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Judy Reservoir Monitoring Project 2012 Final Report

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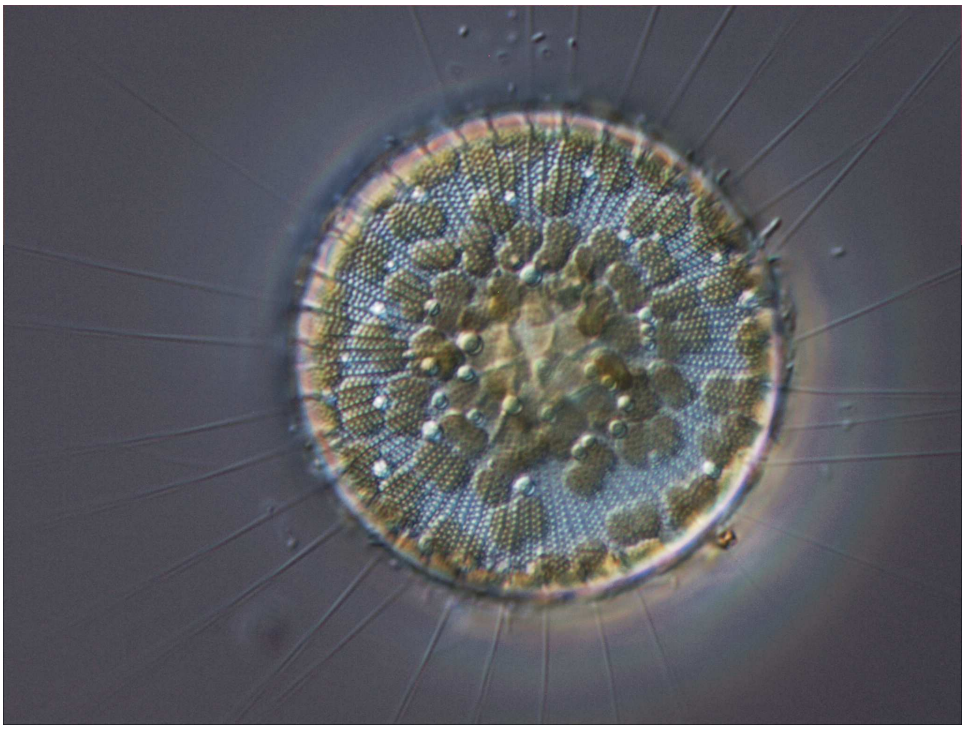

Judy Reservoir Monitoring Project
2012 Final Report

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November 15, 2012

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Introduction

The purpose of this study was to identify and count the phytoplankton and measure chlorophyll, total nitrogen, and total phosphorus levels in water samples collected from Judy Reservoir. Water quality and algal data have been collected on a weekly basis since October 2006; annual reports have been sent to the Skagit Public Utility District No. 1 in 2007, 2008, 2010 (January and December), and 2011.

This report will include a description of the water quality and algal data collected from October 2006 through October 2012. The data will be described in a series of annotated figures, beginning on page 5.[1] Appendix A, beginning on page 19, contains an updated photographic record of our calculations for estimating algal biovolume. Appendix B, beginning on page 53, contains updated tables of the data that include all corrections and revisions to the data set, including biovolume estimates for most types of algae.

Methods

Skagit Public Utility District No. 1 personnel collected water samples from the pump house at Judy Reservoir once a week from October 26, 2006 through October 25, 2012. The samples were shipped on ice by courier to the Institute for Watershed Studies laboratory the same day.

Samples for chlorophyll-a were collected in amber polyethylene bottles, transported on ice, then measured in the lab using a fluorometer and an acetone extraction as described by Standard Method 10200 H. (APHA, 2012). Samples were measured in duplicate and the mean was reported.

Samples for total phosphorus and total nitrogen analyses were collected in 500 mL acid-washed polyethylene bottles. The samples were preserved upon arrival in the laboratory then measured by methods as described in Table 1.

[1] Three water quality parameters, nitrate, soluble phosphate, and turbidity, were collected during the first year, but were discontinued in October 2007. The data for these parameters are included in Appendix B but will not be discussed in this report.

Samples for phytoplankton identification were collected in polyethylene bottles and preserved with Lugol's solution as described in Standard Method 10200 A (APHA, 2012). During the first year of monitoring, an improved method of concentrating the algae samples was introduced. The original method was used on samples collected from October 26, 2006 through May 16, 2007. Algae were concentrated by filtering the sample through 20 μm Nitex mesh and counted using a Palmer counting cell. This method can miss cells smaller than 10–20 μm, so we adopted a revised method that uses a settling chamber to retain all cells. Beginning in March 2007, samples were counted using a 25-, 50- or 100-mL settling chamber.[2] Counts were made using a compound microscope at 200x or 400x. Multiple fields were counted on each slide, with the number of fields being determined by cell density.

Algal biovolume calculations were made following the procedures outlined by EPA (2008). When possible, at least 10 photographs were taken of each algal species identified from the site.[3] The images were calibrated using a stage micrometer and biovolume was estimated based on a representative geometric shape (e.g., ovoid, sphere, rectangle). To estimate phytoplankton biovolume, the weekly species counts were multiplied by the corresponding average biovolume for that species.

[2] Samples were counted using both methods from March through May 2007.

[3] Algal species that were too rare to provide at least 10 images were omitted from the biovolume calculations. This has little effect on biovolume because the species represent a small fraction of the total count.

Analyte	Abbr.	Method Reference (APHA 2012)	Detection Limit/ Sensitivity
Algae counts (Oct 2006 - May 2007)	NA	SM10200 C. Membrane filtration†	NA
Algae counts (Mar 2007 - Oct 2008)	NA	SM10200 C. Sedimentation	NA
Algae biovolume	NA	SM10300 C. Biovolume	NA
Chlorophyll - lab	Chl	SM10200 H, Chlorophyll	$\pm$0.1 mg/m^3
Nitrogen - total	TN	SM4500-NO3 I., flow inject, persulfate digest	10 μg N/L
Phosphorus - total	TP	SM4500-P G., flow inject, persulfate digest	5 μg P/L

Table 1: Summary of analytical methods used by the Institute for Watershed Studies in the Judy Reservoir monitoring project.

References

APHA, 2012. Standard Methods for the Examination of Water and Wastewater, 22st Edition. American Public Health Association, American Water Works Association, and Water Environment Federation, Washington D. C.

Carlson, R E. and J. Simpson. 1996. A Coordinator's Guide to Volunteer Lake Monitoring Methods. North American Lake Management Society. 96 pp.

Annotated Figures

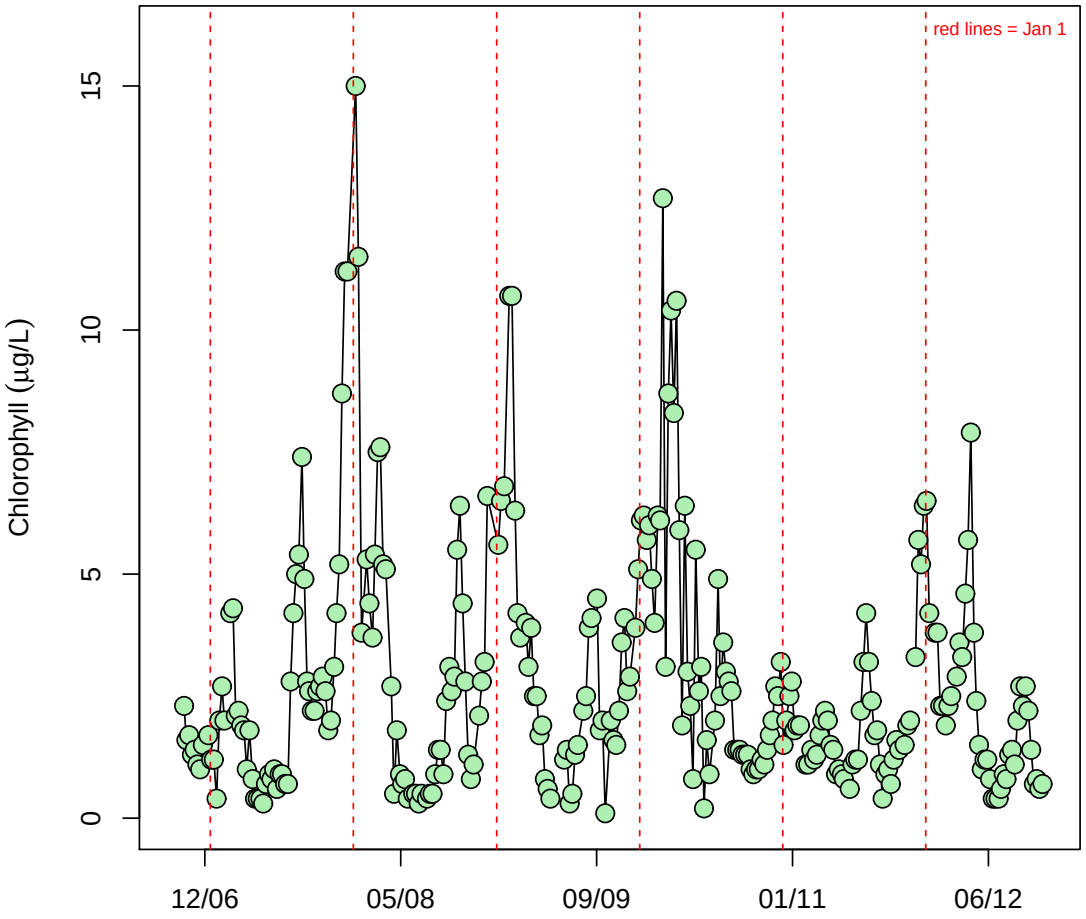
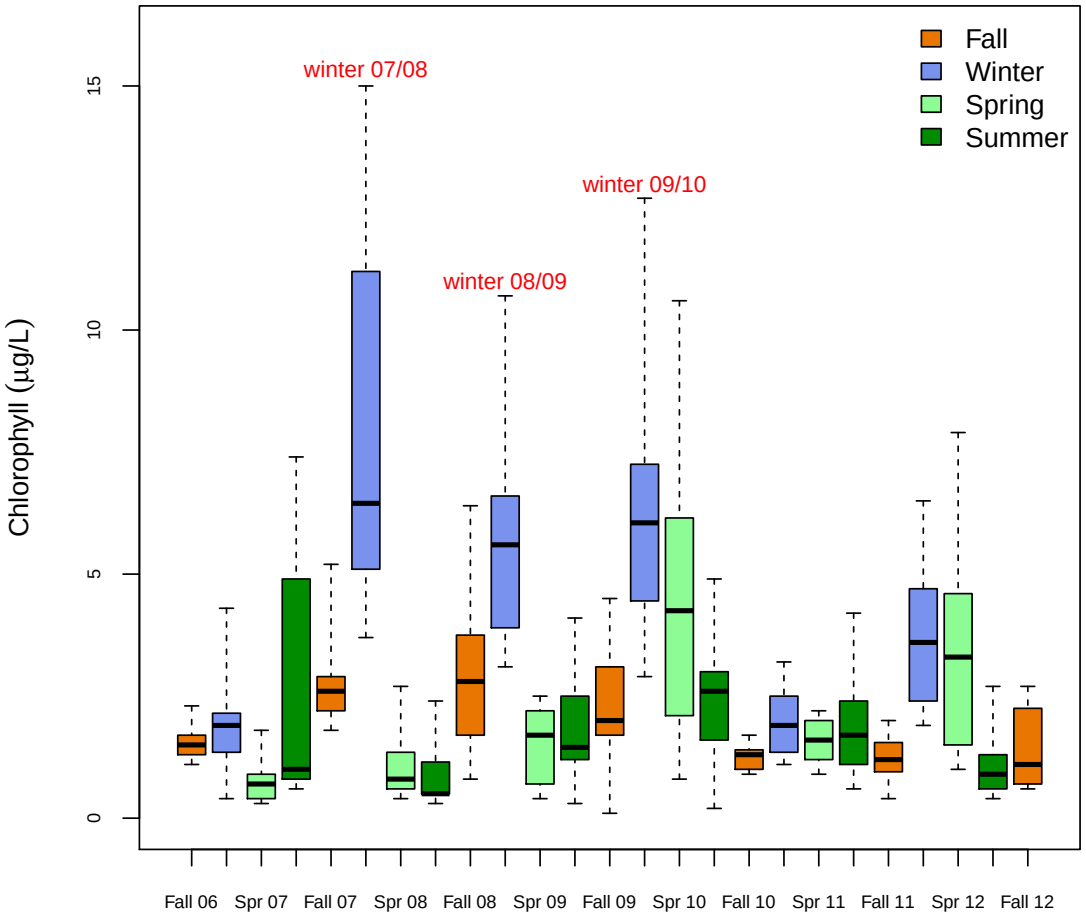


Figure 1: Chlorophyll is the primary photosynthetic pigment in algal cells and is used to indicate the amount of algae in a sample. In typical lakes, chlorophyll levels are high during the summer and fall, coinciding with summer/fall algal blooms. In Judy Reservoir, the chlorophyll concentrations were occasionally high during the winter as well, which was usually associated with chrysophyte blooms (see Figure 6). The median 2006–2012 chlorophyll concentration was 2.0 μg/L. The median chlorophyll concentrations were slightly lower in 2011 and 2012 compared to previous years.

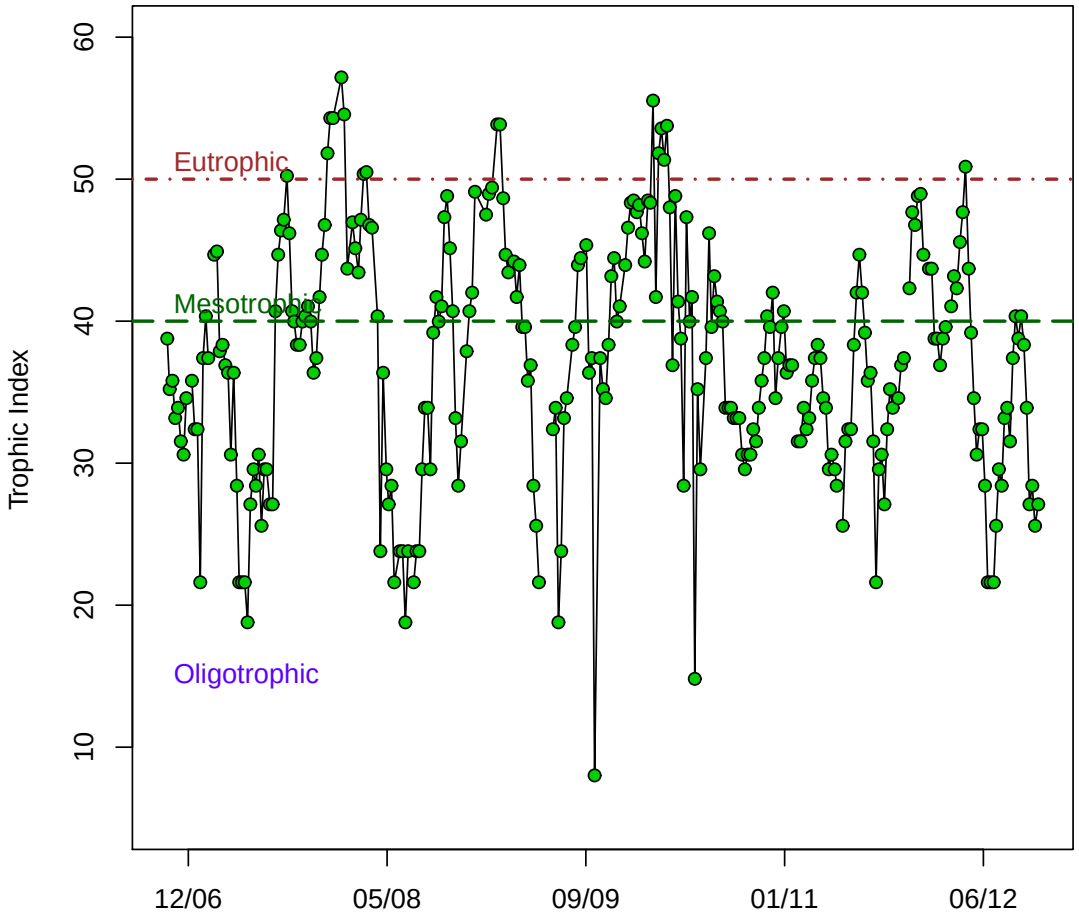
	All Data	2007	2008	2009	2010	2011	2012[†]
Median Chl (μg-L)	2.00	2.05	2.50	2.50	2.60	1.55	2.00

[†]partial year – 2012 does not include November/December



Spring = April-May Summer = June-August Fall = September-November Winter = December-March

Figure 2: This boxplot shows median chlorophyll (center line) and upper/lower 25% quartiles by season; the dashed lines show the minimum/maximum values for each season. The extremely high winter chlorophyll levels were unexpected; the moderately high levels in the fall are similar to what has been observed in other regional lakes and reservoirs. The 2007/2008 and 2008/2009 winter peaks appear to have been caused by chrysophyte blooms. The chrysophyte density was lower in the winter of 2009/2010, but increased again in the winter and spring of 2011/2012 (Figure 7).



$$\mathrm{TSI_{chl}} = 9.81\ (\ln \mathrm{chl}) + 30.6$$

Figure 3: Carlson's trophic state index ($\mathrm{TSI_{chl}}$) is often used to classify lakes based on biological productivity (Carlson and Simpson, 1966). Productive or *eutrophic* lakes have high TSIs ($\geq$50); unproductive or *oligotrophic* lakes have low TSIs ($\leq$40); lakes falling between these ranges are labeled *mesotrophic*. Trophic state is usually measured during the summer, or whenever algae populations are expected to be high. In Judy Reservoir the highest TSIs usually occur during the winter (December-March), which is unusual for lakes in this region. During most of the year, the $\mathrm{TSI_{chl}}$ was fairly low, with the median falling at the boundary between mesotrophic and oligotrophic (median $\mathrm{TSI_{chl}} = 37$).

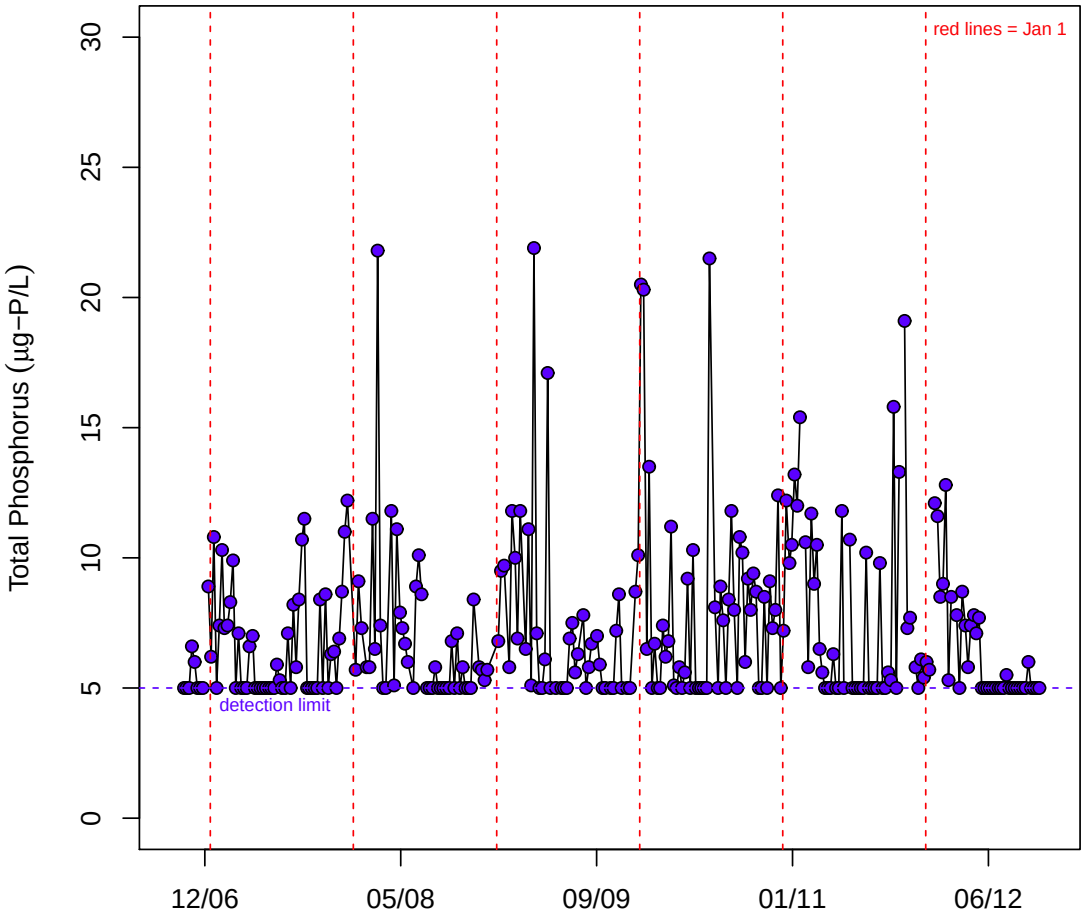


Figure 4: Total phosphorus includes organic phosphorus (phosphorus associated with algae and other biota) and dissolved phosphorus (primarily soluble orthophosphate). Phosphorus is an important nutrient for algae, and is generally considered the nutrient that limits the amount of algae in a lake. The median total phosphorus concentration in Judy Reservoir was only 5.8 μg-P/L (barely above the detection limit of 5 μg-P/L), and all but nine of the 286 samples were $<$15 μg-P/L. Given the relatively high chlorophyll levels that occur in the reservoir, the low phosphorus may seem surprising, but algae are very efficient at extracting this nutrient from the water column.

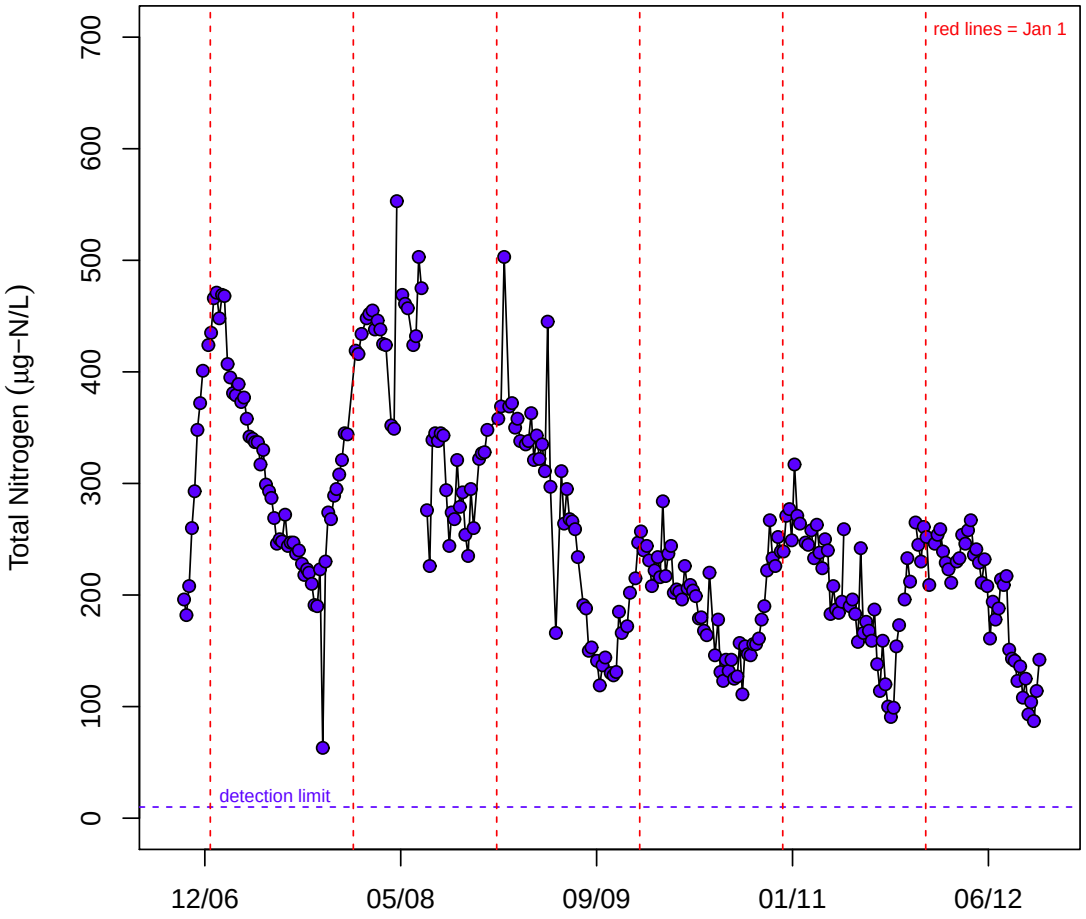


Figure 5: Total nitrogen represents the combined concentrations of organic nitrogen (nitrogen associated with algae and other biota) and dissolved inorganic nitrogen (nitrate, nitrite, and ammonium). Based on data from 2006–2007, about half of the total nitrogen in Judy Reservoir is inorganic (nitrate sampling was discontinued in 2007). Algae use inorganic nitrogen for growth, so it is common to see depletion of total nitrogen as algae take up nitrate during the summer. Nitrogen rarely limits total algal growth, but low concentrations of *inorganic* nitrogen can favor the growth of cyanobacteria. Total nitrogen concentrations appear to have decreased slightly, and the seasonal patterns have become more stable. This may be related to changes in the source water entering the reservoir or the lower algal densities (see Figures 1 and 6).

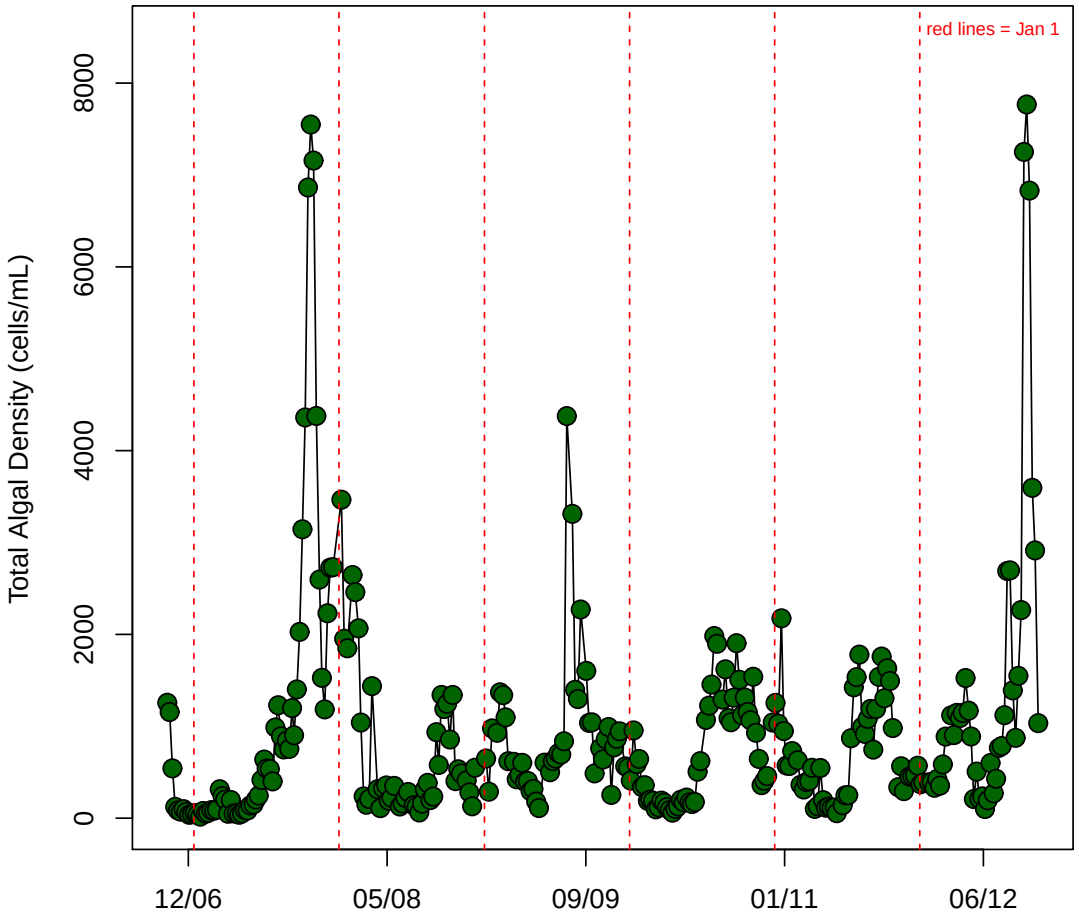


Figure 6: Algal density is determined by settling a known volume of water, then counting and identifying the settled algae. The highest algal counts usually occurred from summer to late fall, which is typical for lakes in our region, or in the winter. High winter counts are unusual for most lakes, but consistent with occasional high winter chlorophyll concentrations in Judy Reservoir (Figures 1 and 2). Although the 2011 algal densities lacked extreme peaks, the median density was higher than 2007–2010. The data from 2012 are incomplete; the 2012 median will probably be lower after the November/December counts are added to the data set.

	All Data	2007	2008	2009	2010	2011	2012†
Median density (cells/mL)	571	416	354	670	506	570	888

†partial year – 2012 does not include November/December

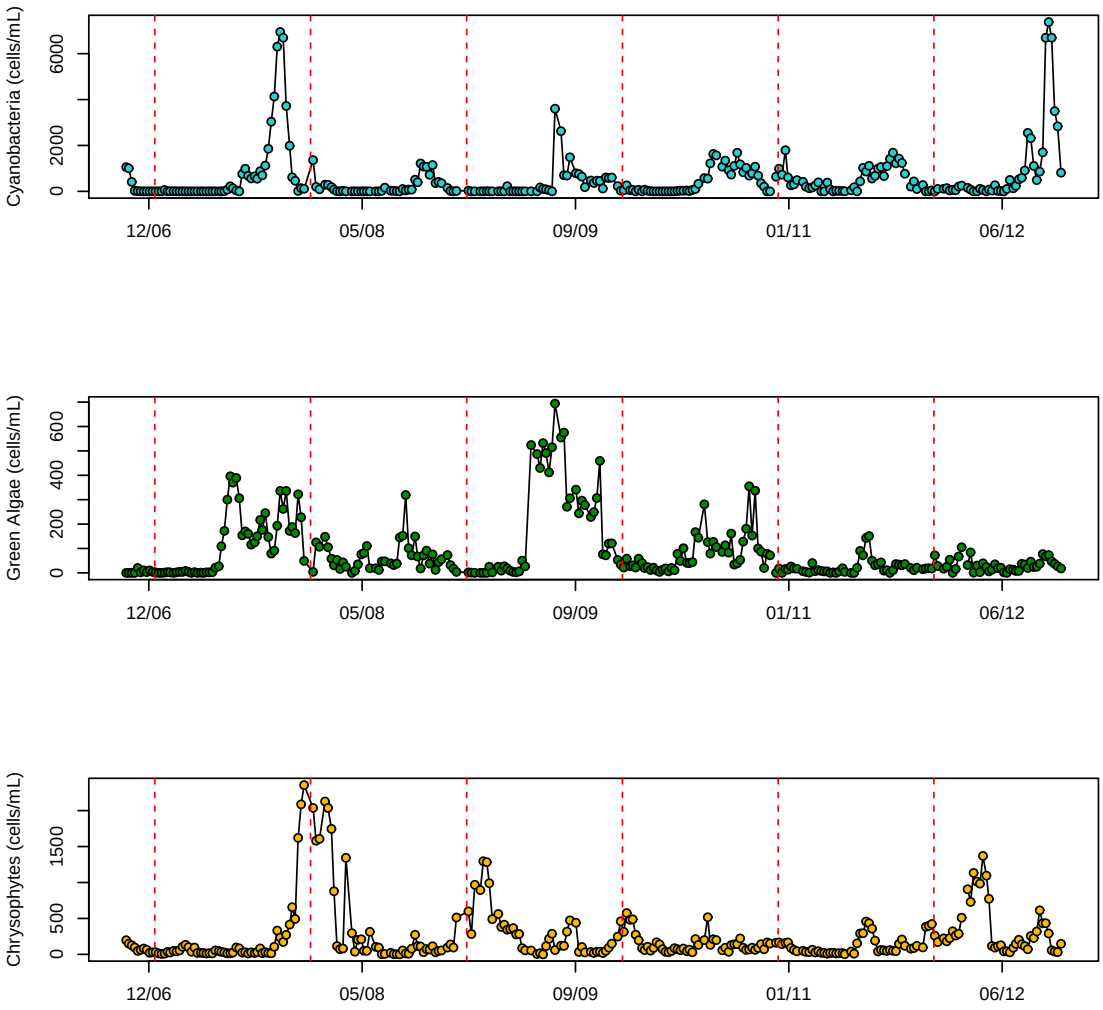


Figure 7: Cyanobacteria, green algae, and chrysophytes usually dominate the cell counts in Judy Reservoir. Cyanobacteria (bluegreen "algae") typically bloom during fall, and were especially dense in October 2007 and October 2012. Green algae had rather erratic counts, but were usually higher during the summer and fall. The chrysophyte counts were very high during the winter/spring of 2007/2008 and moderately high during the winter/spring of 2008/2009 and 2011/2012. Chrysophytes often bloom during cool temperatures, so the winter blooms are not too unusual. Of the three algae types, chrysophytes are most likely to cause taste and odor problems.

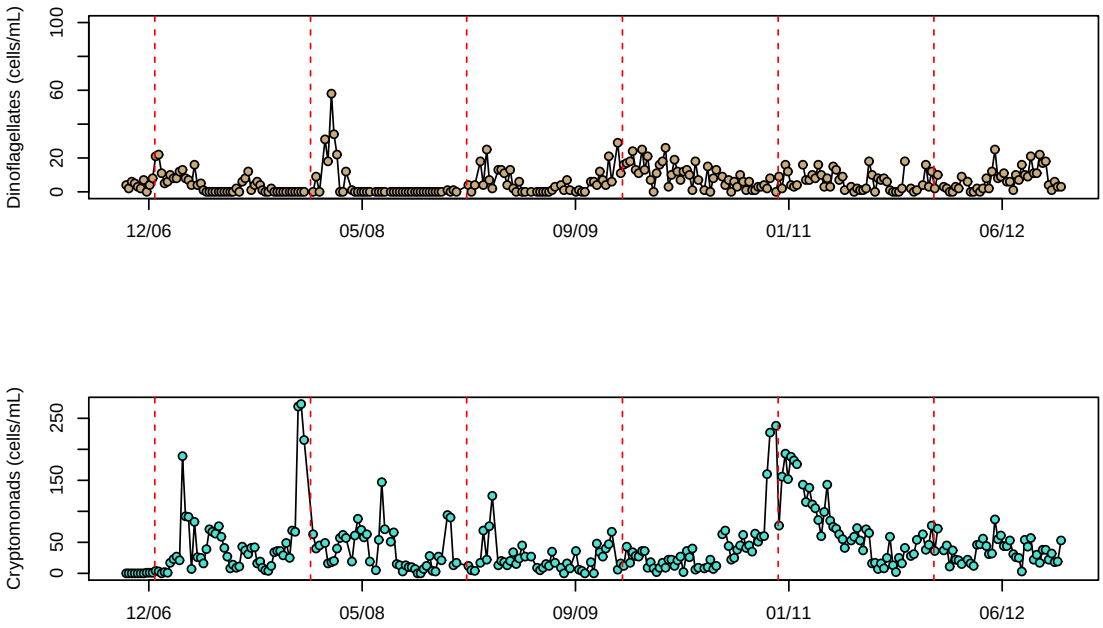


Figure 8: Dinoflagellates and cryptomonads are usually less abundant than other types of algae (note scale difference in this figure compared to Figure 7), but the species that are present in Judy Reservoir are often large in size. As a result, they can contribute disproportionately to algal biovolume and chlorophyll measurements. The cryptomonad densities in 2011 were slightly higher than in previous years, but did not appear to have much effect on the 2011 chlorophyll or biovolume levels (see Figures 1 and 11).

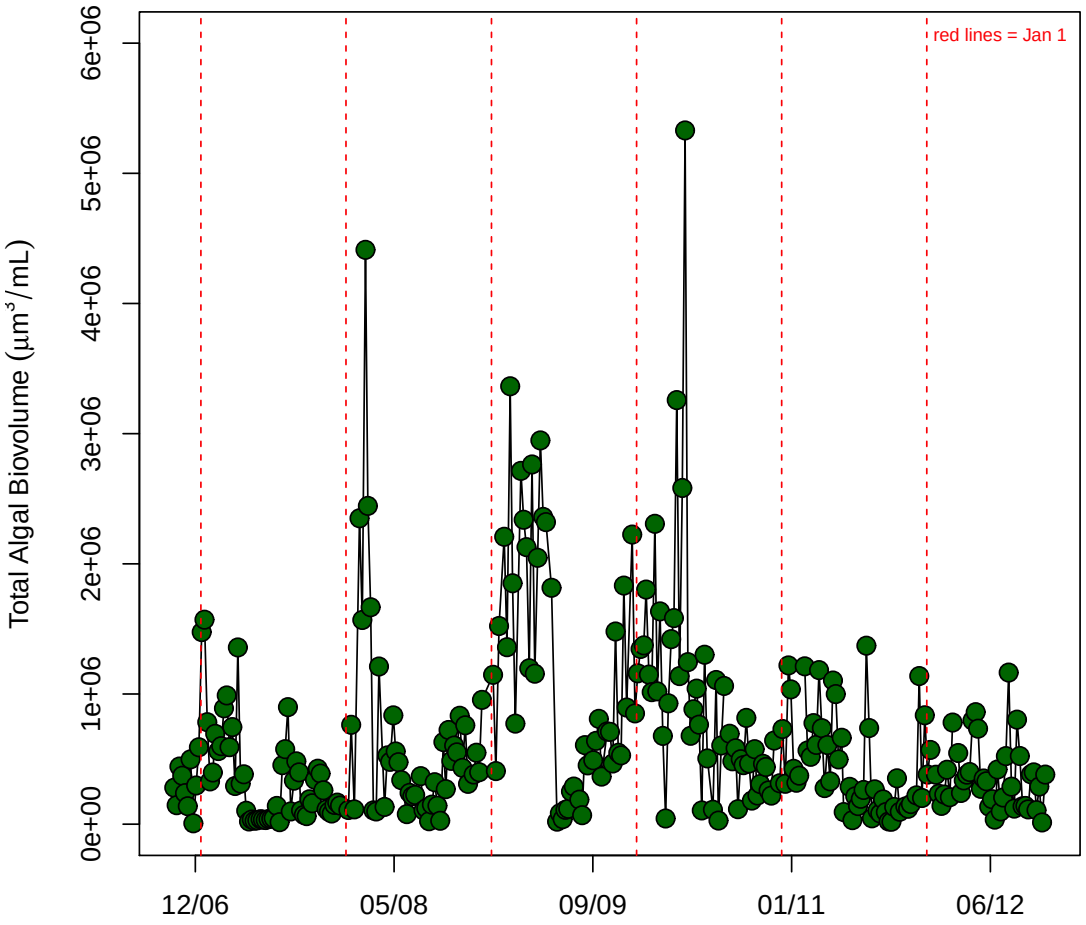


Figure 9: Freshwater algae range in size from very tiny (<2 μm diameter) to large enough to see without magnification (>1 mm diameter). Algal biovolume is calculated by measuring the size of the algal cell, calculating the volume occupied by that cell, then multiplying the individual "biovolume" by the number of algal cells in the sample. The biovolume results matched chlorophyll results, decreasing slightly in 2011 and 2012.

	All Data	2007	2008	2009	2010	2011	2012[†]
Median biovolume (μm^3/mL $\times$ 10^5)	4.2	2.6	4.2	8.3	6.9	3.1	3.4

[†]partial year – 2012 does not include November/December

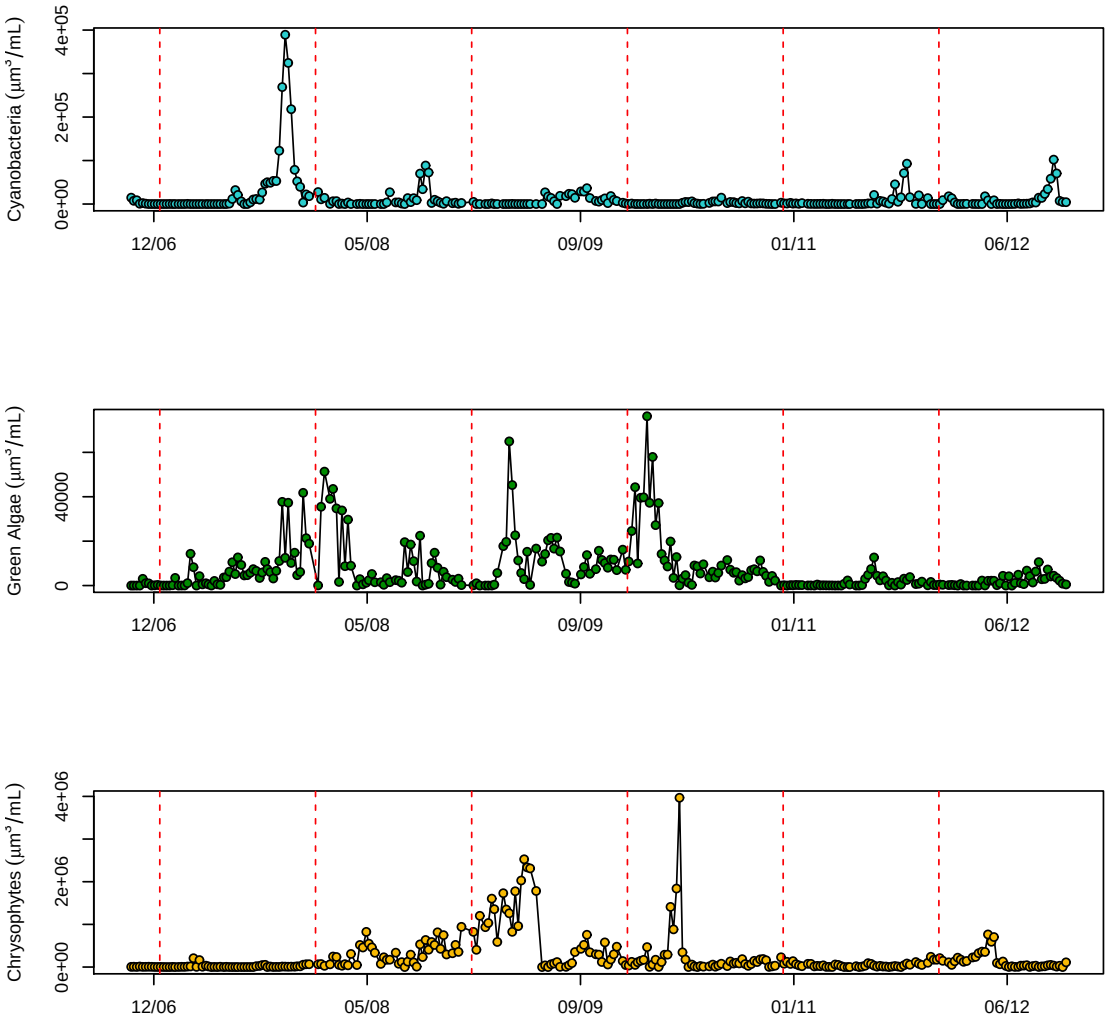


Figure 10: Cyanobacteria, green algae, and chrysophytes usually dominate the biovolume estimates as well as the cell counts. Several species that are present in the numerical counts do not yet have biovolume measurements. These include two large colonial species (*Woronichinia* - cyanobacteria; *Botryococcus* - green algae) and four diatoms (*Asterionella*, *Cyclotella*, *Navicula*, and *Surirella*). Adding biovolume estimates for these six species may slightly alter the biovolume patterns.

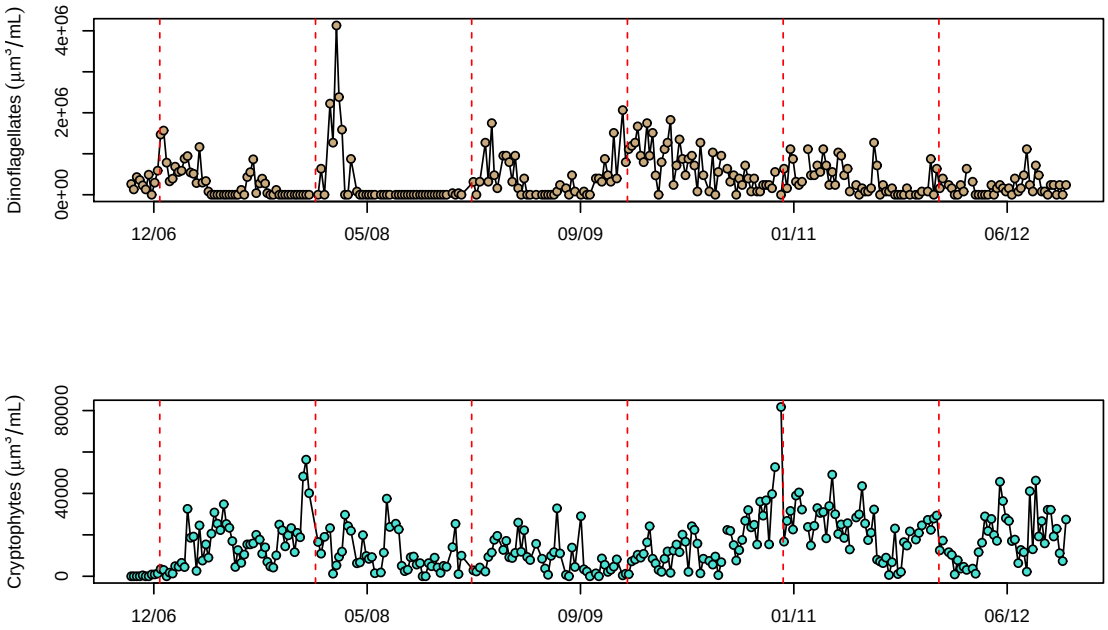


Figure 11: Cryptomonads (lower plot) were rarely common in the Judy Reservoir samples, so they rarely contributed much to algal biovolume estimates. Dinoflagellates occasionally formed blooms in the reservoir, and because the dinoflagellate cells are quite large, blooms can have an influence on biovolume.

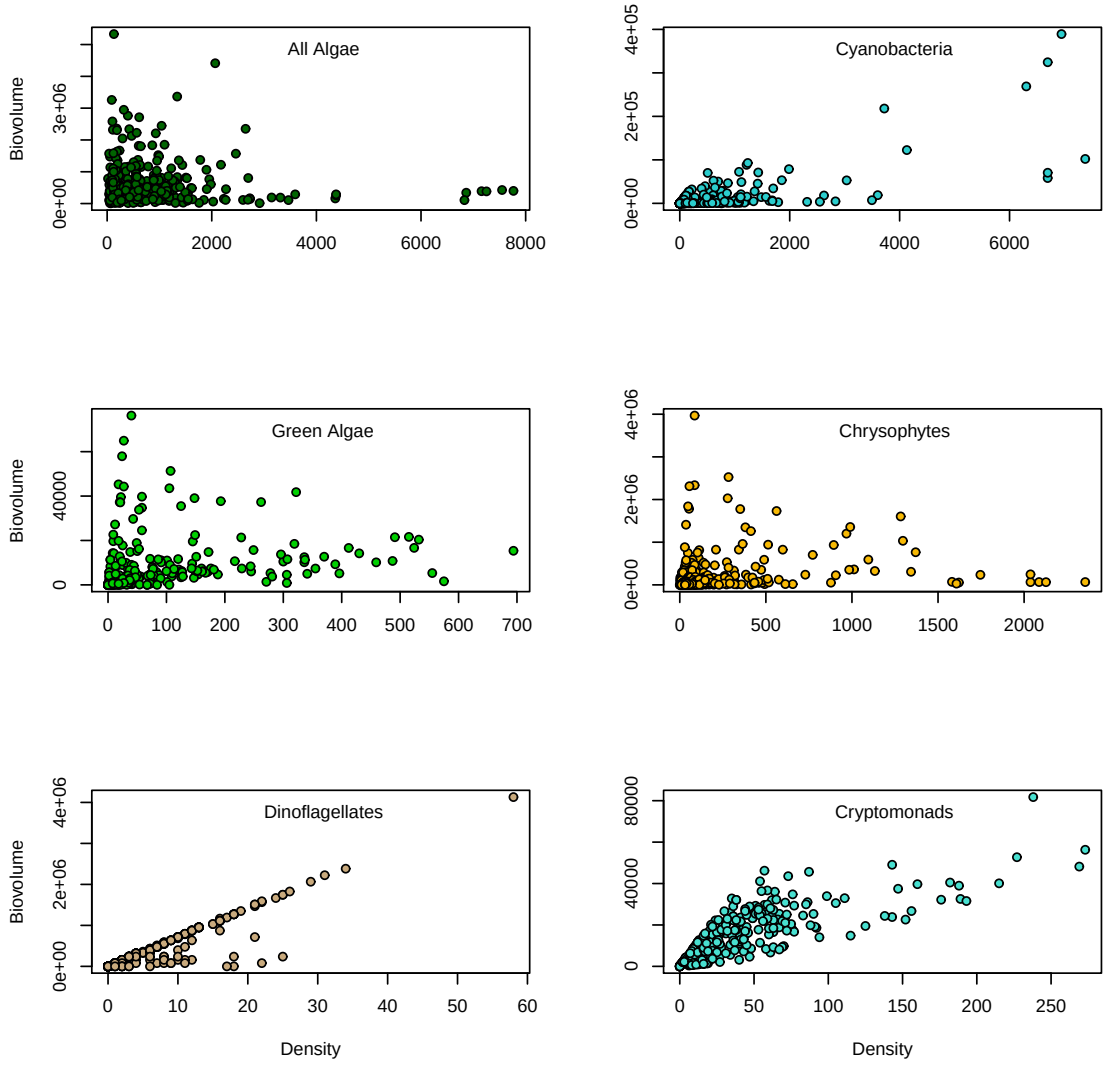


Figure 12: This figure illustrates how variation in cell size affects biovolume. If all of the species in an algal group are approximately the same size, the relationship between density and biovolume is nearly linear (e.g., dinoflagellates). If, however, the group contains species that are very different in size, as is the case for green algae and chrysophytes, there is little relationship between density and biovolume. Some types of algae, like the cyanobacteria, have many species present in Judy Reservoir, but the different species have somewhat similar cell shapes and sizes. The cryptomonads are interesting because there are only a few species present, and the cells are all basically the same shape (ovals), but they range from tiny to very large.

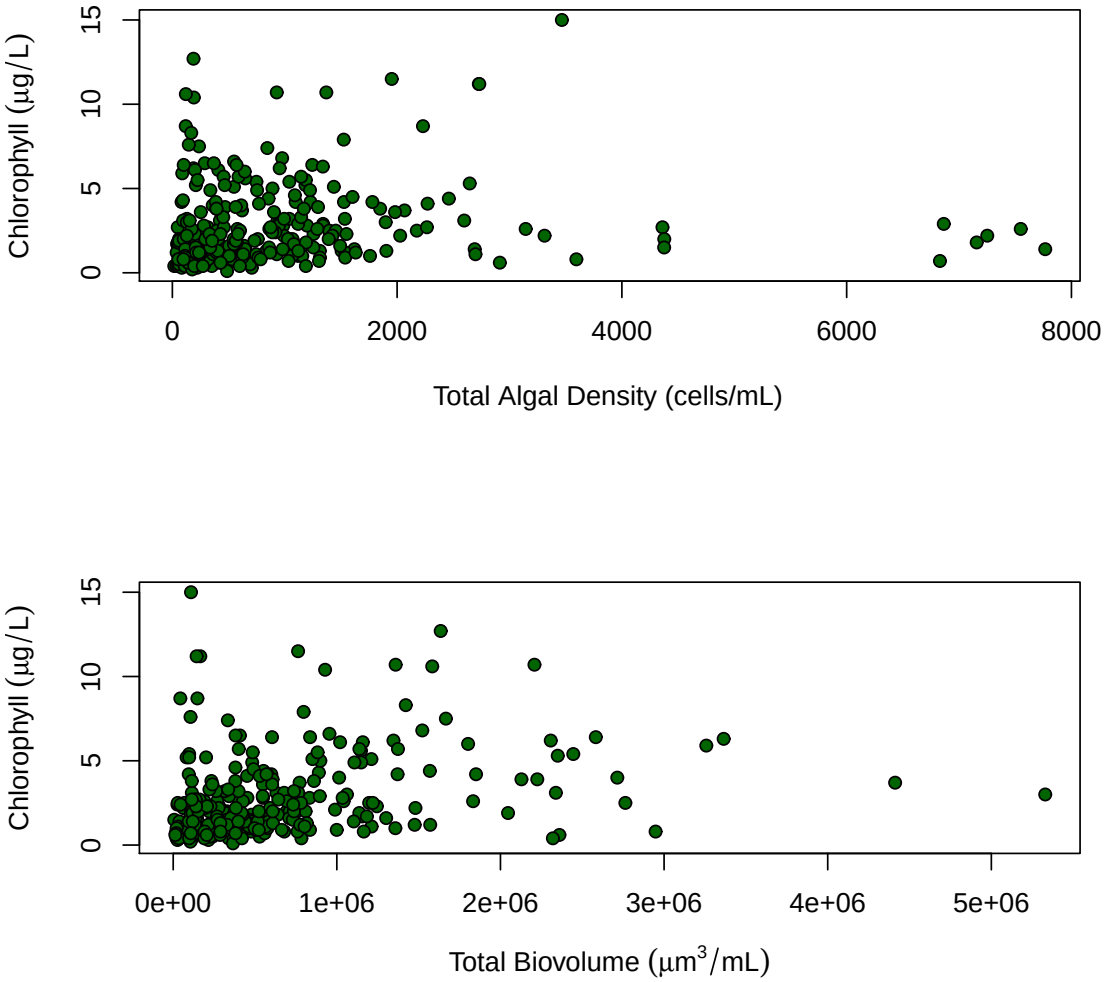


Figure 13: Although algal counts, algal biovolume, and algal chlorophyll levels are related, each measurement tells you something distinctly different about the amount of algae in a sample. Numerical counts show general patterns in algal population dynamics. For example, the Judy Reservoir counts revealed unusually high winter densities of chrysophytes (Figure 7). Chlorophyll measurements are fast, inexpensive, and widely used to indicate trophic state (Figure 3), but won't let you distinguish algae by type. Algal biovolume is the most direct measurement of the "weight" of algae in the sample, but needs to be measured for each species separately. As a result, it is not unusual to see weak relationships like this when you plot the measurements against each other.

A Plankton Images

This appendix contains photographic images and biovolume equations for most of the phytoplankton in Judy Reservoir. Biovolume calculations require measurements from a minimum of ten cells, so only moderately common taxa are used for biovolume estimates.

Cyanobacteria (bluegreen algae)		Green algae	
Anabaena	●	*Ankyra*	○
Aphanocapsa	●	*Botryococcus*	○
Chroococcus dispersus	●	*Chlamydomonas*	○
Chroococcus limneticus	○	*Chlorella*	○
Chroococcus turgidus	●	*Cosmarium*	●
Gloeocapsa	●	*Crucigenia*	●
Merismopedia	○	*Crucigeniella*	○
Microcystis	●	*Dictyosphaerium*	●
Pseudanabaena	○	*Elakatothrix*	●
Unidentified bluegreen	●	*Eudorina*	●
Woronichinia	○	*Gloeocystis*	●
		Oocystis	●
Golden algae		*Pediastrum*	○
Bitrichia	○	*Scenedesmus*	●
Dinobryon bavaricum	●	*Selenastrum*	○
Dinobryon sertularia	●	*Sphaerocystis*	●
Gloeobotrys	○	*Spondylosium*	○
Mallomonas	●	*Staurastrum*	○
Synura petersenii	●	*Tetraedron*	●
Synura uvella	●		
Unidentified golden	●	Dinoflagellates	
Uroglena	●	*Ceratium hirudinella*	●
Asterionella (diatom)	○	*Gymnodinium*	●
Aulacoseira (diatom)	●	*Peridinium*	○
Cocconeis (diatom)	○		
Cyclotella (diatom)	○	Cryptomonads	
Fragilaria (diatom)	○	*Cryptomonas*	●
Navicula (diatom)	○	*Komma/Chroomonas*	●
Stephanodiscus (diatom)	●		
Surirella (diatom)	○		
Synedra (diatom)	●		
Tabellaria (diatom)	●		
Unidentified diatoms	○		

Table 2: List of algae collected in Judy Reservoir, October 2006 - October 2012. Algae with density measurements are identified using an open circle (○); algae that also have biovolume measurements are identified using a solid circle (●).

Figure 14: *Anabaena* spp. (cyanobacteria).

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 6.07\,\mu\text{m} \\
\text{Avg. length} &= 7.97\,\mu\text{m} \\
\text{Avg. biovolume} &= 159.3\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 124.1 - 194.5\,\mu\text{m}^3
\end{aligned}$$

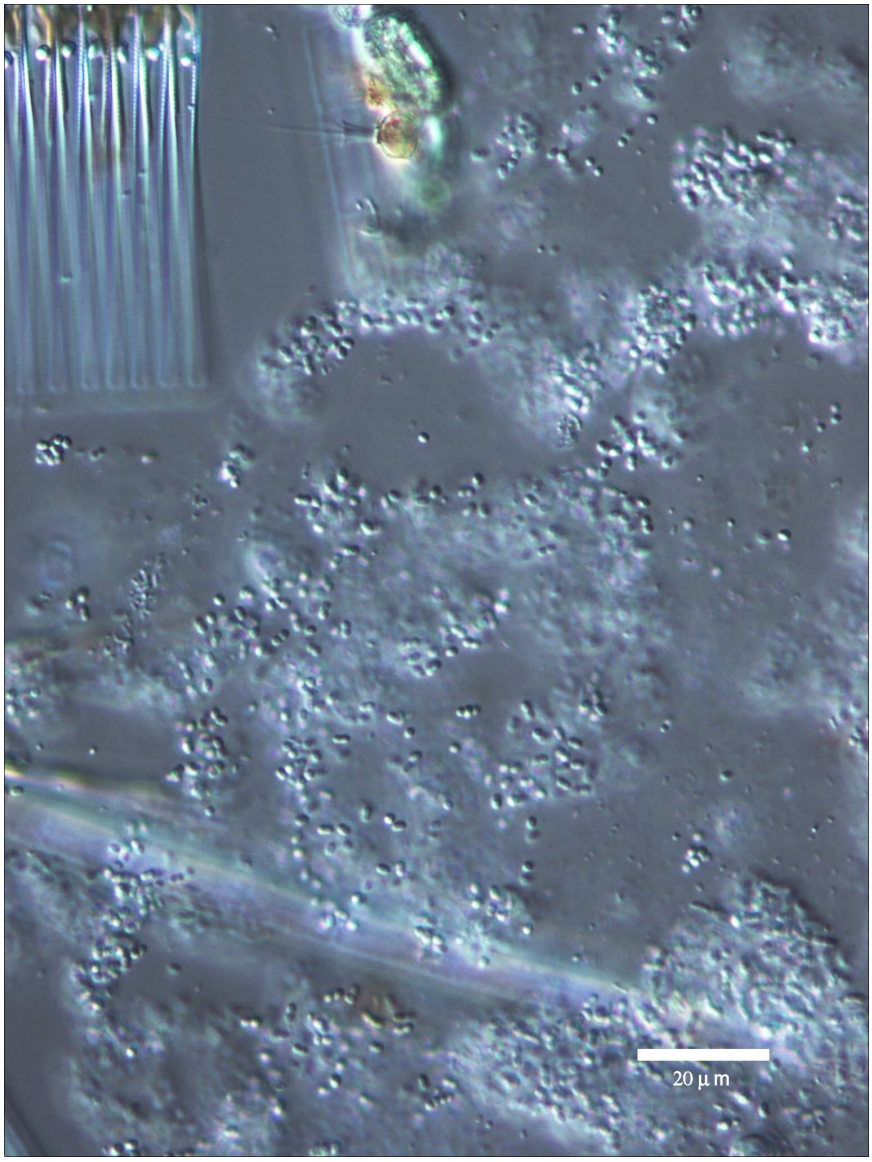


Figure 15: *Aphanocapsa* (cyanobacteria).

$$\text{Ovoid biovolume} = \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right)$$

$$\begin{aligned}
\text{Avg. width} &= 1.34\,\mu\text{m} \\
\text{Avg. length} &= 1.54\,\mu\text{m} \\
\text{Avg. biovolume} &= 1.50\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 0.96 - 2.03\,\mu\text{m}^3
\end{aligned}$$

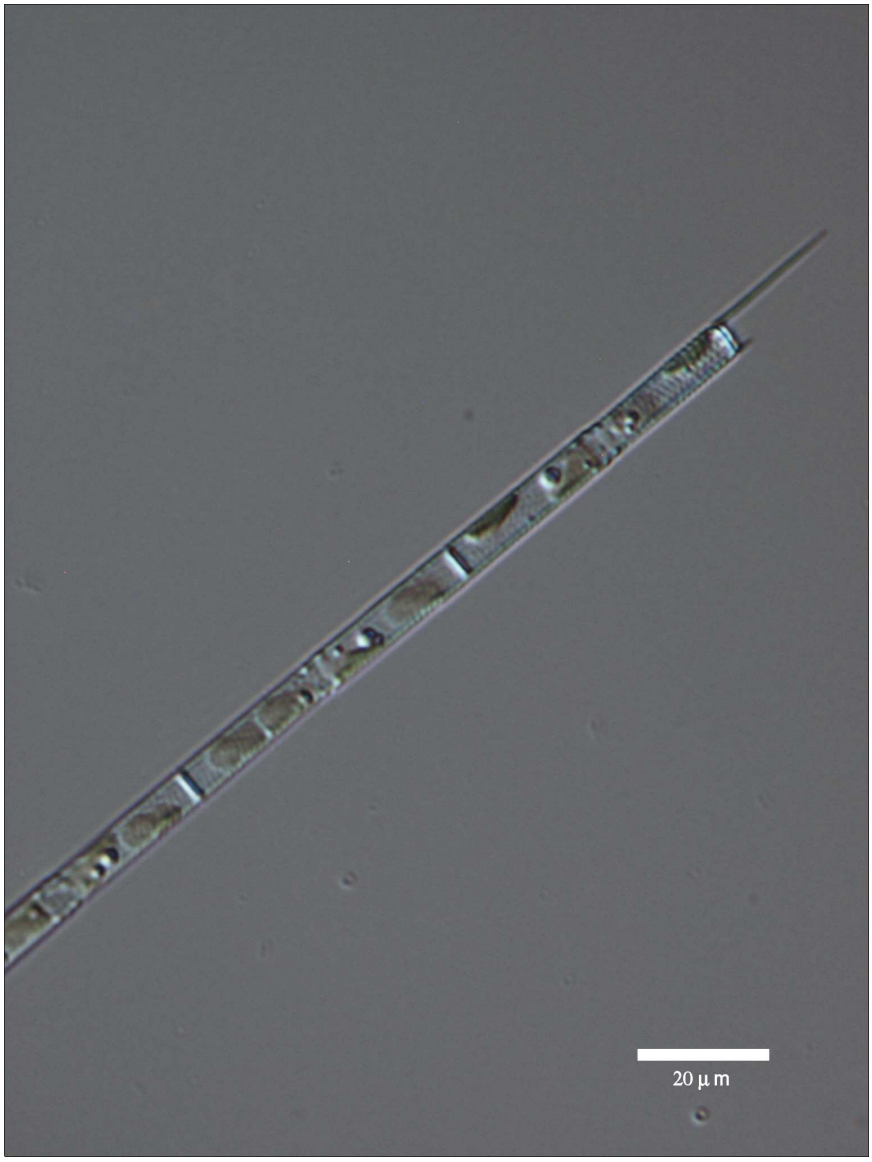


Figure 16: *Aulacoseira* (diatom).

$$\begin{aligned}
\text{Cylinder biovolume} &= \pi \times \left(\frac{\text{width}}{2}\right)^2 \times \text{length} \\
\\
\text{Avg. width} &= 6.6\,\mu\text{m} \\
\text{Avg. length} &= 29.0\,\mu\text{m} \\
\text{Avg. biovolume} &= 1,033\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 769 - 1,296\,\mu\text{m}^3
\end{aligned}$$

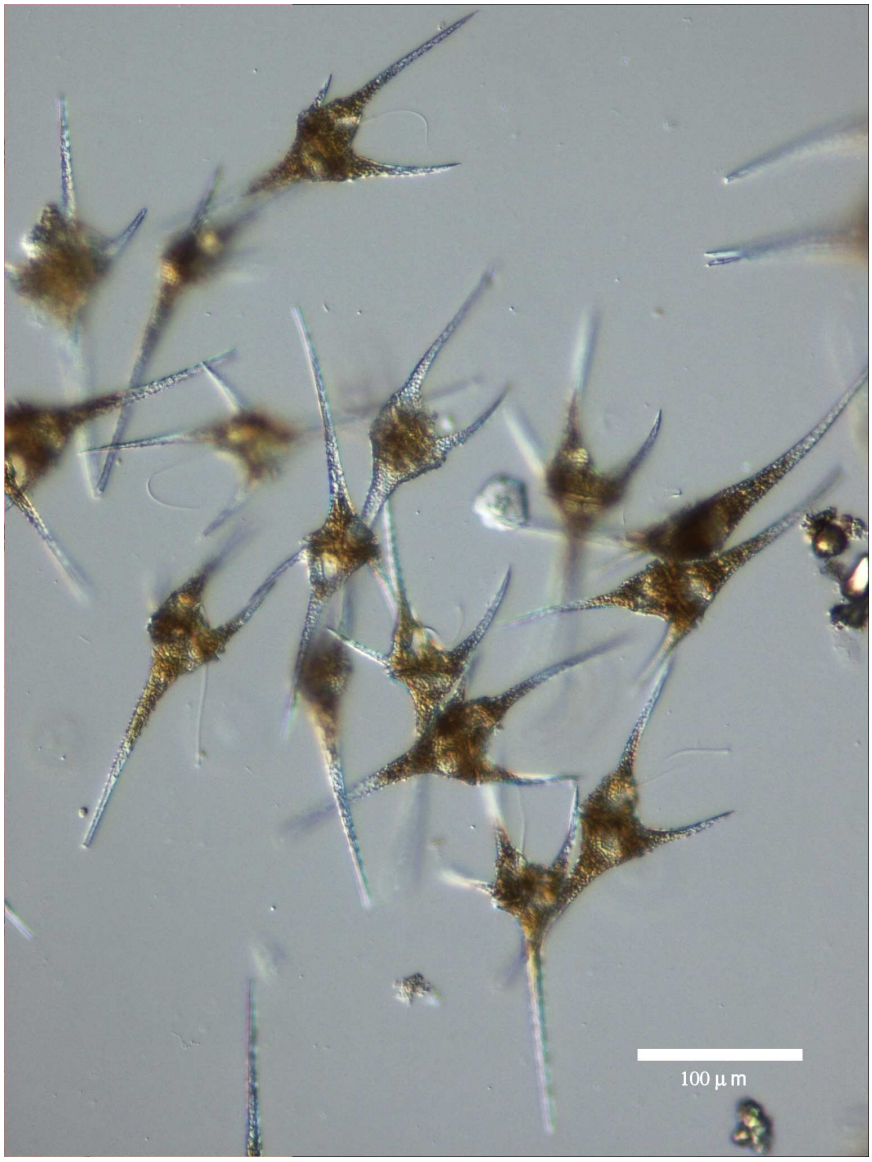


Figure 17: *Ceratium hirundinella* (dinoflagellate).

$$\text{Ceratium biovolume} = \left(\frac{4}{3}\pi \times \left(\frac{\text{diameter}}{2}\right)^2 \times \text{length}\right) + \left(\pi \left(\frac{\text{width}}{2}\right)^2 \times \text{depth}\right)$$

$$\begin{aligned}
\text{Avg. width} &= 44.3\,\mu\text{m} \\
\text{Avg. length} &= 52.4\,\mu\text{m} \\
\text{Ave. depth} &= 43.2\,\mu\text{m} \\
\text{Ave. diameter} &= 9.4\,\mu\text{m} \\
\text{Avg. biovolume} &= 72,215\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 61,334 - 83,096\,\mu\text{m}^3
\end{aligned}$$

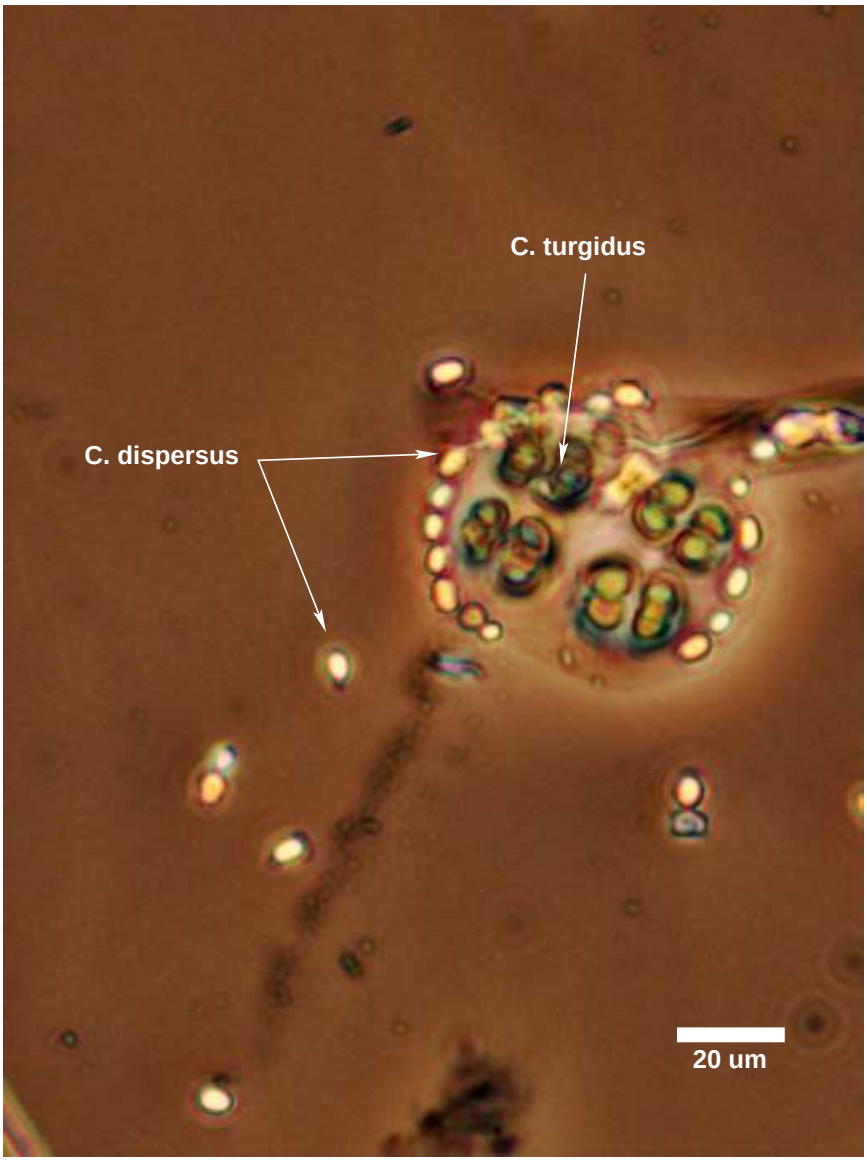


Figure 18: *Chroococcus dispersus* (cyanobacteria)

$$\text{Ovoid biovolume} = \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right)$$

$$\begin{aligned}
\text{Avg. width} &= 1.52\,\mu\text{m} \\
\text{Avg. length} &= 2.20\,\mu\text{m} \\
\text{Avg. biovolume} &= 2.95\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 2.26 - 3.64\,\mu\text{m}^3
\end{aligned}$$

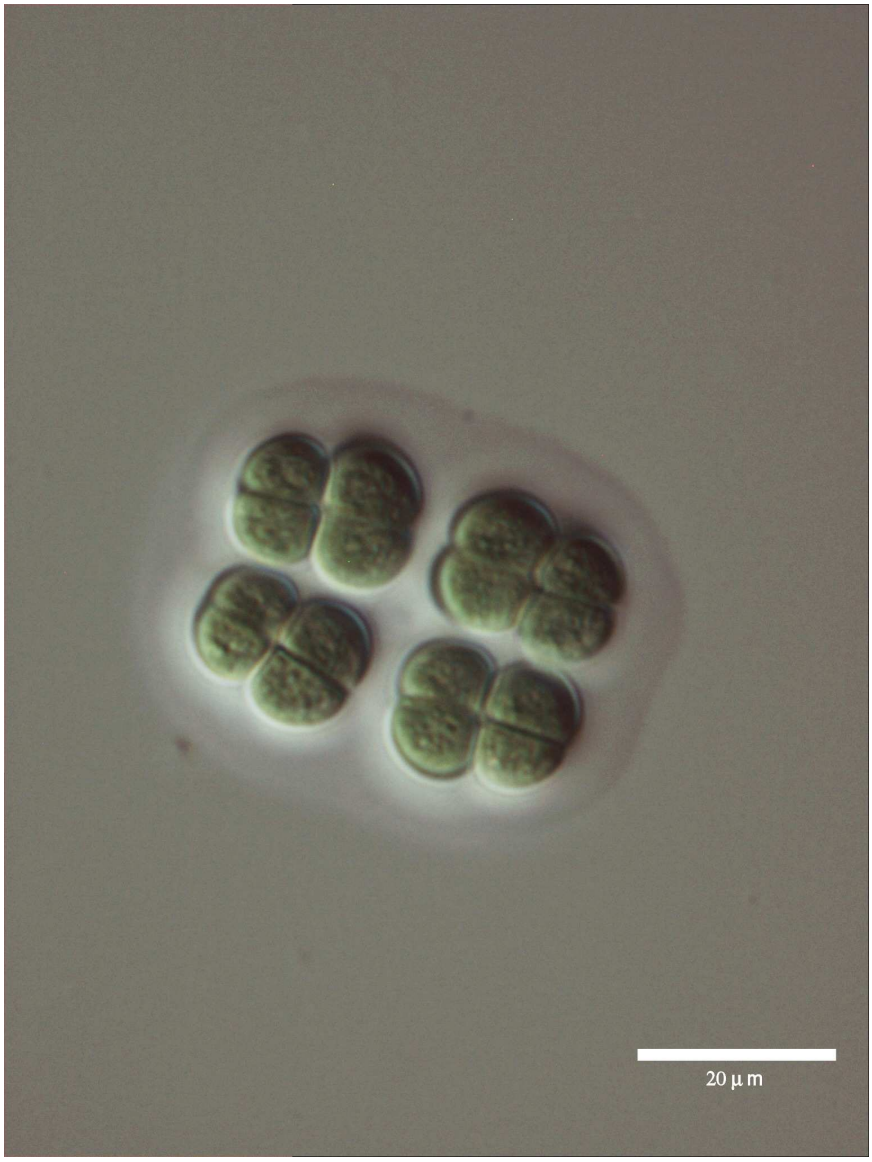


Figure 19: *Chroococcus turgidus* (cyanobacteria)

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 6.52\,\mu\text{m} \\
\text{Avg. length} &= 7.22\,\mu\text{m} \\
\text{Avg. biovolume} &= 187.5\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 143.0 - 232.1\,\mu\text{m}^3
\end{aligned}$$

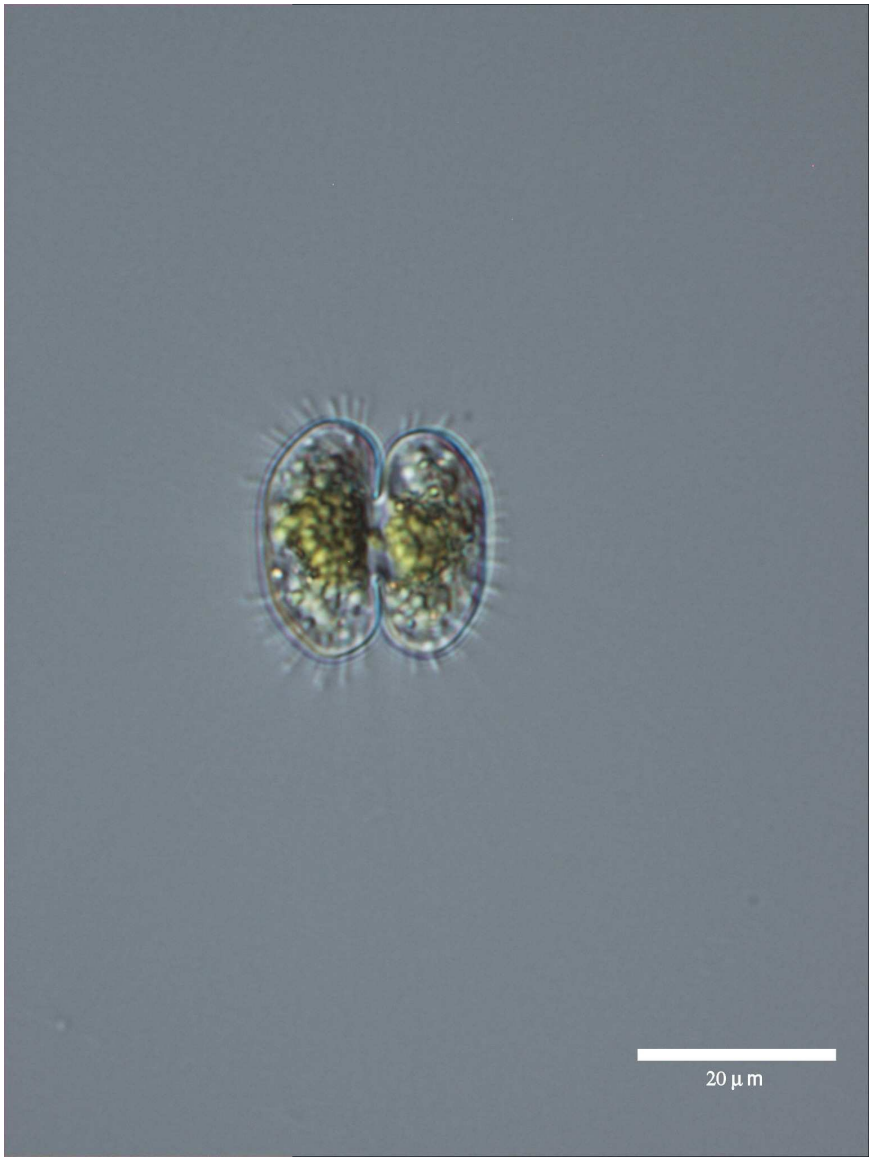


Figure 20: *Cosmarium* (green algae - desmid).

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 15.11\,\mu\text{m} \\
\text{Avg. length} &= 15.39\,\mu\text{m} \\
\text{Avg. biovolume} &= 1,866\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 1,535 - 2,197\,\mu\text{m}^3
\end{aligned}$$

Figure 21: *Crucigenia* (green algae).

$$\text{Ovoid biovolume} = \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right)$$

$$\begin{aligned}
\text{Avg. width} &= 2.51\,\mu\text{m} \\
\text{Avg. length} &= 2.11\,\mu\text{m} \\
\text{Avg. biovolume} &= 11.06\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 4.22 - 17.90\,\mu\text{m}^3
\end{aligned}$$

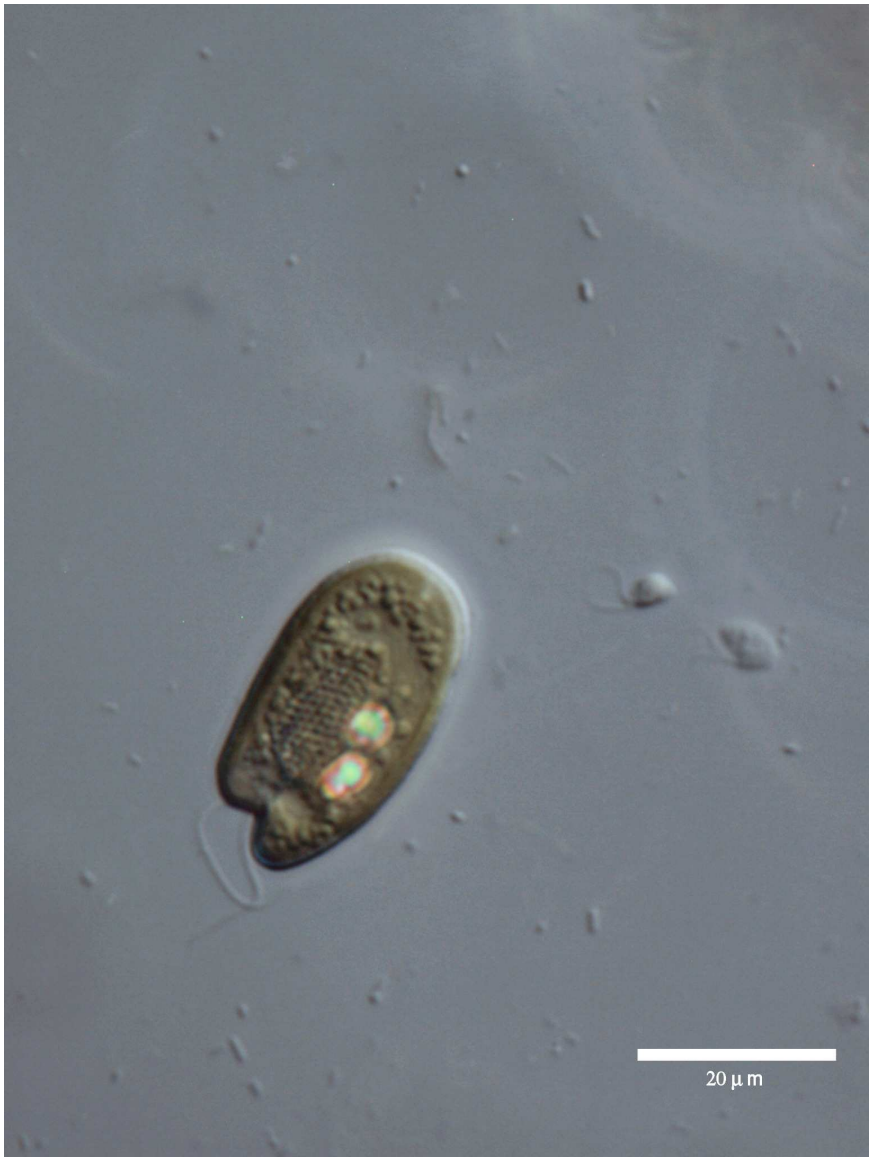


Figure 22: *Cryptomonas* (cryptomonad).

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 8.85\,\mu\text{m} \\
\text{Avg. length} &= 17.51\,\mu\text{m} \\
\text{Avg. biovolume} &= 945.4\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 226.7 - 1,664\,\mu\text{m}^3
\end{aligned}$$

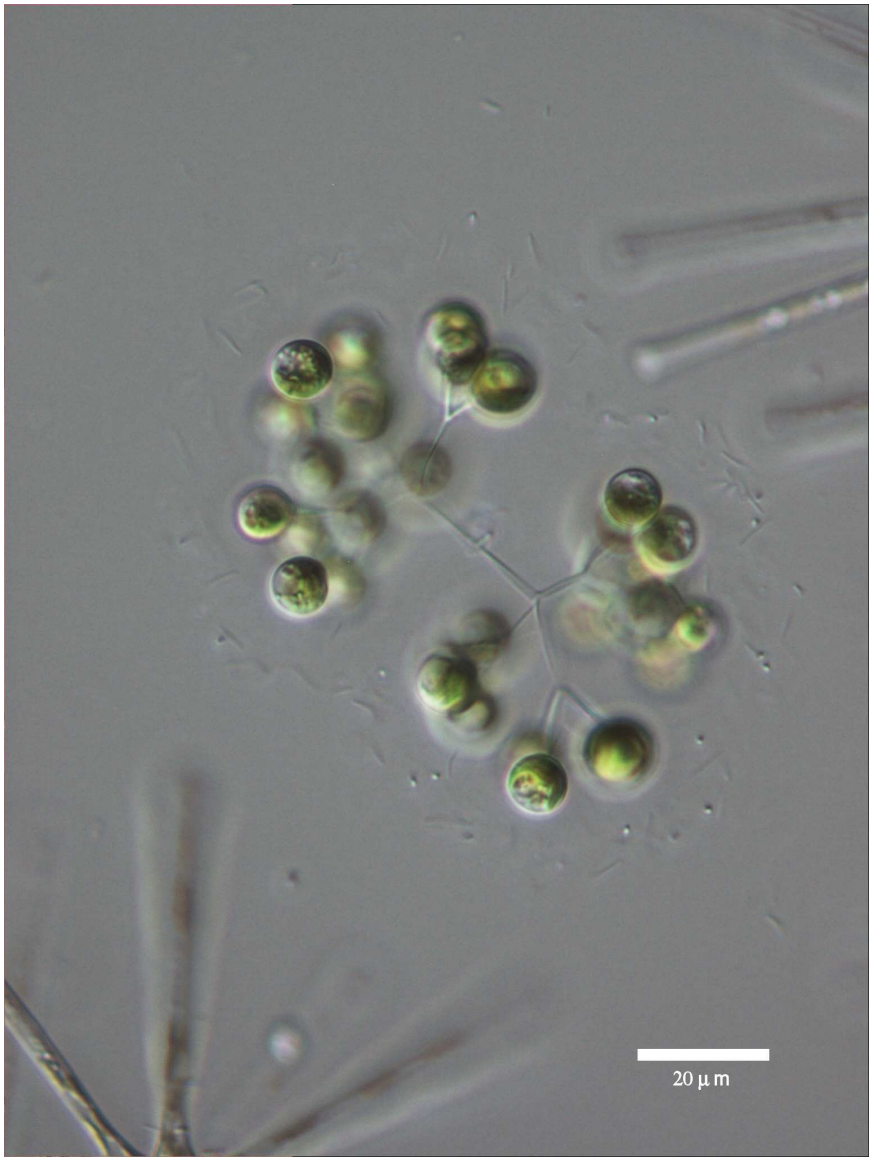


Figure 23: *Dictyosphaerium* (green algae).

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 6.64\,\mu\text{m} \\
\text{Avg. length} &= 7.27\,\mu\text{m} \\
\text{Avg. biovolume} &= 169.2\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 138.2 - 200.2\,\mu\text{m}^3
\end{aligned}$$

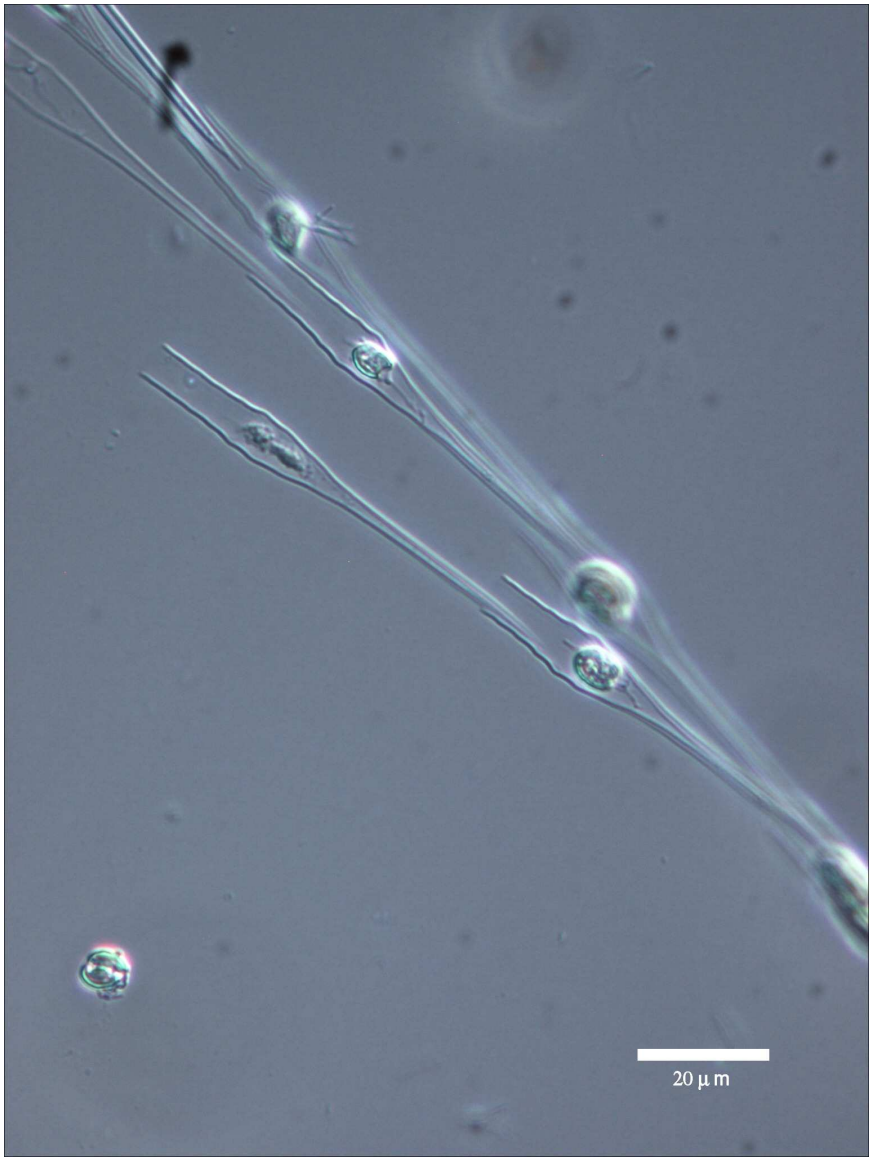


Figure 24: *Dinobryon bavaricum* (chrysophyte).

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 2.51\,\mu\text{m} \\
\text{Avg. length} &= 8.06\,\mu\text{m} \\
\text{Avg. biovolume} &= 122.4\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 43.2 - 201.5\,\mu\text{m}^3
\end{aligned}$$

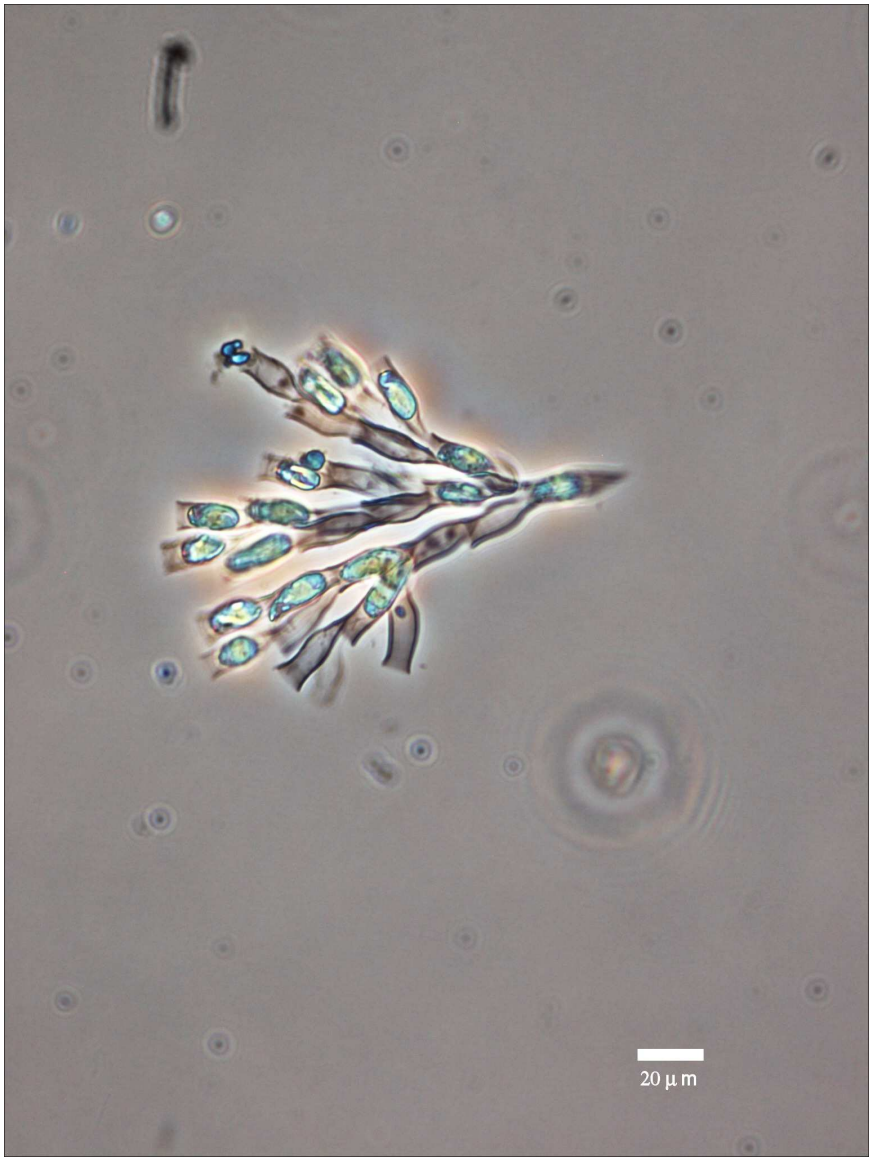


Figure 25: *Dinobryon sertularia* (chrysophyte).

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 1.63\,\mu\text{m} \\
\text{Avg. length} &= 9.91\,\mu\text{m} \\
\text{Avg. biovolume} &= 17.2\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 6.81 - 27.6\,\mu\text{m}^3
\end{aligned}$$

Figure 26: *Elakatothrix* (green algae).

$$\begin{aligned}
\text{Fusiform biovolume} &= \frac{2}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 1.64\,\mu\text{m} \\
\text{Avg. length} &= 14.58\,\mu\text{m} \\
\text{Avg. biovolume} &= 11.81\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 8.44 - 15.17\,\mu\text{m}^3
\end{aligned}$$

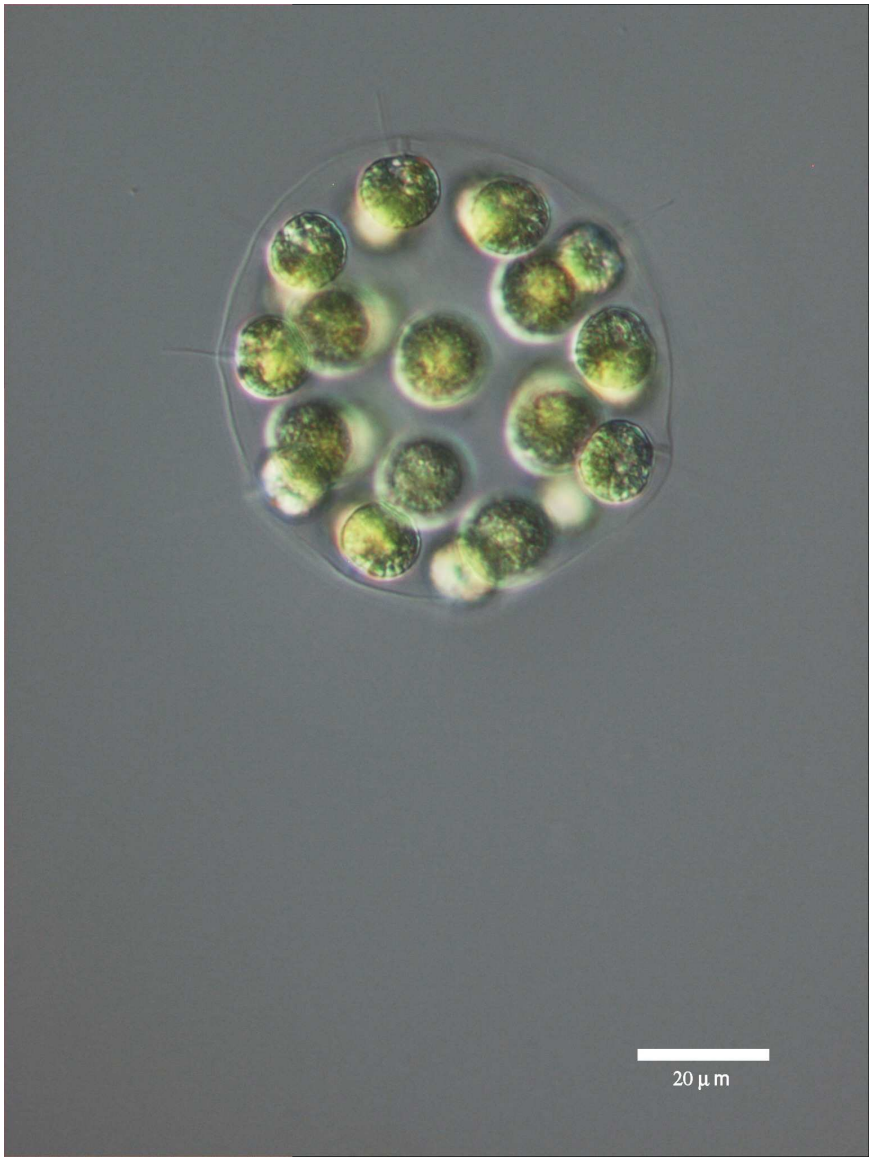


Figure 27: *Eudorina* (green algae).

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 5.41\,\mu\text{m} \\
\text{Avg. length} &= 5.99\,\mu\text{m} \\
\text{Avg. biovolume} &= 180.2\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 69.6 - 290.7\,\mu\text{m}^3
\end{aligned}$$

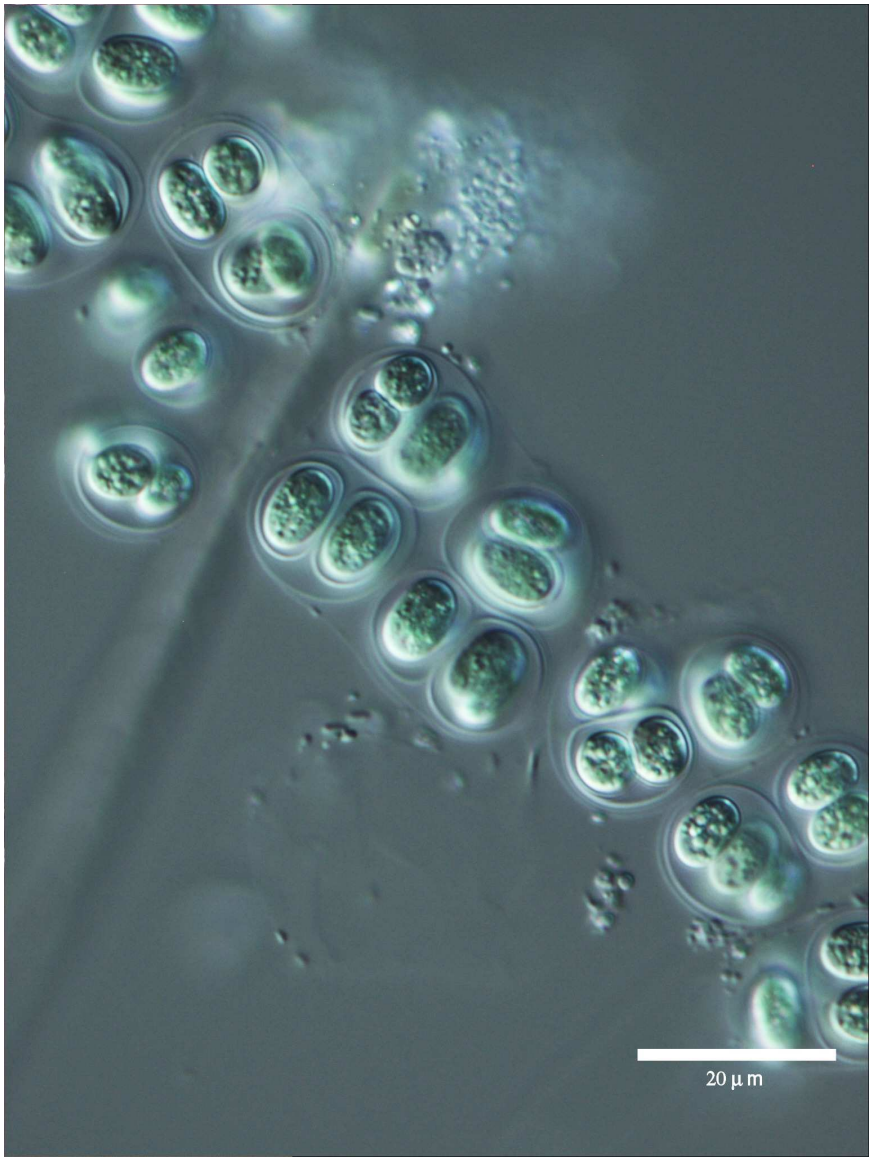


Figure 28: *Gloeocapsa* (cyanobacteria).

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 6.0\,\mu\text{m} \\
\text{Avg. length} &= 6.5\,\mu\text{m} \\
\text{Avg. biovolume} &= 124.6\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 104.7 - 144.5\,\mu\text{m}^3
\end{aligned}$$

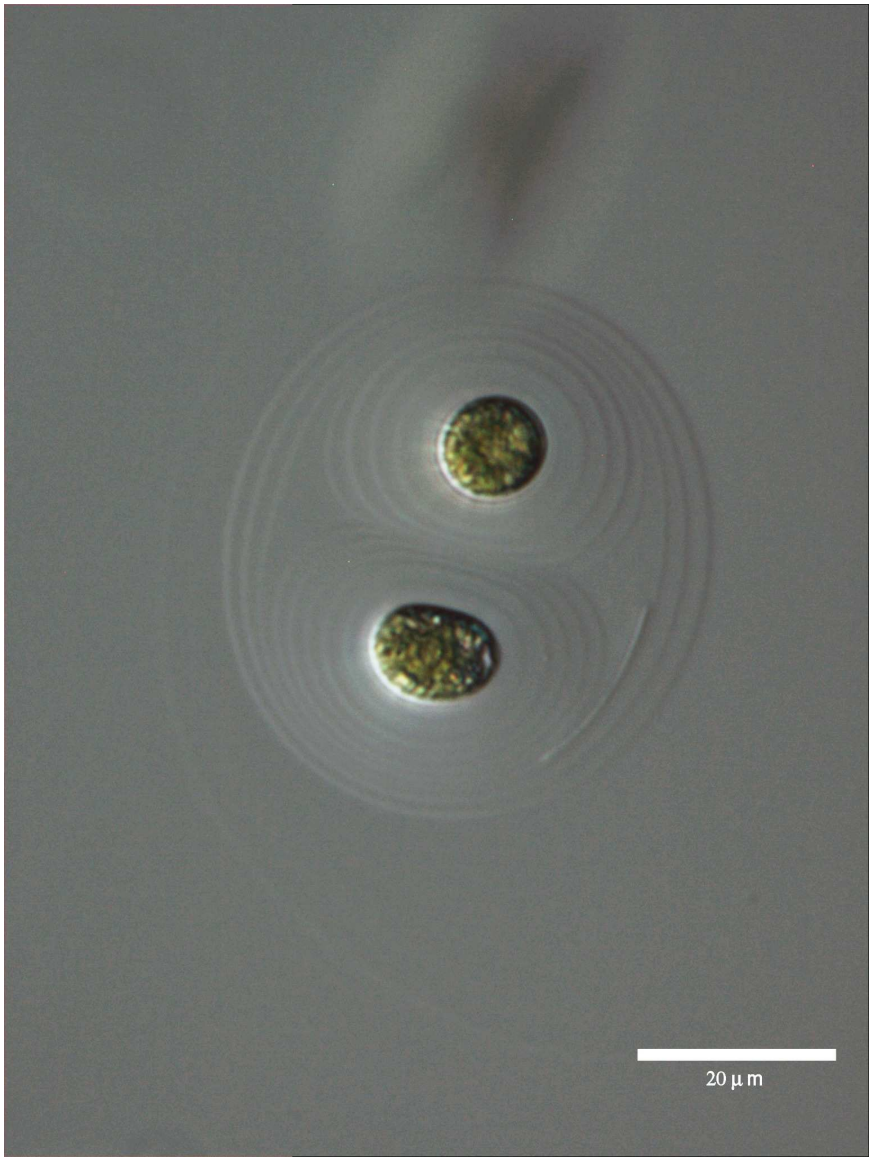


Figure 29: *Gloeocystis* (green algae).

$$\text{Ovoid biovolume} = \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right)$$

$$\begin{aligned}
\text{Avg. width} &= 6.1\,\mu\text{m} \\
\text{Avg. length} &= 7.8\,\mu\text{m} \\
\text{Avg. biovolume} &= 153.1\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 120.8 - 185.5\,\mu\text{m}^3
\end{aligned}$$

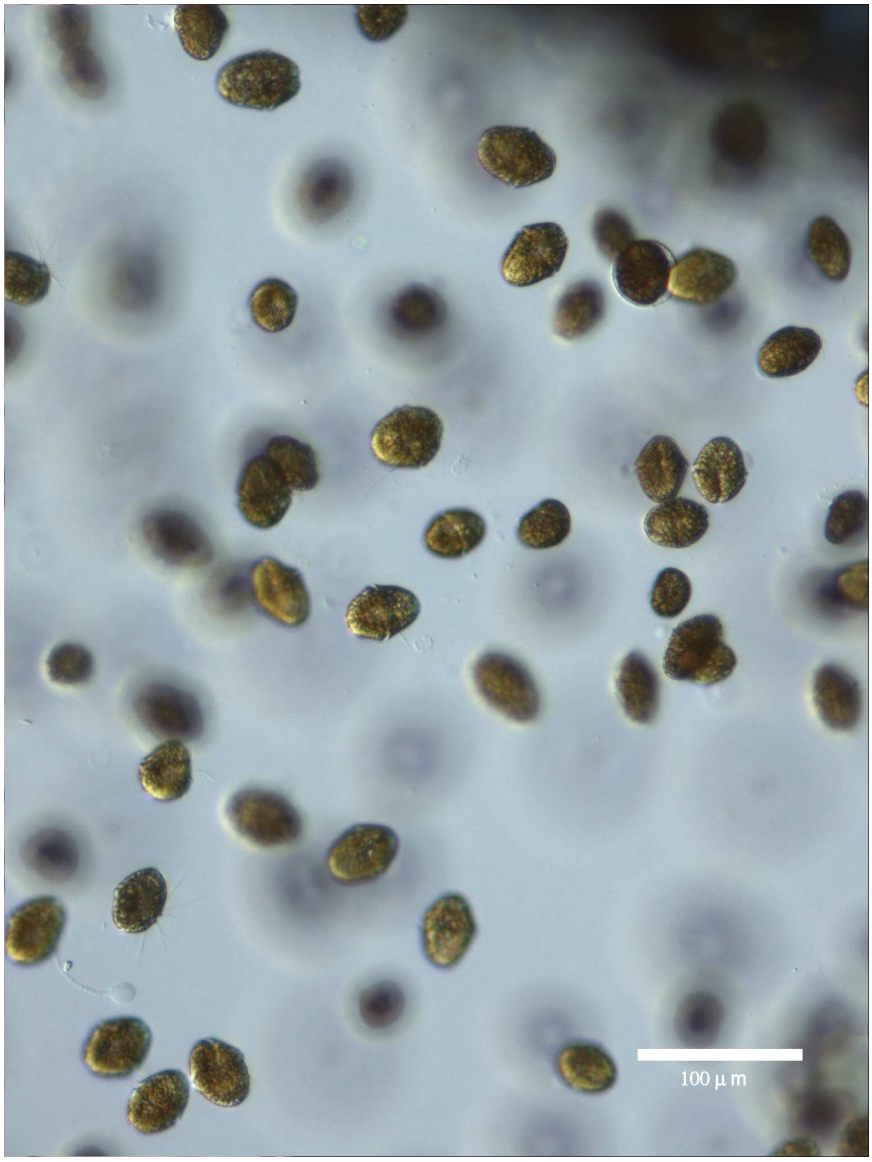


Figure 30: *Gymnodinium* (dinoflagellate).

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 50.4\,\mu\text{m} \\
\text{Avg. length} &= 51.4\,\mu\text{m} \\
\text{Avg. biovolume} &= 70,953\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 53,043 - 88,863\,\mu\text{m}^3
\end{aligned}$$

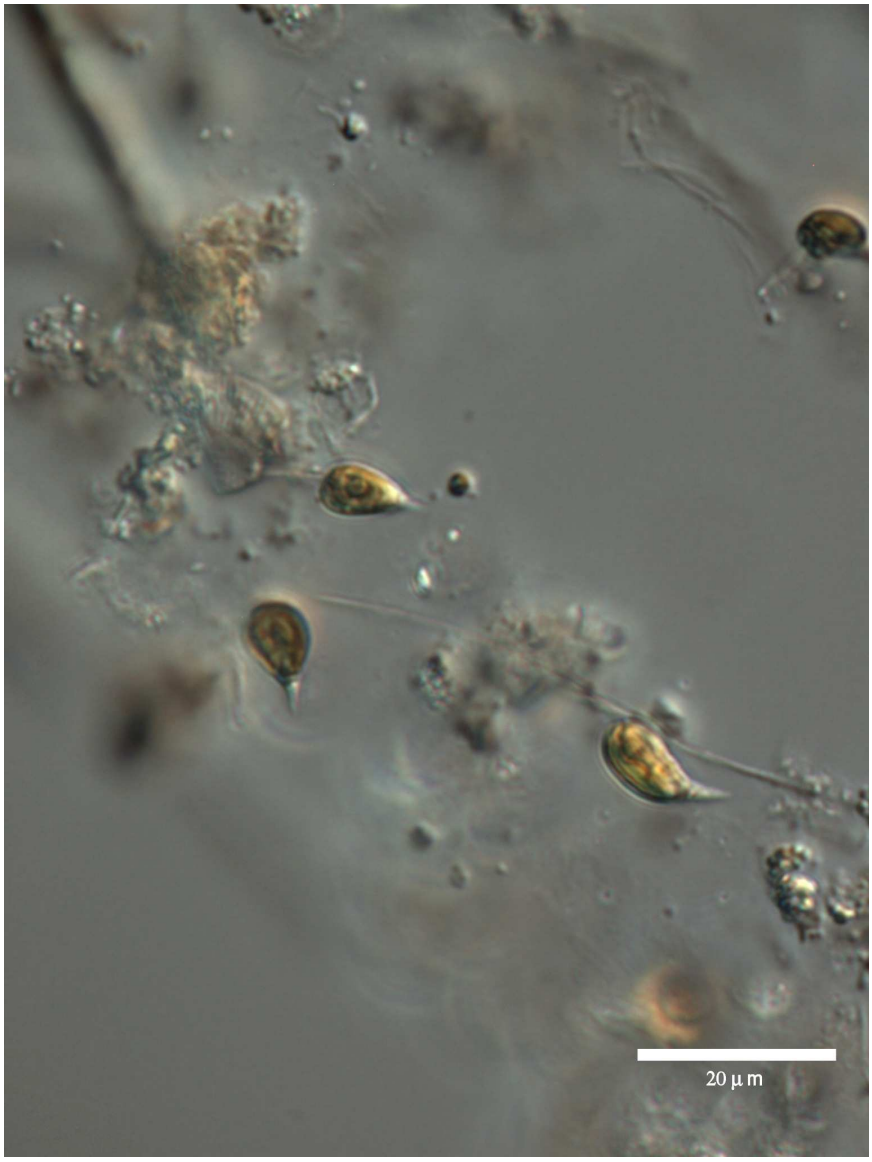


Figure 31: *Komma caudata* (cryptomonad; a.k.a *Chroomonas acuta*)

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 3.84\,\mu\text{m} \\
\text{Avg. length} &= 7.18\,\mu\text{m} \\
\text{Avg. biovolume} &= 78.2\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= < 1 - 161.8\,\mu\text{m}^3
\end{aligned}$$

Figure 32: *Mallomonas* (chrysophyte).

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 20.0\,\mu\text{m} \\
\text{Avg. length} &= 41.6\,\mu\text{m} \\
\text{Avg. biovolume} &= 8,951\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 6,989 - 10,913\,\mu\text{m}^3
\end{aligned}$$

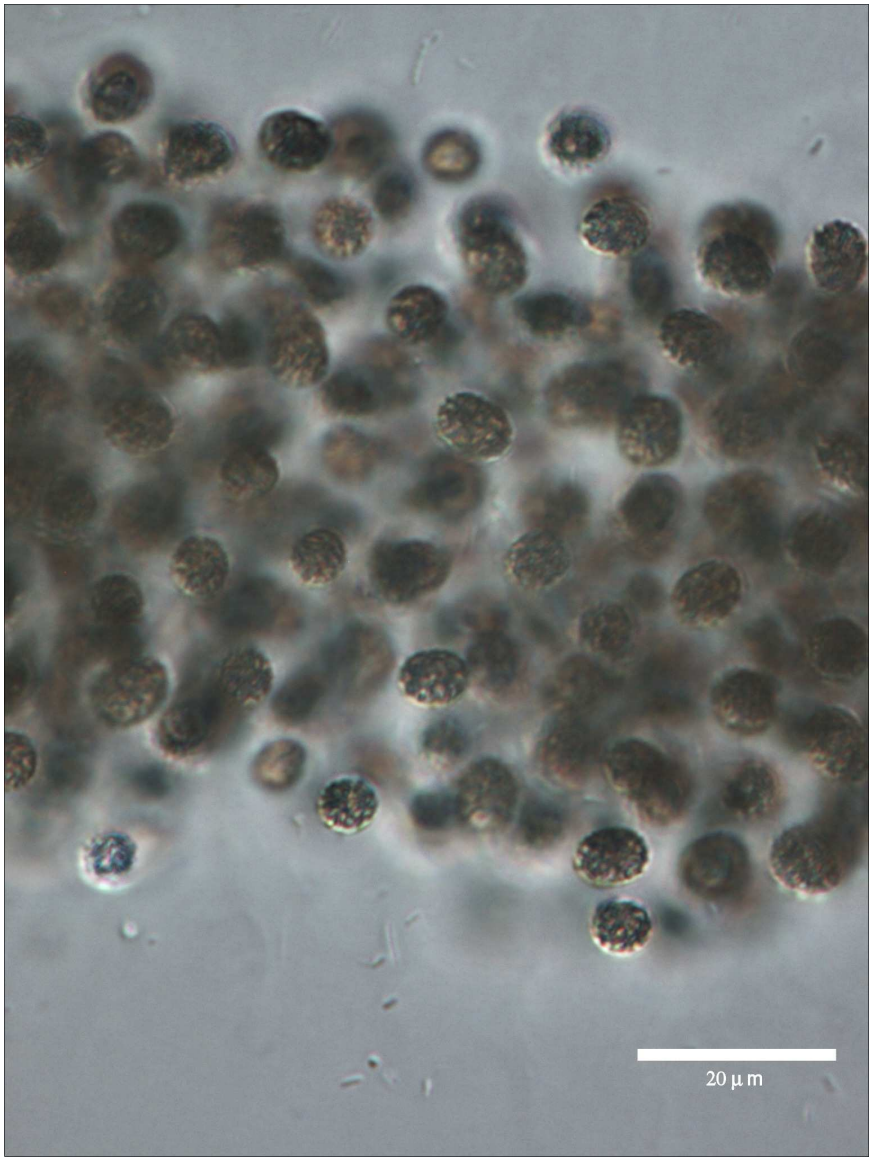


Figure 33: *Microcystis* (cyanobacteria).

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 5.42\,\mu\text{m} \\
\text{Avg. length} &= 6.17\,\mu\text{m} \\
\text{Avg. biovolume} &= 96.1\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 80.1 - 112.1\,\mu\text{m}^3
\end{aligned}$$

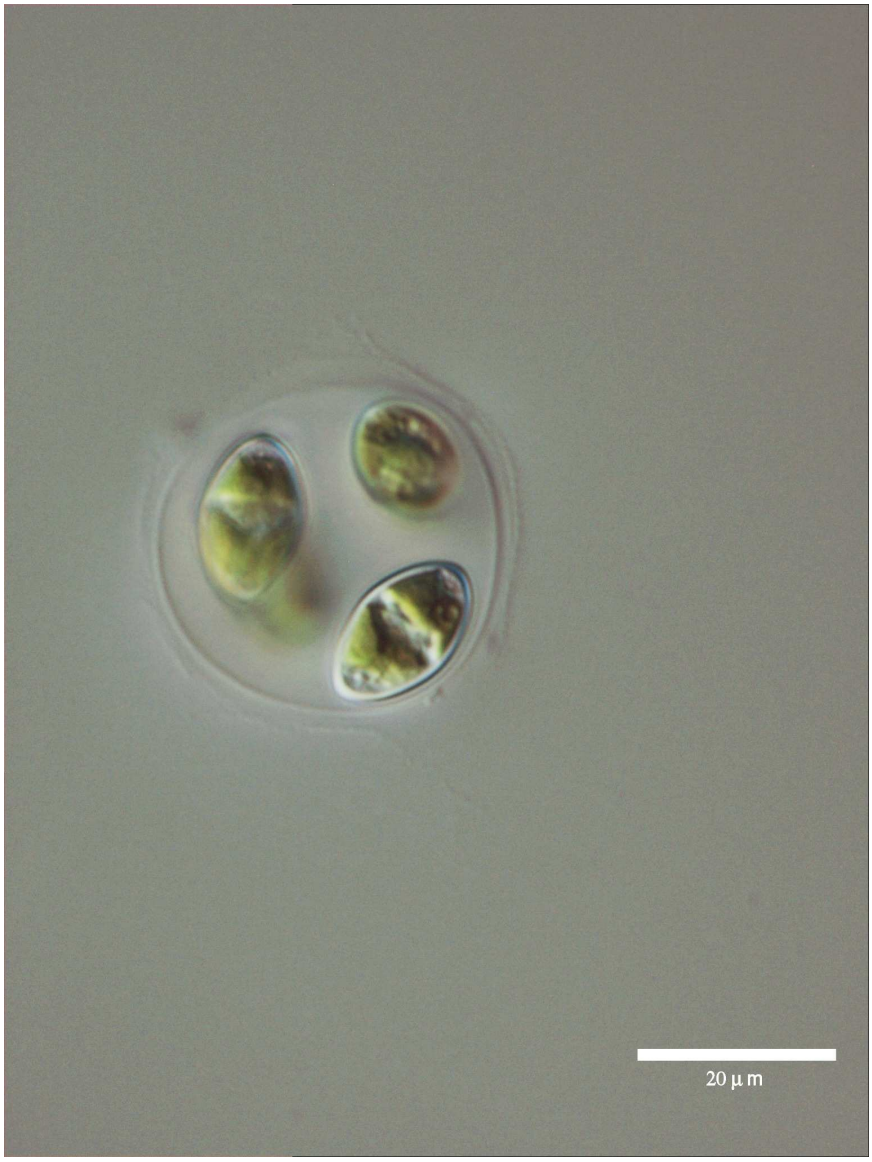


Figure 34: *Oocystis* (green algae).

$$\text{Ovoid biovolume} = \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right)$$

$$\begin{aligned}
\text{Avg. width} &= 5.48\,\mu\text{m} \\
\text{Avg. length} &= 8.38\,\mu\text{m} \\
\text{Avg. biovolume} &= 138.5\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 113.7 - 163.4\,\mu\text{m}^3
\end{aligned}$$

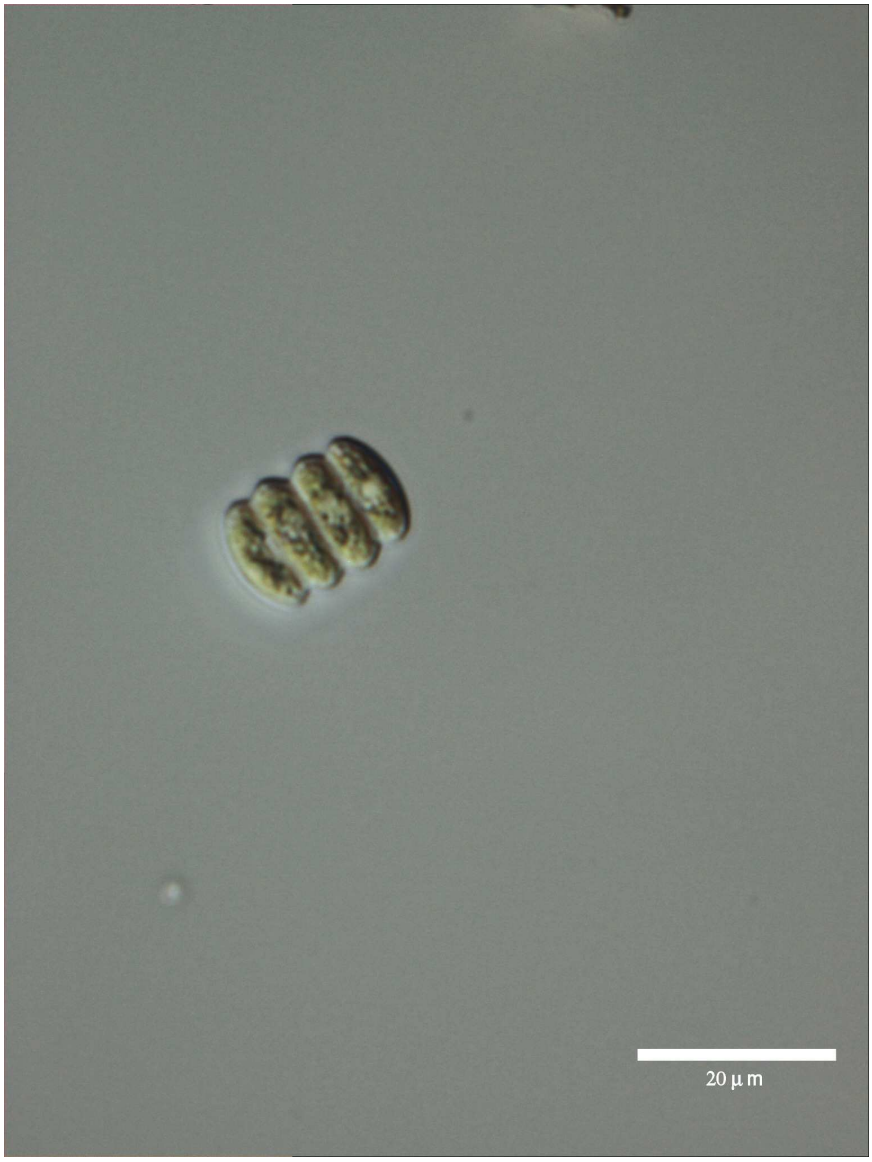


Figure 35: *Scenedesmus* (green algae).

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 2.89\,\mu\text{m} \\
\text{Avg. length} &= 9.20\,\mu\text{m} \\
\text{Avg. biovolume} &= 43.2\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 33.7 - 52.6\,\mu\text{m}^3
\end{aligned}$$

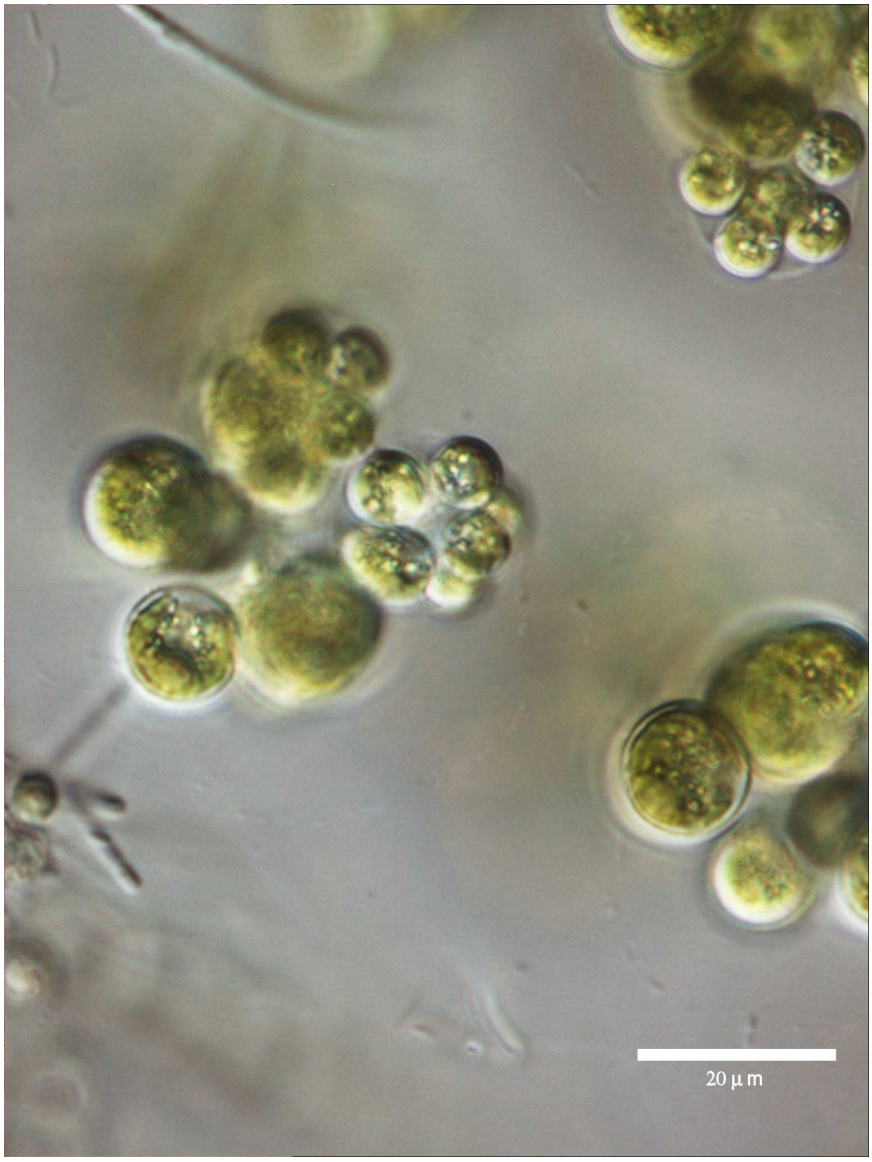


Figure 36: *Sphaerocystis* (green algae).

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 1.53\,\mu\text{m} \\
\text{Avg. length} &= 1.64\,\mu\text{m} \\
\text{Avg. biovolume} &= 2.57\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 1.71 - 3.43\,\mu\text{m}^3
\end{aligned}$$

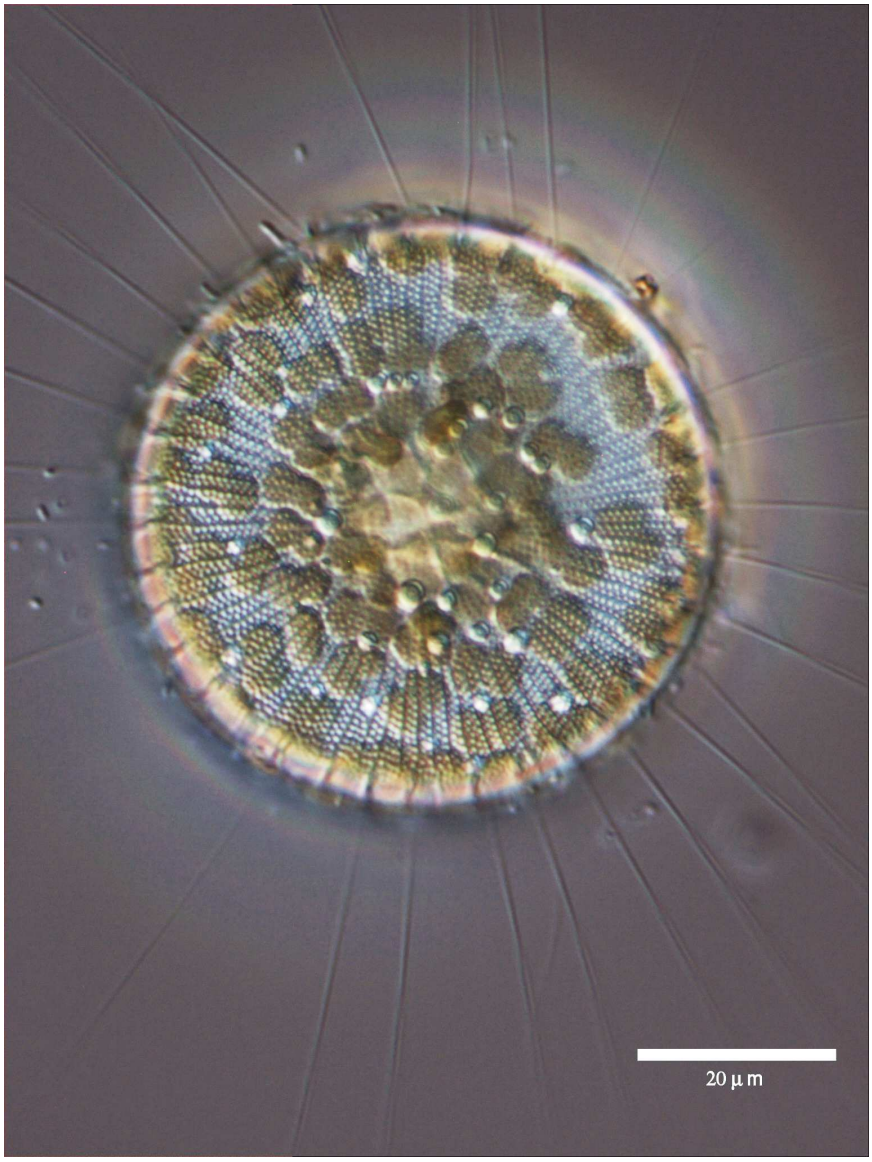


Figure 37: *Stephanodiscus* (chrysophyte - diatom).

$$\begin{aligned}
\text{Cylinder biovolume} &= \pi \left(\frac{\text{diameter}}{2} \right)^2 \times \text{depth} \\
\\
\text{Avg. diameter} &= 48.8\,\mu\text{m} \\
\text{Avg. depth} &= 26.7\,\mu\text{m} \\
\text{Avg. biovolume} &= 51,354\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 37,935 - 64,773\,\mu\text{m}^3
\end{aligned}$$

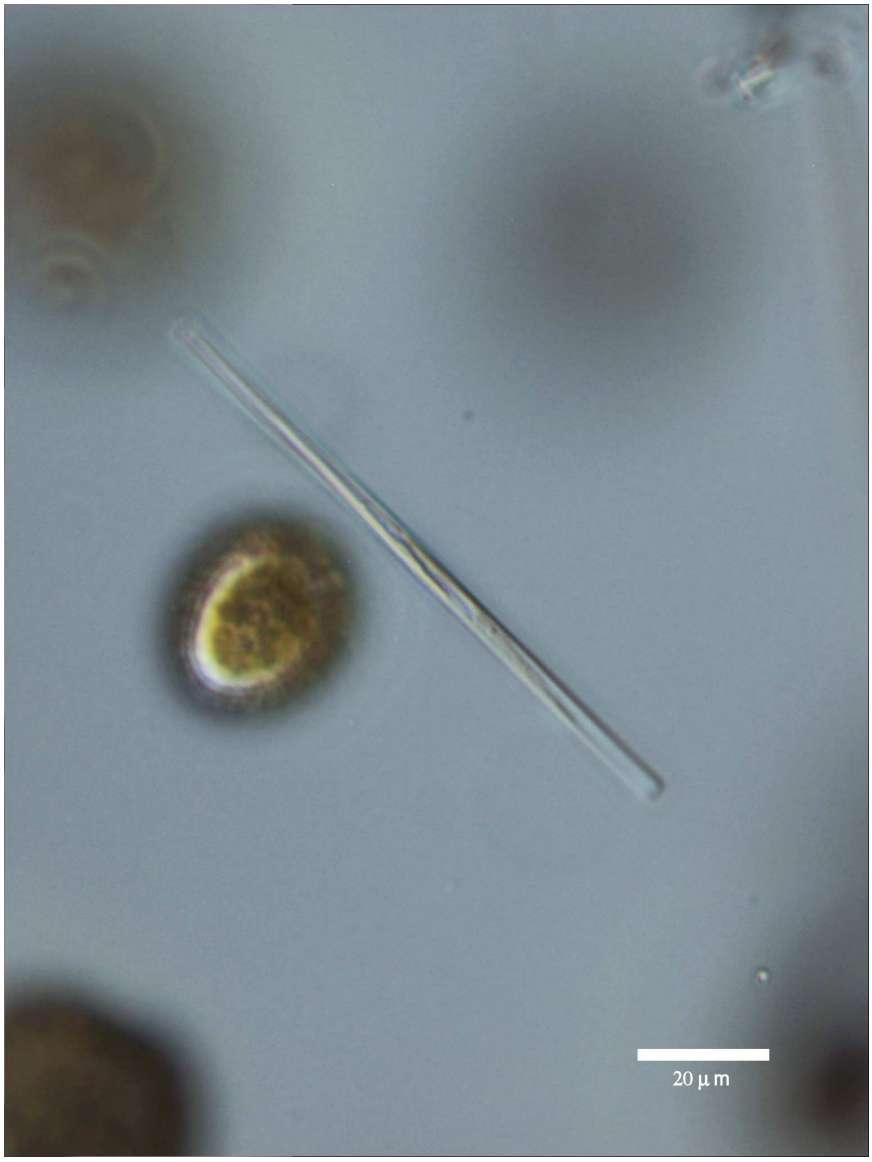


Figure 38: *Synedra* (chrysophyte - diatom).

$$\text{Diamondbox biovolume} = \text{width} \times \text{length} \times \frac{\text{depth}}{2}$$

$$\begin{aligned}
\text{Avg. width} &= 2.7\,\mu\text{m} \\
\text{Avg. length} &= 87.6\,\mu\text{m} \\
\text{Avg. depth} &= 1.7\,\mu\text{m} \\
\text{Avg. biovolume} &= 195.9\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 156.3 - 235.5\,\mu\text{m}^3
\end{aligned}$$

Figure 39: *Synura petersenii* (chrysophyte).

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 7.8\,\mu\text{m} \\
\text{Avg. length} &= 12.8\,\mu\text{m} \\
\text{Avg. biovolume} &= 649.5\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= < 1 - 1,468\,\mu\text{m}^3
\end{aligned}$$

Figure 40: *Synura uvella* (chrysophyte).

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 8.25\,\mu\text{m} \\
\text{Avg. length} &= 17.8\,\mu\text{m} \\
\text{Avg. biovolume} &= 653.1\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 481.9 - 824.2\,\mu\text{m}^3
\end{aligned}$$

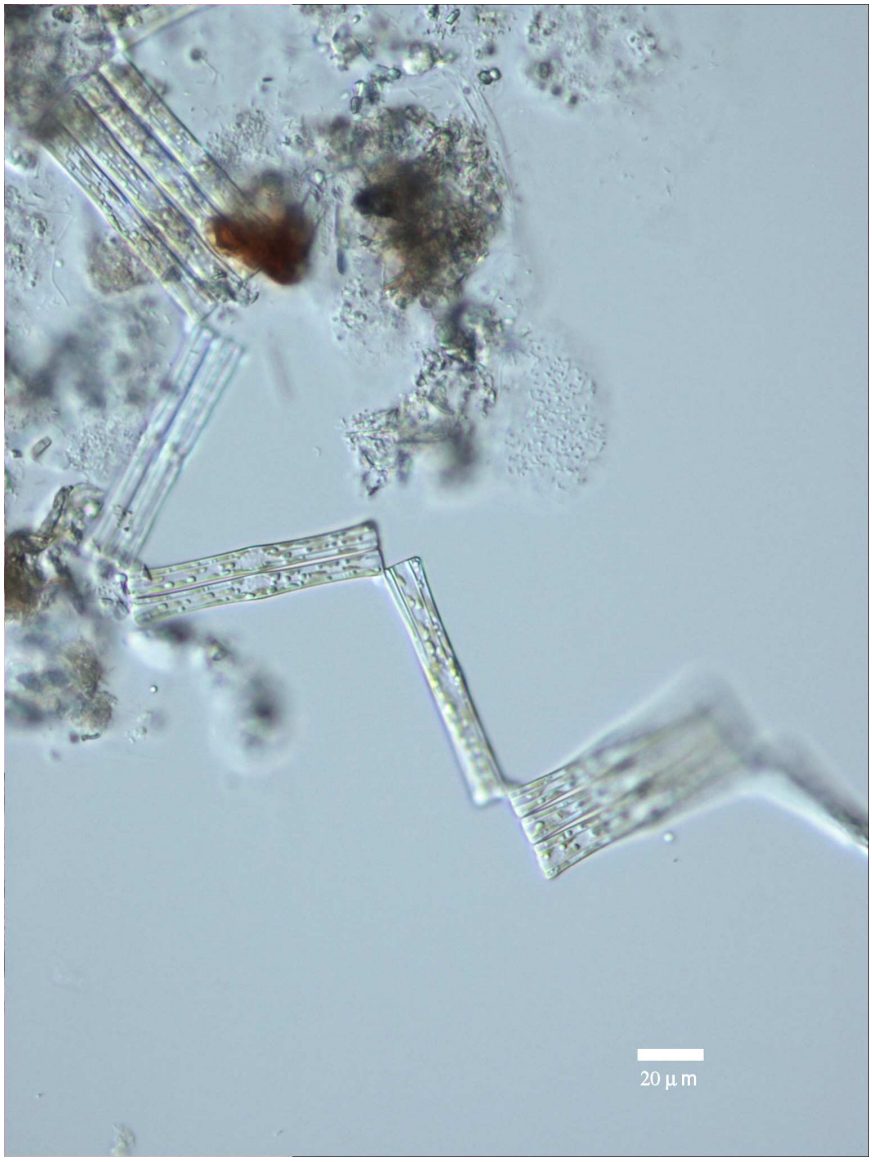


Figure 41: *Tabellaria* (chrysophyte - diatom).

$$\begin{aligned}
\text{Rectangle biovolume} &= \text{length} \times \text{width} \times \text{depth} \\
\\
\text{Avg. width} &= 7.07\,\mu\text{m} \\
\text{Avg. length} &= 39.7\,\mu\text{m} \\
\text{Avg. depth} &= 2.38\,\mu\text{m} \\
\text{Avg. biovolume} &= 661.5\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 596.3 - 726.6\,\mu\text{m}^3
\end{aligned}$$

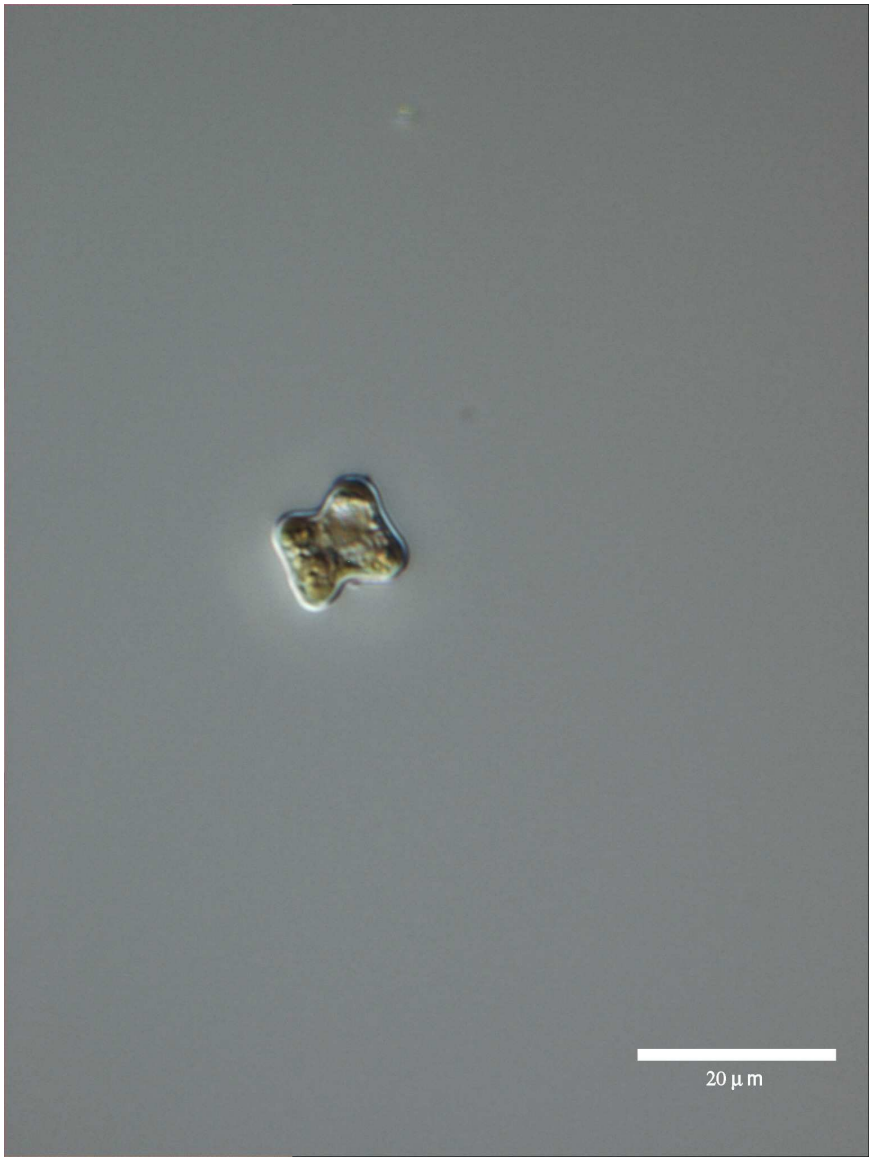


Figure 42: *Tetraedron* (green algae).

$$\text{Box biovolume} = \frac{(\text{length})^3}{4}$$

$$\begin{aligned} \text{Avg. length} &= 19.8\,\mu\text{m} \\ \text{Avg. biovolume} &= 2,528\,\mu\text{m}^3 \\ \text{Biovolume 95\% CI} &= 1,223 - 3,833\,\mu\text{m}^3 \end{aligned}$$

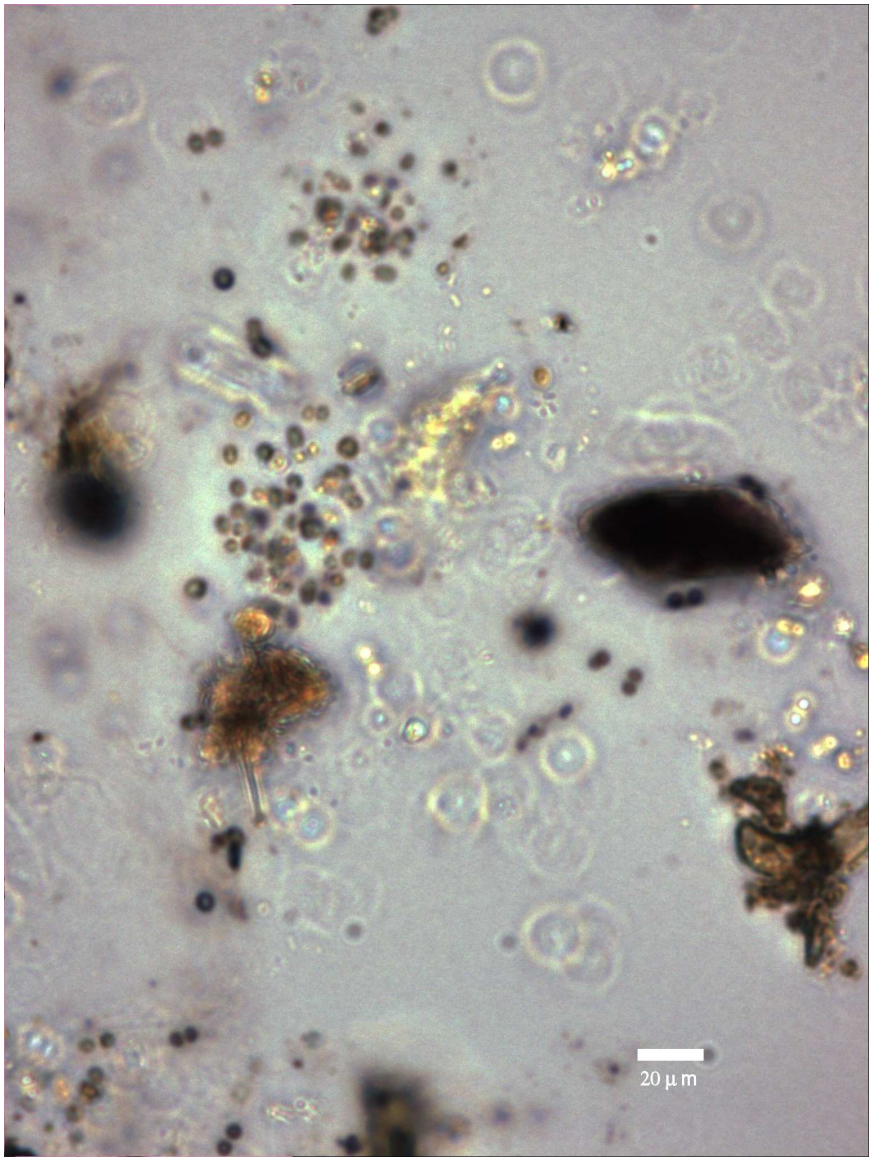


Figure 43: Unidentified bluegreen (cyanobacteria).

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 4.89\,\mu\text{m} \\
\text{Avg. length} &= 4.84\,\mu\text{m} \\
\text{Avg. biovolume} &= 63.7\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 46.0 - 81.4\,\mu\text{m}^3
\end{aligned}$$

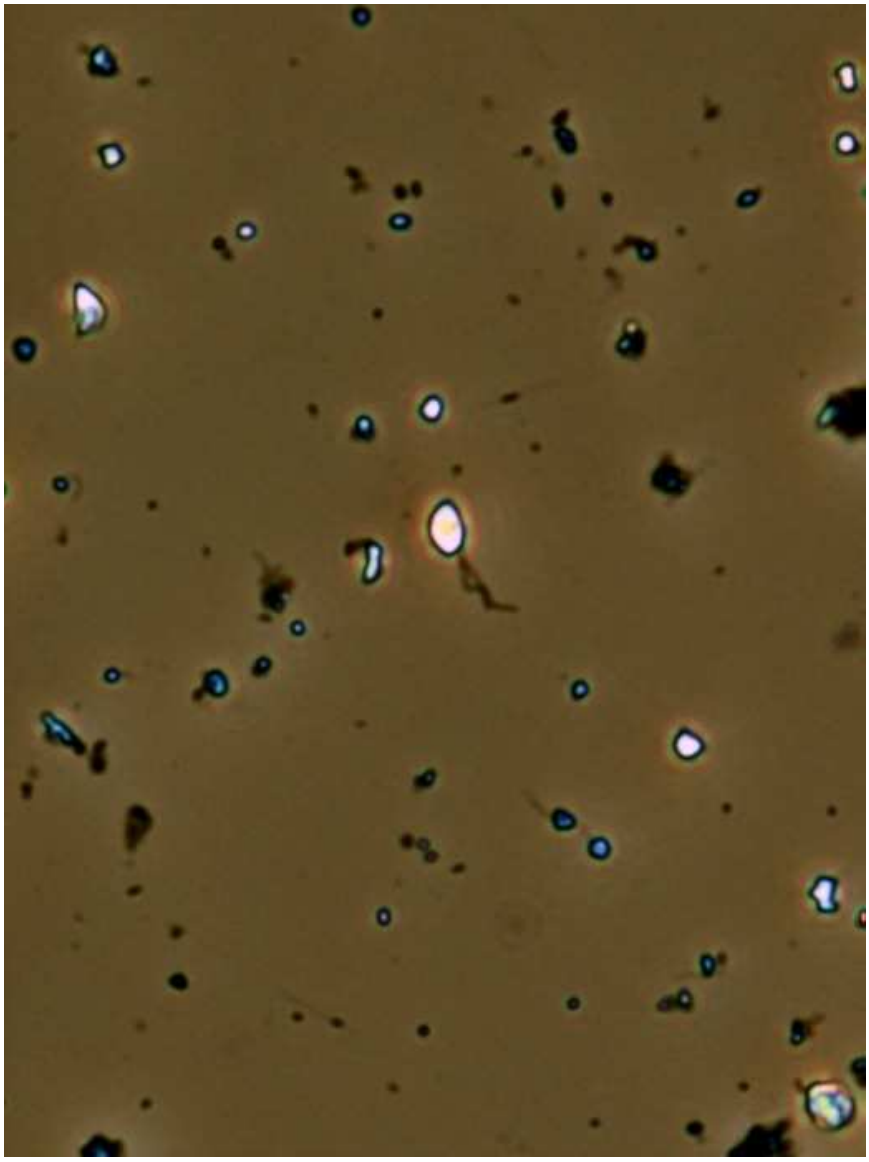


Figure 44: Unidentified golden (chrysophyte).

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 2.5\,\mu\text{m} \\
\text{Avg. length} &= 4.3\,\mu\text{m} \\
\text{Avg. biovolume} &= 15.0\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 9.82 - 20.2\,\mu\text{m}^3
\end{aligned}$$

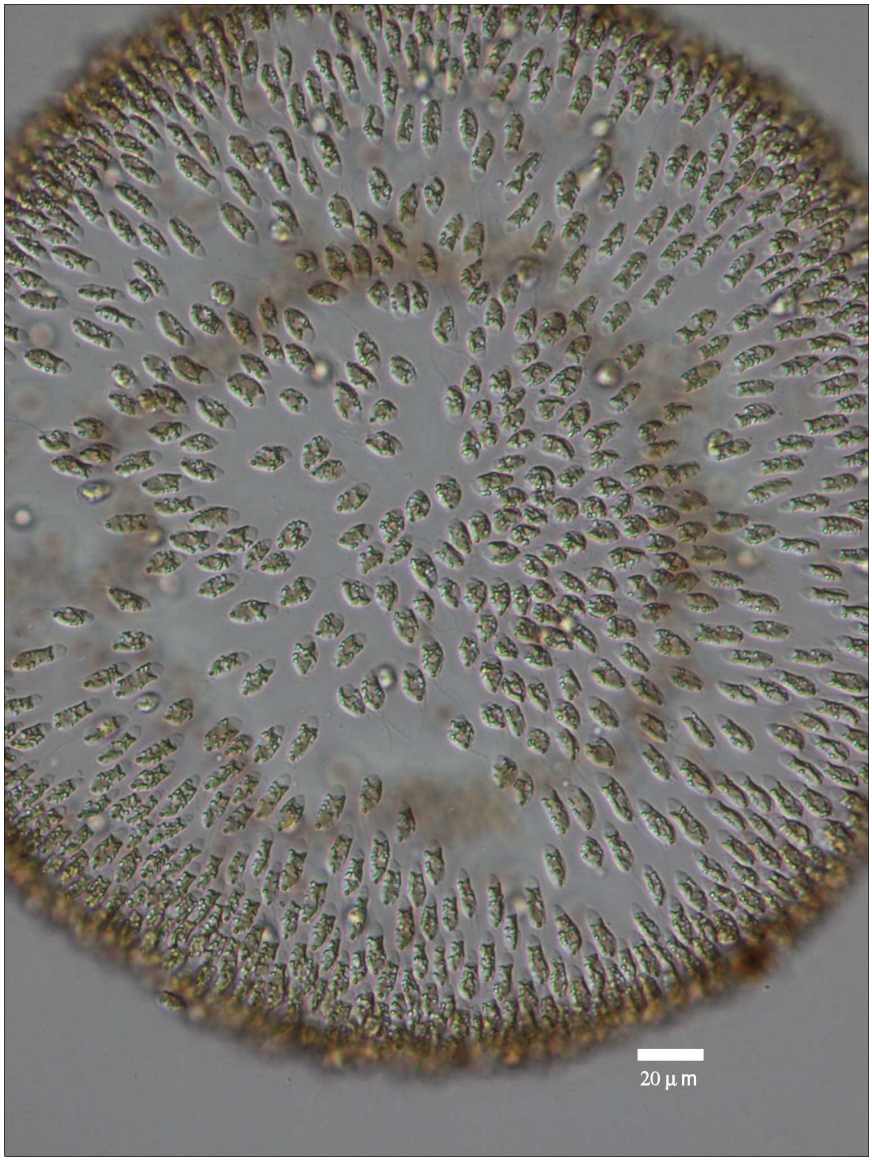


Figure 45: *Uroglena* (chrysophyte).

$$\begin{aligned}
\text{Ovoid biovolume} &= \frac{4}{3}\pi \times \left(\frac{\text{width}}{2}\right)^2 \times \left(\frac{\text{length}}{2}\right) \\
\text{Avg. width} &= 6.50\,\mu\text{m} \\
\text{Avg. length} &= 7.11\,\mu\text{m} \\
\text{Avg. biovolume} &= 165.0\,\mu\text{m}^3 \\
\text{Biovolume 95\% CI} &= 130.9 - 199.1\,\mu\text{m}^3
\end{aligned}$$

B Judy Reservoir Water Quality and Algae Data

Printed versions of this report include tables of the 2006–2012 data, edited to show detection limits. Online reports do not include copies of the original data, but electronic data files are available from the Institute for Watershed Studies. In addition, the IWS web site (http://www.wwu.edu/iws) features "dynamic" plots of the water quality data and tables containing the most recent results from the lake.

These pages represent updated water quality data, algal counts, and algal biovolume estimates, and should serve as the verified data source for results collected from October 2006 through October 2012. Electronic copies of the verified data are available from the Institute for Watershed Studies (IWS), Western Washington University, Bellingham, WA.

The code "NA" has been entered into all empty cells in the ascii data files to fill in unsampled dates and depths, missing data, etc. Questions about specific missing data should be directed to the IWS director.

Unless otherwise indicated, the electronic data files have NOT been censored to flag or otherwise identify below detection and above detection values. As a result, the ascii files may contain negative values due to linear extrapolation of the standards regression curve for below detection data. It is essential that any statistical or analytical results that are generated using these data be reviewed by someone familiar with statistical uncertainty associated with uncensored data.