

## CHAPTER 5

# PHYTOPLANKTON COMMUNITY STRUCTURE WITH SPECIAL REFERENCE TO SPECIES DIVERSITY IN FIVE TROPICAL ASIAN WATER BODIES

<sup>1</sup>\* Eugen Rott, <sup>2</sup> E. Ivan L. Silva, <sup>3</sup> Evangeline E. Enriquez & <sup>4</sup> Suchart Ingthamjit

<sup>1</sup> *Institute of Botany, University of Innsbruck, Sternwartestrasse 15,  
A-6020 Innsbruck, Austria*

<sup>2</sup> *Institute for Fundamental Studies, Hantana Road, Kandy, Sri Lanka*

<sup>3</sup> *Ateneo de Manila University, Loyola Heights Campus, Katipunan Avenue, Loyola  
Heights, Quezon City 1108, Philippines and previously Institute of Biology, College of  
Science, University of the Philippines, Diliman, Quezon City, Philippines.*

<sup>4</sup> *Mekong River Commission, Vientiane, People's Republic of Laos, and formerly Inland  
Fisheries Resources Research and Development Institute, Inland Fisheries Research  
and Development Bureau, Department of Fisheries, Ministry of Agriculture and  
Cooperatives, Bangkok, Thailand*

(\*Author for Correspondence: Tel.: +43-0512-507-594;

Fax: +43-0512-507-2715; E-mail: eugen.rott@uibk.ac.at)

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### Abstract

This is a detailed investigation and documentation of phytoplankton species composition of three reservoirs in Sri Lanka, one large reservoir in NE Thailand and a natural caldera lake in the Philippines. More than 160 taxa were identified from which 50% are illustrated. 19% can be assumed as tropical and/or subtropical warm temperate. The cluster analysis of the overall species lists indicated highest similarity for samples from water bodies within the same geographic region. Shannon diversity and evenness indices based on quantitative phytoplankton evaluations selected for maximum difference roughly followed a trophic ranking. Most of the samples from reservoirs in Sri Lanka were classified as mesotrophic in contrast to those from the large shallow Ubolratana reservoir in NE Thailand and the volcanic Lake Taal in the Philippines which were classified as eutrophic. Under eutrophic conditions high chlorophyll concentrations were linked with reduced species diversity.

In spite of the low number of samples studied, the selection of data for extreme seasons (dry, wet) and the more frequently sampled chlorophyll data allowed some general trends to become evident. The most striking trends were: (A) Highest phytoplankton quantities in the shallow Minneriya reservoir (Sri Lanka) related to low water periods in the dry season. (B) A contrasting situation in the deep, volcanic and eutrophic Lake Taal (Philippines) showing low phytoplankton quantities during the dry season due to high mixing depth induced by strong winds, and peak quantities with intermonsoonal stratification during the first period of the rainy season. For a general assessment of relationships of phytoplankton to environmental variables a crossing tables bivariate regression model was used to test chlorophyll time series against a few key variables. In addition some specific questions about functional ecology of phytoplankton taxa, and their relationship to other biota are discussed.

## Introduction

Phytoplankton is a key component of the microbial foodweb in the pelagic zone reflecting trophic status of the environment in both temperate and tropical standing waters. In tropical aquatic environments it can play an additional important role within the pelagic food web as a direct and valuable food source for seston-feeding fish which are common in many tropical lakes (see Schiemer, 1983; Payne, 1986; Talling & Lemoalle, 1998; Chapter 22). However, in view of the large diversity of standing water types within the tropics caused by a large variety of climates (influenced by latitude, altitude, geographic position and ocean currents, see Chapters 2, 3 & 4) detailed diversity-based phytoplankton investigations over an extended biogeographic gradient are rare. Generalisations of results from a few studies to other situations are questionable and may hinder the progress in tropical freshwater research (Lewis, 1987).

This study focused on man-made lakes/reservoirs which because of variable areas and depths, are subject to variable flushing rates and seasonal monsoon-driven climates (Chapter 22). The main objective of this study was to elaborate reliable data for phytoplankton identification, community composition and relative dominance to set at least some flashlights on potential differences of the pelagic food web between the five water bodies (Chapter 22). Additional objectives were the test of biogeographical similarity, and the overall trophical ranking of selected samples based on structural data (species composition and biovolume, size, chlorophyll). We use the more frequently sampled time series of chlorophyll as an indicative parameter for temporal and quantitative phytoplankton changes. We also tried to follow relevant hypotheses concerning tropical phytoplankton community composition and temporal changes raised by several authors, especially concerning trophic status (e.g. Thornton, 1979; Zauke *et al.*, 1992) and natural temporal variations (e.g. Melack, 1979, Payne, 1986, Talling & Lemoalle, 1998, Chapter 6).

Although some preliminary approaches are made to identify the most important functional species groups of phytoplankton and potential key variables shaping phytoplankton chlorophyll and species composition, many other aspects having an influence on phytoplankton structure are the subject of other contributions: namely the driving variables for primary production with special reference to light climate and mixing depth (Chapter 6), the microbial aspects in carbon dynamics (Chapter 7), and the effects of grazing pressure by microcrustacea (Chapter 8) and fish (Chapter 22).

## Materials and methods

### *The sites and sampling dates*

The three reservoirs from Sri Lanka (Tab. 5.1) were comprised of one long and deep, canyon-shaped reservoir (Victoria) with steep slopes, situated in the central mountain area of the island and two shallow, medium-sized reservoirs situated close to the eastern and southern foothills of the mountains (Minneriya and Udawalawe respectively). The reservoir in NE Thailand had the largest surface area but shallow banks which can to a large extent fall dry during low water periods. The fifth water body studied is situated in central Luzon (a main island of the N Philippines) and is a large and deep caldera lake close to the sea, has steep slopes and is divided by a central island group into two basins. Samples from central lake stations were studied predominantly but some aspects of horizontal variation were considered as well. In the large Ubolratana reservoir - in addition to the central station (Station 5) - one station in the S bay of the reservoir (Station 3) was studied, which is characterized by an extended floating macrophyte cover (*Eichhornia*).

Samples were taken between August 1998 and July 2000 with the intention to cover the major seasons and waterlevel extremes, respectively. The densest sampling scheme was reached for chlorophyll (9 to 11 sampling periods including both vertical and horizontal variation) and for environmental variables. In order to focus on temporal variation of phytoplankton structure the seasonality of chlorophyll was used to select extreme situations (maxima and minima) during wet and dry season for phytoplankton structure and biomass studies. This resulted in two to six analyses per water body comprising phytoplankton counts and biovolume assessment.

### *Identification*

For identification both 10  $\mu\text{m}$  net-hauls integrated over the near surface layers (down to 5 m), and samples taken with a water sampler were used. Fixation was made with 2%

*Table 5.1:* Morphology and geography of the five water bodies (abbreviations of sites in brackets) and two additional small reservoirs in N-Thailand (data from Peerapornpisal, 1996). Lat.=latitude, Alt.=altitude (m), Area=surface area ( $\text{km}^2$ ),  $z_{\text{min}}$ =mean depth (m),  $z_{\text{max}}$ = maximum depth (m), Retent.= theoretical retention time (years), WL fluct.=mean seasonal water level fluctuation (m).

	Lat.	Alt.	Area	$z_{\text{min}}$	$z_{\text{max}}$	Retent.	WL fluct.
PHILIPPINES							
Lake Taal (TA)	14°0'N	3	237	40	198	45	1.7
SRI LANKA							
Minneriya Reservoir (MIN)	8°02'N	95	28	6	13	0.8	7.3
Udawalawe Reservoir (UDA)	6°27'N	88	34	8	20	0.4	6.2
Victoria Reservoir (VIC)	7°13'N	438	24	30	98	0.5	27.1
THAILAND							
Ubolratana Reservoir (UR)	16°40'N	182	410	5	20	0.5	8.3
Huai Hong Khrai Reservoir A (HA)	18°51'N	300	<1	3.5	8	0.3	4.0
Huai Hong Khrai Reservoir C (HC)	18°50'N	290	1	4.2	7	0.6	3.0

neutralized formaline. For a quick check of sample density and species dominance under a standard light microscope, a suitable concentration was obtained by sedimentation of a larger sample volume (reducing 100 ml to 10 ml) and the check of the sample in a Lund-chamber (approximately 0.2 ml volume). In this case the close working distance of the objectives only did not allow for the use of more than 400-times magnification thus hindering precise species identification in many cases. Therefore frequent taxa were studied from net samples on slides with the research microscope (WILD BX 50, magnifications up to 1000-times). For completion of the taxonomic work water samples were concentrated in a sedimentation chamber and investigated under the inverted microscope by up to 630-times magnification. For diatom investigation samples were cleaned with peroxide and mounted in Naphrax. The SEM studies are based on washed and dried samples sputtered with gold (details see Rott *et al.*, 2001). Measurements for identification purposes and biovolume estimates in the LM were made with (A) a calibrated micrometer ocular and (B) from photo prints calibrated with the object micrometer print. Size spectra for dominant taxa were based on direct microscopical measurement using the greatest axial linear dimension (GALD) approach.

#### *Biovolume and chlorophyll*

Quantitative phytoplankton biovolume data are based on Lugol fixed water samples from near surface layers (0.5 or 1.5 m) counted in compound plankton counting chambers according to Utermöhl (1958). For calculation of the species biovolumes, geometric approximations (see Rott, 1981) were applied using measurements made during the counts. Due to the high number of taxa in most samples (between 30 and 60), especially from Victoria, the scatter of replicates was reduced by making a strict counting plan for the different magnifications (60, 160, 400 and 630-times). Compared to most temperate and less species-rich phytoplankton samples this process was much more time-consuming.

Chlorophyll, the second measure of biomass was analysed from water samples taken from the same bottle as the phytoplankton counting samples and/or within routine sampling of water along vertical profiles used for primary production measurements and studies of horizontal variations of water chemistry. The water was kept in the dark until it was vacuum filtrated through glassfiber filters (GFC). The filters were kept dark and frozen before extraction. The extraction and quantification method followed the ISO 10260 (1992) hot ethanol method with acidification and pheophytine correction. Extraction efficiency was continuously checked by a second extraction of filters.

#### *Environmental data*

Methods for the assessment of hydrological data, climatological data, data on catchment and basin morphology followed Silva & Gamlath (2000) and Chapter 22 protocols. Some physico-chemical parameters were measured with portable calibrated meters in the field (WTW-pH, conductivity- and oxygen-meters). For selected samples and parameters a later check of samples was made in the laboratory. Nutrient analyses were based on specific and standard wet chemical methods (details see Chapter 7) with special attention to high performance detection.

### *Numerical evaluations*

The first numerical approach to test similarity of taxa lists between the water bodies used Jaccard's index (Digby & Kempton, 1987, p. 15-19) irrespective of the abundance of the taxa. For the second approach phytoplankton species lists combined with relative portions of total biomass were used to calculate Shannon's diversity and evenness indices (Chapman, 1996, p. 201-203). From this analysis samples with the highest diversity were selected to identify maximum differences between the water bodies. Phytoplankton samples from rainy and dry season situations (or high and low water level/rainfall in the case of Udawalawe) were selected to show maximum temporal changes. For the identification of temporal variation over longer time periods, chlorophyll data were used since the number of quantitative phytoplankton samples was not high enough to study details of seasonality. Simple linear bivariate regressions were used for a rough indication of the relationships between environmental data and phytoplankton quantities and a similarity matrix listing Pearson's  $r$ .

For phytoplankton community-based analysis, a total of 21 counted phytoplankton samples were classified using TWINSpan (Hill, 1979). In order to facilitate the numerical evaluation of biodiversity and trophic ranking, six samples from two small reservoirs from N Thailand near Chiang Mai both situated in a forested area but with an agricultural catchment upstream were included (for details see Table 5.1 and Peerapornpisal, 1996). For the six phytoplankton sample groups obtained from TWINSpan the averages of key environmental variables were calculated and used for trophic ranking.

## **Results: Biodiversity**

### *Species richness and diversity*

A total of 166 taxa were recorded from the five water bodies (Tab. 5.2). Total species richness varied between a maximum of more than 70 in Victoria and the large Ubolratana, and a minimum of 43 in Lake Taal. Altogether species from nine classes of algae were found with a maximum of 47 taxa for chlorophytes (Plates 5.6g-8k; group designation used in the classical broad sense now reclassified within different new orders and classes/subclasses) and 40 taxa belonging to Desmidiaceae, class Zygnemaphyceae (Plates 5.9-11). A high number of taxa (32) was also found for cyanophytes/cyanobacteria with both unicellular colony-forming taxa and filaments being common (Plates 5.1-3). The variability of species richness between the water bodies was highest for desmids where 31 taxa were found in Victoria and six taxa in Lake Taal respectively. In contrast chlorophytes (mainly classical Chlorococcales) were found to be rich in almost all samples. A new species of centric diatoms from the genus *Urosolenia* (= the freshwater section of the earlier larger genus *Rhizosolenia*) *U. diademata* Rott & Kling found in Victoria and Minneriya reservoirs has been described (Rott *et al.* 2006) within the context of the project. In addition several common diatom taxa (mainly centric forms, Plate 5.4) were found in all water bodies and dominated the plankton at times with *Aulacoseira granulata*. Several small centric diatom taxa, rarely recorded from freshwaters, typical for Lake Taal have been studied in detail earlier (Rott *et al.*, 2001). Dinoflagellates were represented by a few uncommon taxa (e.g. *Ceratium furcoides*, *Peridinium penardiforme*, Plates 5.5f-6f) and dominated in several samples. Cryptophytes and unicellular xanthophytes (Plate 5.5d, e)

Table 5.2: Phytoplankton species list for the five water bodies (Abbreviations: BN = biogeographic notes; t = tropical, tw = tropical and warm-temperate; r = rare, f = frequent, ff = very frequent, abbreviations of reservoirs see Table 5.1).

	BN	MI	UD	VI	UR	TA
<b>Cyanophyceae/Cyanobacteria</b>						
<i>Anabaena</i> sp.				r	r	
<i>Aphanothece minutissima</i> (W.West) Komárková-Legnerová et Cronberg		r		r		r
<i>Aphanizomenon volzi</i> (Lemmermann) Komárek	tw	r	f	f		
<i>Aphanizomenon</i> sp.			r	r	r	
<i>Aphanocapsa delicatissima</i> W.et G.West		r		r		
<i>Aphanocapsa holsatica</i> (Lemmermann) Cronberg et Komárek		f	f	f		
<i>Aphanothece</i> sp. ad <i>A. stagnina</i> (Sprengel) A. Braun					r	
<i>Aphanothece minutissima</i> (W.West) Komárková & Cronberg		r				
<i>Chroococcus dispersus</i> (Keissler) Lemmermann		f			r	r
<i>Chroococcus</i> cf. <i>limneticus</i> Lemmermann			r	r		
<i>Coelomonon microcystoides</i> Komárek	t	r	r		r	
<i>Coelosphaerium</i> sp.		r	r	r		
<i>Cyanodictyon imperfectum</i> Cronberg & Weibull		f	ff	f		r
<i>Cyanothece</i> sp. ad <i>C. halobia</i> Roussomoustakaki et Anagnostidis						r
<i>Cylindrospermopsis philippinensis</i> (Taylor) Komárek	t	r	r			
<i>Cylindrospermopsis raciborski</i> (Woloszynska) Seenayya & Subba Raju	tw	f			ff	r
<i>Eucapsis parallelepipedon</i> (Schmidle) Komárek et Hindák	tw					r
<i>Gloetrichia</i> sp.			r			
<i>Lemmermaniella</i> cf. <i>pallida</i> (Lemmermann) Geitler		r	f		r	
<i>Merismopedia africana</i> Komárek & Cronberg	t	f				
<i>Merismopedia punctata</i> Meyen		f	r	f	r	r
<i>Merismopedia tenuissima</i> Lemmermann		f	r			
<i>Microcystis aeruginosa</i> (Kützing) Kützing		ff	f	ff		
<i>Microcystis flos-aquae</i> (Wittrock) Kirchner		f			f	
<i>Microcystis lamelliformis</i> Holsinger	t		r	r	r	
<i>Microcystis smithi</i> Komárek et Anagnostidis					r	
<i>Microcystis wesenbergi</i> (Komárek) Komárek in Kondrateva		ff	ff	f		
<i>Oscillatoria</i> sp.						r
<i>Oscillatoria raciborski</i> Woloszynska		f			r	
<i>Planktolyngbya circumcreta</i> (G.S. West) Anagnostidis & Komárek	tw	f			r	
<i>Planktolyngbya limnetica</i> Lemmermann		f	r		f	r
<i>Pseudanabaena</i> sp.					f	
<b>Diatomophyceae</b>						
<i>Actinocyclus normani</i> (Gregory) Hustedt						f
<i>Aulacoseira ambigua</i> (Grunow) Simonsen					r	
<i>Aulacoseira granulata</i> (Ehrenberg) Simonsen		f	ff	f	f	
<i>Cyclotella</i> cf. <i>comensis</i> Grunow						f
<i>Cyclotella comta</i> Kützing				r		
<i>Cyclotella</i> cf. <i>meneghiniana</i> Kützing		r	r	r	r	f
<i>Cyclotella pseudostelligera</i> Hustedt		f	f	f		
<i>Fragilaria (Synedra) acus</i> (Ehrenberg) Cleve		r	r		r	
<i>Nitzschia acicularis</i> (Kützing) W. Smith					r	
<i>Stephanodiscus</i> sp. ad <i>St. neoastraea</i> Hakansson & Hickel		f		f		
<i>Thalassiosira weissflogi</i> (Grunow) Fryxell & Hasle						r
<i>Thalassiosira visurgis</i> Hustedt						f
<i>Urosolenia diademata</i> Rott, Kling & McGregor	t	f		f		
<b>Chrysophyceae</b>						
<i>Dinobryon acuminatum</i> Ruttner					r	
<i>Dinobryon sertularia</i> Ehrenberg					ff	
<i>Kephyrion</i> sp.					r	
<i>Mallomonas</i> sp.			r	r		
<b>Cryptophyceae</b>						
<i>Cryptomonas marssoni</i> Skuja			f		f	r
<i>Cryptomonas</i> cf. <i>erosa</i> Ehrenberg					f	
<i>Cryptomonas</i> sp. ad <i>C. rostratiformis</i> Skuja		f	r	r		
<i>Rhodomonas</i> (= <i>Plagioselmis</i> ) <i>minuta</i> Karsten		r	f	r	f	f
<i>Rhodomonas</i> sp.						r

	BN	MI	UD	VI	UR	TA
<b>Xanthophyceae</b>						
<i>Centrtractus belenophorus</i> Lemmermann					r	
<i>Isthmochloron lobulatum</i> (Naegeli) Skuja		r		r	r	
<b>Dinophyceae</b>						
<i>Ceratium furcoides</i> (Levander) Langhans	tw				f	ff
<i>Ceratium hirundinella</i> (O.F.) Müller					f	
<i>Gymnodinium</i> sp.		r				
<i>Peridiniopsis cunningtoni</i> Lemmermann					r	
<i>Peridiniopsis elpatiewskyi</i> (Ostenfeld) Bourrelly					f	
<i>Peridiniopsis penardiforme</i> (Lindemann) Bourrelly		r			r	
<i>Peridinium gatunense</i> Nygaard	tw	r	f	r	r	
<i>Peridinium inconspicuum</i> f. Lemmermann			f		ff	
<i>Sphaerodinium</i> sp.						r
<b>Chlorophyceae</b>						
<i>Ankistrodesmus bernardi</i> Komárek	t	r	r	r	r	
<i>Botryococcus</i> sp. ad <i>B. protuberans</i> Swirenko	t	r	f	r		
<i>Carteria</i> sp.						r
<i>Chlamydomonas</i> sp.		r	r	r		r
<i>Coelastrum indicum</i> Turner	t		r			r
<i>Coelastrum polychordum</i> (Kors.) Hindak		r	r			
<i>Coelastrum pulchrum</i> Schmidle	tw	r	r		r	
<i>Coelastrum reticulatum</i> var. <i>cubanum</i> Komárek	t	r		f		
<i>Coenococcus</i> cf. <i>fotti</i> Hindak			r	r		r
<i>Crucigeniella pulchra</i> (West & West) Komárek						r
<i>Crucigeniella saguei</i> Komárek	t	r			r	r
<i>Dictyosphaerium pulchellum</i> var. <i>minimum</i> Deflandre	t		r	r	r	
<i>Dictyosphaerium tetrachotomum</i> var. <i>fallax</i> Komárek				r		r
<i>Elakatothrix acuta</i> Pascher						r
<i>Eudorina</i> sp.						r
<i>Golenkinia radiata</i> Chodat					r	
<i>Kirchneriella diana</i> (Bohlin) Comas	t	r		r		
<i>Kirchneriella</i> sp.						r
<i>Koliella</i> sp.				r		
<i>Lagerheimia citriformis</i> (Snow) Coll.			r			r
<i>Monoraphidium arcuatum</i> (Kors.) Hindak				r		
<i>Monoraphidium contortum</i> Komarkova-Legnerova			r	r	f	r
<i>Monoraphidium minutum</i> Komarkova-Legnerova				r		
<i>Monoraphidium</i> sp. ad <i>M. caribeum</i> Comas	t		r	r		
<i>Nephrocytium schilleri</i> Comas	t			r		
<i>Oocystis marssonii</i> Lemmermann		r	r	r		r
<i>Oocystis</i> cf. <i>parva</i> W. & G.S. West				r		
<i>Pediastrum duplex</i> Meyen						
<i>Pediastrum simplex</i> Meyen var. <i>simplex</i>		r	r	r	r	
<i>Pediastrum simplex</i> var. <i>biwaense</i> Fucush.	tw	f	r		r	
<i>Pediastrum simplex</i> var. <i>echinulatum</i> Wittrock	tw				r	
<i>Pediastrum tetras</i> Ralfs			r			r
<i>Scenedesmus acuminatus</i> (Lagerheim) Chodat					r	
<i>Scenedesmus communis</i> Hegewald					r	r
<i>Scenedesmus disciformis</i> (Chodat) Fott & Komárek					r	
<i>Scenedesmus opoliensis</i> P. Richter					r	
<i>Scenedesmus tropicus</i> Crow.	tw		r			
<i>Scenedesmus spinosus</i> Chodat			r			r
<i>Selenodictyum brasiliense</i> Uherk. & Schmidt	t	r	r			r
<i>Sorastrum americanum</i> (Bohlin) Schmidle			r			
<i>Tetraedron incus</i> (Teiling) G.M. Smith			r		f	
<i>Tetraedron minimum</i> (A. Braun) Hansgirg						
<i>Tetraedron regulare</i> Kützing					r	r
<i>Tetrastrum heteracanthum</i> (Nordstedt) Chodat					r	
<i>Tetrastrum staurogeniaeforme</i> (Schroeder) Lemmermann		r			r	r
<i>Tetrastrum triangulare</i> Korshikov					r	r
<i>Treubaria triappendiculata</i> Bernard				r	r	
<b>Zygnemaphyceae (including Desmidiaceae)</b>						
<i>Closterium aciculare</i> T. West		r		r		
<i>Closterium acutum</i> var. <i>variable</i> (Lemmermann) Krieger		r			r	r
<i>Closterium</i> sp.		r				
<i>Cosmarium contractum</i> var. <i>ellipsoideum</i> (Elfving) West & West		r	r	f		
<i>Cosmarium contractum</i> Kirchner f.						
<i>Cosmarium depressum</i> var. <i>planctonicum</i> Reverdin			r	r	r	r



	BN	MI	UD	VI	UR	TA
<i>Cosmarium depressum</i> var. <i>reniforme</i> West & West		r		r		
<i>Cosmarium</i> cf. <i>incavatum</i> Turner		r				
<i>Cosmarium lundelli</i> Delponte			r			
<i>Cosmarium moniliforme</i> var. <i>limneticum</i> W. & G.S.West				r		
<i>Cosmarium</i> cf. <i>regnelli</i> Wille						r
<i>Cosmarium tuddalense</i> Ström				r		
<i>Cosmarium</i> sp.					r	
<i>Mougeotia</i> sp.				r	r	r
<i>Euastrum denticulatum</i> (Kirchner) Gay.			r		r	
<i>Euastrum spinulosum</i> var. <i>burmense</i> (West & West) Krieger					r	
<i>Staurastrum bigibbum</i> Skuja				r		
<i>Staurastrum brachioprominens</i> var. <i>africanum</i> Bourrelly	t			r		
<i>Staurastrum brevispina</i> (Brébisson) Croasdale				r		
<i>Staurastrum cerastes</i> var. <i>pulchrum</i> Scott & Grönblad				r		
<i>Staurastrum gracile</i> Ralfs ex Ralfs		r	r	f	r	
<i>Staurastrum gracile</i> var. <i>kriegeri</i> Scott et Prescott				r	f	
<i>Staurastrum laeve</i> Ralfs					r	
<i>Staurastrum leptocladum</i> var. <i>cornutum</i> Wolle	t?	r	r	r		
<i>Staurastrum leptopus</i> var. <i>variabile</i> Skuja	t?				r	
<i>Staurastrum limneticum</i> var. <i>burmense</i> West & West	t?				f	
<i>Staurastrum longipes</i> (Nordstedt) Teiling				r	r	
<i>Staurastrum muticum</i> Brébisson					f	
<i>Staurastrum nodulosum</i> Prescott					r	
<i>Staurastrum octoverrucosus</i> var. <i>simplicius</i> Scott & Grönblad					r	
<i>Staurastrum pingue</i> Teiling f.						r
<i>Staurastrum playfairi</i> Scott & Prescott		r				
<i>Staurastrum protectum</i> var. <i>rangoonense</i> (Skuja) Scott & Prescott	t				r	
<i>Staurastrum punctulatum</i> Brébisson					r	
<i>Staurastrum smithi</i> Nordstedt		r			r	
<i>Staurastrum tetracerum</i> (Kützing) Ralfs				r	r	r
<i>Staurastrum tohopekaligense</i> Wolle	tw	r	r	f		
<i>Staurodesmus aristiferus</i> (Ralfs) Thomasson					r	
<i>Staurodesmus convergens</i> (Ehrenberg) Teiling				r	f	
<i>Staurodesmus omeari</i> (Archer) Teiling					r	
<i>Staurodesmus spetsbergensis</i> (Nordsted) Teiling					r	
<b>Euglenophyceae</b>						
<i>Euglena acus</i> Ehrenberg			r		f	
<i>Euglena pisciformis</i> Klebs					r	
<i>Euglena</i> sp.					r	
<i>Lepocinclis ovata</i> (Playfair) Conrad					r	
<i>Phacus curvicauda</i> Swirenko					r	
<i>Phacus longicauda</i> (Ehrenberg) Dujardin					r	
<i>Phacus orbicularis</i> Hübner					r	
<i>Strombomonas gibberosa</i> (Playfair) Deflandre					r	
<i>Trachelomonas armata</i> (Ehrenberg) Stein				r	r	
<i>Trachelomonas hispida</i> (Perty) Stein em. Deflandre				r	r	
<i>Trachelomonas verrucosa</i> Stokes				r	r	
<i>Trachelomonas volvocina</i> Ehrenberg		r	r	r	r	
<i>Trachelomonas volvocinopsis</i> Swirenko		r		r	r	

made only a minor contribution to taxa richness. Chrysophytes were normally found in very low numbers, except at Station 3 in Ubolratana, where euglenophytes (Plate 5.12) were also present with several taxa.

The overall similarity of the taxa lists from the different lakes that were calculated by means of Jaccard's index showed mainly a geographic ranking (Tab. 5.3) corresponding in general to the results obtained by TWINSpan (Fig. 5.3). The two reservoirs situated close by within the same catchment in N Thailand showed very high similarity, followed by the three reservoirs from Sri Lanka of which two, Minneriya and Victoria, are partly linked by a channel. For the next ranking the two remote stations of Ubolratana can



Table 5.3: Jaccard's contingency index based on overall phytoplankton taxa lists from the five FISHSTRAT water bodies with two sites from Ubolratana kept separately and two additional reservoirs in N Thailand (for site abbreviations see Table 5.1). Thailand 1996 (see Peerapornpisal, 1996).

	Sri Lanka		Thailand, this study		Thailand, 1996		Philipp.
	UD	VI	UR3	UR5	HA	HC	TA
MIN	0.38	0.35	0.11	0.24	0.14	0.11	0.14
UDA		0.37	0.13	0.23	0.25	0.20	0.17
VIC			0.07	0.14	0.12	0.11	0.11
UR3				0.29	0.16	0.20	0.09
UR5					0.17	0.17	0.17
HA						0.71	0.16
HC							0.18

be considered similar although the similarity is largely reduced. The taxa list from the volcanic Lake Taal is the most distantly related because of its very low similarity to any other site.

Shannon's diversity index selected for quantitative samples with maximum differences between the five water bodies (Shannon/Evenness Tab. 5.4) paralleled the ranking of total species richness (Tab. 5.4) both of which followed a trophic gradient. A similar ranking can be observed for evenness although the greatest differences are found between the group of oligotrophic plus meso-eutrophic situations contrasting to the eutrophic situations.

### *Tropical and rare phytoplankton taxa*

For taxa occurring mainly in tropical freshwaters and some generally rarely recorded ones, diacritical features for species identification based on morphology and comments to biogeographic distribution are given.

#### *1) Cyanophyceae / Cyanobacteria*

##### *Aphanizomenon volzi*

Filaments in bundles disintegrating by fixation. Terminal cells attenuated, not extended into haircells. Typical arrangement of heterocytes close to the single akinetes (Rott & Lenzenweger, 1994). Tropical-warm-temperate taxon.

Table 5.4: Trophical ranking of the most diverse phytoplankton samples of the seven water bodies in Table 5.1.

Code		Shannon's H	Evenness	Taxa total	Trophic rank
VIC	1.5 m / Jan 99	3.180	0.851	42	oligo-meso
UDA	1.5 m / Feb 99	2.772	0.742	42	oligo-meso
MIN	0.5 m / Aug 99	2.943	0.809	38	meso-eu
UR3	0.5 m / Feb 99	2.529	0.796	24	meso-eu
HA	0.0-4.0 m / Dec 92	2.212	0.664	28	eu
UR5	0.5 m / Oct 98	2.152	0.627	31	eu
HC	0.0-4.0 m / Dec 92	1.863	0.502	41	eu
TA	5.0 m / Feb 99	1.627	0.601	15	volcanic eu

*Aphanocapsa delicatissima* (Plate 5.2b)

The small cells are regularly and loosely arranged in large colonies. Cosmopolitan taxon. *Aphanocapsa holsatica* (Plate 5.1a) differs from it by somewhat larger and much more densely arranged cells. It is unclear if the *A. holsatica* found here is corresponding to *Aphanocapsa cumulus* Komárek & Cronberg (2001) recently described from Africa although the latter taxon forms larger and denser colonies with a distinct mucilage margin.

*Chroococcus taxa* (Plate 5.2c, d)

In Victoria reservoir a very distinct *Chroococcus* species (Plate 5.2c) was found with homogeneously blue-green cells arranged in pairs, within a special mucilage layer and an indistinct colonial mucilage altogether giving the appearance of *Chr. limneticus* from temperate lakes, however the cell dimensions (4-4.5 x 3.5-4 µm) are smaller than for *Chr. limneticus*. The cell size corresponds to *Chr. dispersus*, which was observed in Lake Taal (Plate 5.2d). There is also similarity to *Chr. cronbergae* Komárek & Novelo (1994) described from African ponds but the distinct mucilage structures are missing in this case.

*Coelomonon microcystoides* (Plates 5.2e, f)

Tropical taxon (Komárek & Anagnostidis, 1998). Cell size around 2 µm, spherical to slightly elongated. Colonies 30-40 µm, first with distant, later with densely arranged cells and diffuent mucilage margins. Planktonic in the shallow reservoir Minneriya. In Ubolratana small colonies of ellipsoidal cells were found which are closer to *C. tropicalis* Senna, Perez & Komarek according to Senna *et al.* (1998).

*Cyanodictyon imperfectum* (Plate 5.1c)

This is a common taxon with minute cells arranged in short filament-like chains, irregularly arranged within mucilage. Cosmopolitan planktonic taxon.

*Cylindrospermopsis philippinensis*

Regularly spirally coiled filaments, cells 2-2.5 x 2-3 µm with 0.5 to 2.5 turns arranged close by with a diameter between 25 and 30 µm. The terminal heterocytes (2.5-3 x 4-4.5 µm) are attenuated but with a round tip, whereas in *C. raciborski* the heterocytes found were normally longer (5 to 6-times the diameter) and with a more pointed tip. It corresponds largely to the figures given for an enriched shallow lake in Mexico (Komárková-Legnerova & Tavera, 1996) but shows less morphological variability. Tropical taxon.

*Cylindrospermopsis raciborski* (Plate 5.1d)

Filaments more or less straight, often with only one terminal heterocyte and a pointed anterior end (as in Plate 5.1d); sometimes devoid of both heterocytes and therefore difficult to differentiate from other taxa (for extreme variability see Komárková *et al.*, 1999). Tropical and warm temperate taxon.

*Eucapsis parallelepipedon* (Plate 5.2g)

Colonies with the typical 3-dimensional arrangement of small, pale blue-green cells. Cell size around 2 µm. Taxon which mainly occurs in warm and tropical regions but also in alkaline ponds (Komárek & Anagnostidis, 1998). Only recorded in volcanic Lake Taal.

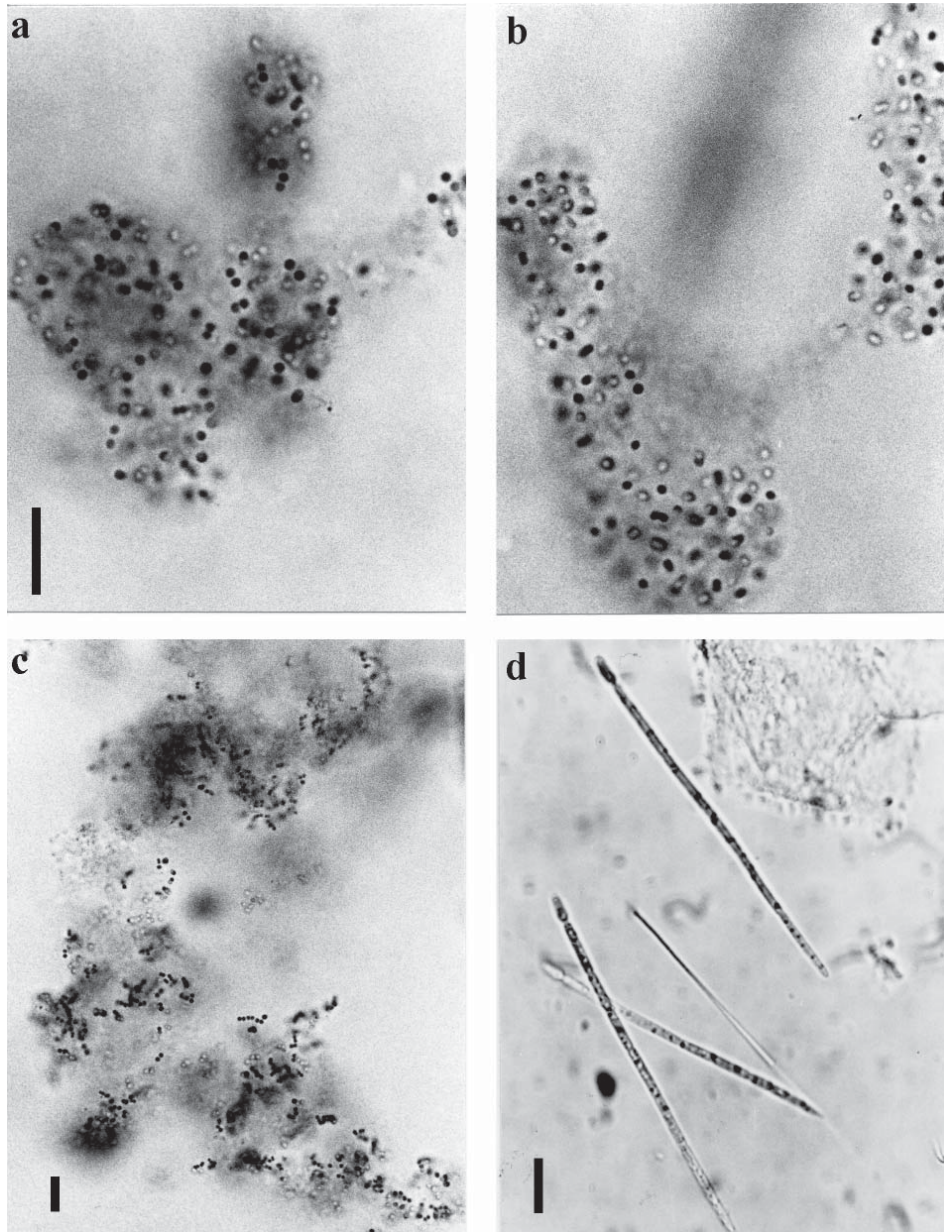


Plate 5.1: Cyanophyceae/Cyanobacteria 1: (a) *Aphanocapsa holsatica*, MI; (b) *Aphanothece minutissima*, MI; (c) *Cyanodictyon imperfectum*, UD; (d) *Cyndrospermopsis raciborski* (3 filaments with 1 heterocyte each) and *Planktolyngbya limnetica*, UR. (a, b 1000x; c 400x; d 630 x; size bars in a, c, d = 10  $\mu\text{m}$  each).



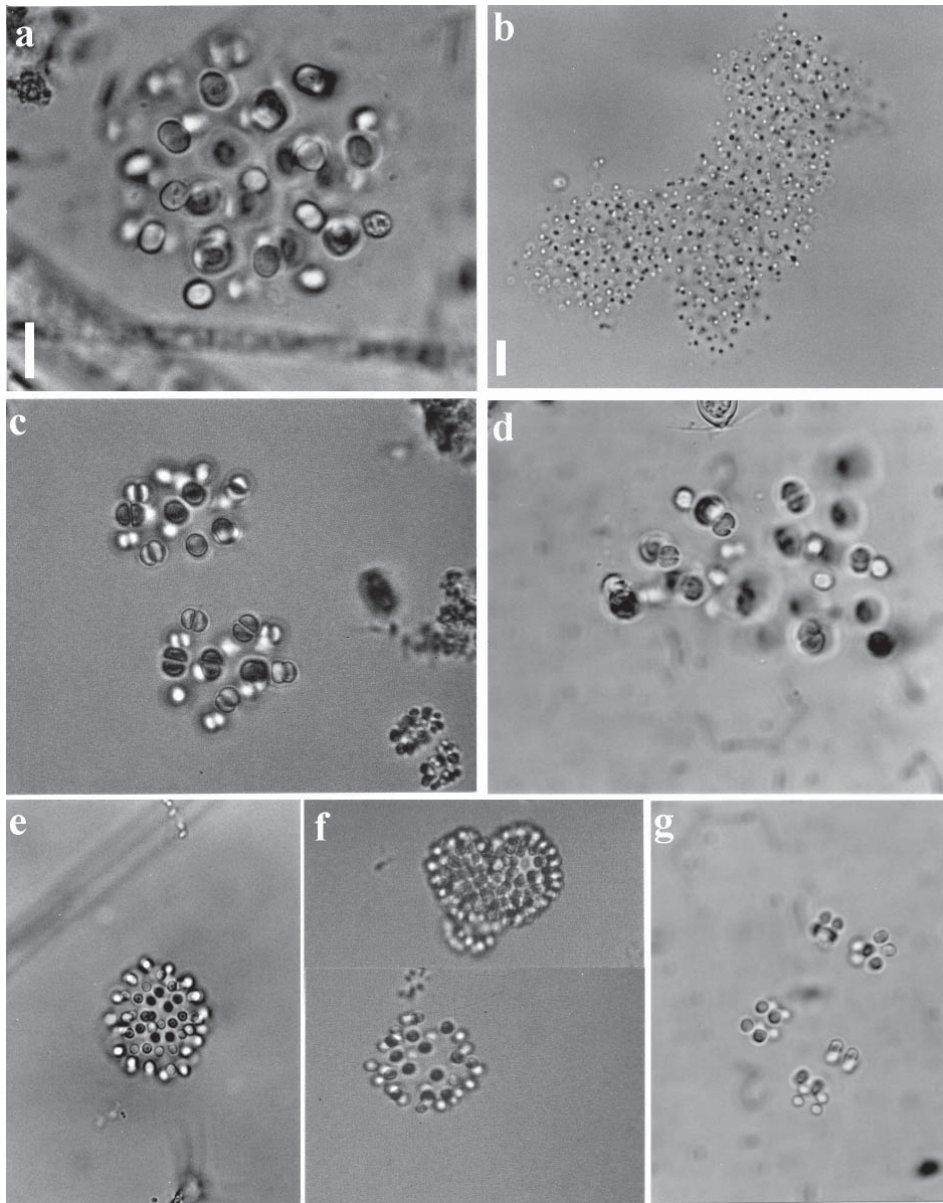


Plate 5.2: Cyanophyceae/Cyanobacteria 2: (a) *Aphanothece* sp. ad *A. stagnina*, UR; (b) *Aphanocapsa delicatissima*, MI; (c) *Chroococcus* cf. *limneticus*, VI; (d) *Chroococcus dispersus*, TA; (e-f) *Coelomoron microcystoides*, (e) MI; (f), UD; (g) *Eucapsis parallelepipedon*, TA. (a, c, d, g 630x; b, e, f 400x; size bars in a, b = 10  $\mu$ m).

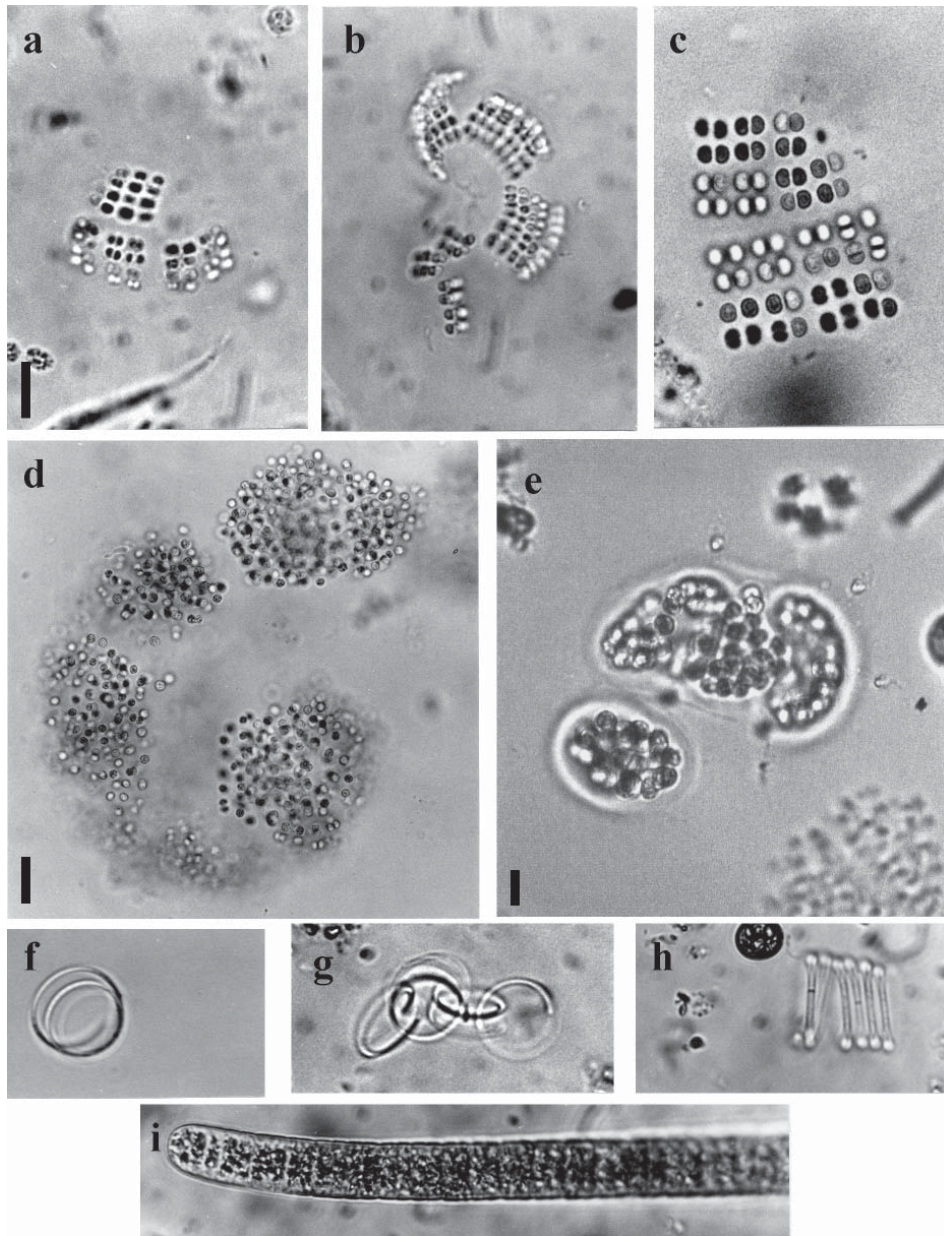


Plate 5.3: Cyanophyceae/Cyanobacteria 3: (a-b) *Merismopedia africana*, VI; (c) *Merismopedia punctata*, MI; (d) *Microcystis flos-aquae*, MI; (e) *Microcystis wesenbergi*, MI; (f-h) *Planktolyngbya circumcreta*, (f) MI; (g, h) UR; (i) *Oscillatoria raciborski*, UR. (a-c, f-i 630x; d 200 x; e 400x; size bars in a, e = 10  $\mu\text{m}$  each and in d = 20  $\mu\text{m}$ ).



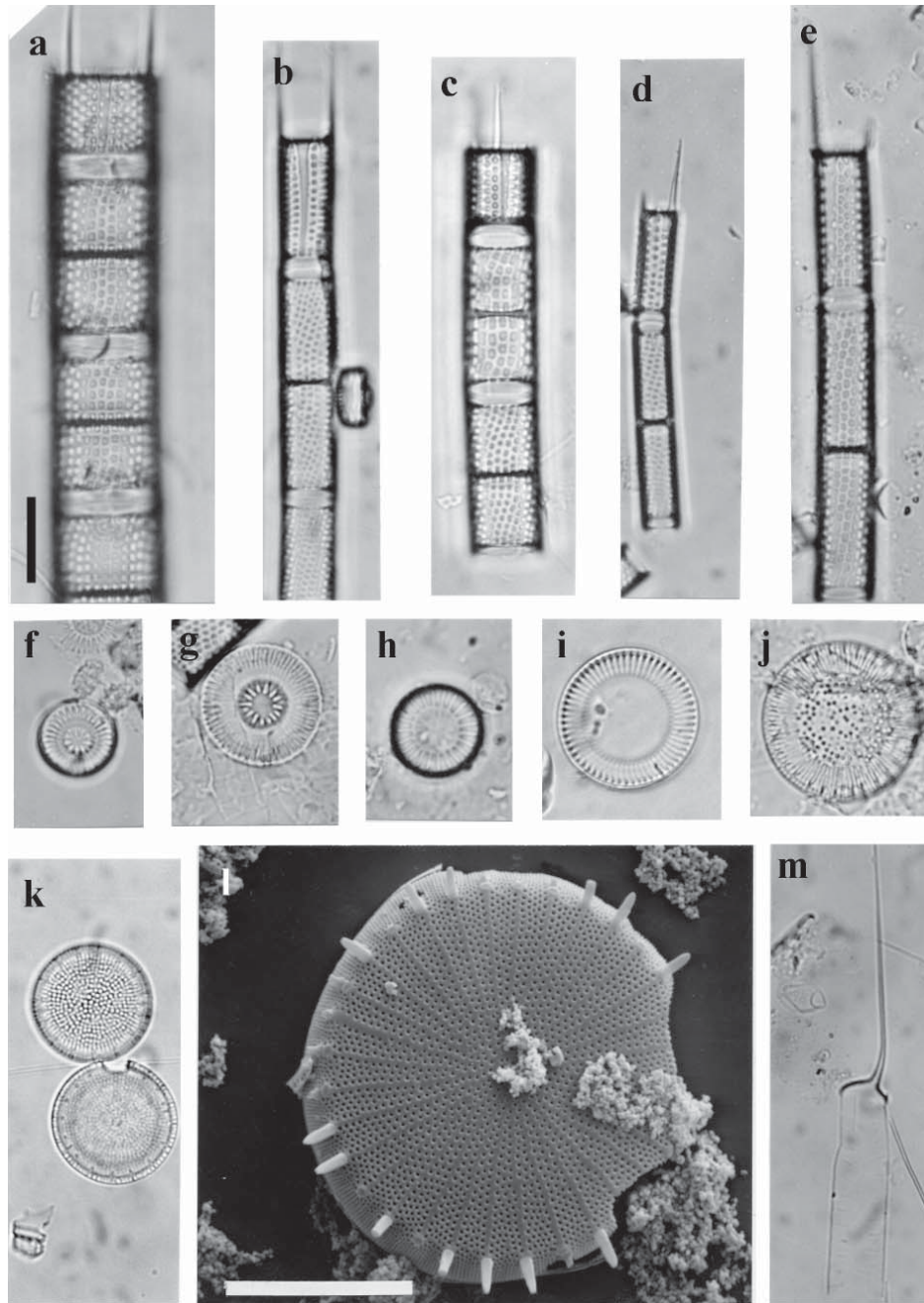


Plate 5.4: Diatomophyceae from cleaned mounts: (a-e) *Aulacoseira granulata*; (a-c) MI, (d) VI, (e) UR, (f-g) *Cyclotella pseudostelligera*, VI; (h-i, *Cyclotella* sp. ad *C. meneghiniana*; (h) UR, (i) TA; (j) *Cyclotella comta*, VI; (k-l) *Stephanodiscus* cf. *St. neoastreaa*, VI (k) LM, (l) SEM; (m) *Urosolenia diademata*, VI. (a-k, m 1000x; LM and SEM size bars in a, l = 10  $\mu$ m each).

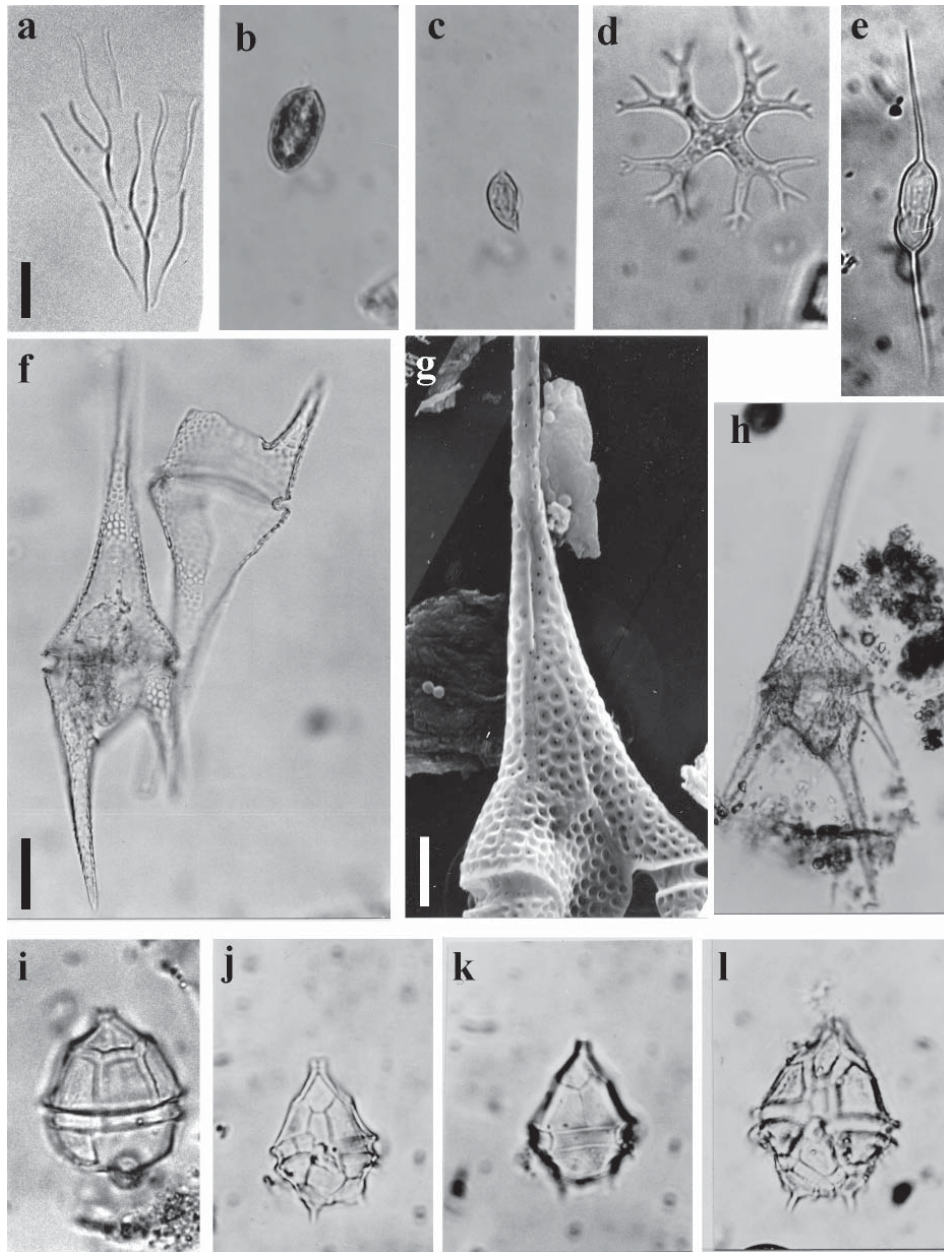


Plate 5.5: Chrysophyceae, Xanthophyceae, Cryptophyceae, Dinophyceae 1: (a) *Dinobryon sertularia*, UR3; (b) *Cryptomonas cf. erosa*, TA; (c) *Rhodomonas minuta*, TA; (d) *Isthmochloron lobulatum*, VI; (e) *Centritractus belanophorus*, UR; (f-g) *Ceratium furcoides*, TA, (f) LM, (g) SEM; (h) *Ceratium hirundinella*, UR3; (i) *Peridiniopsis elpatiewskyi*, UR; (j-l) *Peridiniopsis cunningtoni*, UR3. (a-e, i-l 630x; f, h 400x; LM size bars in a, f = 10  $\mu$ m each and SEM in g = 20  $\mu$ m)



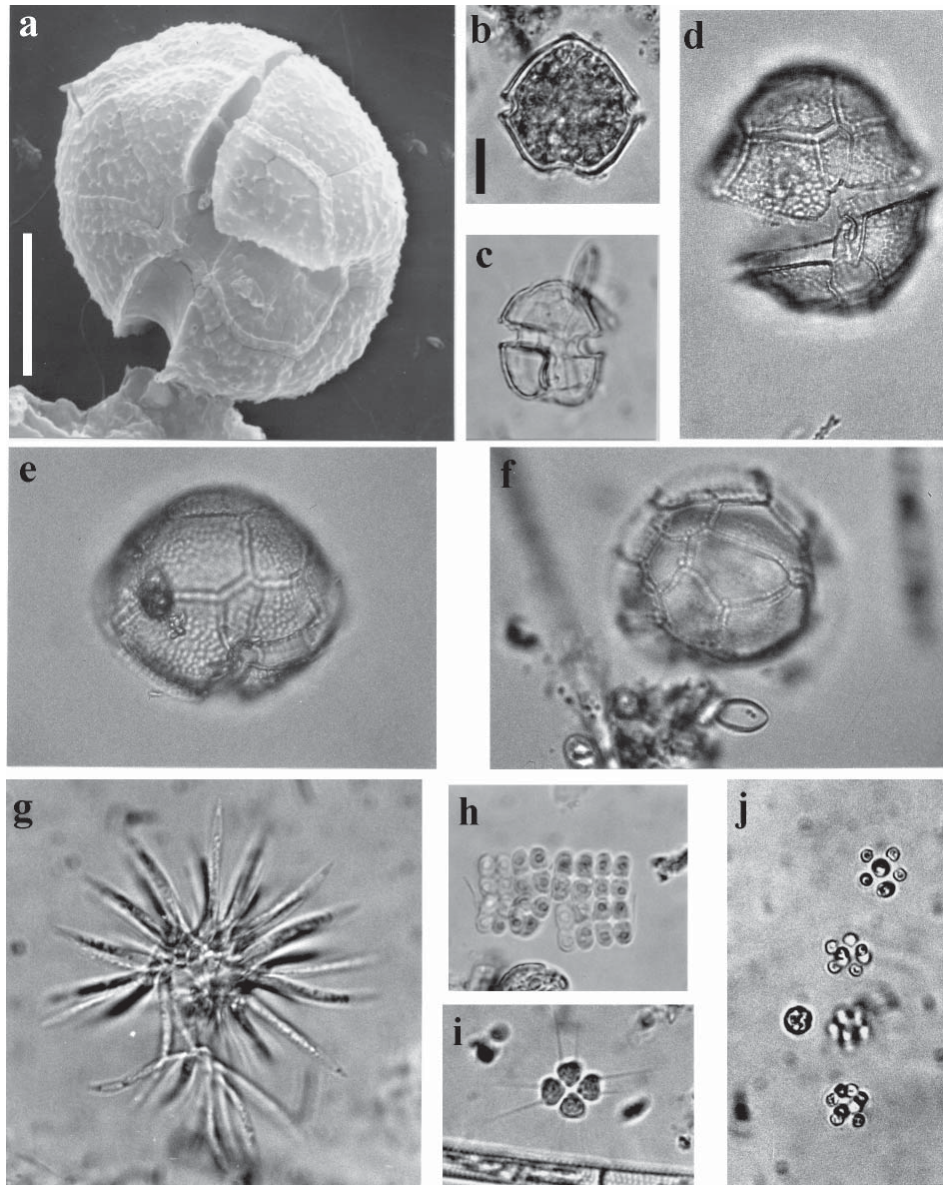


Plate 5.6: Dinophyceae 2, Chlorophyceae 1: (a-c) *Peridiniopsis penardiforme*, TA, (a) SEM, (b-c) LM; (d-f) *Peridinium gatunense*, UD; (g) *Ankistrodesmus bernardi*, VI; (h) *Crucigeniella saguei*, VI; (i) *Tetrastrum heteracanthum*, UR; (j) *Coenococcus cf. fotti*, VI. (b-j 630x; SEM and LM size bars in a, b = 10  $\mu$ m each)

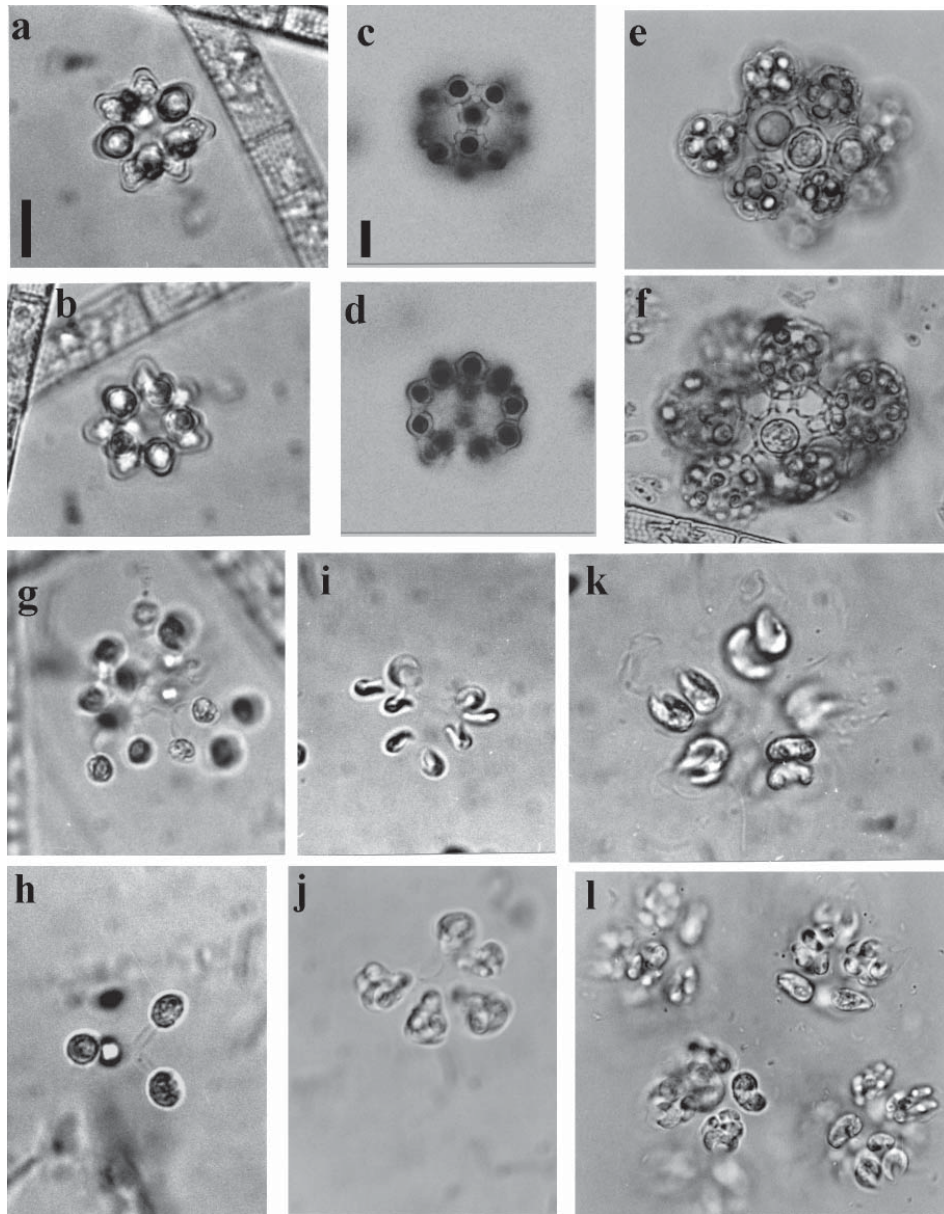


Plate 5.7: Chlorophyceae 2: (a-b) *Coelastrum pulchrum*, UR; (c-d) *Coelastrum indicum*, UD; (e) *Coelastrum reticulatum* var. *cubanum*, MI; (f) *Coelastrum polychordum*, MI; (g-h) *Dictyosphaerium pulchellum* var. *minimum*, UR; (i-j) *Selenodictyum brasiliense*, (i) VI, (j) TA; (k-l) *Kirchneriella diana*, (k) VI, (l) UD. (a, b, f-k 630X; c-e, l 400x; size bars in a, c = 10  $\mu$ m each).



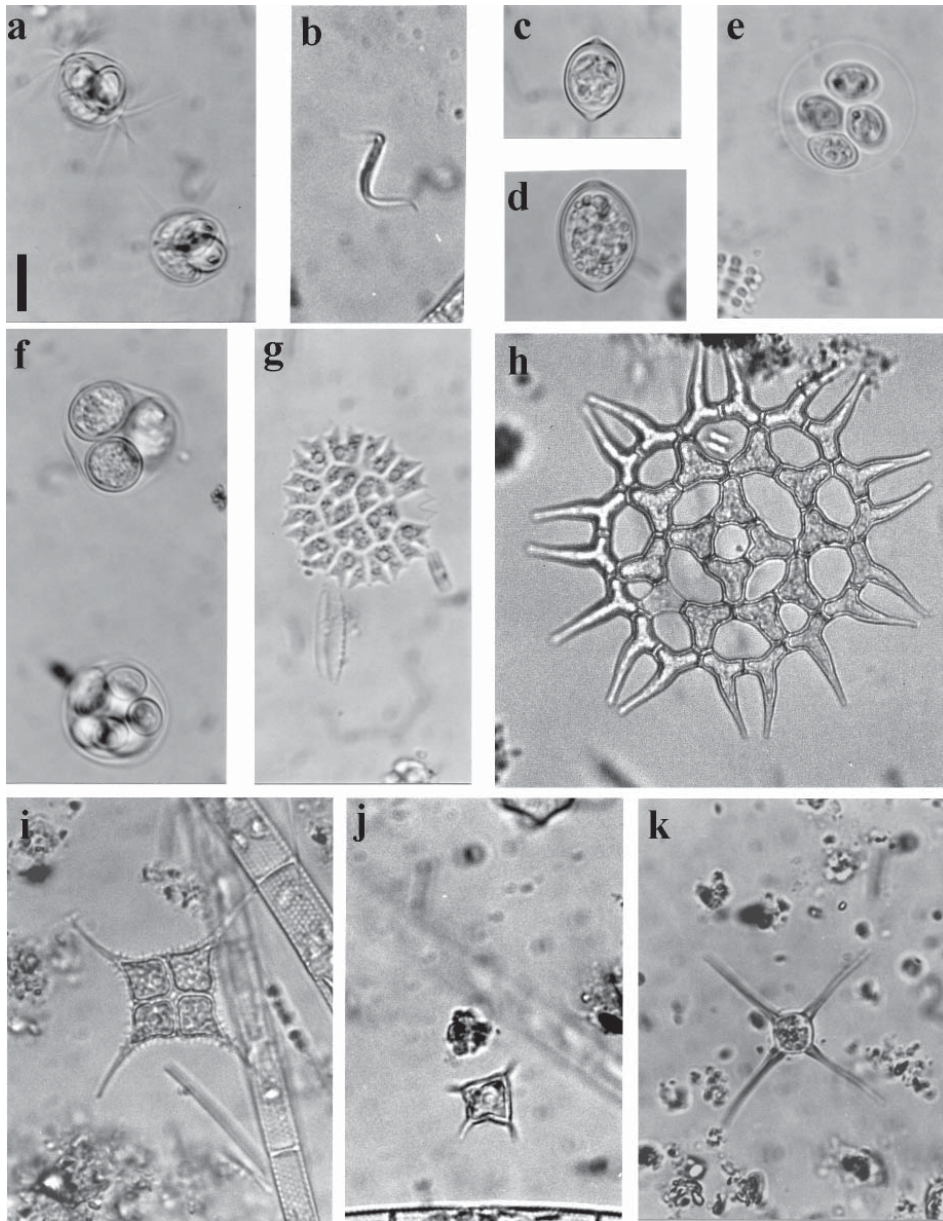


Plate 5.8: Chlorophyceae 3: (a) *Lagerheimia citriformis*, TA; (b) *Monoraphidium contortum*, UR; (c-f) *Oocystis marssoni*, TA; (g) *Pedastrum tetras*, TA; (h) *Pedastrum simplex* var. *biwaense*, VI; (i) *Pedastrum simplex* var. *echinulatum*, UR; (j) *Tetradron incus*, UR; (k) *Treubaria triappendiculata*, UR. (All 630x; size bar in a = 10  $\mu$ m).

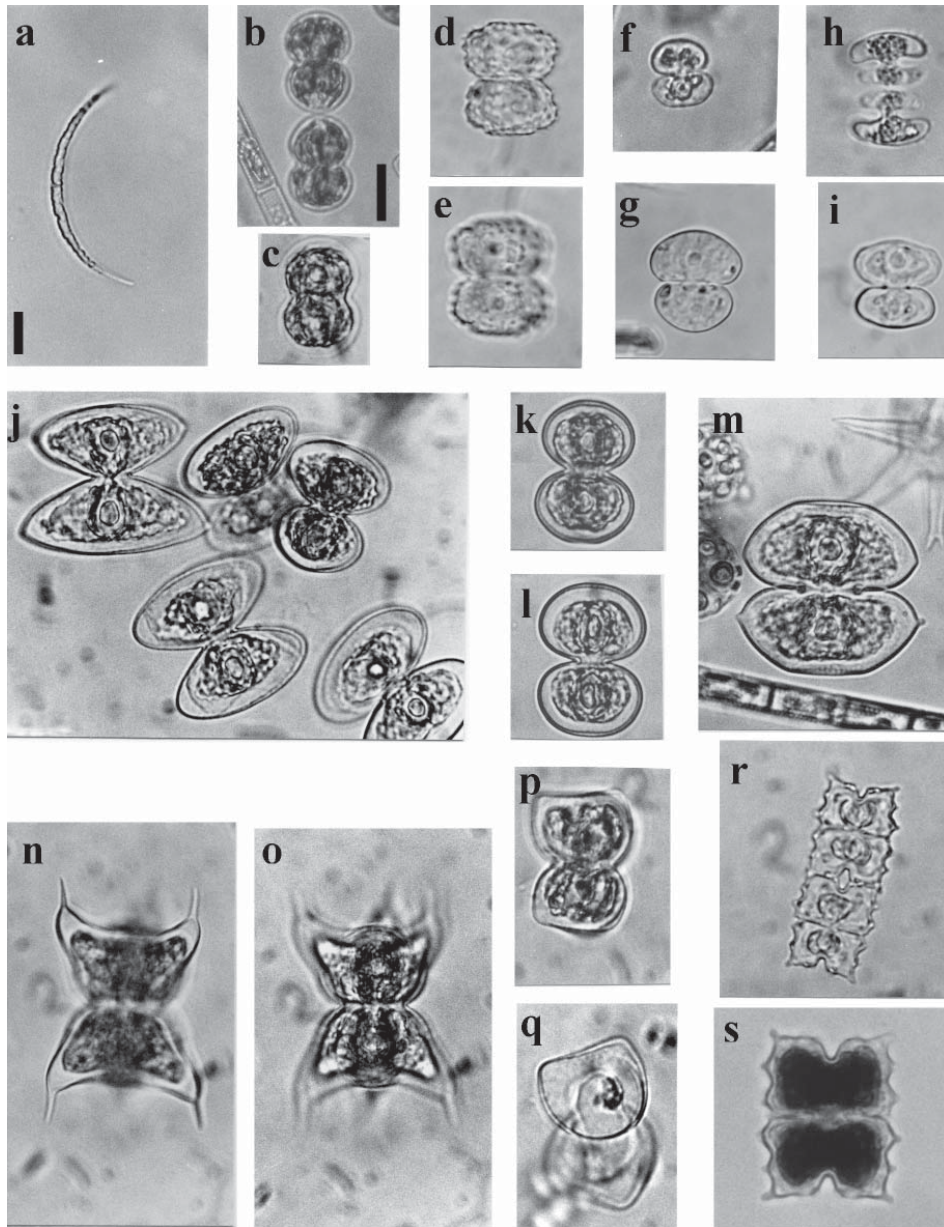


Plate 5.9: Desmidiales 1: (a) *Closterium acutum* var. *variabile*, MI; (b-c) *Cosmarium moniliforme* var. *limneticum*, VI; (d-e) *Cosmarium* cf. *incavatum*, TA; (f-g) *Cosmarium depressum* var. *planctonicum*, VI; (h) *Cosmarium depressum* var. *reniforme*, VI; (i) *Cosmarium* cf. *regnelli*, TA; (j) *Staurodesmus spetsbergensis* (two specimens on the left), VI; (k) *Staurastrum muticum*, VI; (l) *Cosmarium contractum*, VI; (m) *Staurodesmus convergens*, VI; (n-o) *Staurodesmus aristiferus*, VI; (p-q) *Staurastrum punctulatum*, VI; (r-s) *Euastrum denticulatum*, VI. (a 400x; b-s 630x; size bars in a and b = 10  $\mu$ m each).



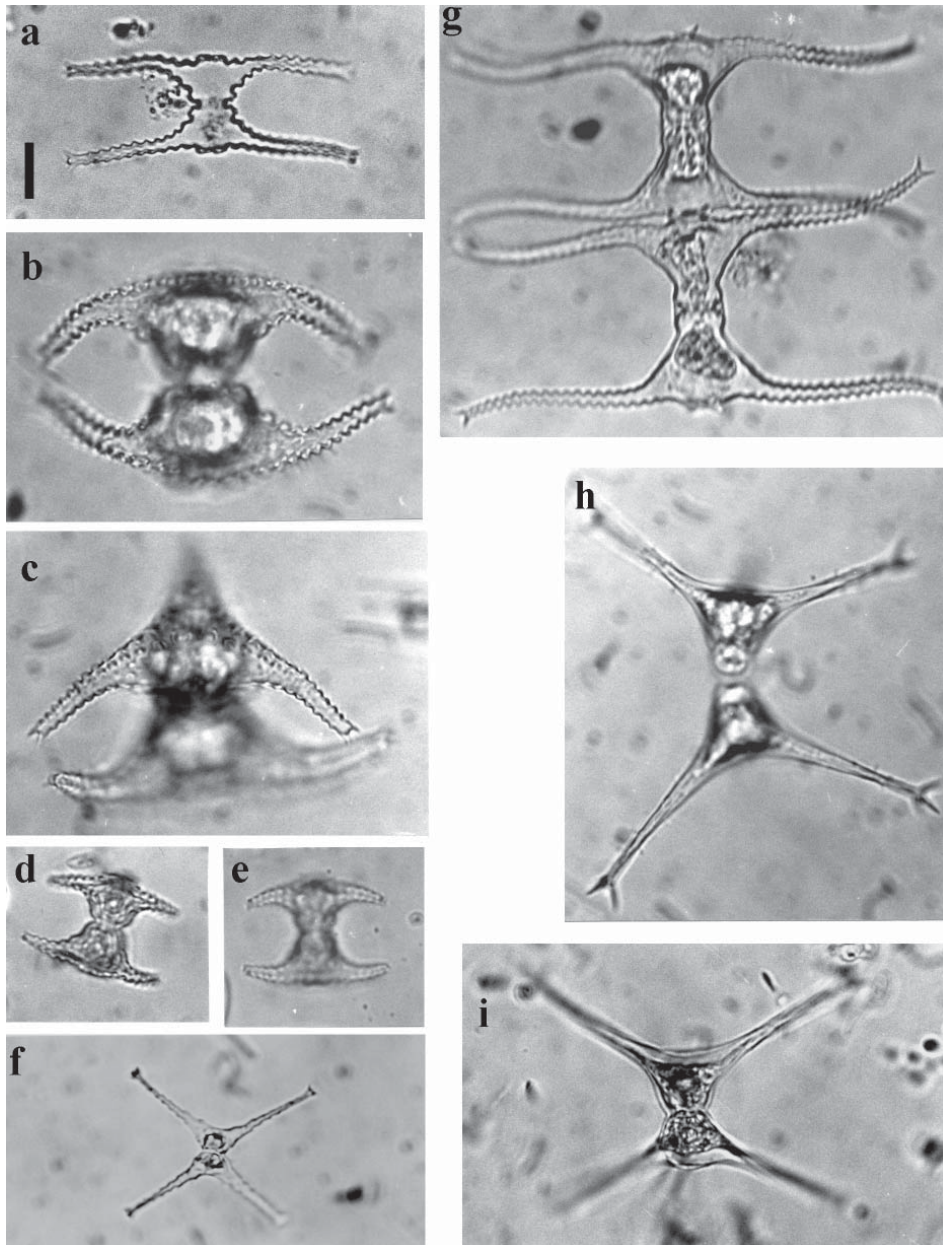


Plate 5.10: Desmidiaceae 2: (a) *Staurastrum brachioprominens* var. *africanum*, VI; (b-c) *Staurastrum cerastes* var. *pulchrum*, VI; (d-e) *Staurastrum gracile* var. *kriegeri*, VI; (f) *Staurastrum tetracerum*, UR; (g) *Staurastrum leptocladum* var. *cornutum*, VI; (h-i) *Staurastrum leptopus* var. *variabile*, VI. (All 630x; size bar in a = 10  $\mu$ m).

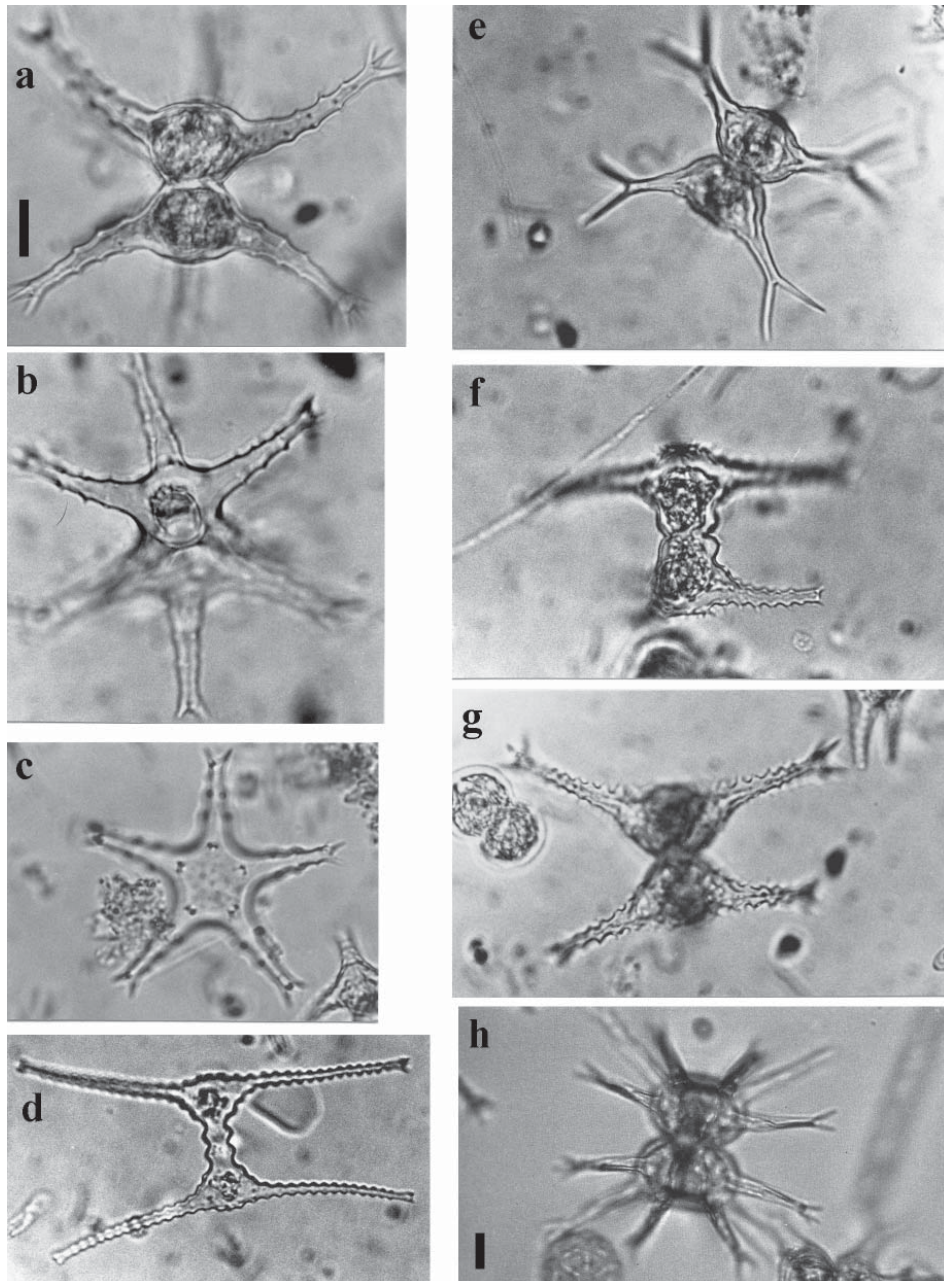


Plate 5.11: Desmidiales 3: (a-c) *Staurastrum limneticum* var. *burmense*, VI; (d) *Staurastrum nodulosum*, VI; (e) *Staurastrum protectum* var. *rangoonense*, VI; (f-g) *Staurastrum pingue* f., VI; (h) *Staurastrum tohopekaligense*, VI. (a-g 630x; h 400x; size bars in a and h = 10  $\mu$ m).



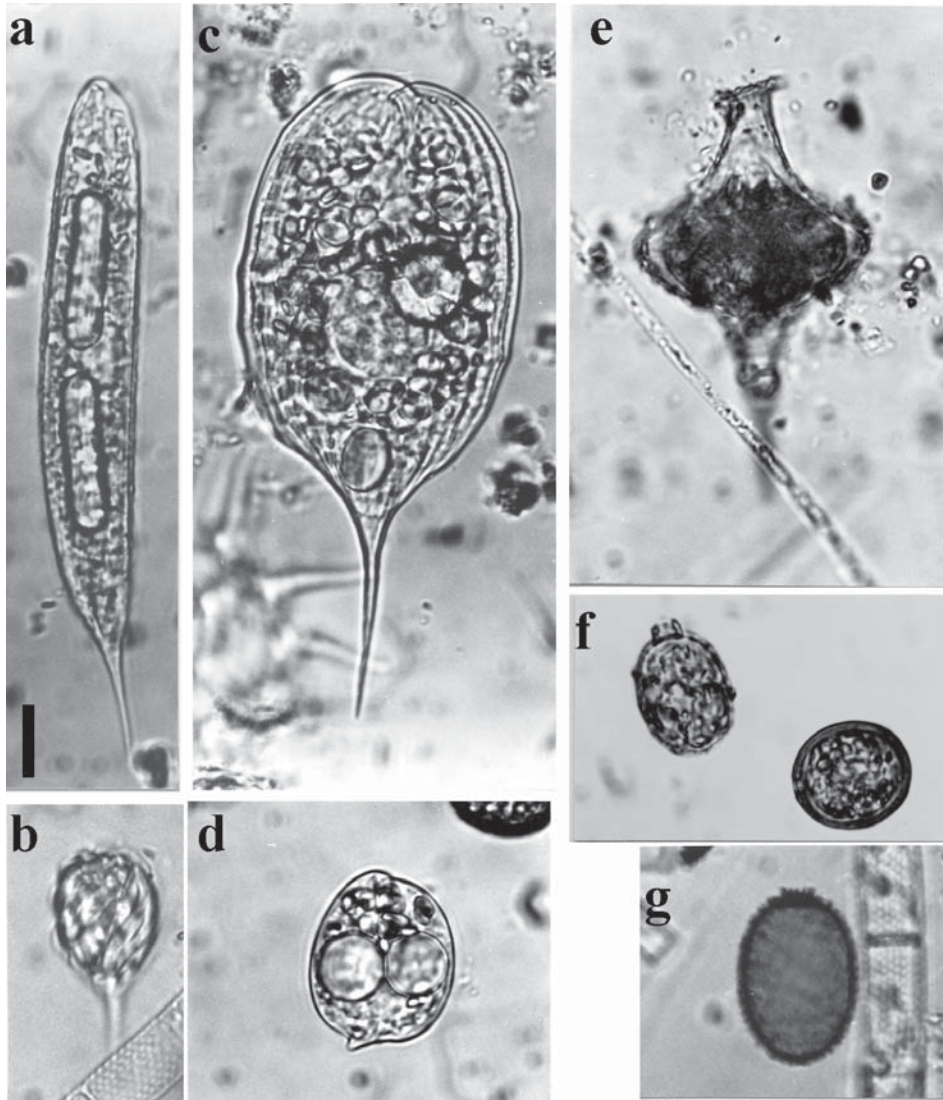


Plate 5.12: Euglenophyceae: (a) *Euglena acus*, UR; (b) *Lepocinclis ovata*, UR; (c) *Phacus orbicularis*, UR; (d) *Phacus curvicauda*, UR3; (e) *Strombomonas gibberosa*, UR; (f) *Trachelomonas verrucosa* (left) and *Trachelomonas volvocina* (right), UR; (g) *Trachelomonas hispida*, UR. (All 630x; size bar in a = 10  $\mu$ m).



*Merismopedia africana* (Plates 5.3a, b)

Colonies plate-shaped but arcuated. The cells are around 1.5-2 µm. This taxon has recently been described by Komárek & Cronberg (2001) from Africa. Most likely a tropical taxon. It differs from *M. tenuissima* by larger cell size, smaller colonies and the typical colony shape.

*Microcystis* taxa (e.g. Plates 5.3d, e)

In tropical freshwaters the genus *Microcystis* reaches the highest morphological variability (see Komárek *et al.*, 2002) with some taxa only recorded from singular tropical regions but possibly overlooked in other regions. The three clearly different but cosmopolitan taxa *M. aeruginosa*, *M. flos-aquae* (Plate 5.3d) and *M. wesenbergi* (Plate 5.3e) were common but also a taxon closer to *M. lamelliformis* (a medium-sized tropical taxon with lenticulate, flat coenobia) and to *M. smithi* (an original temperate taxon with scattered cells) were found. The species *M. comperei* recorded from Sri Lanka earlier (Rott & Lenzenweger, 1994) was not found during this study.

*Planktolyngbya* taxa (Plates 5.1d, 5.3f-h)

The two taxa recorded here are the circular coiled taxon with short cells *P. circumcreta* (Plates 5.3f-h), a tropical and warm-temperate taxon (Komárek & Kling, 1991) and the straight and cosmopolitan taxon *Planktolyngbya limnetica* (Plate 5.1d).

2) *Diatomophyceae**Stephanodiscus* cf. *neoastraea* (Plates 5.4k, l)

This is a medium-sized taxon with very regular and fine alveoles (5-6 rows of points between the spines).

*Urosolenia diademata* (Plate 5.4m)

This taxon is easily overlooked in fixed samples as a consequence of its weak silicification. The SEM study revealed distinct differences to *Urosolenia eriensis*, a common planktonic taxon from temperate environments and often classified as cosmopolitan. The most striking difference to *U. eriensis* visible in the LM (here on the right from the spine) is seen by one small tooth (sometimes part of a diadema-like rim) on one or both sides of the valve margin (mantle) distant from the basis of the spine. Details of the ultrastructure and additional LM are given in Rott *et al.*, 2006. The taxon was recorded from three reservoirs in Sri Lanka (Victoria, Minneriya, Kandy) until now, but could be more widespread in tropical SE-Asia or other tropical regions.

3) *Dinophyceae**Ceratium furcoides* (Plates 5.5f, g)

Often overlooked and confused with *Ceratium hirundinella*. It has a distinct character for differentiation: the fourth median apical plate does not reach the apex whereas all four median apical plates reach the apex in *C. hirundinella*. In addition the overall shape is normally more narrow and fusiform than in *C. hirundinella*. The number of anterior horns varies between two and three in both taxa. Dominant taxon in Lake Taal. A warm-

temperate species occurring in temperate lakes in summer, but also widely distributed in tropical freshwaters.

*Peridiniopsis cunningtoni* (Plates 5.5j-l)

Small cosmopolitan taxon with six pre-equatorial plates and five asymmetrically arranged median apical plates all reaching the apex. Whereas the overall shape is characterized by a steep conical epitheca, the number and arrangement of spines on the hypotheca are variable.

*Peridiniopsis elpatiewskyi* (Plate 5.5i)

This species differs from *P. cunningtoni* by only four median apical plates, which are more symmetrically arranged around the apex. The overall shape is more or less ovoid.

*Peridiniopsis penardiforme* (Plates 5.6a-c)

The shape is pentangular in cross-section (Plate 5.6b). Deep transversal cingulum, the deep sulcus reaches the antapex. The first median apical plate has an extended hexangular shape, but does not reach the apex. Probably a cosmopolitan taxon.

*Peridinium gatunense* (Plates 5.6d-f)

Cells almost spherical with broadly rounded apex and antapex. Beside the seven pre-equatorial plates, there are four median apical plates plus three asymmetrical (one large, two small) median apical plates (see Plate 5.6f). This taxon seems to occur more frequently in tropical than in warm-temperate regions.

#### 4) Chlorophyceae

*Ankistrodesmus bernardi* (Plate 5.6g)

Semi-cells narrow, sharply pointed from the centre to the poles. Cell axis sigmoidally curved. Cell shape and the irregular twisted arrangement of the cells are typical for this tropical taxon in contrast to the fascicle forming *A. falcatus* which is cosmopolitan (Komárek & Fott, 1983).

*Coelastrum* species (Plates 5.7a-f)

The species of this genus show some variability of cell shape from young to old colonies (young colonies of *C. pulchrum* in Plates 5.7a, b; although *C. pulchrum* has a stout process on each cell missing in *C. astroideum*). The tropical taxon *C. indicum* (Plates 5.7c, d) differs from *C. microporum* by broader cells and distinct links to the neighbour cells. The tropical *C. reticulatum* var. *cubanum* has pentangular cells with a short wart-like process on each cell. In *C. polychordum* the cells are linked normally by more than one (two or more) connection to the neighbour cells. Three of the four *Coelastrum* species are centred in the tropics (Tab. 5.2).

*Crucigeniella saquei* (Plate 5.6h)

Crucigenoid taxon with specific slightly asymmetric cell structure lacking apical thickening as typical for the close *C. apiculata* (Komárek, 1983). Since its description from slightly salted brackish waters in Cuba, it was found in other tropical freshwaters.

*Dictyosphaerium pulchellum* var. *minimum* (Plates 5.7g, h)

Young cells slightly elongated, later almost spherical with one chloroplast with pyrenoid. The small specimens here correspond to the var. *minimum* Defl. given by Komárek & Fott (1983), a taxon more common in tropical environments.

*Kirchneriella diana* (Plates 5.7k, l)

Cells with a deep, rounded incision and elongated pointed ends, elongated moon-shaped with somewhat distorted poles, typical in numerous mucilaginous colonies. Typical for mesotrophic tropical lakes.

*Lagerheimia citrifomis* (Plate 5.8a)

Cells ellipsoidal with a small papilla on both ends and four or more, colourless bristles on each pole. Found in both temperate and tropical environments.

*Monoraphidium taxa* (Plate 5.8b)

At least three taxa of this genus were found with *M. contortum* (Plate 5.8b) for which a mother cell division stage is shown being the most common. A *Monoraphidium* taxon close to the tropical *M. caribeum*, a presumably tropical taxon, has been found in reservoirs in Sri Lanka (Tab. 5.2).

*Oocystis species* (Plates 5.8c-f)

Within this genus a small form close to *O. parva* was found and the larger *O. marssoni* (Plates 5.8c-f). The latter has a thickened cell wall with additional thickening at the poles in adult stages.

*Pediastrum species* (Plates 5.8g-i)

The species recorded here are *P. duplex*, *P. simplex* with three varieties (two shown in Plates 5.8h and i respectively) and *P. tetras* (Plate 5.8g). Common cosmopolitan taxa in eutrophic waters with somewhat higher frequency of some varieties in the tropics (*P. simplex* var. *biwaense* and *P. simplex* var. *echinulatum*).

*Selenodictyum brasiliense* (Plates 5.7i, 5.7j)

This taxon from *Dictyosphaeriaceae* was recorded here and there from tropical environments (Schabetsberger *et al.*, 2004). In contrast to *Dictyosphaerium* the cells are fusiform with attenuated poles. Furthermore, the poles are still linked to the remnants of the mother cell wall and arranged into clusters within a mucilage matrix. Only found in the tropics until now.

*Tetraedron incus* (Plate 5.8j)

Cell shape tetrahedral with spines on each corner. Common but never frequent cosmopolitan taxon.

*Tetrastrum heteracanthum* (Plate 5.6i)

Crucigenoid taxon with a rectangular central opening and two asymmetric spines on each lateral corner of the cells. Found in eutrophic waters all over the world.

### 5) Zygnemaphyceae

#### *Euastrum denticulatum* (Plates 5.9r, s)

Here the subquadrate form by West & West (1905) with a pronounced median notch, but more even lateral margins and a singular longer lateral spine was found. There are also some similarities to *E. divaricatum* Lundell. The size (length 28-33, width 22-22, isthmus 8-10) is within the range given for both taxa (Förster, 1982). It is likely that the variability of this taxon is higher in tropical than in temperate environments.

#### *Staurastrum brachioprominens* var. *africanum* (Plate 5.10a)

This tropical taxon has recently been found in Sri Lanka (Rott & Lenzenweger, 1994). The actual specimen has longer processes than recorded before (total width including processes 57 µm).

#### *Staurastrum leptocladum* var. *cornutum* (Plate 5.10g)

This taxon has one pronounced alternating pair of apical teeth which frequently hold two cells together after division. Dimensions: length 37 µm, width with branches 95 µm, isthmus 8 µm. The processes are S-shaped and variably bent to the lateral sides. Frequently recorded from tropical freshwaters (e.g. in Africa by Compère, 1967 and Lind, 1971), unclear if also temperate.

#### *Staurastrum leptopus* var. *variabile* (Plates 5.10h, i)

This variety has been described from Burma by Skuja (1949) and recorded in Sri Lanka earlier (Rott & Lenzenweger, 1994). The wall of the specimens is smooth and the processes have largely variable and sometimes uneven lengths.

#### *Staurastrum limneticum* var. *burmense* (Plates 5.11a-c)

The five processes are divergent and bent upward. It corresponds exactly to the figures given by Croasdale *et al.* (1994) with the exception of the four pairs of small teeth arranged in a circle at the basis of the processes (see also Rott & Lenzenweger, 1994). Dimensions: length 32 µm, width 20 µm, isthmus 11 µm, with processes length 55 µm, width 50-80 µm. This taxon has some similarities to *St. rotula* but differs by a constant number of branches per semicell. Tropical taxon.

#### *Staurastrum muticum* (Plate 5.9k)

This taxon is highly variable in shape and size especially in Victoria reservoir. It belongs into the group of *Staurastrum* species with *Cosmarium*-like rounded semicells and can be classified into the subgenus *Prostaurastrum* which is closer to the genus *Stauroidesmus* than to the genus *Staurastrum*. We found variable elliptic to almost circular semicells, from which an extremely circular shaped specimen is shown in Plate 5.9k. This type can hardly be distinguished from a *Cosmarium* (*C. contractum* as shown in Plate 5.9l). However *St. muticum* is tripolar whereas for *St. spetsbergensis* both bi- and tripolar forms were found (see below). The problematic classification of this section of *Staurastrum* was recently also shown by genetic studies (Gontcharov *et al.*, 2003).

#### *Staurastrum nodulosum* (Plate 5.11d)

This is a small slender bipolar taxon with variable surface undulations, variable length and curved processes. It has been recorded at many sites in Sri Lanka before (see Rott

& Lenzenweger, 1994). Although there are some similarities with *St. leptocladum* its dimensions are much smaller; cell 28 x 10 µm, with processes 45 x 75 µm, isthmus 4 µm.

*Staurastrum pingue* f. (Plates 5.11f, g)

Cells including processes 28 x 65 µm, isthmus 8µm. This uncommon spiny form of *St. pingue* has been studied in detail by Thomasson (1974) from New Zealand. It has similarities to the *St. manfeldti-sebaldi-planctonicum* species-group and to *St. submanfeldti* described by West *et al.* (1923) from Sri Lanka from which it differs mainly by the shape, length and arrangement of processes.

*Staurastrum protectum* var. *rangoonense* (Plate 5.11e)

Skuja (1949) has described this variety under *St. lacustre* var. *rangoonense* from Burma. The high variability in cell wall texture, shape of the body and length of processes and the number of spines on the branches (two to three) is especially striking (see also Rott & Lenzenweger, 1994). Tropical taxon.

*Staurastrum tohopekaligense* (Plate 5.11h)

The apical view of the cells is triangular which is different from *St. leptacanthum* that has also been recorded from Sri Lanka. However, the branches are often only ending in two spines. This taxon is more frequent in tropical than in temperate plankton.

*Staurodesmus spetsbergensis* (Plate 5.9j)

From this taxon we found both bi- and tri-polar specimens. Since the opening angle of the isthmus and the shape of the semicells are variable it is in some cases difficult to separate specimens from *St. muticum*. We preferred to use the approach by Teiling (1967) who suggested replacing the ambivalent *St. biennianum* with other more clear taxa. Our specimens corresponded to figures given in Croasdale *et al.* (1994) although for *Staurodesmus spetsbergensis* bipolar forms were not recorded. We saw similarities to *St. grande* var. *parvum* West of which bipolar specimens were recorded by Thomasson (1974). In fact this species complex as well as the delimitation of sections within the genus *Staurastrum* is a matter of future revisions indicated by the genetically problematic position of the genus *Staurodesmus* (see Gontcharov *et al.*, 2003).

## 6) Euglenophyceae

Almost all taxa of the genera *Euglena* (Plate 5.12a), *Lepocinclis* (Plate 5.12b), *Phacus* (Plate 5.12c-d), *Strombomonas* (Plate 5.12e) and *Trachelomonas* (Plate 5.12f-g) found here are designated as “cosmopolitan” taxa. If all these taxa found have a real cosmopolitan distribution would require additional refined (genetic) analysis.

### *Phytoplankton community and size structure*

In Minneriya, phytoplankton was dominated at high water level in February 1999 by unicellular centric diatoms (*Stephanodiscus neoastraea*, *Cyclotella pseudostelligera*, Plate 5.4) and small colony-forming cyanophytes (Tab. 5.6). Although a high reduction in water and an increase in phytoplankton biovolume took place until August, the phytoplankton composition change was mainly a replacement of small centric diatoms to large centric chain-forming diatoms (*Aulacoseira granulata* as subdominant) and an increase of several filamentous cyanophytes from variable size classes. This shift in the

species composition caused a shift in the size spectrum from the smaller to the larger size classes (Tab. 5.5).

In Victoria, the reservoir with the highest species diversity, mainly three taxonomic groups of desmids (with many taxa), cyanophytes and chlorophytes dominated with especially high water level in January 1999. A shift towards a large chain-forming diatom-dominated plankton with *Aulacoseira granulata* (38%) was observed until August 1999. At this point in time the cyanophyte *Microcystis aeruginosa* reached 12% (Tab. 5.6). The size spectrum in this reservoir showed in both situations a clear maximum within the largest size class (larger than 40 µm) and a secondary maximum within the smallest size class (< 10 µm).

For Udawalawe two situations from February of consecutive years were compared. Here, the rainfall pattern changes from year-to-year much more than at the other two sites in Sri Lanka since it is more influenced by rainfalls from the SW (the permanently wet area of the island). In February 1999 the colony-forming cyanophyte *Cyanodictyon imperfectum* was most frequent with a small dinoflagellate and cryptophytes as subdominants. With higher water levels and flushing in February 2000, the phytoplankton was dominated by *Aulacoseira granulata* causing a strong shift of the size spectrum from the small (11-20 µm) to the largest size class (Tab. 5.5).

In the central basin of Ubolratana (Station 5), flagellated unicells of both small and large dinoflagellates dominated during the rainy season in October 1998, whereas in February 1999 with a largely reduced water level, the nitrogen-fixing cyanophyte *Cylindrospermopsis raciborski* pre-dominated (78% of biovolume). The latter alga forms long filaments that are ranked within the largest size class according to the GALD approach although its volume is much smaller than the volumes of large dinoflagellates. In February 1999 phytoplankton reached the highest biovolume (9567 mm l<sup>-1</sup>) recorded in this environment. In Ubolratana large horizontal variations in phytoplankton species composition were found. The phytoplankton at station 3 had a different composition with generally lower number of taxa than Station 5 and consisted mainly of flagellates (*Dinobryon* and several euglenophytes). Here high flushing and macrophytes seem to be important.

At Lake Taal in February 1999, the phytoplankton was dominated by small centric diatoms, some of which are typical for brackish waters (*Actinocyclus*, *Thalassiosira*-species see Rott *et al.*, 2001). A shift to the large Dinoflagellate *Ceratium furcoides* took place until August (Tab. 5.6). The size distribution in this lake showed a clear shift from small taxa during mixing in February to large taxa during the stagnant situations in August 1999 (see also Chapter 22, Fig. 22.4).

#### *Species groups evaluated by TWINSPAN*

The grouping of the 27 quantitative phytoplankton samples selected for maximum difference (comprising 21 samples from FISHSTRAT water bodies plus six samples from two small reservoirs in N-Thailand) was obtained by TWINSPAN (Fig. 5.1). The primary separation of samples was based on geographical position. The two small reservoirs from N Thailand were separated on the first level from all the other environments with the filamentous cyanophyte *Cylindrospermopsis philippinensis* as a differentiating species. Within the other group mainly samples from the same water body were grouped together



Table 5.5: Phytoplankton biovolume (Biovol. mm<sup>3</sup> l<sup>-1</sup>) based size spectra (size classes in percent) for the rainy and dry seasons or high and low water levels respectively shown in Figure 5.3 (for dominant taxa see Table 5.6). Depth= water depth of samples (m).

	Depth	Date	≤10µm	11-20µm	21-40µm	>40µm	Biovol.
MIN	1.5	05-02-99	25	31	22	22	761
MIN	0.5	10-08-99	12	22	35	31	2872
VIC	1.5	24-01-99	17	4	27	51	1211
VIC	1.5	05-08-99	18	6	12	64	1740
UDA	1.5	11-02-99	19	48	13	21	503
UDA	1.5	02-02-00	7	14	15	64	2334
UR5	0.5	01-10-98	2	65	7	26	4588
UR5	1.0	18-02-99	16	2	2	80	9567
TA	1.0	28-02-99	9	76	12	2	207
TA	1.0	01-08-99	2	4	1	93	2522

with no separation by seasonal and horizontal variations. Samples for rainy and dry season situations however were separated within the lake specific sample group on the third division level. On the second division level all samples from Ubolratana, irrespective of the stationary differences, plus an exceptional group of samples from Udawalawe and Taal were grouped together. The latter group was characterised by *Coenococcus fotti*. All other samples from lake Taal and from the three reservoirs in Sri Lanka were classified in section A. The differentiating species for the sections A-C and D-E respectively were the filamentous *Planktolyngbya limnetica* for Ubolratana and the green alga *Oocystis parva* plus the cryptoflagellate *Rhodomonas minuta* for the Sri Lanka reservoirs and Lake Taal. On the third division level the samples from Lake Taal were clearly separated from the Sri Lankan reservoirs by the centric diatom *Thalassiosira visurgis* that was only found in Lake Taal. The average environmental variables evaluated for the six sample groups followed a trophic gradient for the groups B to F, with group A being an exceptional case, a naturally enriched lake of volcanic origin (Tab. 5.7).

## Results: Ecological aspects

### *The environment*

Although the climate of all five water bodies is strongly influenced by the seasonal changes of monsoon winds (the three reservoirs in Sri Lanka are situated within the intermediate zone between the continuous wet zone in the SW and the dry zone in the NE) with SW monsoon periods during temperate summer months and NE monsoon in autumn and winter, the rainfall patterns differ to some extent. While in N-Thailand and on the Philippines most rainfall is normally recorded with the summer monsoon (between July and September) and an irregular smaller peak during the warm inter-monsoonal period in May/June, most rainfall in Central E Sri Lanka occurs during the peak of the winter monsoon from October until January. In this area of Sri Lanka the summer months (June to September) are normally dry. However, the rainfall pattern in tropical Asia (and the total rainfall for a rainy season) is variable (Zubair, 2002) so that even within the short period of the investigations considerable year-to-year differences were found and are normally reinforced by high water demand during dry periods (e.g. high water levels in



Table 5.6: Dominant phytoplankton taxa (&gt; 5%) of the samples in Figure 5.3 and in Table 5.5.

Lake	Depth	Date	Species and % of biovolume
MIN	1.5	05-02-99	<i>Stephanodiscus neoastraea</i> (23), <i>Cyanodictyon imperfectum</i> (9) <i>Cyclotella pseudostelligera</i> (8), <i>Merismopedia africana</i> et <i>M. tenuissima</i> (7)
MIN	0.5	10-08-99	<i>Merismopedia tenuissima</i> (17), <i>Cryptomonas</i> sp. (8), <i>Planktolyngbya limnetica</i> (7), <i>Cylindrospermopsis raciborski</i> (6), <i>Aulacoseira granulata</i> (6), <i>Planktolyngbya circumcreta</i> (5), <i>Oscillatoria raciborski</i> (5)
VIC	1.5	24-01-99	<i>Aphanizomenon volzii</i> (10), <i>Aulacoseira granulata</i> (9), <i>Coelastrum reticulatum</i> (8), <i>Cyanodictyon imperfectum</i> (8), <i>Staurastrum gracile</i> (7) <i>Stephanodiscus neoastraea</i> (7), <i>Staurodesmus convergens</i> (5)
VIC	1.5	05-08-99	<i>Aulacoseira granulata</i> (38), <i>Microcystis aeruginosa</i> (12), <i>Aphanizomenon volzii</i> (6)
UDA	1.5	11-02-99	<i>Cyanodictyon imperfectum</i> (28), <i>Peridinium inconspicuum</i> (12), <i>Aulacoseira granulata</i> (11), <i>Cryptomonas marssoni</i> (9), <i>Cryptomonas</i> sp. (5)
UDA	1.5	02-02-00	<i>Aulacoseira granulata</i> (58), <i>Peridinium gatunense</i> (10), <i>Ankistrodesmus bernardi</i> (5)
UR5	0.5	01-10-98	<i>Peridinium inconspicuum</i> (28), <i>Ceratium furcoides</i> (20), <i>Peridiniopsis elpatiewskyi</i> (15), <i>Cylindrospermopsis raciborski</i> (11), <i>Aulacoseira granulata</i> (8)
UR5	1.0	18-02-99	<i>Cylindrospermopsis raciborski</i> (78), <i>Planktolyngbya limnetica</i> (8), <i>Pseudanabaena</i> sp.(6)
TA	1.0	28-02-99	<i>Thalassiosira visurgis</i> (32), <i>Rhodomonas minuta</i> (22), <i>Actinocyclus normani</i> (21), <i>Cyclotella meneghiniana</i> (8)
TA	1.0	01-08-99	<i>Ceratium furcoides</i> (92)

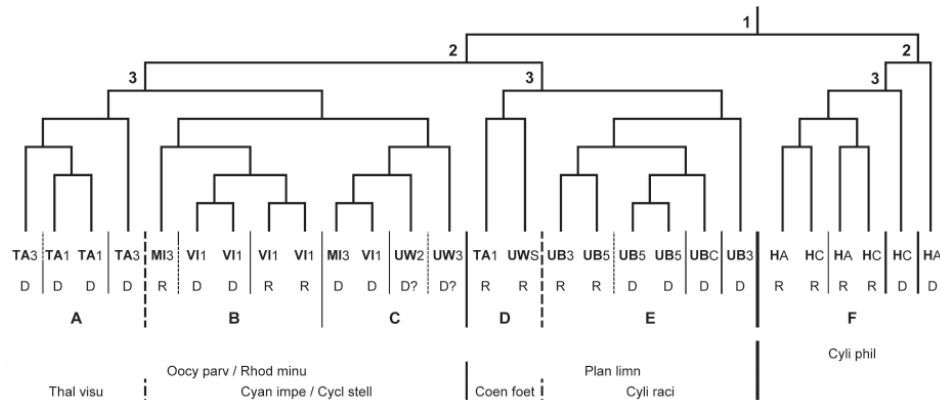


Figure 5.1: TWINSpan classification of 21 project samples plus six supplemented samples and related indicator species for division level 1, 2, 3. For environmental data to groups A-F see Table 5.6. (Abbreviations: TA - Lake Taal, MI - Minneriya, VI - Victoria, UW - Udawalawe, UB - Ubol-ratana, HA - Huay Hong Khrai Reservoir A, HC - Huay Hong Khrai Reservoir C. D - Dry season, R - Rainy season. Coen foet - *Coenococcus fotti*; Cyan impe - *Cyanodictyon imperfectum*; Cycl stell - *Cyclotella stelligera*; Cyli phil - *Cylindrospermopsis philippinensis*; Cyli raci - *Cylindrospermopsis raciborski*; Thala visu - *Thalassiosira visurgis*; Oocy parv - *Oocystis parva* f.; Plank limn - *Planktolyngbya limnetica*; Rhod minu - *Rhodomonas minuta*).

Victoria beginning of 1999 and low water levels beginning of 2000; extremely low water levels in Ubolratana in February 1999 and high water in February 2000).

The annual temperature variation in the Sri Lankan reservoirs was not more than 5°C with a minimum in January. Also, while little variation was found in Lake Taal (4°C), higher variation was recorded in Ubolratana (10°C) with a minimum of 22°C by December and a strong warming during the inter-monsoonal period of March/April to almost 32°C in May.

In all five water bodies temporal variations of light transparency (Secchi depth and TSS) were frequently found to be related to changes in phytoplankton quantities. However, during extreme draw-down periods and/or during extreme rainfall situations inorganic suspended solids can have a shading effect for phytoplankton growth (Chapters 6 & 22). With high water levels in the reservoirs Secchi depth was increasing. Variations in nutrient concentrations are in general related to changes in water level, flushing and phytoplankton growths (Chapter 6). Although high variations of both P- and N-compounds are common, the average nutrient levels allow the ranking of the water bodies along a trophic gradient.

Table 5.7: Environmental data averaged for the sample groups obtained by TWINSpan shown in Figure 5.1 (O-M oligo-mesotrophic; M mesotrophic, EU eutrophic).

TWINSpan-Group	A	B	C	D	E	F
trophic status	EU	O-M	M	EU	EU	EU
mean water depth (m)	40	25	13	24	8	3
Secchi depth (m)	5.7	2.3	1.7	3.4	1.0	0.8
P <sub>tot</sub> (µg l <sup>-1</sup> )	202	15	24	110	46	118
chlorophyll-a (µg l <sup>-1</sup> )	3.9	12.8	13.8	7.2	17.8	27.6
biovolume (g m <sup>-3</sup> )	0.5	1.4	1.8	2.3	6.5	5.5
conductivity (µS cm <sup>-1</sup> )	1663	76	119	907	220	216
pH	7.0	7.7	6.9	7.3	8.3	7.8
nitrate (µg l <sup>-1</sup> )	125	56	67	72	214	9
season (dry / rainy)	D	R+D	D	R	D+R	R+D

Carbon supply is influenced by comparably low buffering capacity with the lowest values in Victoria reservoir and variations in pH from neutral to highly alkaline (diurnal raise of pH over 8.1 in most cases). High pH values (up to 9.1) were reached during the most productive situations (warm temperatures, low water) in the eutrophic Ubolratana reservoir, in Lake Taal during stagnation and during a shorter period of extreme draw-down in Minneriya reservoir.

### Chlorophyll

Phytoplankton quantities in terms of chlorophyll concentrations for the central lake stations and near surface layers (0.5 and 1.5 m respectively) on the same time scale in Figure 5.2 show clear temporal variations in all five water bodies. In the volcanic Lake Taal the highest variation over time with a relationship of 1:10 between minimum and maximum was recorded. The minimum is reached during the dry windy season (deep mixing situation in this deep lake) in January and February and peaks were found during the rainy season from May until August.

The temporal variations in Ubolratana reservoir were smaller, but showed a clear decrease of chlorophyll concentrations from a longer lasting dry period and low water

level in 1999 (an 'El Niño' year) to the wet situation at the end of 1999 and beginning of 2000. Chlorophyll decreased continuously from August 1999 with a water level increase of more than 3 m. The average chlorophyll of this reservoir was higher than in all three reservoirs from Sri Lanka and the Secchi depth values were lower (note that a different scale had to be used for Secchi depth in Figure 5.2). In this reservoir significant horizontal variation in chlorophyll was common with low values near the main inflows. The inflow areas however were influenced by dense macrophyte stands with a dominance of *Eichhornia crassipes* covering large portions of the shallow areas.

High temporal variability of phytoplankton chlorophyll was also found for the shallow reservoir Minneriya in Sri Lanka with a peak during 1999 from August to October during minimum water level (reduced to more than 3 m below average). This peak was not observed during the same time period in 1998. Secchi depth decreased to less than 50 cm during the chlorophyll peak in 1999. Variation of chlorophyll in the deep Victoria reservoir was low. It did not show a clear seasonal pattern or an increase of chlorophyll during draw-down periods: even low chlorophyll values with low water levels have been found (e.g. in November 1999) and this in spite of the high water level variations of up to a total of 27 m in this reservoir. In Udawalawe low variations of chlorophyll and Secchi depth were found lacking clear seasonal trends and/or long-term variations during 21 months of observations.

#### *Functional species groups*

In all water bodies phytoplankton biovolume and species composition showed changes over time. With the exception of Lake Taal, biovolume was low during the peak of the rainy season (high water levels) and high during the dry season (low water level) (Fig. 5.3) with a significant change in phytoplankton composition during the dry season. The predominant taxonomic groups (in terms of biomass) were diatoms during the dry season (low water level) in three out of the five cases and cyanophytes in two cases, while during the rainy season, dinoflagellates were dominant in two cases and diatoms, desmids and chlorophytes in one case each.

Altogether six functional species groups were found in the five water bodies comprising the following:

- (A) Filamentous nitrogen-fixing cyanophytes/cyanobacteria dominant during low water periods: *Cylindrospermopsis raciborski*, a typical representative of warm mixed water columns and potentially contributing to an equilibrium phase (see also Padisak, 1997; Reynolds *et al.*, 2002; Rott, 2002)
- (B) Small colony-forming cyanophytes/cyanobacteria not forming surface scums (*Merismopedia* in Minneriya and *Cyanodictyon* in Udawalawe), potential r-strategists, were found during low water periods
- (C) Small centric diatoms (highly productive r-strategists acc. to Reynolds *et al.*, 2002) common during mixing periods
- (D) Large centric diatoms (mainly *Aulacoseira granulata*) dominating during mixing periods (K-strategists, see Reynolds *et al.*, 2002)
- (E) Large dinoflagellates (*Ceratium furcoides*) K-strategists dominating under more stagnant situations

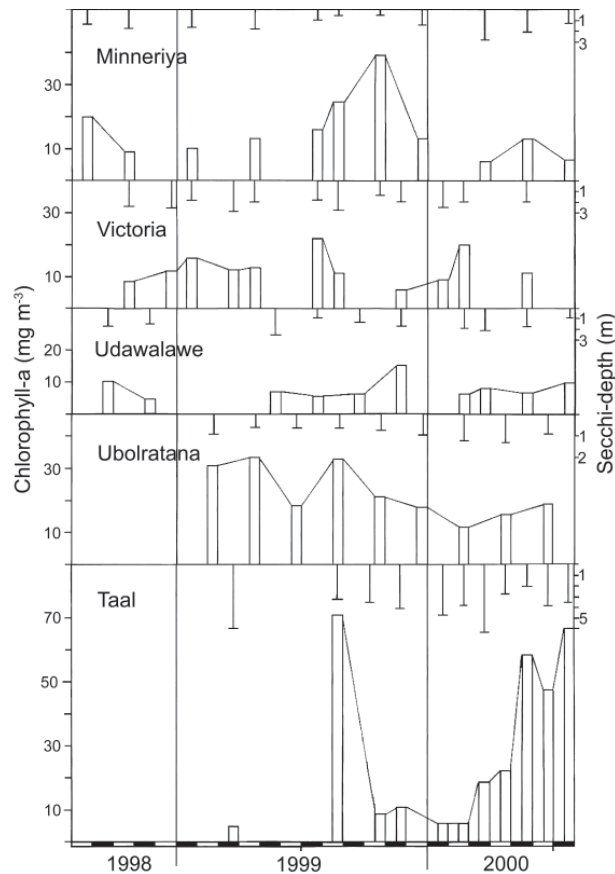


Figure 5.2: Temporal changes of chlorophyll and Secchi depth for the main sampling station in the five water bodies (Black triangles indicate quantitative phytoplankton samples as shown in Figure 5.3 and Table 5.5 ).

(F) Unicellular desmids: especially species-rich in Victoria with the high water levels and lower conductivity and pH.

In Minneriya the change of dominance from group (C) found during the rainy season to (B) during draw-down in August was striking. In Victoria the phytoplankton at high water level was characterised by (F) and chlorococcal green algae and changed to (D) during the dry and windy season. In Ubolratana high water levels in the central station were linked with large dinoflagellates (E) and changes to potential filamentous nitrogen-fixing taxa (A) during draw-down independent from lower temperatures. In Lake Taal a peak of (E) during the rainy season and stagnation and a dominance of (C) during the dry, strong windy season is typical.

### *Testing key variables related to chlorophyll*

Bivariate regression cross-tables (Tab. 5.8) for the five water bodies show the highest number of statistically significant relationships for the shallow reservoirs Minneriya and Ubolratana both of which have a high water level variability. In Minneriya five significant relationships of chlorophyll to environmental variables were found with negative correlation to water level and Secchi depth and positive relations to TSS (total suspended solids) and nutrients. This was due to the extreme variation of this reservoir during draw-down in August 1999. In Ubolratana (St 5) chlorophyll showed a significant negative correlation to Secchi depth and water level and a positive correlation to TSS. The latter observation indicates that the phytoplankton chlorophyll makes up a high portion of TSS. This seems to be similar in Victoria where chlorophyll shows a significant positive correlation to TSS. For Lake Taal and Udawalawe reservoir a significant positive correlation between P-t and nitrate was recorded but the nitrate values were generally low. This simple approach indicates that key variables for understanding phytoplankton changes over time in the reservoirs can be found within the variables TSS, water level and chlorophyll. However, it is possible that the nitrogen supply has been underestimated by using dissolved nitrate data only (see Chapter 7).

## **Discussion**

The result of the multiple approaches (taxa lists, community and species group analysis, site ranking etc.) used to characterise and classify the water bodies according to phytoplankton to some extent correspond to the overall tropical ranking of the macrocrustacean zooplankton (Chapter 8). However, in contrast to microcrustaceans we found some striking seasonal differences in phytoplankton community structure. The TWINSPAN analysis shows that most of the volcanic Lake Taal samples are separated from the reservoirs first and the large eutrophic reservoir Ubolratana (Thailand) is classified as intermediate to the group of Sri Lankan reservoirs. In contrast to zooplankton the overall taxa richness is reduced in Lake Taal with a larger portion of taxa (35% of total in Taal) confined to this lake only indicating its short history as a freshwater habitat. It seems likely, in this case at least, that phytoplankton is more influenced by the specific waterchemical conditions and mixing pattern than by zooplankton grazing. The comparison of phytoplankton structure indicates a pronounced gradient of complexity (species number per sample and diversity) positioned along a trophic gradient from the most eutrophic reservoir Ubolratana to the mesotrophic reservoirs Udawalawe and Victoria.

For Lake Taal high seasonal changes of phytoplankton seem to be related to the strong seasonal changes of mixing pattern and nutrient supply as observed earlier for the large Philippine Lake Lanao (Lewis, 1973, 1978). For the three Sri Lankan reservoirs the water chemistry related to the catchment geology, water basin morphology and water renewal and management are important for both the selection of dominating phytoplankton taxa (e.g. dominance of desmids in the soft water Victoria) and the seasonal shifts of functional species groups. For the shallow reservoirs Minneriya and to some extent also for Ubolratana phytoplankton concentrations and composition are influenced by water level changes with peak concentrations during draw-down periods.

When the data on phytoplankton chlorophyll, Secchi depth and total phosphorus are ranked using the classical criteria of Vollenweider's model (OECD, 1982) for temperate

Table 5.8: Correlation matrix showing Pearson's r for the bivariate regression of time series of main environmental factors related to phytoplankton chlorophyll in the five water bodies (significance of correlations: \* = significant at 95% level, \*\* = highly significant at 99% level, all other cases non significant) ( $z_{SD}$  - Secchi depth (cm), WL water level (m), TSS total suspended solids ( $\text{mg l}^{-1}$ ), P-t total phosphorus ( $\mu\text{g l}^{-1}$ ),  $\text{NO}_3\text{-N}$  ( $\mu\text{g l}^{-1}$ ) numbers in brackets = number of samples, abbreviations of reservoirs see Table 5.1).

<b>MIN</b>					
	$z_{SD}$	WL	TSS	P-t	$\text{NO}_3\text{-N}$
chl-a	- <b>0.75*</b> (13)	- <b>0.61*</b> (11)	+ <b>0.81*</b> (8)	+ <b>0.58*</b> (11)	+ <b>0.66*</b> (13)
$z_{SD}$		+ <b>0.82*</b> (11)	- <b>0.84*</b> (8)	- <b>0.67*</b> (12)	- <b>0.54*</b> (13)
WL			- <b>0.65*</b> (9)	- <b>0.77*</b> (12)	- 0.20 (13)
TSS				+ 0.56 (9)	+ <b>0.81*</b> (9)
P-t					+ 0.41 (14)

<b>VIC</b>					
	$z_{SD}$	WL	TSS	P-t	$\text{NO}_3\text{-N}$
chl-a	- 0.43 (11)	+ 0.48 (9)	+ <b>0.65*</b> (9)	+ 0.11 (10)	- 0.56 (11)
$z_{SD}$		+ 0.36 (11)	- 0.25 (9)	- 0.23 (10)	+ 0.32 (11)
WL			+ 0.55 (7)	+ 0.21 (9)	- 0.24 (9)
TSS				+ 0.07 (11)	- 0.29 (9)
P-t					+ 0.07 (11)

<b>UDA</b>					
	$z_{SD}$	WL	TSS	P-t	$\text{NO}_3\text{-N}$
chl-a	- 0.15 (12)	+ 0.04 (7)	+ 0.09 (6)	- 0.21 (6)	- 0.21 (12)
$z_{SD}$		+ 0.52 (8)	- <b>0.80*</b> (10)	- 0.17 (11)	- 0.36 (12)
WL			+ 0.09 (6)	+ 0.25 (8)	- 0.29 (8)
TSS				+ 0.51 (10)	+ 0.46 (10)
P-t					+ <b>0.78*</b> (12)

<b>UR5</b>					
	$z_{SD}$	WL	TSS	P-t	$\text{NO}_3\text{-N}$
chl-a	- <b>0.64*</b> (9)	- <b>0.77*</b> (9)	+ <b>0.86*</b> (9)	- 0.44 (9)	+ 0.53 (9)
$z_{SD}$		+ 0.39 (9)	- <b>0.89**</b> (9)	+ 0.61 (9)	- 0.58 (9)
WL			- <b>0.69*</b> (9)	+ 0.25 (9)	- 0.43 (9)
TSS				- 0.53 (9)	+ <b>0.71*</b> (9)
P-t					- 0.12 (9)

<b>TA</b>					
	$z_{SD}$	WL	TSS	P-t	$\text{NO}_3\text{-N}$
chl-a	- 0.50 (11)	- 0.07 (11)	+ 0.33 (9)	+ 0.25 (10)	- 0.43 (10)
$z_{SD}$		- 0.31 (11)	+ 0.21 (11)	+ 0.17 (11)	+ 0.82 (10)
WL			+ 0.49 (10)	- 0.10 (11)	- 0.07 (10)
TSS				- 0.22 (10)	+ 0.33 (9)
P-t					+ <b>0.82*</b> (10)

lakes, all water bodies would fall into the eutrophic category not allowing for differentiation. However, the modification of this model by Zauke *et al.*, 1992, with the criteria for tropical and subtropical water bodies (see also Thornton, 1979) ranks the average chlorophyll data in the three Sri Lankan reservoirs into the mesotrophic category. In the latter model higher average P-t values than in temperate waters but lower nitrate values are identified to differentiate between the mesotrophic and eutrophic categories.

The series of selected phytoplankton samples from all five water bodies are classified between oligo-mesotrophic and eutrophic status when ranked according to TWINSpan sample groups (Tab. 5.7) although the specific selection of indicator taxa may cause some bias. These results correspond largely to the ranking of situation by Shannon's diversity and evenness (Tab. 5.4). In addition, for all the shallow reservoirs (MI, UR, UD) strong effects of variations in water level and temporarily reduced water renewal have to be considered causing general variations in TSS and thus an increase in trophic status. In the deep volcanic Lake Taal the opposite to the reservoirs occurs: during the dry season the strong trade winds cause a continuous deep mixing of the lake (much deeper than the euphotic zone) and thus a reduction of phytoplankton biovolume. This can be interpreted as an apparently more oligotrophic situation (Fig. 5.3), when at the beginning of the rainy season temperature stagnation, and additional nutrient supply by runoff from the watershed enhances trophic status.

In contrast to a general assumption that the geographic position may not matter and all phytoplankton species would be cosmopolitan (Lewis, 1987), we found both tropical and tropical-warm temperate taxa within three out of the six dominant functional species groups. The comparison of the overall taxa lists highlights more than 20 tropical and warm temperate taxa giving the samples a specific character also shown by the TWINSpan ranking according to the geographic position (e.g. the group of reservoirs from Sri Lanka and/or of the N-Thailand reservoirs). Many tropical plankton taxa are misclassified when routine floras specific for temperate latitudes are used only. Therefore multiple additional monographs and floristic papers from tropical environments and the specific ecoregions (e.g. Skuja, 1949; Rott, 1983; Rott & Lenzenweger, 1994) had to be used. In smaller water bodies of Sri Lanka and for desmids, a larger portion of tropical to sub-tropical taxa (40%) was recently recorded by Williamson (2005).

Although temperature variations in all water bodies except Ubolratana are small, variations of the environmental conditions, in particular, connected to hydrological conditions and mixing with regular changes between the rainy and the dry season are large enough to cause a shift in phytoplankton size and species structure corresponding to the seasonal rain and mixing type (A) by Melack (1979). The species richness of the five water bodies is highly different, as are Shannon's diversity and evenness. The overall variability of Shannon's diversity does not seem to be higher than in temperate environments (Büsing, 1998) and must be related more to trophic status than to stability/variability patterns of the environment (Tolotti, 2002). With the exception of the much more intense study of the small reservoirs in N Thailand used for comparison here where phytoplankton was found to be very stable over several weeks and remained unaffected by gradual environmental changes (see Peerapornpisal, 1996), the restricted number of samples does not allow more clear general conclusions on phytoplankton stability in the 5 water bodies here. Additional aspects contributing to the instability of annual patterns in the environment are based on changes of rainfall pattern, which in all three countries are strongly influenced by the South Pacific Oscillations (see e.g. Zubair, 2002). In addition



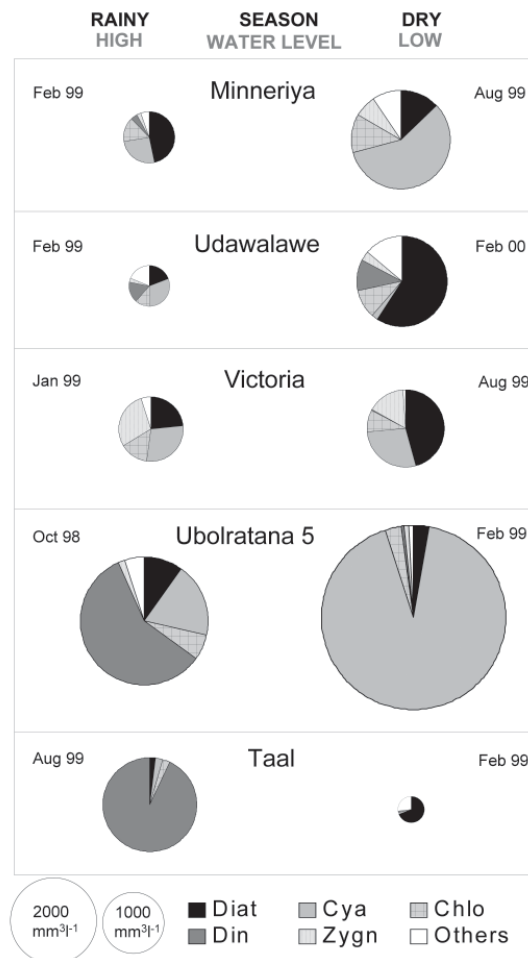


Figure 5.3: Subsurface phytoplankton biovolume selected for maximum annual variability (rainy and dry seasons) and portions of taxonomic groups for the five water bodies. (Abbreviations: Diat - Diatomophyceae, Cya - Cyanophyceae, Chlo - Chlorophyceae, Din - Dinophyceae, Zygn – Zygnemaphyceae, for dominant taxa see Table 5.6; radius of cycles indicates the square root of the biovolume related to the unit circle given).

these oscillations have an influence on the formation and frequency of typhoons affecting all three countries but with the highest frequency on the Philippines.

In contrast to deep polymictic deep lakes of the central tropical belt, situated at higher altitudes (see Hutchinson & Löffler, 1956; Talling & Lemoalle, 1998) and not found in the dataset, phytoplankton changes seemed to be slower than expected especially in the deep water bodies (Victoria and Taal). Although both large water bodies are strongly influenced by monsoon winds Lake Taal has an especially prolonged and defined wind mixing period by the NE monsoon lasting for more than two months. In Lake Taal phytoplankton remained stable from the strong-wind season in February/March to an almost stagnant situation in May followed by abrupt changes with the first strong rainfalls

in May. In Victoria reservoir these phytoplankton changes were not as clear since this canyon-shaped reservoir is more protected against wind, and the monsoon intensity is reduced by the higher altitude and the geographic position closer to the equator (6°N) compared to the Philippines situated at 14°N. In the shallow reservoirs organic matter stirred up by wind at low water levels (Chapter 7) is important, may lead to reduced primary productivity first but dense phytoplankton blooms later, whereas the changes at high water levels are moderate and mediated by increased flushing rates. In addition to mainly physical regulation biotic control by size selective feeding fishes (Chapter 22) effective in the Sri Lankan reservoirs is another possible reason regulating phytoplankton composition and size spectra not evaluated in detail in this context by lack of data.

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