Species of phytoplankton can indicate the water quality

According to the investigation, *Cylindrospermopsis raciborskii* was the dominant species with a high phytoplankton biovolume through the study in both lakes. In the first lake, the phytoplankton biovolume of dominant species exceeded 5,000 mm^3.m^{-3}. in April, July, December 2000 and January 2001 and tended to reflect the total phytoplankton biovolume which exceeded 5,000 mm^3.m^{-3}. in March to July 2000, November to December 2000 and January 2001. The amount of total phosphorus was low, between 10-20 μg.l^{-1} throughout this study. The amount of chlorophyll a was high, exceeding 10 μg.l^{-1} in early March 2000, the end of April

2000, early June 2000, the end of July 2000, August 2000, the end of October 2000, November 2000 and the end of December 2000 and the end of January 2001. These values can be categorized as trophic classes in temperate lakes. Following Lampart and Sommer, 1993 quoted in Peerapompisal, 1996 this lake was mesotrophic classification to eutrophic.

In the second lake, the phytoplankton biovolume of the dominant species was highest in January 2001 whereas the total phytoplankton biovolume was at its highest in the some month too. However, phytoplankton biovolume was low throughout the investigation and did not exceed 2000 $mm^3.m^{-3}$. The amount of total phosphorus was at its largest at 30 $\mu g.l^{-1}$ in January 2001 and in the other months was low throughout the investigation. The amount of chlorophyll a was low and did not exceed 3 $\mu g.l^{-1}$; however, throughout the study sometimes this value did exceed 3 $\mu g.l^{-1}$, such as at the end of May 2000 at 12 $\mu g.l^{-1}$ and at 7 $\mu g.l^{-1}$ in early June 2000. These values could be categorized as oligotrophic to mesotrophic according to Lamport and Sommer, 1993 quoted in Peerapompisal, 1996. The study of *C. raciborskii* in this investigation was compared with the report by Peerapompisal (1996) who studied phytoplankton in Huai Hong Khrai Royal Development Study Centre, Chiang Mai. Her finding showed that the phytoplankton of three reservoirs of Huai Hong Khrai Royal Development Study Centre was dominated by *C. raciborskii* as found throughout this investigation.

According to the investigation, *C. raciborskii* tended to have negative correlation with nitrate-nitrogen and ammonia-nitrogen (Figure 4.61). Although these nutrients decreased at the water surface the phytoplankton biovolume did not decrease because this phytoplankton can adapt in low nitrogen water. *C. raciborskii* is able to fix nitrogen from the environment and convert it to ammonium and protein (Relynalds 1984; Harris 1986). Furthermore, this phytoplankton has various abilites as mentioned in part 4.4.4.3 regarding to the dominant species. This result corresponds to the study of Peerapompisal (1996) and Pooarlai (1999) who found that *C. raciborskii* showed a positive correlation with soluble reactive phosphorus and chlorophyll a; however, it showed a negative correlation with nitrate-introgen and ammonium-nitrogen and indicated mesotrophic to eutrophic status. In addition, this result resembles the report of Bronco and Senna, (1994, 1996) who studied phytoplankton composition and seasonal changes in Paranoa's Reservoir in Brazil and found that during the rainy season, the rainfall diluted nitrate and soluble reactive phosphorus levels. The decrease in these two

nutrients caused an increase in the densities of *C. raciborskii*. The high biomass of *C. raciborskii* found in the Paranoa's Reservoir seemed to influence directly most of the physico-chemical parameters such as pH, temperature and oxygen saturation. The physio-chemical parameters have been explained as a consequence of temperature increase that accelerates photopsynthesis, which in turn absorbs carbondioxide, altering the bicarbonate equilibrium; raising the pH and producing oxygen.

Furthermore, according to the investigation the second dominant phytoplankton were *Peridiniopsis cunningtonii* and *Trachelomonas volvocina*, etc. In the first lake, *T. volvocina* had a positive correlation with SRP (P = 0.05). This finding corresponds to the report of Presscott, 1962 who found that the water resources contained high levels of phosphorus which meant there were few species of phytoplankton, some examples were *Microcystis, Oscillatoria, Anabaena* etc. and dinoflagellates. *Peridinium* and *Ceratium* were found in high quantities. According to Figure 4.61 when the increase in the growth of *Peridiniopsis cunningtonii* occurred the total phosphorus increased as in April 2000. Based on the study of phytoplankton biovolume the dominant species of phytoplankton, chlorophyll a and total phosphorus compared to the study trophic status by Lampert and Sommer, 1993, quoted in Peerapompisal, 1996, Lorraine and Vollenweider (1981) and Wetzel (1983), which found that *C. raciborskii, Peridiniopsis cunningtonii* and *Trachelomas volvocina* were dominants and indicated as mesotrophic to eutrophic the water status in the first lake. This result corresponds to the work of Kalff and Watson (1986) who studied *C. raciborskii* in an eutrophic lake of the tropical zone in Kenya. They found *C. raciborskii* was the dominant species, but when the nutrients increased *C. raciborskii* decreased whilst *Microcystis aeruginosa* and Chlorophyceae, sach as *Botryococcus braunii, Cosmarium pseudoprotuberans* var. *alpinum* increased. Furthermore, Gunatilaka (1984) and Rott (1983; quoted in Schiemer, n.d.) found a large amount of *C. raciborskii* in the Parakrama Samuda, a shallow man-made lake in Sri Lanka (PSN Lake) in an eutrophic well with low water levels.

In the second lake, *C. raciborshii* was the dominant species and the next dominant species were *T. volvocina, Peridinium* sp.1, *Peridiniopsis cunningtonii, Ceratium furcoides* etc. respectively. *Peridiniopsis cunningtonii* had a positive correlation with SRP (P = 0.01) whereas *Peridinium* sp.1 had a negative correlation with TDS (P = 0.05) (Table II-3;
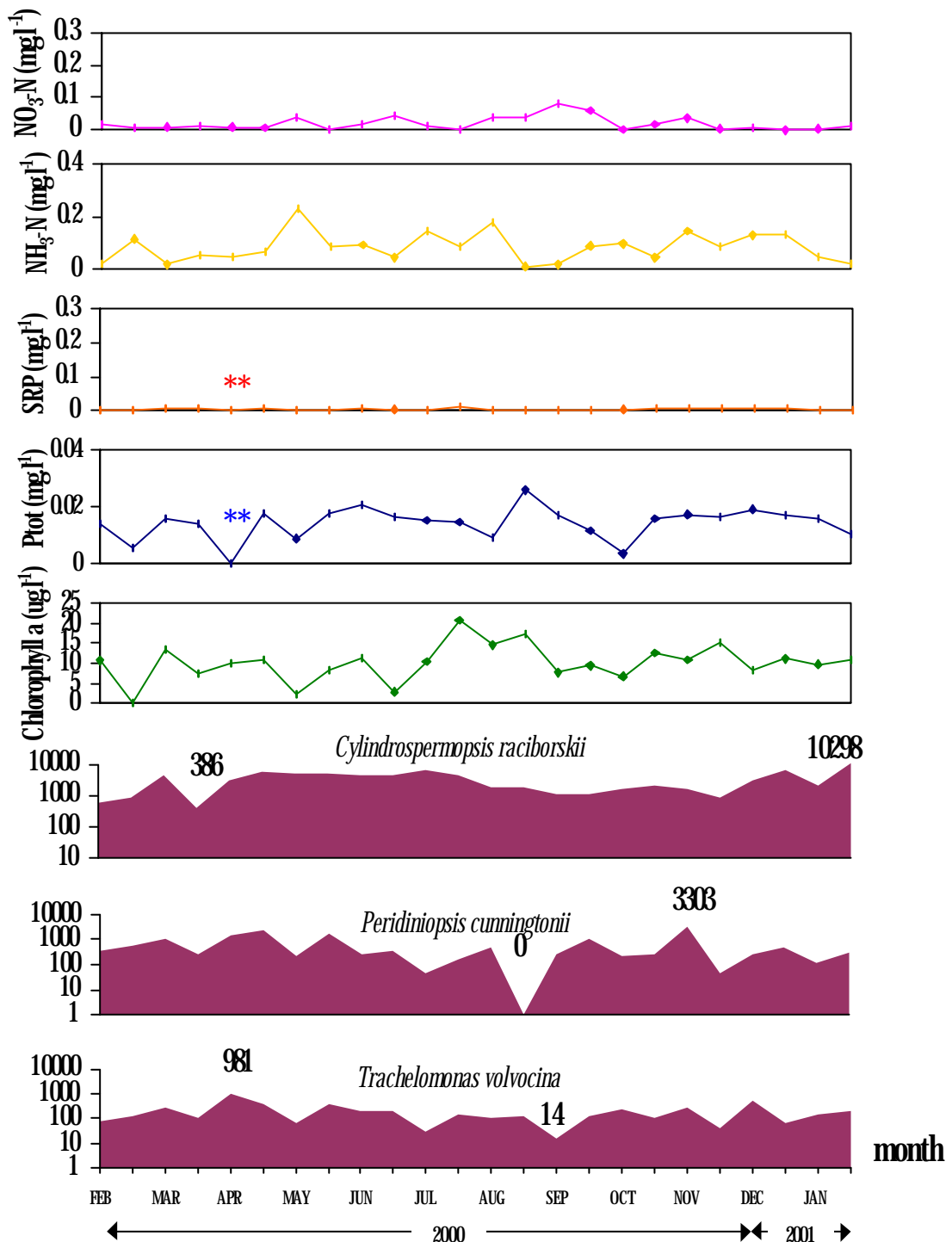
Figure 4.61   The correlation between dissolved nutrient (mg.l⁻¹), total phosphorus (mg.l⁻¹) chlorophyll a (g.l⁻¹), related to the dominant species in the first lake of Rama IX lake (February 2000-January 2001) ** = not analysed

Appendix II) *C. raciborskii, T. volvocina, Peridiniopsis cunningtonii* tended to indicate mesotrophic status *Peridinium* sp. 1 had a negative correlation with TDS. It showed an increase in ion, nutrients etc. which caused a decrease in the quantities of *Perdinium* sp. 1. Figure 4.62 shows a decrease of nitrate-nitrogen and total phosphorus, especially in June 2000. This increased the quantities of *Peridinium* sp.1. In addition, there are many publications which show the use of *Peridinium* as an indicator of water quality. Ariyadej (1997) who studied the correlation of some nutrients and phytoplankton distribution in the reservoir of Mae Kuang Udomtara dam, Chiang Mai found that the phytoplankton which showed a close relationship between the nutrients were *Peridinium cintum* and *Ceratium hirundinella*. The phytoplankton, commonly found, were *Peridinium cinctum, Ceratium hirundinella, Staurastrum* spp. and *Ankistrodesmus* spp. and indicated a oligotrophic-mesotrophic reservoir. Wannasai (1999) analysed the water quality using phytoplankton and coliform bacteria as indicators in Huai Mae Yen reservoir, Chiang Mai and found that *P. cinctum* had a negative correlation with the nutrients. It increased when the nitrate-nitrogen and SRP decreased. Sommer (1959) found that the amount of nitrogen and phosphorus had a negative correlation with the growth of *Ceratium hirundinella, Peridinium cinctum* and *Peridinium* spp. Furthermor, Reynolds (1984) found that the oligotrophic lake had low nitrogen and phosphorus levels cannot found fixing nitrogen phytoplankton. When the amount of nitrogen and phosphorus were low the dinoflagellate such as *Ceratium* sp. and *Peridinium* spp. were the dominant species. Chorum (1998) who studied the biological analysis of water quality using phytoplankton and coliform-bacteria in Ang Kaew reservoir, Chiang Mai University 1996-1997 and found that phytoplankton such as *Coelastrum reticulatum, Aulacoseira granulata,* and *Peridinium inconspicuum* could indicate the presence of moderate and polluted water.

The aforementioned species are of a particular kind, usually a flagellated form with considerable cellular volume, they contain high levels of chlorophyll a and reproduce slowly having adapted to surroundings with low mineral nutrients. The slow rate of reproduction results in an expansion of specific diversity with a very high volume of pigment diversity according to Moyá and Romá, 1984.

The second lake had water with low acidity at the bottom of the lake. *Cylindrospermopsis raciborskii* was the dominant species in this lake. This finding corresponds
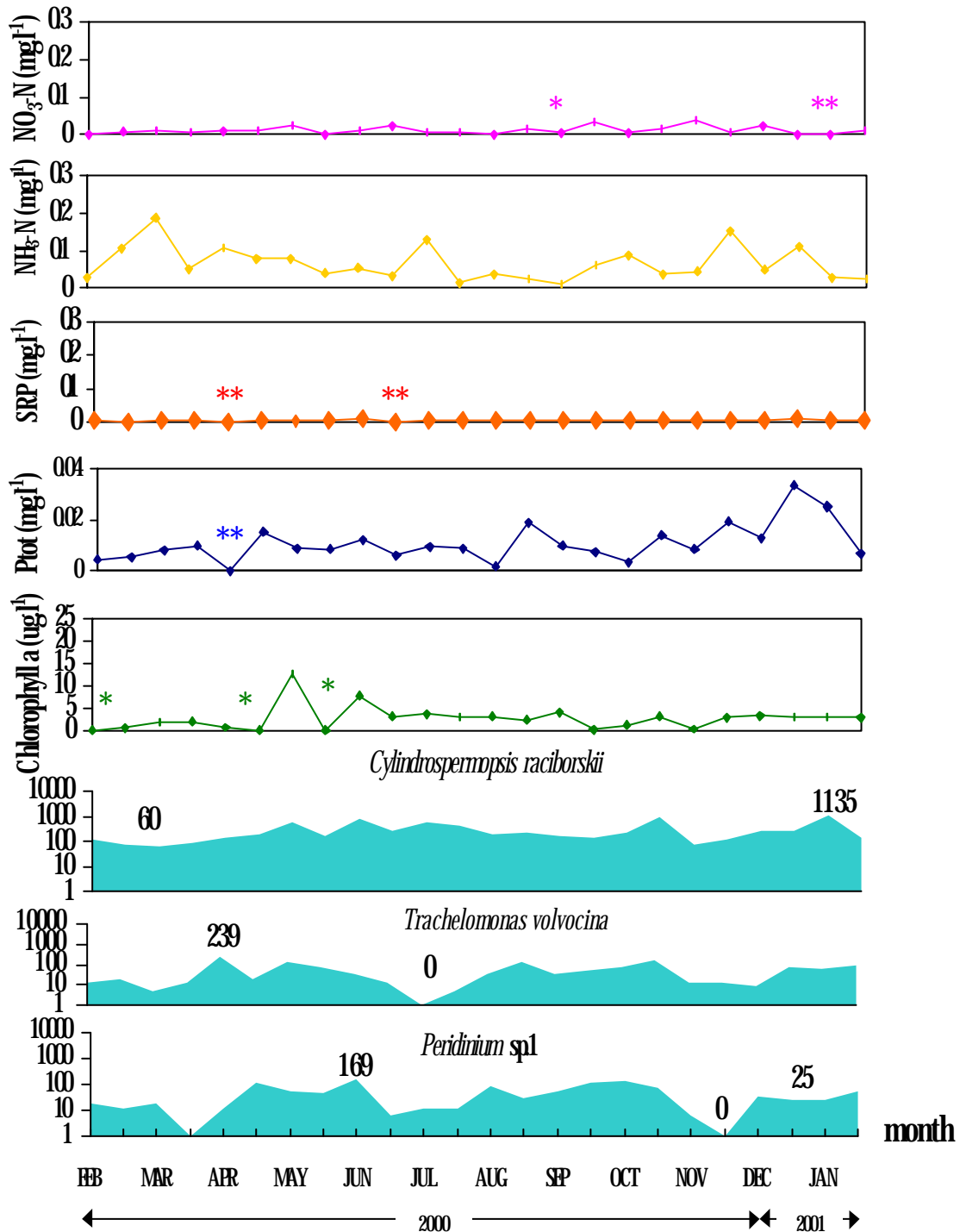
Figure 4.62 The correlation between dissolved nutrient (mg.l⁻¹), total phosphorus (mg.l⁻¹) chlorophyll a (μg.l⁻¹), related to the dominant species in the second lake of Rama IX lake (February 2000-January 2001) * = non detectable and ** not analysed

to the studies of Almer, Dickson, Ekström, Hornström and Meller (1974), Conroy, Hawley, Keller & Lafrance, (1975) and Kwiatkowski and Roff (1976) who found that blue green algae can be dominant in lakes of moderate acidity. In addition, the conductivity in the second lake was found to be higher than that of the first lake. The high phytoplankton biovolume such as *Anoemoeoneis vitrea* in the second lake could be used as indicator of high level of conductivity. The result corresponds to the report of Round, Crawford and Mann, 1990. They found that *Anoemoeoneis vitrea* was found in waters with high conductivity.

In both lakes, the water hardness was quite high. The dominant phytoplankton were *C. raciborskii*, other dominants were Dinophyceae and Euglenophyceae. This finding coresponded to the work, of Smith (1950) who studied the correlation between phytoplankton and total hardness and found that the quantities of Chrysophyta, Bacillariophyta and Pyrrophyta had a positive correlation with total hardness at the water surface. It shows the quantities of the phytoplankton increase when the total hardness in the water increases.

Water hardness consists of two elements of divalent melaltic cation such as calcium and magnesium elements as well as other metals such as Fe^{++}, Mn^{++} etc.; however, calcium and magnesium are essential metals for the growth of algae (Smith, 1950). The minerals in the waters are essential for the existence and growth of phytoplankton. Since magnesium is a constituent of chlorophyll, it is plainly an absolute requirement of pigmented algae of all groups and is also necessary for the formation of catalase. Magnesium is an essential cofactor or activator in many reactions, such as nitrate reduction, sulfate reduction and phosphatetransfers involving adenosine triphosphate and diphosphate (ATP and ADP). Calcium ions undoubtedly play a part in the maintenance of cytoplasmic membranes and in wall structures (Home and Goldman, 1994; Vymazal, 1995). Fogg (1975) found that some genus of Chrysophyta, such as *Dinobryon* and Diatom were found in high quantities in high hardness water. Some groups of Chyrsophyta, such as coccolithophorid use calcium as cover for protection called coccolith thrives when there is high water hardness and high calcium in the water. Putthathorn (1986) who studied the abundance and distribution of algae as related to some water quantities of Ping-Wang River Basin and found that the quantities of diatoms had positive correlation with calcium quantity whereas Pyrrophyta and *Euglena* could grow well in high calcium water resources Boonyapiwat (1987) and Suravit (1996) studied the relationsphips between phytoplankton and

water quality in Racha-Prabha Reservoir, Suratthani province and found that *Peridinium* sp. had a positive correlation with the water hardness calcium and the conductivity. According to the investigation of both lakes apart from *C. raciborskii*, Euglenophyceae such as *Euglena* and *Trachelomonas* and others were the only dominant species because at the ground level high ammonia nitrogen was present. These aforementioned phytoplankton grow well in water with organic and decomposing matter. They move vertically up and down through the water column and this vertical movement allows access to the nutrient-rich hypolimnion during periods of low nutrients levels in the epilimnion. So these phytoplankton can adapt to both lakes although there are low nutrients at the epilimnion.

CHAPTER V
CONCLUSION

This investigation is a study of water quality using phytoplankton biodiversity as the monitoring indicator combined with a study of water quality using physical, chemical and some biological parameters in Rama IX lake, Pathumthani province, Thailand from February 2000 to January 2001. The objectives of the study are: (1) To study the biodiversity of phytoplankton in Rama IX lake (2) To study the correlation between, the physical, chemical and other biological parameters of water quality according to the changes in phytoplankton in order to find out the trends for monitoring water quality in terms of the biological quality of the water in Rama IX lake. Collection of water samples was conducted twice a month at the deepest points of both lakes in a total of 15 points. Rama IX is a big lake and consists of 2 parts. The first lake covers an area of about 790 rai and the second lake covers an area approximately 1,790 rai.

5.1 The results

5.1.1 Lake's morphometry

The study of the lake's morphometry was done by making contour lines of both lakes for finding the deepest points of both lakes. It was found that in the first lake, the widest part was 1,110 metres and the longest part was 1,195 metres. The surface area of this lake was 1,264,000 square metres. The capacity of this lake was 7,820,000 cubic metres and the deepest point was 19.63 metres. The second lake, at its widest was 1,150 metres, at its longest was 2,215 metres. The surface area was 2,864,000 square metres and the capacity was 17,400,000 cubic metres. The deepest point was 21.63 metres.

5.1.2 The study of the physical parameters of water quality

In the first lake, the depth of the water varied from 15.00-18.40 metres, the average depth was 16.40 metres. The Secchi depth fluctuated between 0.67-1.32 metres, with an average Secchi depth of 0.96 metres. The water temperature ranged from 27.60-32.83°C with an average of 30.36°C . The turbidity varied from 3.15-8.58 NTU, the average turbidity was 5.66 NTU. The conductivity measured between 620-870 μs.cm^1, with an average of 717.75 μs.cm^1 The total dissolved solids (TDS) fluctuated between 300-430 mg.l^1 with an average of 351.38

$mg.l^{-1}$

In the second lake, the depth of the water rose and fell from 18.32-22.43 metres, with the average being 20.33 metres. The Secchi depth was from 1.50-2.40 metres. The average of this value was 1.86 metres. The water temperature fluctuated between 27.17-32.50°C, the average of this value was 30.06°C. The turbidity measured between 1.93-3.77 NTU with an average being 2.14 NTU. The conductivity ranged between 1,110-1,360 $\mu s.cm^{-1}$, with an average of 1,160.50 $\mu s.cm^{-1}$. The total dissolved solids varied from 550-670 $mg.l^{-1}$, with an average of 576.25 $mg.l^{-1}$

5.1.3 The study of the chemical parameters of water quality

In the first lake, the pH of the water was between 7.68-8.87, the average pH was 8.33. The average alkalinity content was 63.52 $mg.l^{-1}$, ranging from 53.30-99.50 $mg.l^{-1}$. The dissolved oxygen varied from 4.96-9.70 $mg.l^{-1}$, with an average DO of 7.54 $mg.l^{-1}$. The biochemical oxygen demand varied from 0.30-4.20 $mg.l^{-1}$, with an average BOD of 1.53 $mg.l^{-1}$. The water hardness average was 182.13 $mg.l^{-1}$, with values between 174-190 $mg.l^{-1}$. The amount of nitrate–nitrogen varied from 0.0006-0.0839 $mg.l^{-1}$, with an average of 0.0204 $mg.l^{-1}$. The amonia–nitrogen fluctuated from 0.0120-0.2300 $mg.l^{-1}$, with the average ammonia nitrogen of being 0.0846 $mg.l^{-1}$. The average nitrite–nitrogen content was 0.0021 $mg.l^{-1}$, with values between 0-0.0068 $mg.l^{-1}$. The amount of total phosphorus ranged from 0.0035-0.0259 $mg.l^{-1}$, with an average of 0.0148 $mg.l^{-1}$. The SRP content was between 0.0006-0.0129 $mg.l^{-1}$, with an average of 0.0043 $mg.l^{-1}$.

In the second lake, the pH fluctuated between 7.25-7.92, with an average pH of 7.61. The alkalinity of the water ranged from 22.40-38.00 $mg.l^{-1}$, with an average of 26.10 $mg.l^{-1}$. The dissolved oxygen swung from 5.60-7.42 $mg.l^{-1}$, with an average of 6.80 $mg.l^{-1}$. The average BOD was 0.70 $mg.l^{-1}$, with values between 0.61-2.60 $mg.l^{-1}$. The water hardness ranged from 275-290 $mg.l^{-1}$, with an average of 280.73 $mg.l^{-1}$. The nitrate–nitrogen content fluctuated between non-detectable (ND)–0.0393 $mg.l^{-1}$, the average being of 0.0121 $mg.l^{-1}$. The average content of ammonia–nitrogen was 0.0658 $mg.l^{-1}$, with values between 0.01190-0.1874 $mg.l^{-1}$. The amount of nitrite–nitrogen varied from 0-0.0136 $mg.l^{-1}$, with an average of 0.0025 $mg.l^{-1}$. The amount of total phosphorus ranged from 0.0017-0.0335 $mg.l^{-1}$, the average content of SRP was 0.0043 $mg.l^{-1}$, with values ranging from 0.0009-0.0113 $mg.l^{-1}$.

5.1.4 The study of the biological parameters of water quality

In the first lake, the gross primary production (GP) varied from 0.10-0.97 mg.O_2.l^{-1}. hr.$^{-1}$, with an average of 0.52 mg.O_2.l^{-1}. hr.$^{-1}$ Net primary production (NP) fluctuated from 0.03-0.75 mg.O_2.l^{-1}. hr.$^{-1}$, with the average being of 0.32 mg.O_2.l^{-1}. hr.$^{-1}$ The respiration ranged from 0.02-0.82 mg.O_2.l^{-1}. hr.$^{-1}$, with a mean of 0.23 mg.O_2.l^{-1}. hr.$^{-1}$ The amount of chlorophyll a rose and fell from 0.1184-20.6608 μg. l^{-1}, the average chlorophyll a was 10.0810 μg. l^{-1}. The coliform bacterias ranged from 4-460 MPN.100 ml^{-1}, with the average being 113.75 MPN.100 ml^{-1}. The phytoplankton biovolume varied from 967.24-11,084.16 mm^3.m^{-3}, the mean was 4,451.55 mm^3.m^{-3}.

In the second lake, gross primary production fluctuated from 0.10-0.55 mg.O_2.l^{-1}. hr.$^{-1}$, with an average of 0.25 mg.O_2.l^{-1}. hr.$^{-1}$. Net primary production was between 0.02-0.8 mg.O_2.l^{-1}. hr.$^{-1}$, the average was 0.15 mg.O_2.l^{-1}. hr.$^{-1}$ Respiration fluctuated from 0.03-0.37 mg. O_2.l^{-1}. hr.$^{-1}$, with the average being 0.13 mg.O_2.l^{-1}. hr.$^{-1}$ The chlorophyll a varied from non-detectable (ND)-12.6096 μg.l^{-1}, the average was 3.00 μg.l^{-1}. The coliform bacterias ranged from 4-240 MPN.100 ml^{-1}, with an average of 45.17 MPN.100 ml^{-1}. The phytoplankton biovolume fluctuated from 137.34-1,426.98 mm^3.m^{-3}.

5.1.5 The study of phytoplankton biodiversity

Phytoplankton was found in both lakes and was classified into 6 divisions, 12 orders, 28 families, 62 genera and 95 species of phytoplankton. The first lake was classified into 6 division, 12 orders, 26 families, 58 genera and 86 species. The second lake was classified into 6 divisions, 12 orders, 23 families, 48 genera and 59 species.

5.1.6 The use of phytoplankton biodiversity for monitoring water quality in Rama IX lake

Assessment of water quuality indicated that the first lake was mesotrophic to eutrophic. The phytoplankton which could be used to indicate mesotrophic to eutrophic status were: *Cylindrospermopsis raciborskii* (Wolosz.) Seenayya & Subba, *Peridiniopsis cunningtonii* Lemmermann, *Trachelomonas volvocina* Ehrenberg, *Peridinium* sp.1 and *Ceratium furcoides* (Levander) Langhans. The second lake was oligotrophic to mesotrophic. The phytoplankton, which could used to indicate oligotrophic to mesotrophic status were : *Cylindropsermopsis raciborskii* (Wolosz.) Seenayya & Subba, *Trachelomonas volvocina* Ehrenberg, *Peridinium* sp.1,

Peridiniopsis cunningtonii Lemmermann, *Ceratium furcoides* (Levander) Langhans and *Anomoeoneis vitrea* (Grunow) Ross Considering the water quality of both lakes as classified by surface water quality standards of Thailand, the surface water in Rama IX lake could be placed in the second category, but the water hardness exceeded the water quality standards of water supply. So, the water at the surface from both lakes are relatively clean for household consumption after proper treatment.

5.2 The limitations in the investigation

This investigation is a study of water quality using biodivesity phytoplankton as the monitoring indicator combined with a study of quality using physical, chemical and other biological parameters in Rama IX lake, Pathumthani province.

This study of the essential identification of the various phytoplankton to species level was an arduous task as there are very few experts on this field in Thailand. In this research the dominant phytoplankton, as well as some other species found, had to be confirmed by Prof. Rupert Lenzenweger from Ried in Innkreis, Austria and Assoc. Prof. Dr. Eugen Rott from Institut für Botanik Innsbruck, Universitat Innsbruck, Austria. Apart from this confirmation, the researcher was taught methods of identification and confirmation of the various phytoplankton by Prof. Dr. Eugen Rott. Furthermore, Dr. Barbara Meyer from Max – Planck – Institut für Limnologie, Plön, Germany kindly helped to confirm some species of dinoflagellates.

5.3 Prospective applications of the research

5.3.1 To compile a data base list of various species of phytoplankton biodiversity in the water resources in the central part of Thailand.

5.3.2 To provide the fundamental data for future researchers in phytoplankton biodiversity and the fundamental data to improve the water quality in Rama IX lake.

5.3.3 To use the biodiversity of phytoplankton as species indices and indicator of water quality.

5.4 Suggestions for further research

5.4.1 Study phytoplankton which shows tolerance to various environments and complete species indices of phytoplankton in tropical regions as water quality indicators.

5.4.2 Study survey and compile a list of the strains of phytoplankton from various water resources to form a data base of algae strains for future benefit such as for water treatment of wastewater.

5.4.3 Study the quantity of ions of metals and find the relationship between dominant species of phytoplankton as indicator of the presence of high levels of salts in Rama IX lake.

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APPENDIX I
THE DATA OF THE CLIMATE OF THE STUDY AREA

Table I-1 The mean temperature per month and humidity of Rama IX lake,
Pathumthani province (February 2000-January 2001)

Month and Year	Temperature			Relative humidity (%)
	Maximum	Minimum	Mean	
February 2000	32.9	16.6	24.8	78
March 2000	34.3	19.6	27.0	81
April 2000	34.1	21.0	27.6	82
May 2000	34.5	20.6	27.5	76
June 2000	33.4	19.9	26.7	81
July 2000	33.6	19.9	26.8	81
August 2000	33.6	19.6	26.6	80
September 2000	33.0	19.2	26.1	80
October 2000	33.0	19.2	26.1	81
November 2000	32.1	16.8	24.5	67.6
December 2000	32.9	17.1	25.0	68
January 2001	33.3	18.0	25.65	80

From: The Weather Station of Pathumthani Rice Research.

Table I-2 The mean monthly precipitation in Rama IX lake, Pathumthani province
(February 2000-January 2001)

Month	Year	Mean precipitation/month (mm^3)
February	2000	9.10
March	2000	10.30
April	2000	182.70
May	2000	221.40
June	2000	207.20
July	2000	88.60
August	2000	171.70
September	2000	185.00
October	2000	114.80
November	2000	0.20
December	2000	3.20
January	2001	8.30

Form: The Weather Station of Pathumthani Rice Research

APPENDIX II

THE DATA OF PHYSICAL, CHEMICAL AND BIOLOGICAL CHARACTERISTICS OF RAMA IX LAKE

Table II-1 Depth integrals of A) physico-chemical characteristics B) phytoplankton biovolume, chlorophyll a, mid-day primary production and coliform bacteria of both lakes in Rama IX lake (February 2000-January 2001) (ND = non-detectable, n = number of measurements).

A)	Lake 1					Lake 2				
	Min	**Max**	**Mean**	**S.D.**	**n**	**Min**	**Max**	**Mean**	**S.D.**	**n**
Depth (m)	15.00	18.40	16.40	.94	24	18.32	22.43	20.33	1.08	24
Secchi depth (m)	0.67	1.32	0.96	.21	24	1.50	2.40	1.86	.23	24
Temperature (°C)	27.60	32.83	30.36	.32	24	27.17	32.50	30.06	1.27	24
Turbidity (NTU)	3.15	8.58	5.66	1.41	24	1.93	3.77	2.64	.45	24
Conductivity ($\mu s.cm^{-1}$)	620	870	717.75	55.81	24	1,110	1,360	1,160.5	67.79	24
Total dissolved solid ($\mu s.cm^{-1}$)	300	430	351.38	26.72	24	550	670	576.25	33.21	24
pH	7.68	8.87	8.33	.32	24	7.25	7.92	7.61	.19	24
Alkalinity ($mg.l^{-1}$)	53.30	99.50	63.52	9.37	24	22.40	38.00	26.10	3.24	24
dissolved oxygen ($mg.l^{-1}$)	4.96	9.70	7.54	1.19	24	5.60	7.42	6.80	.43	24
BOD ($mg.l^{-1}$)	0.30	4.20	1.53	.86	23	0.16	2.60	0.70	.50	23
hardness ($mg.l^{-1}$)	174	190	182.13	4.64	15	275	290	280.75	3.63	15
NO_3 - N ($mg.l^{-1}$)	0.001	0.084	0.020	2.15	24	ND	0.039	0.012	.011	22
NH_3 - N ($mg.l^{-1}$)	0.0120	0.23	0.08	5.59	24	0.0119	0.1874	0.07	4.61	24
NO_2 – N ($mg.l^{-1}$)	0	0.007	.002	2.43	24	0	0.013	0.003	3.15	24
Total phosphorus ($mg.l^{-1}$)	0.0035	0.025	0.015	.005	23	0.002	0.03	0.011	7.34	23
SRP ($mg.l^{-1}$)	0.001	0.013	0.004	.003	23	0.001	0.011	0.004	.002	22

Table II-1 (cont.)

B)	Lake 1					Lake 2				
	Min	**Max**	**Mean**	**S.D.**	**n**	**Min**	**Max**	**Mean**	**S.D.**	**n**
Phytoplankton biovolume ($mm^3.m^{-3}$)	967.24	11,084.16	4,451.55	2,753.39	24	137.34	1,426.99	494.65	369.41	24
Chlorophlyll a ($\mu g.l^{-1}$)	0.12	20.66	10.08	4.57	24	ND	7.64	2.99	2.75	21
Primary production ($mgO_2.l^{-1}.hr.^{-1}$)	0.10	0.97	0.52	.25	24	0.10	0.55	0.25	0.13	24
Coliform bacteria ($MPN.100\,ml^{-1}$)	4	460	113.75	125.45	24	4	240	45.17	63.40	24

Table II-2 Matrix of product moment correlation between several physico – chemical and biological parameters in the first lake of Rama IX lake (February 2000-January 2001) (P = 0.05*, P = 0.01**)

	Depth	Secchi	Temp	pH	Alk	Turbid	Conduct	TDS	DO	BOD	NO_3	NO_2	NH_3	SRP	PO_4	ChloA	Biovolume	Hardness	Coliform	Primary Produc GP	Primary ProNP	Primary ProRP
Depth	1.0000	-.305	.297	.488*	.421*	-.093	-.370	-.404	.362	.416*	.051	.285	.174	.072	-.130	-.398	-.003	-.590*	.123	.393	.065	.285
Secchi		1.0000	-.360	.069	-.311	-.648**	.677**	.630**	.097	-.083	.041	-.386	-.195	-.188	.077	-.057	-.280	.564*	-.113	-.735**	-.436*	-.360
Temp			1.0000	.214	-.165	.054	-.472*	-.338	-.029	-.121	.184	-.012	.376	.001	-.083	.070	.324	-.318	-.391	.379	.188	.321
PH				1.0000	.389	-.577**	-.037	-.112	.868**	.288	-.372	-.182	.157	.190	-.079	-.129	-.232	.278	-.160	.078	-.179	.376
Alk					1.0000	-.022	-.182	-.243	.385	.365	-.170	.006	.098	-.119	-.253	-.364	-.146	-.579*	.521**	.235	.028	.158
Turbid						1.0000	-.395	-.330	-.527**	-.182	.102	.490*	.119	.019	.164	.183	-.066	-.198	.225	.397	.328	.062
Conduct							1.0000	.964**	.144	-.178	-.040	-.277	-.067	-.003	.028	.102	-.122	.511	.037	-.466*	-.272	-.185
TDS								1.0000	.050	-.278	.017	-.196	-.016	.012	.079	.134	-.092	.402	-.003	-.413*	-.241	-.196
DO									1.0000	.273	-.244	-.109	-.144	.178	.149	.081	.213	.295	.018	.032	-.159	.279
BOD										1.0000	-.158	-.189	-.088	.234	.167	-.147	.046	-.182	.041	.267	.062	.130
NO_3											1.0000	.378	-.019	-.309	.035	-.157	-.259	-.260	.210	-.186	-.058	-.354
NO_2												1.0000	.085	-.037	.091	-.151	-.051	-.235	.196	.200	-.092	.085
NH_3													1.0000	-.036	-.378	-.237	.088	-.097	-.172	.317	.093	.339
SRP														1.0000	.409*	.356	.170	-.255	-.219	.304	.335	.160
PO_4															1.0000	.435*	.175	-.059	-.143	.131	.339	-.208
ChloA																1.0000	.049	.063	-.234	.147	.098	.113
Biovolume																	1.0000	.045	-.486*	.360	.287	.400
Hardness																		1.0000	-.092	-.580*	-.477	-.021
Coliform																			1.0000	-.153	-.259	-.160
Primary Pro GP																				1.0000	.592**	.644**
Primary Pro NP																					1.0000	.029

Table II-3 Matrix of product moment correlation between several physico-chemical and biological parameters in the second lake of Rama IX lake (February 2000-January 2001) (P = 0.05*, P = 0.01**)

|	Depth	Secchi	Temp	pH	Alk	Turbid	Conduct	TDS	DO	BOD	NO_3	NO_2	NH_3	SRP	PO_4	ChloA	Biovolume	Hardness	Coliform	Primary Produc GP	Primary ProNP	Primary ProRP
Depth	1.0000	.164	.470*	.317	-.077	-.202	-.235	-.223	.046	.277	.195	.154	-.101	-.092	-.176	.234	.110	-.244	.325	.028	.314	.183
Secchi		1.0000	-.217	.129	.332	-.492*	.203	.248	.219	.445*	-.286	-.039	-.116	-.049	.011	-.293	-.177	.157	.232	-.008	.193	.162
Temp			1.0000	.444*	-.349	-.136	-.472*	-.476*	-.223	-.377	.098	.028	.022	.053	-.294	.250	.230	-.386	-.235	.332	.350	.391
pH				1.0000	.342	-.353	-.187	-.112	.358	-.149	.068	-.117	.084	-.164	-.303	.175	.295	.084	-.082	.219	.200	.326
Alk					1.0000	-.148	.383	.407*	.109	.071	.014	-.045	.200	-.148	-.004	-.327	-.209	.315	-.074	-.002	.065	.110
Turbid						1.0000	-.069	-.144	.520*	-.140	-.289	.253	.119	.183	.313	.179	.102	.295	-.176	.077	.100	.075
Conduct							1.0000	.989**	-.024	-.011	.427*	-.176	-.182	-.008	.188	-.331	.020	.120	.010	-.059	-.050	-.144
TDS								1.0000	.069	.016	.416	-.199	-.157	-.029	.198	-.379	.023	.100	.044	-.057	-.045	-.158
DO									1.0000	.248	.061	-.157	.104	-.253	-.192	-.039	.105	.046	.288	-.076	-.287	-.247
BOD										1.0000	-.211	.020	.204	-.318	-.127	-.292	-.267	-.190	.691**	.013	.116	.037
NO_3											1.0000	.093	-.184	-.007	-.162	.000	.045	.060	.204	-.206	-.139	-.068
NO_2												1.0000	.372	-.034	.009	.098	-.144	.183	-.034	-.014	.065	.211
NH_3													1.0000	-.031	.159	-.095	-.236	.114	-.120	.467*	.259	.323
SRP														1.0000	.470*	.166	.273	-.027	-.154	.013	.134	.140
PO_4															1.0000	.064	.315	.062	-.152	-.064	.165	-.170
ChloA																1.0000	.521*	-.276	-.220	.252	.115	.249
Biovolume																	1.0000	-.186	-.167	-.012	.115	-.176
Hardness																		1.0000	-.035	-.399	-.424	-.004
Coliform																			1.0000	-.215	.018	-.071
Primary Pro GP																				1.0000	.659**	.743**
Primary Pro NP																					1.0000	.518*
Primary Pro RP																						1.0000

APPENDIX III
FINDING THE BIOVOLUME OF PHYTOPLANKTON

Finding the biovolume of phytoplankton (Rott, 1981) by measuring its width, length and thickness. Classification by the mathematical shapes of the phytoplankton.
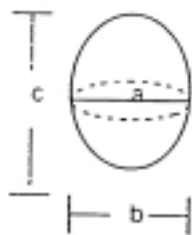
1. The shape of phytoplankton are spherical.

$$Biovolume = \frac{\pi d^3}{3}$$
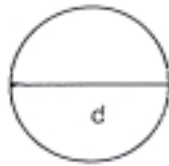
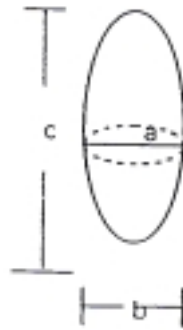d = diameter

2. The shape of phytoplankton are ellipsoidal.

$$Biovolume = \frac{\pi.c.a^3}{6}$$

when a = b

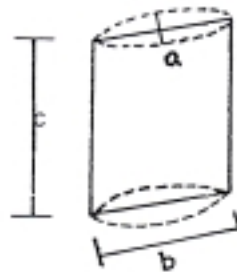3. **The shape of phytoplankton are elliptical – ellipsoid.**

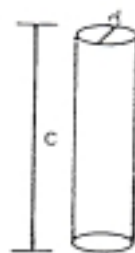$$\text{Biovolume} = \frac{\pi.a.b.c}{6}$$

when a ≠ b

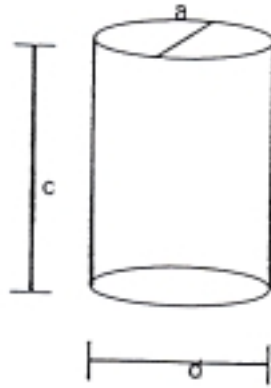4. **The shapes of phytoplankton are pararellelepipedal**

$$\text{Biovolume} = a.b.c$$

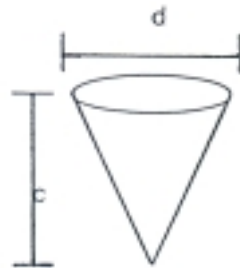5. **The shapes of phytoplankton are cylindrical**

$$\text{Biovolume} = \frac{\pi.c.d^3}{4}$$

6. The shapes of phytoplankton are elliptical - cylinder
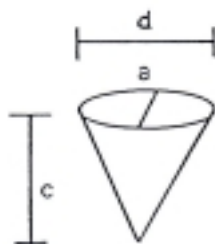
$$\text{Biovolume} = \frac{\pi.c.d.a}{4}$$

7. The phapes of phytoplankton are cone

$$\text{Biovolume} = \frac{\pi.c.d^2}{12}$$

8. The shape of phytoplankton are cone – elliptic

$$\text{Biovolume} = \frac{\pi.c.d.a}{12}$$

9. The shape of phytoplankton are truncated cone

$$Biovolume = \frac{\pi.(a^2 + ab + b^2)}{12}$$
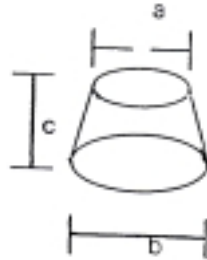
10. The shape of phytoplankton are trapezoid

$$Biovolume = \frac{1(a+b).c.d}{12}$$
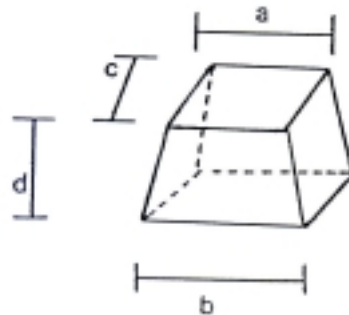
11. The shape of phytoplankton are pyramidal.

$$Biovolume = \frac{1.a.b.c}{3}$$

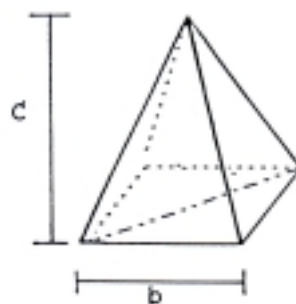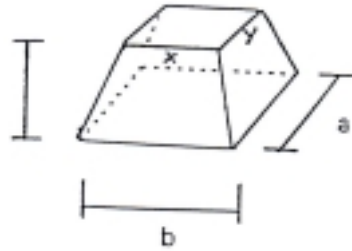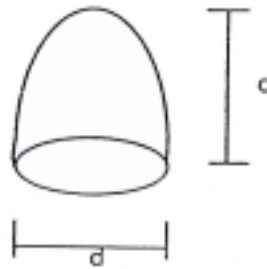12. The shape of phytoplankton are truncated pyramid.

Biovolume $= \dfrac{c\,(a.b + a.b.x.y + x.y)}{3}$

13. The shape of phytoplankton are parobolical.

Biovolume $= \dfrac{\pi.c.d^2}{8}$

APPENDIX IV
STANDARD SURFACE WATER QUALITY OF THAILAND

Clause 32 (1) of The promotion and maintance of Natural Environment Act, 1992 granted authority to the Natianal Environmental Broad to announce in the Royal Gazette the standards of water quality in rivers, khlongs, marshes, lakes, reservoirs and public water resources etc.

Standard surface water quality is classified into the 5 following categories :

Category 1 The water resources contain natural water with no waste water from any resource or activity and is beneficial for :

(1) A household consumption after undergoing compulsory normal sterilization processes.

(2) Natural reproduction of basic living organisms

(3) Ecological conservation of water resources

Category 2 The water resources receive waste water from some activities and can be beneficial for :

(1) Household consumtion after compulsory normal sterilization processes and water quality improvement stages.

(2) Water animal conservation

(3) Fishing

(4) Swimming and aquatic sports

Category 3 The water resources receive waste water from some activities and can be beneficial for :

(1) Household consumtion after compulsory normal sterilization processes and water quality improvement stages.

(2) Agriculture

Category 4 The water resources receive waste water from some activities and can be beneficial for :

    (1) Household consumtion after compulsory normal sterilization processes and water quality improvement stages.

    (2) Industry

   Category 5 The water resources receive waste water from some activities and can benefical for communication.

Table IV-1 The value of standard surface water quality of Thailand

In order	Water quality index	Statistic Valve	Unit	Categories of water quality according to benefit				
				Categories				
				1	2	3	4	5
1.	Color and Odor		-	N	N	N	N	-
2.	Temperature		°C	N	N′	N′	N′	-
3.	pH		-	N	5.0-9.0	5.0-9.0	5.0-9.0	-
4.	DO	P 20	mg.l⁻¹	N	≮ 6.0	≮ 4.0	≮ 2.0	-
5.	BOD	P 80	"	N	≯ 1.5	≯ 2.0	≯ 4.0	-
6.	Total Coliform Bacteria	P 80	MPN/100 ml.	N	≯ 5,000	≯ 20,000	-	-
7.	Faecal Coliform Bacteria	P 80	"	N	≯ 1,000	≯ 4,000	-	-
8.	No₃ in nitrogen unit		mg.l⁻¹	N	Not exceed		5.0	-
9.	NH₃ in nitrogen unit		"	N	"		0.5	-
10.	Phencls		"	N	"		0.005	-
11.	Cu		"	N	"		0.1	-
12.	Ni		"	N	"		0.1	-
13.	Mn		"	N	"		1.0	-
14.	Zn		"	N	"		1.0	-
15.	Cd		"	N	"		0.005*	-
					"		0.05**	-
16.	Cr Hexavalent		"	N	"		0.05	-
17.	Pb		"	N	"		0.05	-
18.	Total Hg		"	N	"		0.05	-
19.	As		"	N	"		0.01	-
20.	Cyanide		"	N	"		0.005	-
21.	Radioactivity							-
	- Alpha		Bekkherell.l⁻¹	N	"		0.1	-
	- Beta		"	N	"		1.0	-
22.	Total Organochlorine Pesticides		Mg.l⁻¹	N	"		0.05	-
23.	DDT		µg.l⁻¹	N	"		1.0	-
24.	Alpha BHC			N	"		0.02	-
25.	Dieldrin			N	"		0.1	-
26.	Aldrin			N	"		0.1	-

Table IV-1 (cont.)

In Order	Water quality index	Statistic valve	Unit	Categories of water quality according to benefit				
				Categories				
				1	2	3	4	5
27.	Heptachor & Heptachlor Epoxide			N	not exceed		0.2	-
28.	Endrin			N	Undetectable by any standard Method			

Data sources : Standard surface water quality of Thailand set by the National Environmental Board edition 8(1994) following legislation to promote and maintain the quality of the National Environment 1992, regarding a setting of standards of surface water quality published in the Royal Gazette volume 11, number 16 on 24 February, 1994.

Footnotes

1/ To stipulate the standard of water resources, categories 2-4, for the first category according to the natural state and water resources, for the fifth category there is no stipulation as to quality.

N Natural state

N′ The temperature of the water must not exceed the natural temperature by 3^oC

* Water hardness did not exceed 100 mg.l^1 in form $CaCo_3$

** Water hardness exceed 100 mg.l^1 in form $CaCo_3$

≮ not less than

≯ did not exceed

- not set

^oC o celcius

P20 The 20th percentile valve from all collected samples by continous checking

P80 The 80th percentile valve from all collected samples by continous checking

Mg.l^1 Milligramme per litre

ml millilitre

MPN Most Probable Number

Table IV-2 General ragaes of total phosphorus, nitrogen, chlorophyll a and Seechi depth characteristics of lakes of different trophic categories (from Lorraine and Vollenweider, 1981).

Variable (Annal Mean Values)		Oligotrophic	Mesotrophic	Eutrophic	Hyper-cutrophic
Total Phosphorus $mg.m^3$	$\bar{X}$	8.0	26.7	84.4	
	$X \pm 1\,SD$	4.85-13.3	14.5-49	38-189	
	$X \pm 2\,SD$	2.9-22.1	7.9-90.8	16.8-424	
	Range	3.0-17.7	10.9-95.6	16.2-386	750-1200
	N	21	19 (21)	71 (72)	2
Total nitrogen $mg.m^3$	$\bar{X}$	6.61	7.53	187.5	
	$X \pm 1\,SD$	371-1180	485-1170	861-4081	
	$X \pm 2\,SD$	208-2103	313-1816	395-8913	
	Range	307-1630	361-1387	393-6100	
	n	11	8	37 (38)	
Chlorophyll a $mg.m^3$	$\bar{X}$	1.7	4.7	14.3	
	$X \pm 1\,SD$	.8-3.4	3.0-7.4	6.7-31	
	$X \pm 2\,SD$	.4-7.1	1.9-11.6	3.1-66	
	Range	0.3-4.5	3.0-11	2.7-78	100-150
	N	22	16 (17)	70 (72)	2
Chlorophyll a Peak Value $mg.m^3$	$\bar{X}$	4.2	16.1	42.6	
	$X \pm 1\,SD$	2.6-7.6	8.9-29	16.9-107	
	$X \pm 2\,SD$	1.5-13	4.9-52.5	6.7-270	
	Range	1.3-10.6	4.9-49.5	9.5-275	
	N	16	12	46	
Secchi Depth m.	X	9.9	4.2	2.45	
	$X \pm 1\,SD$	5.9-16.5	2.4-7.4	1.5-4.0	
	$X \pm 2\,SD$	3.6-27.5	1.4-13	.9-6.7	
	Range	5.4-28.3	1.5-8.1	.8-7.0	0.4-0.5
	N	13	20	70 (72)	2

$\bar{X}$　=　geometric mean

SD　=　standard deviation

( )　=　value in bracket refers to the number of variables (n) employed in the first calculation.

Table IV-3 General rages of primary productivity of phytoplankton and related characteristics of lakes of different trophic categories (from Wetzel, 1983).

TROPHIC TYPE	MEAN PRIMARY PRODUCTIVITY (mgC m⁻²DAY⁻¹)	PHYTO-PLANKTON DENSITY (cm³. m⁻³)	PHYTO-PLANKTON BIOMASS (mgC m⁻³)	CHORO-PHYLL a (mgm⁻³)	DOMINANT PHYTO-PLANKTON	LIGHT EXTINGTION COEFFI-CIENTS (m⁻¹)	TOTAL ORGANIC CARBON (μgl⁻¹)	TOTAL P (μgl⁻¹)	TOTAL N (μgl⁻¹)	TOTAL INORGANIC SOLIDS (μgl⁻¹)
Ultraoligotrophic	< 50	<1	< 50	0.01-0.5		0.03-0.8		<1-5	<1-250	2-15
Oligotrophic	50-300		20-100	0.3-3	Chrysophyceae Cryptophyceae	0.05-1.0	<1-3			
Oligomesotrophic		1-3			Dinophyceae, Bacllarlophyceae			5-10	250-600	10-200
Mesotrophic	250-1000		100-300	2-15		0.1-2.0	<1-5			
Mesoeutrophic		3-5						10-30	500-1100	100-500
Eutrophic	>1000		> 300	10-500	Bacillarlophyceae Cyanophyceae	0.5-4.0	5-30			
Hypereutrophic		>10			Chlorophyceae, Euglenophyceae			30->5000	500->15000	400-60000
Dystrophic	<50-500		<50-200	0.1-10		1.0-4.0	3-30	<1-10	<1-500	5-200

Table IV-4 Characteristics of common major algae associations of the phytoplankton in relation to increasing lake fertility (from Wetzel, 1983).

General Lake Trophy	Water Characteristics	Dominant Algae	Other Commonly Occurring Algae
Oligotrophic	Slightly acidic: very low salinity	Desmids *Staurodesmus. Staurastrum*	*Sphaerocystis, Gloeocystis. Rhizosolenia, Tabellaria*
Oligotrophic	Neutral to slightly alkaline; nutrient – poor lakes	Diatoms, especialy. *Cyclotella* and *Tebellaria*	Some *Asterionella* spp. some *Melosira* spp. *Dinobryon*
Oligotrophic	Neutral to slightly alkaline; nutrient – poor lakes or more productive lakes at seasons of nutrient reduction	Chrysophycean algae Especially *Dinobryon* some *Mallomonas*	Other Chrysophyceans e.g. *Synura, Uroglena*: diatom *Tabellaria*
Oligotrophic	Neutral to slightly alkaline; nutrient – poor lakes	Chlorococcal *Oocysits* or *Chrysophycean Botryococcus*	Oligotrophic diatoms
Oligotrophic	Neutral to slightly alkaline; generally nutrient poor; common in shallow Arctic lakes	Dinollagellates. especially Some *Peridinium* and *Ceratium* spp.	Small chrysophytes cryptophytes and diatoms
Mesotrophic or Eutrophic	Neutral to slightly alkaline; Annual dominants or in Eutrophic lakes at certain Seasons	Dinollagellates. some *Peridunium* and *Ceratium* spp.	Glenodinium and many other Algae
Eutrophic	Usualty alkaline lakes with Nutrient enrichment	Diatoms much of year especially *Asterionella* spp. *Fragilaria crotonensis Synedra, Stephanodiscus* and *Melosira granulata*	Many other algae espesically green and blue-greens during wammer periods of year; desmids of dissolved organic matter is fairly high
Eutrophic	Usualty alkaline ; nutrient Enrichment; common in Warmer periods of temperature Lakes or perennially in enriched tropical lakes	Blue – green algee. especially *Anacystis* (= *Microcystis*). *Aphanizomenon, Anabaena*	Other blue-green algae; euglenophytes if organically enriched or polluted

Table IV-5 Typical phytoplankton species dominating lakes of different trophic states
(from Reynoids, 1980 quoted in Harper, 1992)

Oligotrophic	Mesotrophic	Eutrophic
Staurastrum, Cosmarium, Staurodesmus (desmids)	*Staurastrum, Closterium* (desmid)	*Melosira, Asterionella, Stephanodiscus* (diatoms)
Tubellaria, Cyclotella, Melosira, Rhizoselenia (small diatoms)	*Cyclotella, Stephanodiscus, Asterionella* (diatom)	*Scenedesmus, Eudorina* (green algae)
	Pediastrum, Eudorina (green algae)	
Dinobryon (Chrysophyte)	*Peridinium, Ceratium* (dinoflagellates)	*Aphanizomenon, Microcystis, Anabaena* (cynobacterial)

Table IV-6 Ranges of the indicator variables as given for the trophic classes in temperate lakes
by Lampert and Sommer, 1993 quoted in Yuwadee Peerapompisal, 1996.

Variable	Oligotrophic	Mesotrophic	Eutrophic	Hyperentrophic
Total phosphorus ($\mu g.l^{-1}$)	5-10	10-30	30-100	>100
Chlorophyll a ($\mu g.l^{-1}$)	0.3-3	3-10	10-100	>100
Biovolume ($mm^3.m^{-3}$)	40-2000	2000-5000	> 5000	

CURRICULUM VITAE

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