ALGAE AND PRIMARY PRODUCTIVITY IN RESERVOIRS

ALGAS E PRODUTIVIDADE PRIMÁRIA EM ALBUFEIRAS

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ALOP Alentejo Observation and Prediction systems

ICT G1 Évora Pole

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ESCOLA DE CIÊNCIAS E TECNOLOGIA
DEPARTAMENTO DE BIOLOGIA

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What are algae?

Algae

Very diverse photosynthetic organisms that have neither roots nor leafy shoots, and which also lack vascular tissues

Aquatic Macrophytes

Aquatic photosynthetic beings, large enough to see with the naked eye, that actively grow permanently or periodically submerged below, floating on, or growing up through the water surface.

The majority of aquatic macrophytes are flowering plants (Angiosperms), but may also be ferns, mosses, and even large algal forms such as *Chara* sp.

What are algae?

Five Kingdom system

Monera	Protista	Plantae	Fungi	Animalia

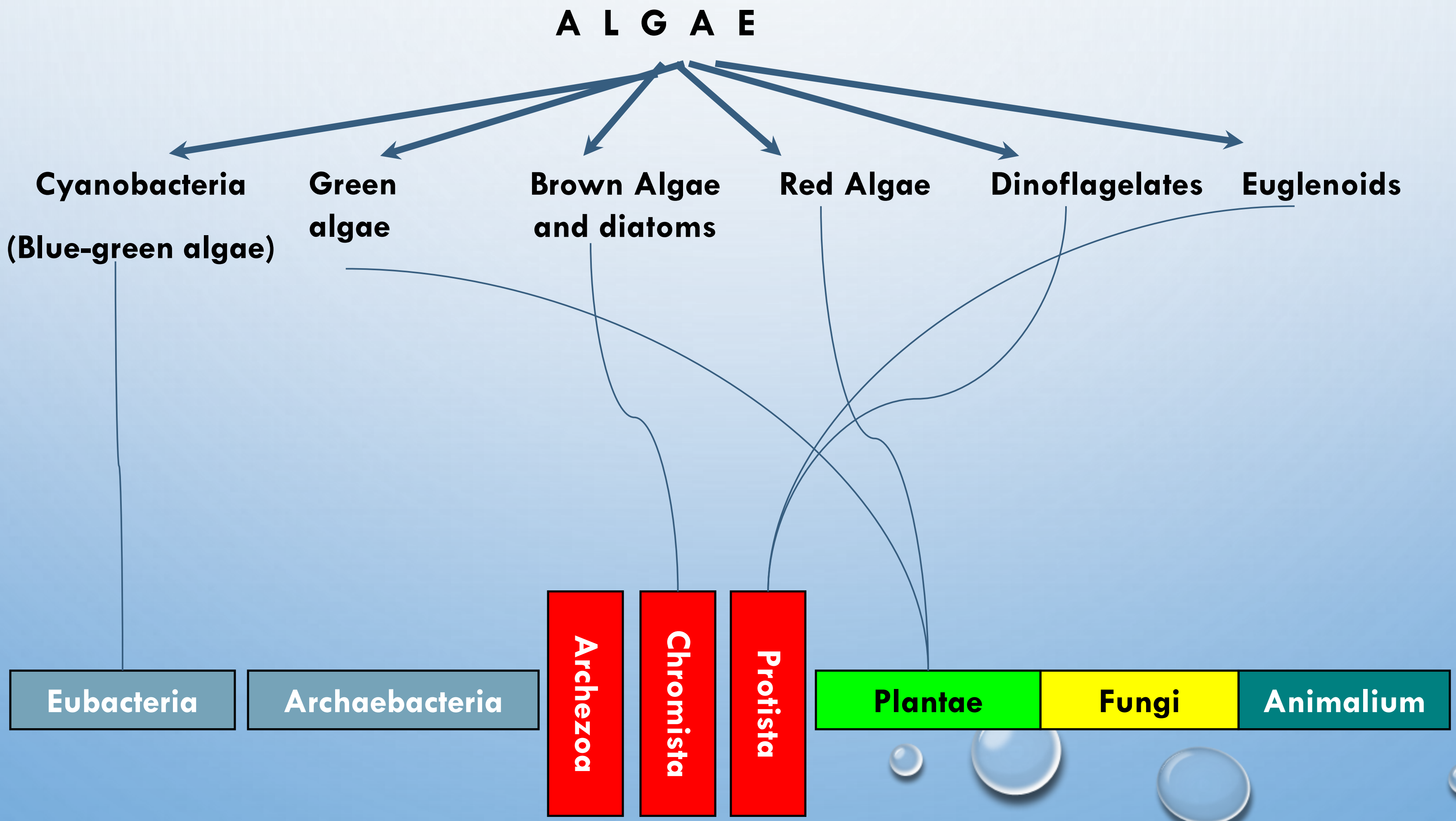
Three Domain/Eight Kingdom system

Bacteria (eubacteria)	Archaea (archaebacteria)	Eukarya (eukaryotes)

Eubacteria	Archaebacteria	Archezoa	Chromista	Protista	Plantae	Fungi	Animalia

What are algae?

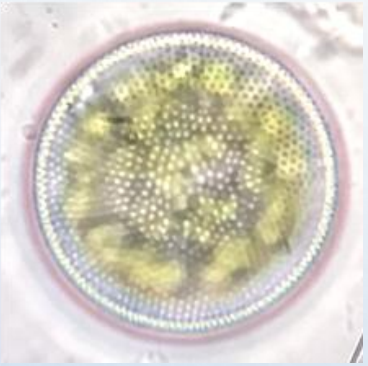
Algae (sing. alga) are a group of unrelated organisms that in reality belong to different kingdoms and classes of organisms.



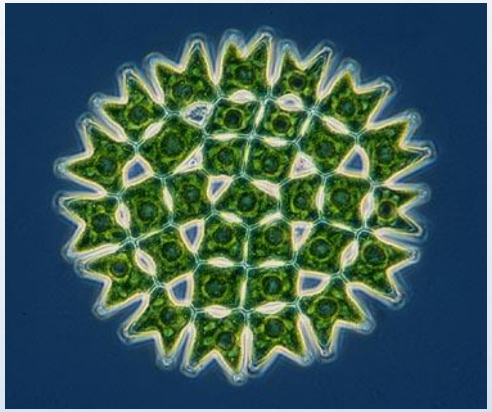
What are algae?

They can be unicells, colonies of spherical cells, filaments, colonies of filaments, or multicellular organisms.

Kelp in marine systems

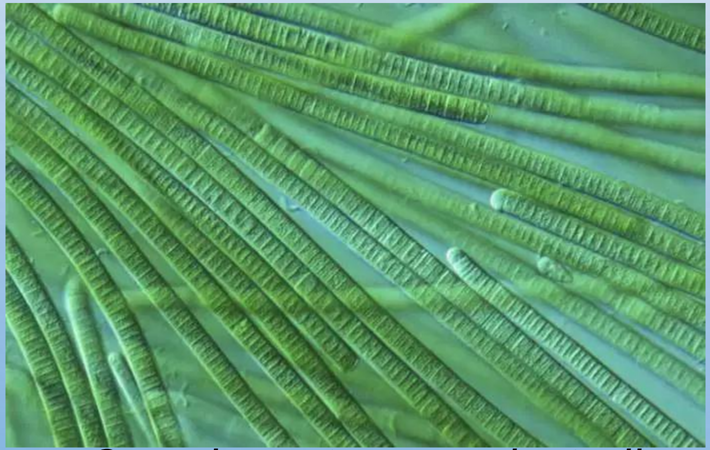


Diatoms, the most productive on earth



Green algae, very diverse and ubiquitous

Chara in freshwater systems



Cyanobacteria, an ecologically very successful group

- *There are and estimate of 30.000 to 1 million species.*
- *It is very possible we only know 40-60% of these.*
- *There are more diatoms than any other group (for now)*
- *It is estimated that there are 4 diatom species for every other algal species of all groups combined.*

Some importante facts about Algae

Approximately, two-thirds of the earth's surface are covered by oceans and seas, where photosynthetic plants we call "algae" live, down to a depth of ca. 150 m (depending on the transparency of the water and the phycoerythrins present).

Altogether, algae certainly account for more than half the total primary production worldwide, on which virtually all aquatic organisms are dependent!

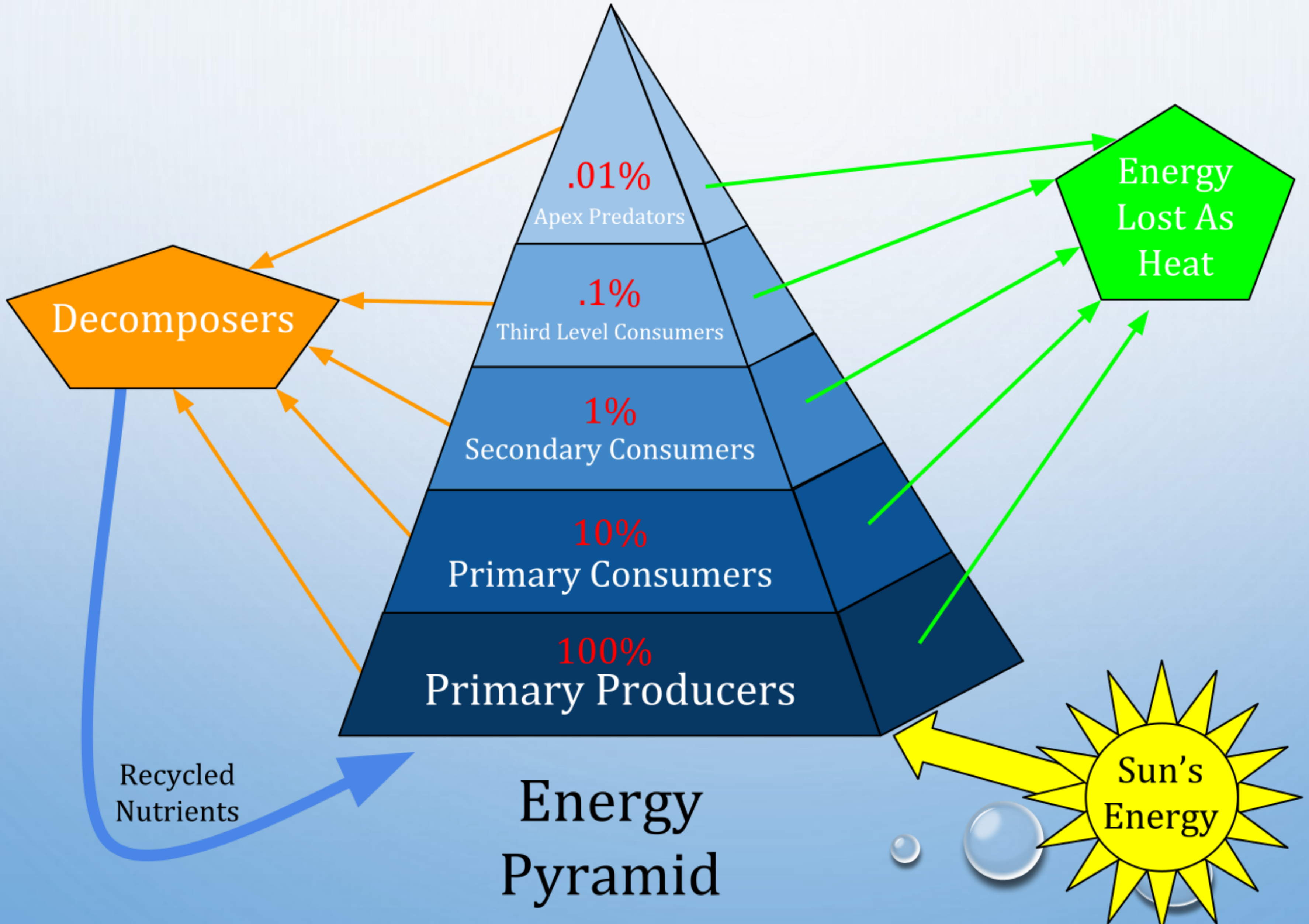
Primary productivity

The rate at which biomass is produced by organisms by the conversion of inorganic substrates into complex organic substances.

Primary production typically occurs through **photosynthesis** (more rarely by chemosynthesis). When photosynthetic organisms convert solar energy, carbon dioxide and water into glucose.

$$6\,CO_2 + 12\,H_2O \xrightarrow[\text{Chlorophyll}]{} C_6H_{12}O_6 + 6\,H_2O + 6\,O_2$$

Trophic network



Reduced efficiency of photosynthesis: 30%

Where can we find algae?

They live everywhere! Think of any environment and most surely there will be an alga living in it! Algae occur on shores and coasts, attached to the bottom (benthic species) or live suspended in the water itself (planktonic species).

Freshwaters too are populated by many different species of algae and there are also terrestrial forms, on soils, among bryophytes and even living in symbioses with different types of organisms.

Lichens are symbioses between algae and fungi!

Where can we find algae?

Algal communities:

- **Benthos** (Perifiton):

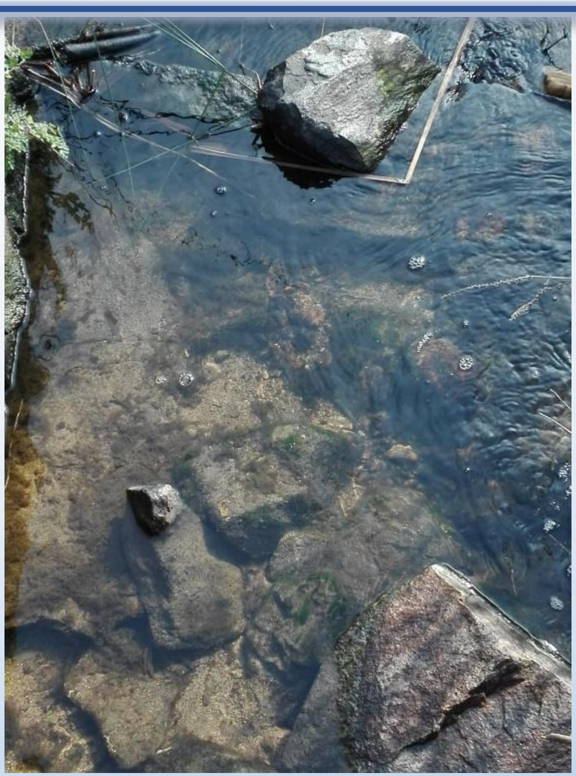
Epiphyton (plants)

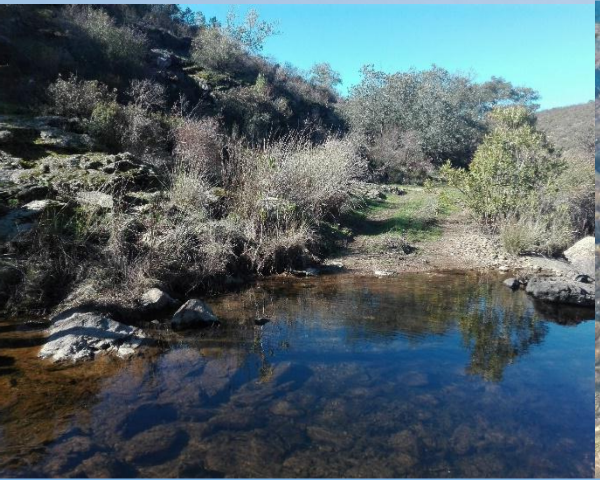
Epilithon (hard substrate)

Epipsammon (sand)

Epipelon (mud)

- **Plankton**
- **Tychoplankton**
- **Epizoon**


Some importante facts about Algae

They respond to environmental factors: temperature, pH, concentrations of nutrients, presence of predators.

Each algal community is adapted to the habitat where it is present. A necessary adaptation given that communities are continuously under evolutive/ecological processes.

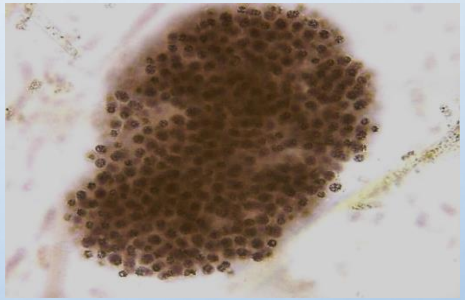
Limiting factors for algal growth: elements or compounds that in low/high concentrations prevent algal growth.

Each alga has specific nutritional requirements and environmental conditions under which it grows.

These are the reasons why they have been used extensively as bioindicators: by studying the kinds and numbers of organisms living in a particular waterbody, you can determine the quality of the water.

They can also be used to assess past conditions: Paleolimnology, paleoecology.

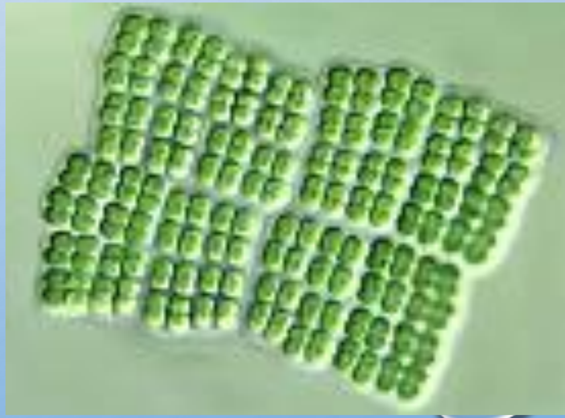
Some importante facts about Algae



Algae have been producing oxygen for more than 2 billion years!

More than **25%** of the oxygen available worldwide for respiration is produced by Algae!

Cyanobacteria are the first photosynthetic organisms, in part responsible for the production of the ozone layer, that absorbs most of the ultraviolet radiation, allowing the evolution of eukaryotes.



Algae are extremely important **ecologically**, but also **phylogenetically**! It is thought that all the major groups (phyla and divisions) of animals and plants originated in the sea. Even today this is where we can find representatives of many ancient evolutionary lineages.

Main groups of algae identified in South of Portugal

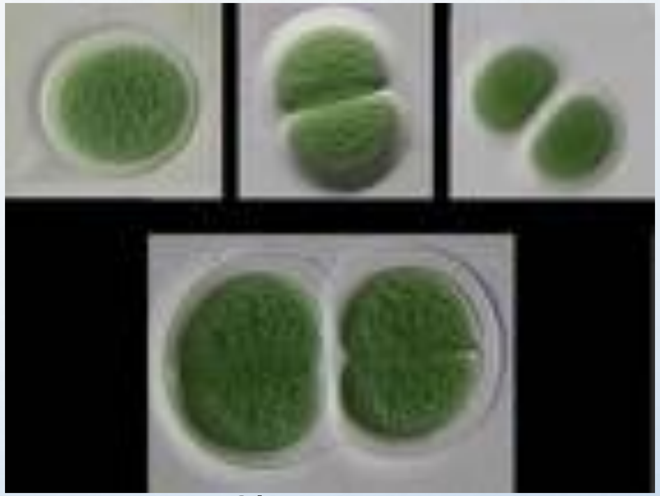
Algal classification is based in several criteria:

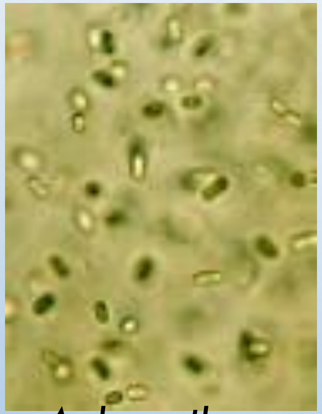
- **Biochemical**
  - Kinds and combinations of photosynthetic pigments (give the color to the algae)
  - Chemical nature of storage products (glycogene, starch, paramilon, chrysolaminarin)
  - Cell wall constituents (cellulose, calcium carbonate, silicon dioxide, other organic, etc.)
- **Cytology and morphology**
  - Presence/absence of flagellate cells and of an endoplasmic reticulum around the chloroplasts
  - Structure of the flagella
- **Pattern and course of the mitosis** (nuclear division) **and cytokinesis** (cell division)
- **Life cycle**

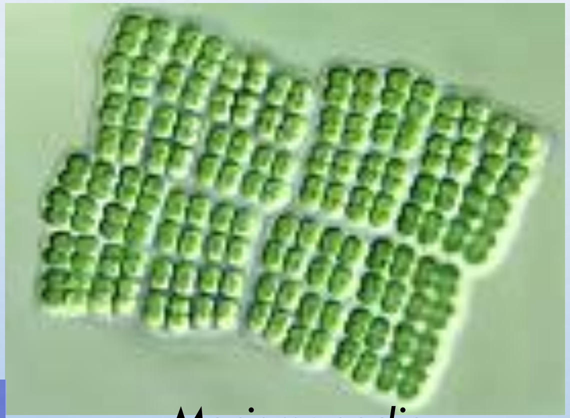
Cyanophyta (= Cyanobacteria)

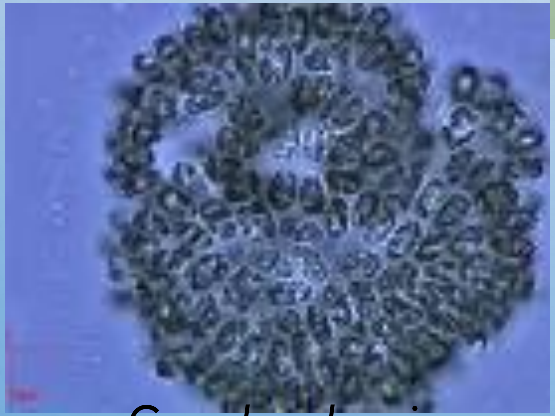

Cyanothece

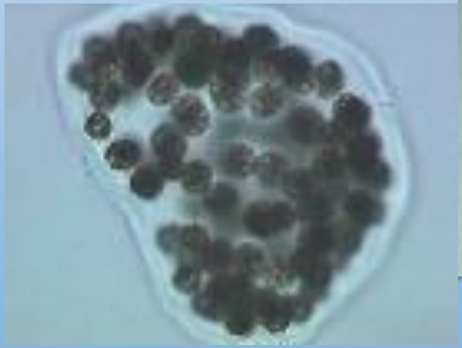

Synechococcus

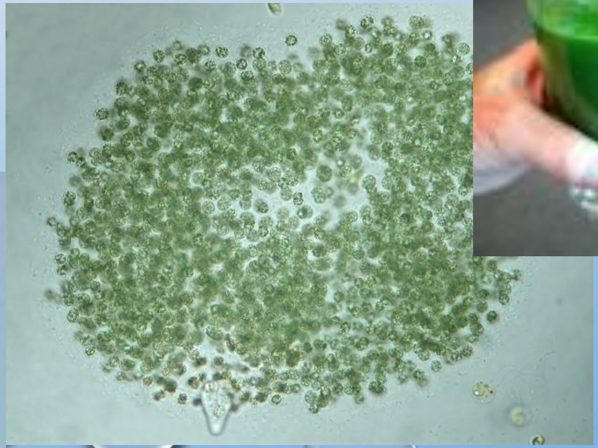

Chroococcus


Aphanothece


Merismopedia

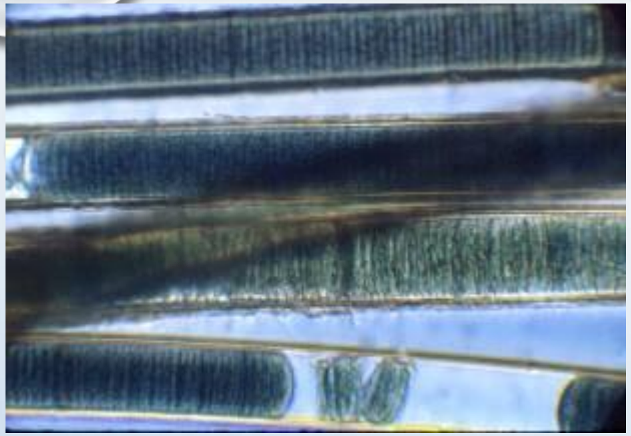

Gomphosphaeria

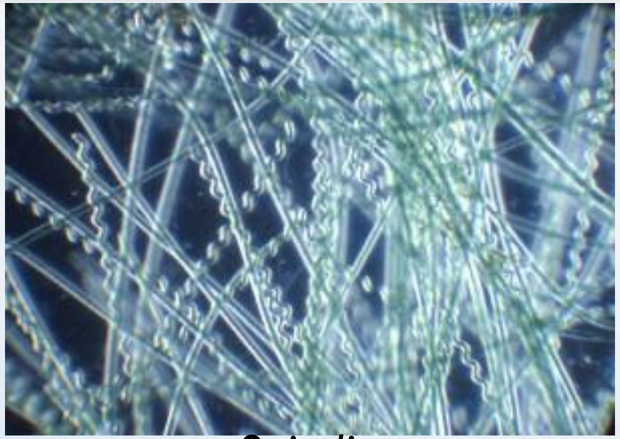





Microcystis

Cyanophyta (= Cyanobacteria)


Oscillatoria


Spirulina

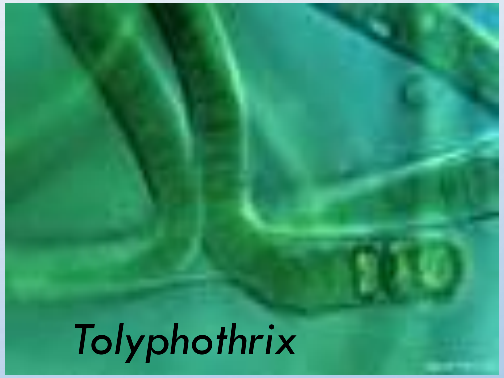
Anabaena

Heterocyte


Nostoc


Scytonema


Stigonema


Tolyphothrix


Lyngbya

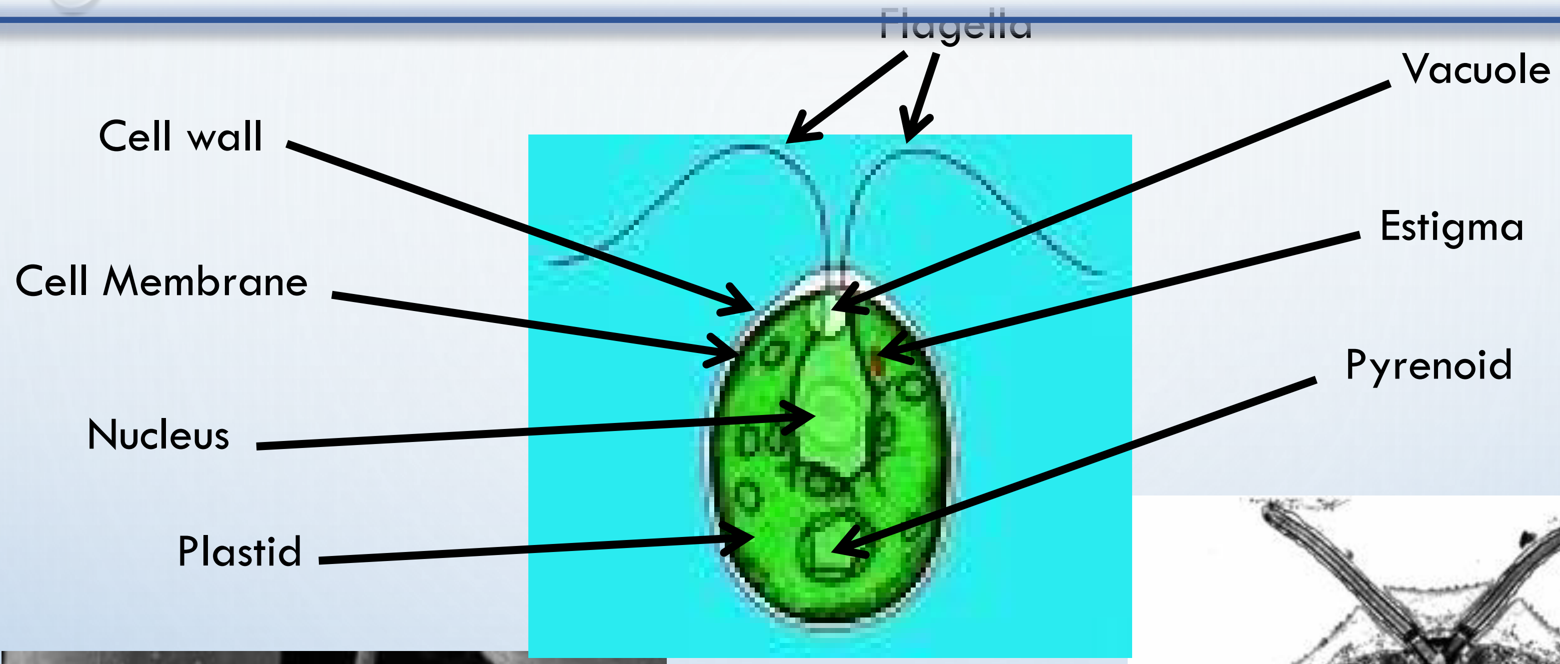

Aphanizomenon

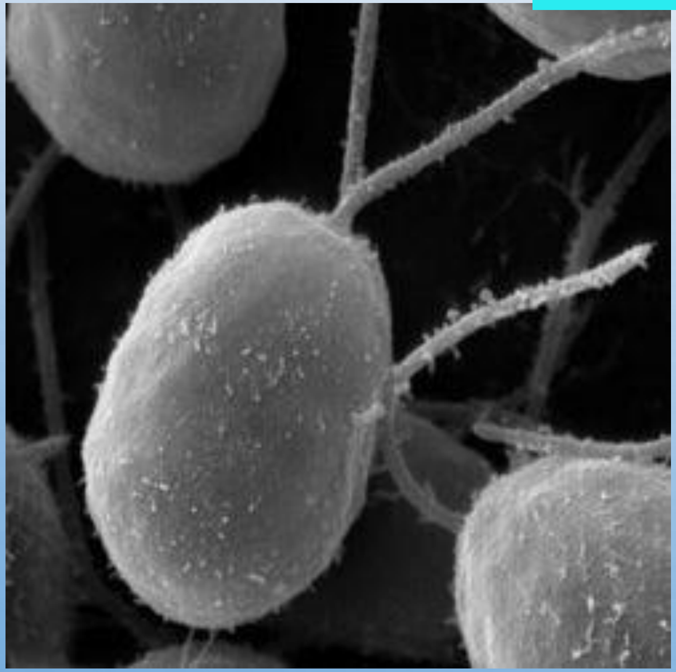

Rivularia


Basal heterocte

Chlorophyta (Green algae)

Motile without asexual reproduction



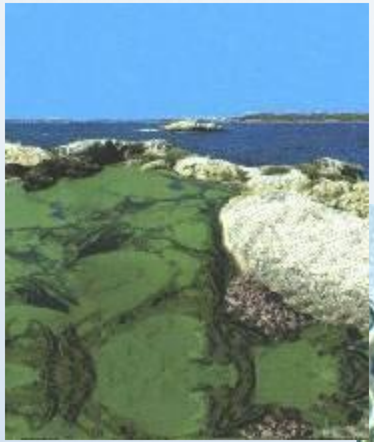


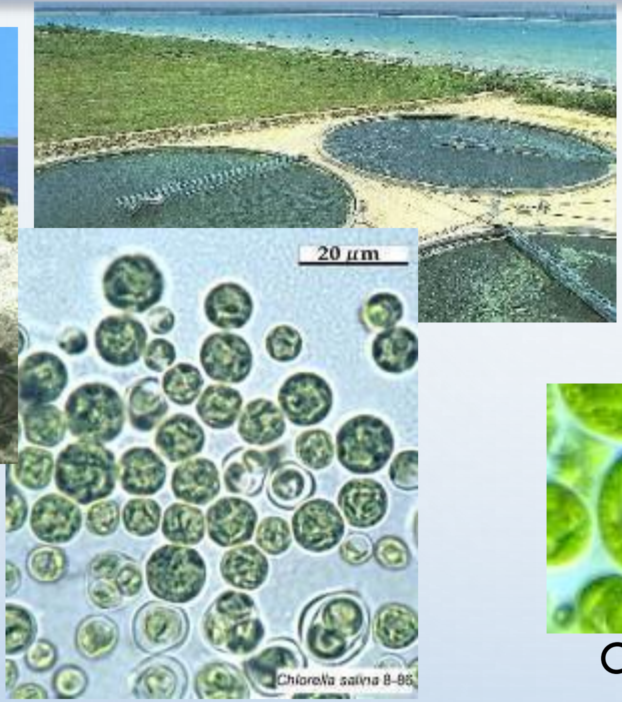
Chlorophyta (Green algae)

Unicellular and colonial flagellates
Motile without asexual reproduction

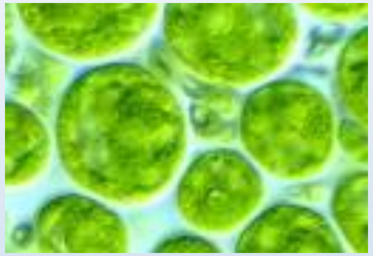
Chlorophyta (Green algae)

Non-motile without asexual reproduction



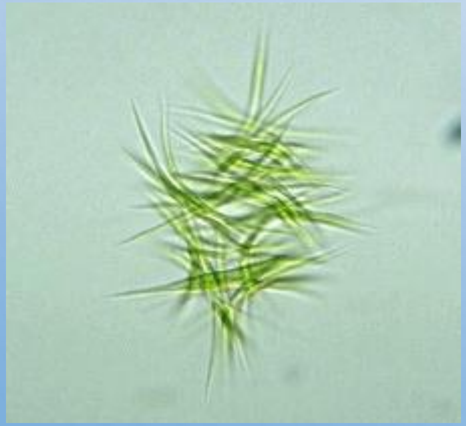


Chlorella

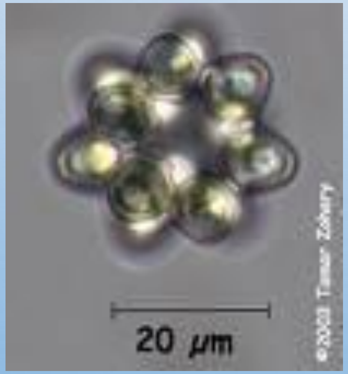


Chlorococcum

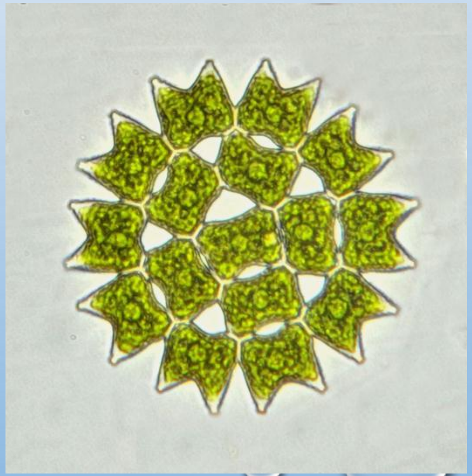
Scenedesmus



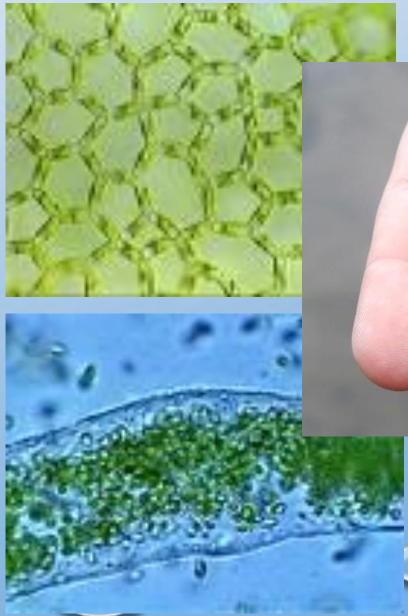
Ankistrodesmus



Coelastrum



Pediastrum

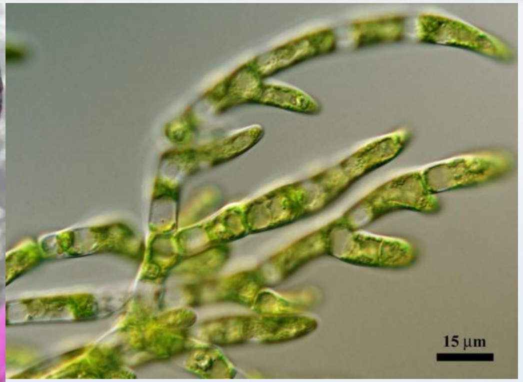


Hydrodictyon

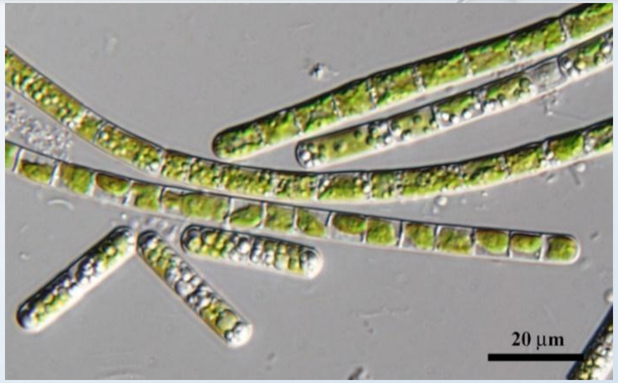
Chlorophyta (Green algae)

Filamentous

Stichococcus



Stigeoclonium



Klebsormidium

Ulothrix

Microspora

Draparnaldia

Cladophora

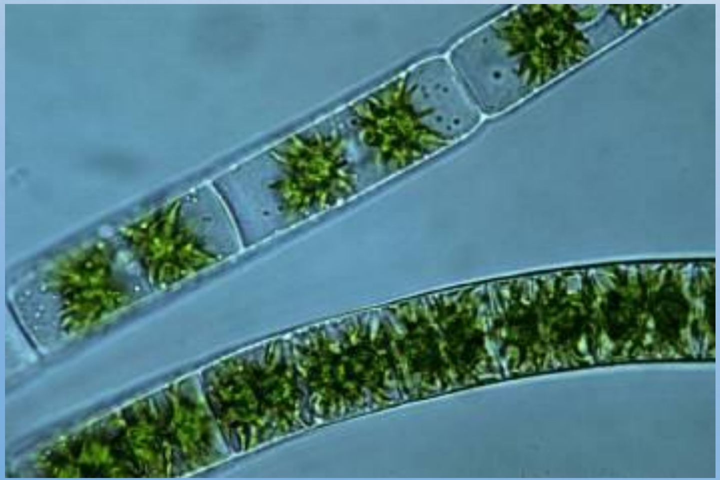
Charophyta

<u>**Gave rise to the rest of the plants!**</u>

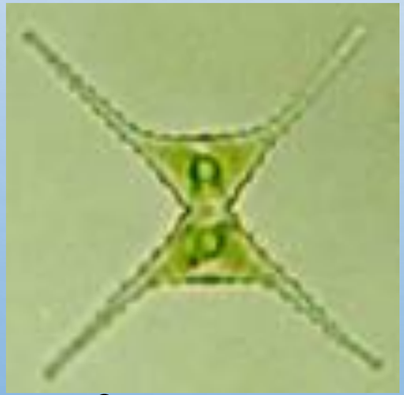
Chara

Chara

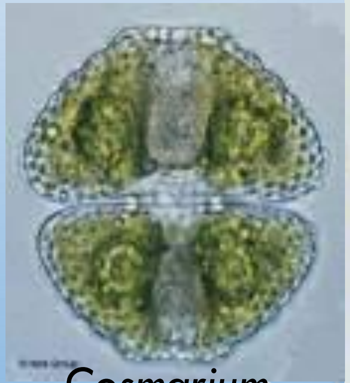
Spirogyra



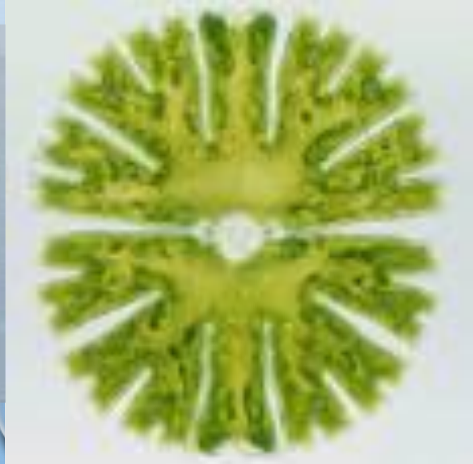
Zygnema



Staurastrum



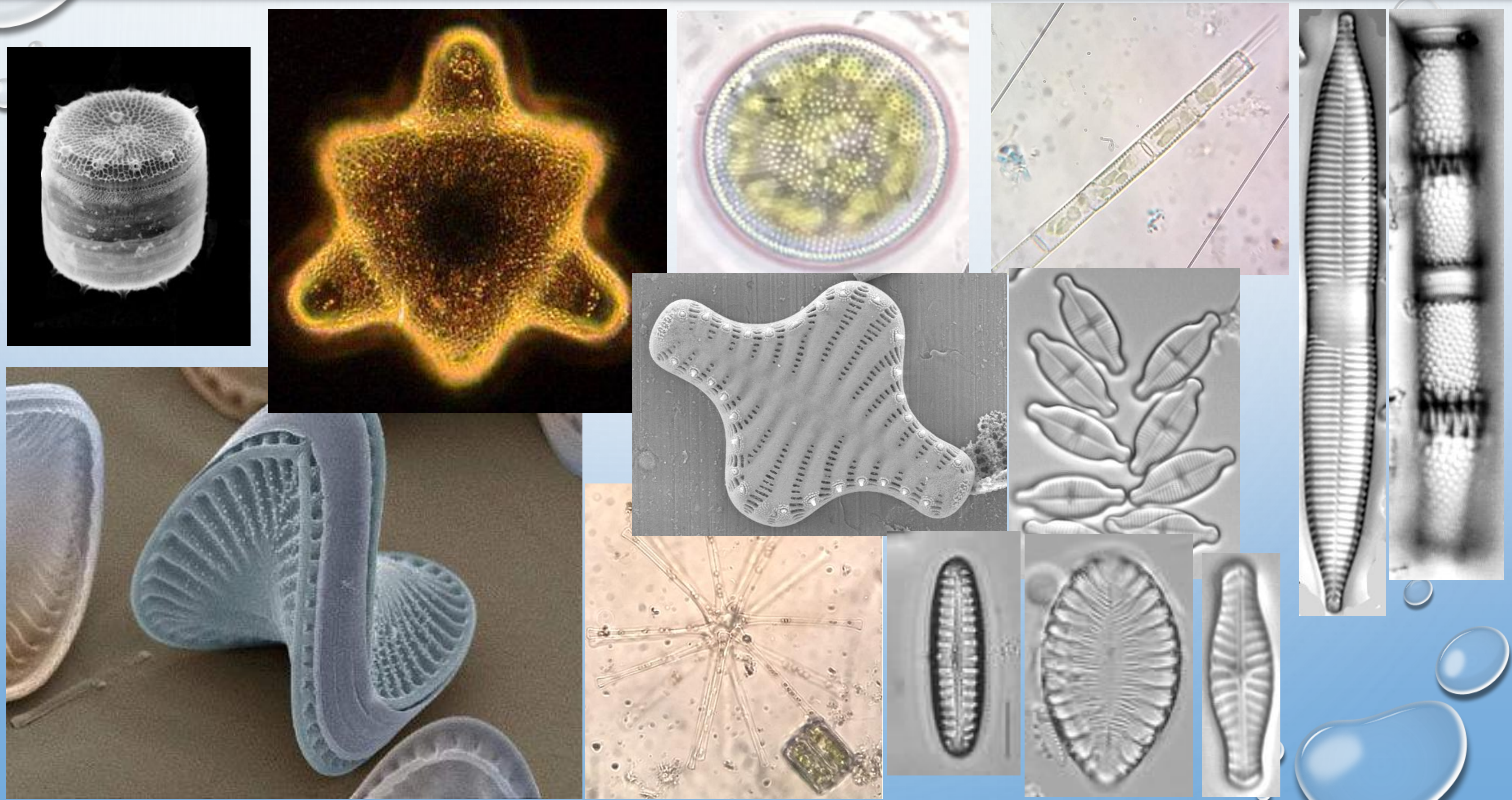
Cosmarium



Micrasterias

Nitella

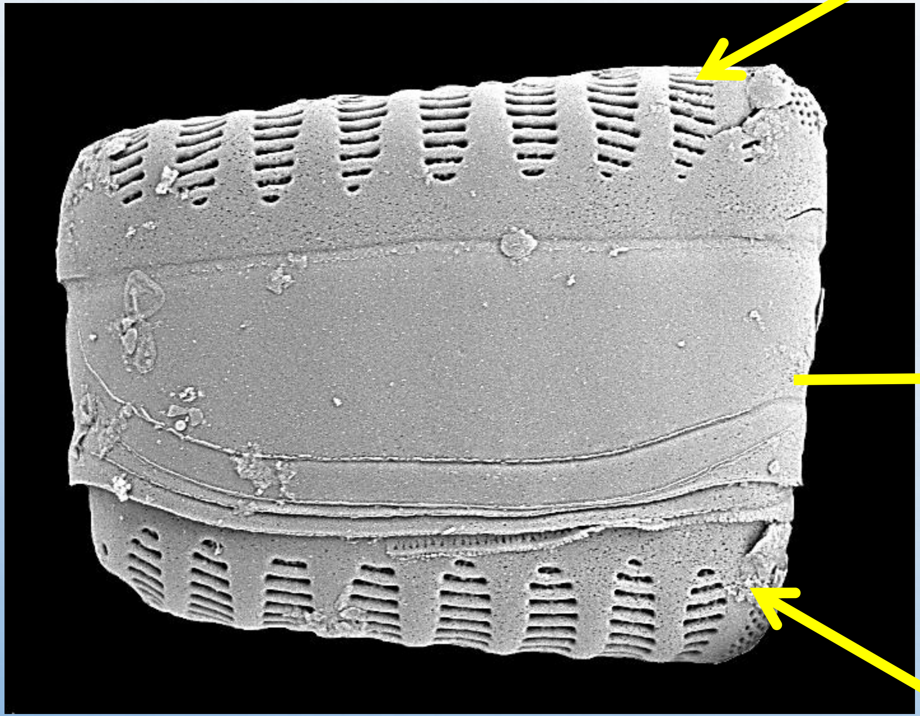
Bacillariophyta (= Diatoms)

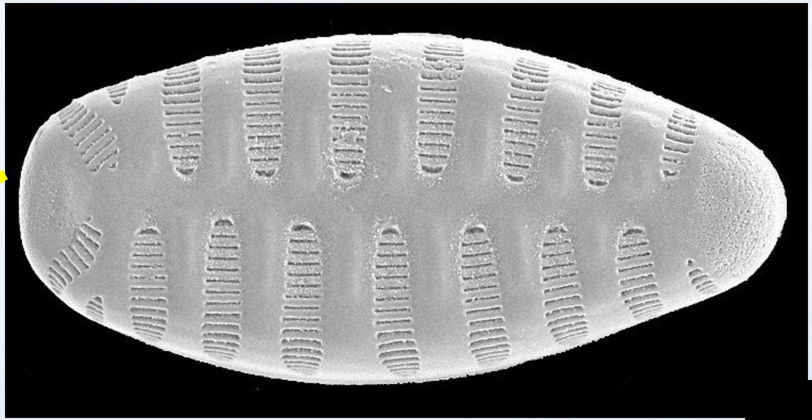


Bacillariophyta (= Diatoms)

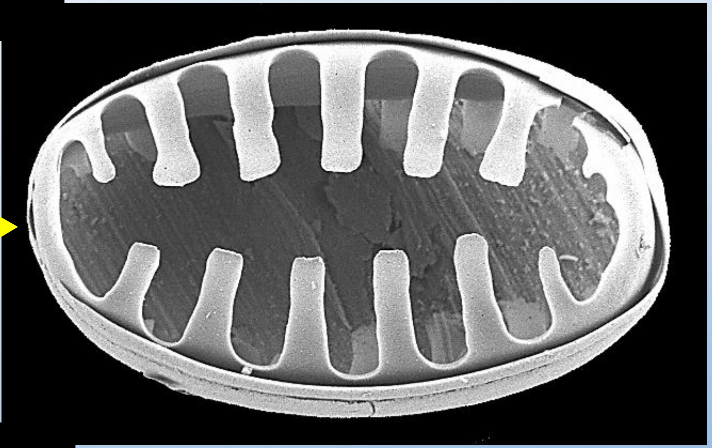
Structure of the cell wall

Frustule

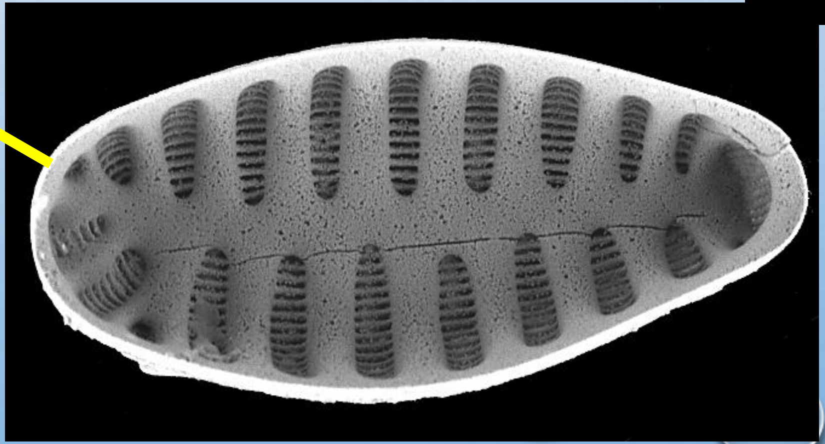




Epivalve (external view)



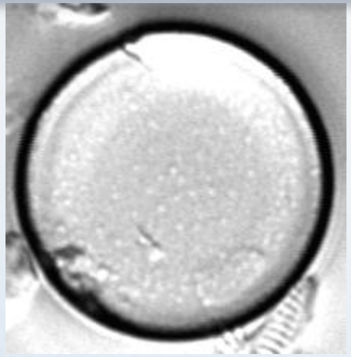
Cingulum (girdle bands)



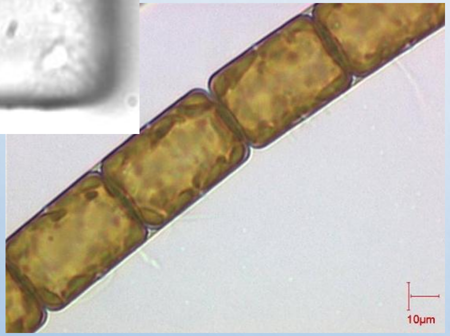
Hypovalve (internal view)

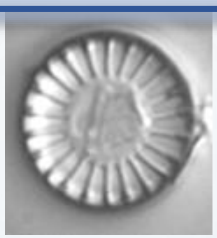
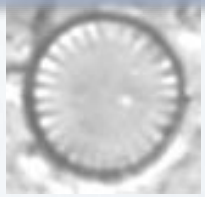
Bacillariophyta (= Diatoms)

Morphological classification - Centrics

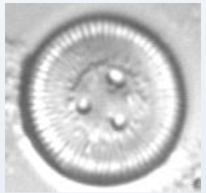
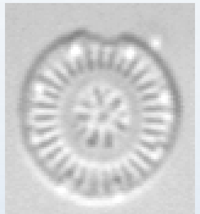



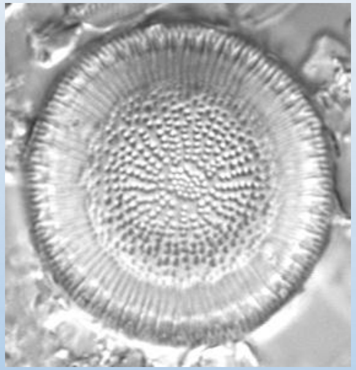
Melosira



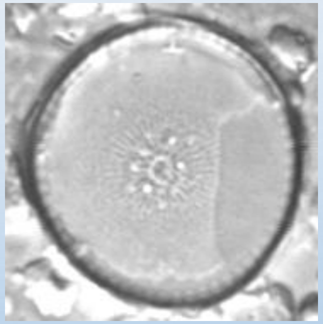




Cyclotella

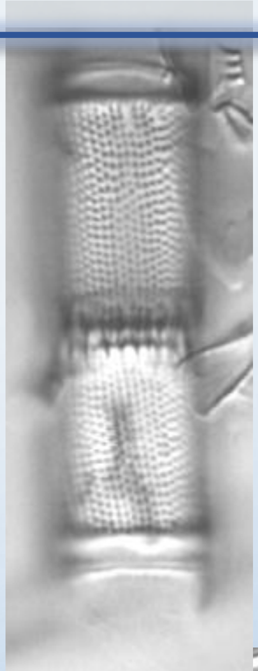
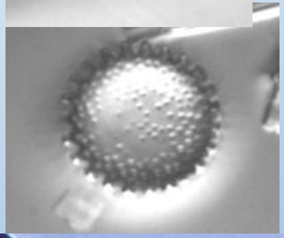
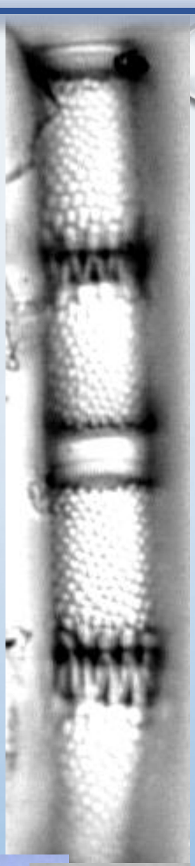
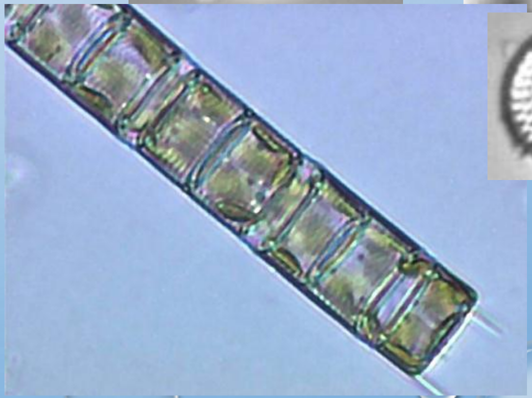
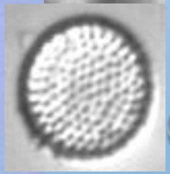





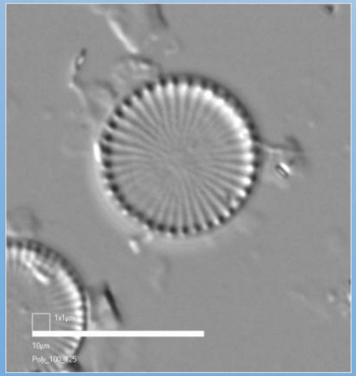
Stephanodiscus



Thalassiosira

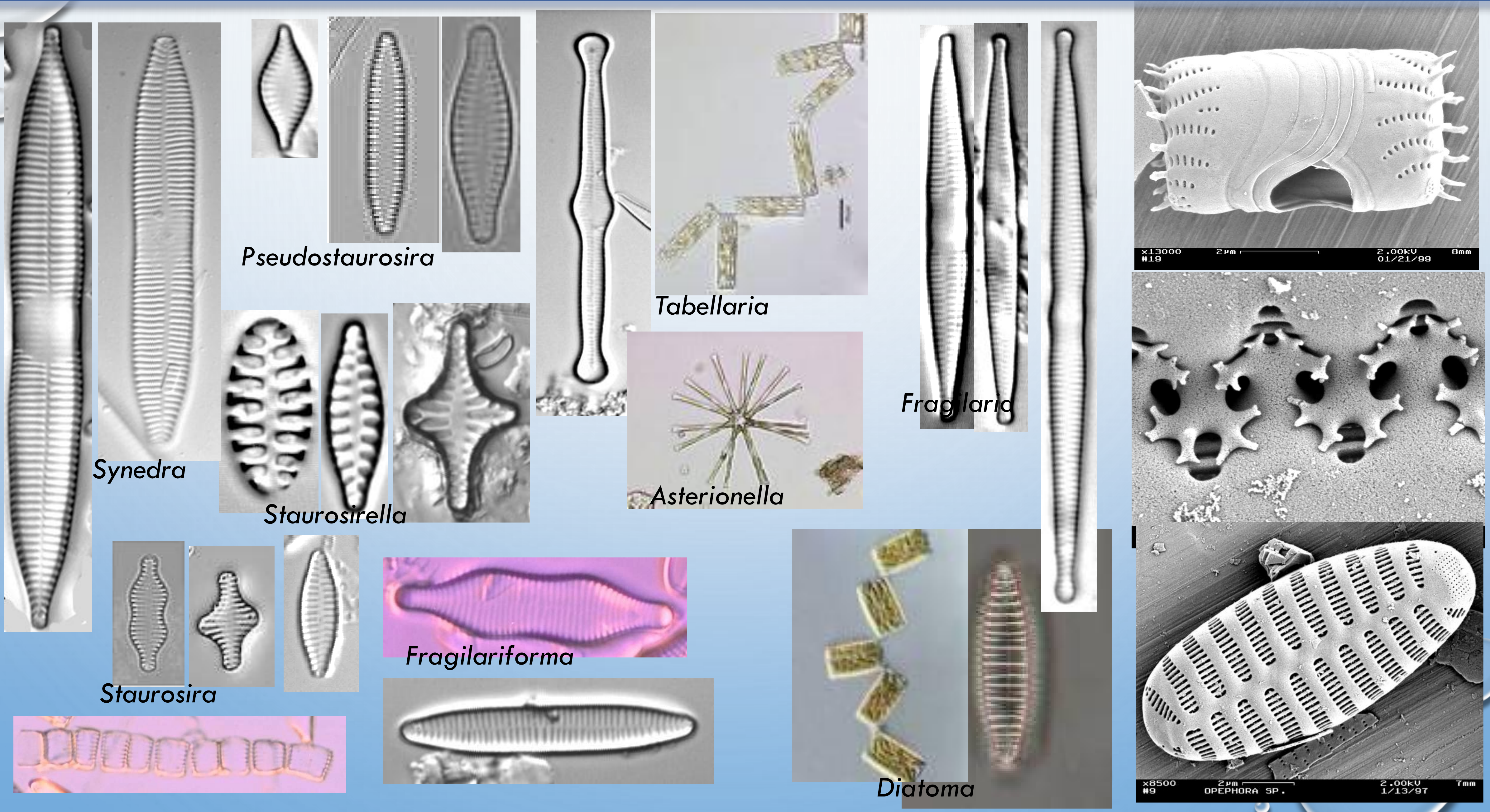
Aulacoseira



Cyclostephanos

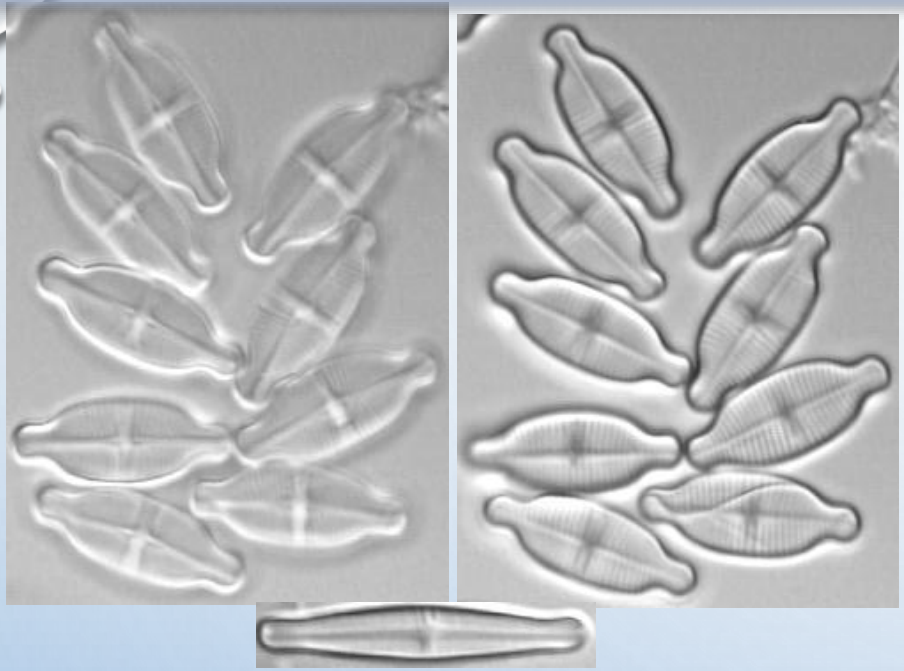
Bacillariophyta (= Diatoms)

Morphological classification – pennates, araphids

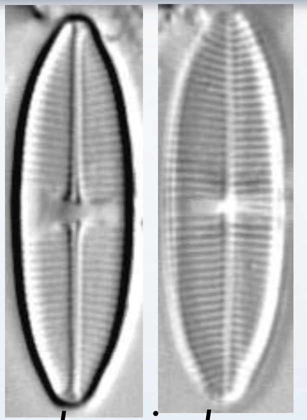


Bacillariophyta (= Diatoms)

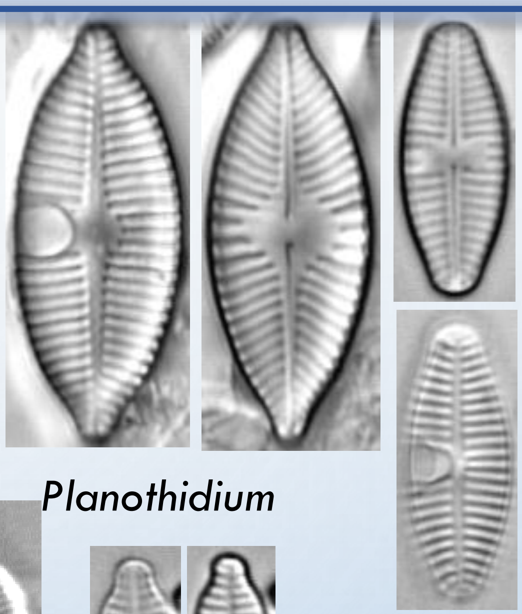
Morphological classification – pennates, monoraphids



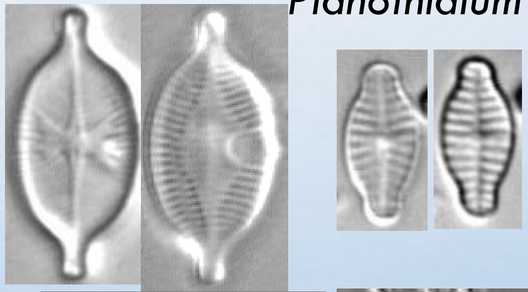
Achnanthidium

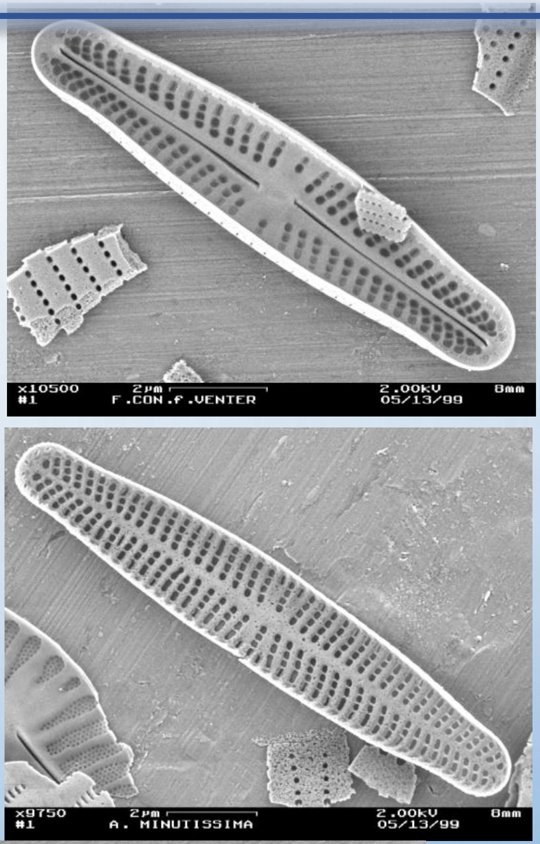


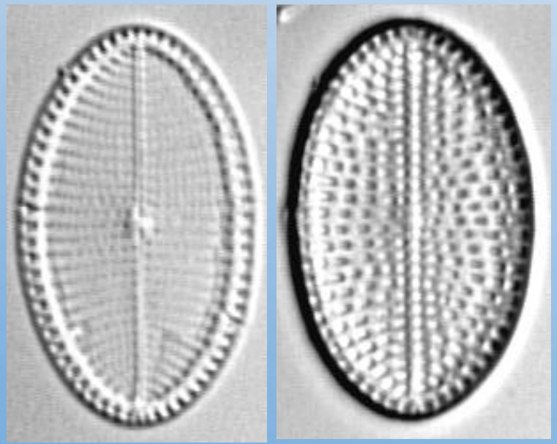
Lemnicola



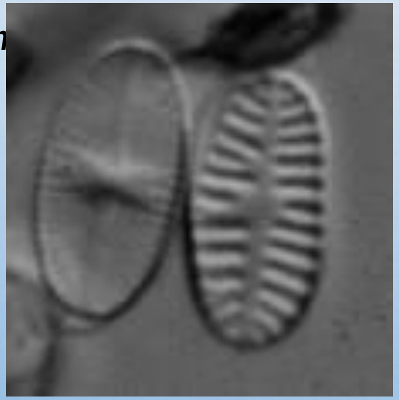
Planothidium



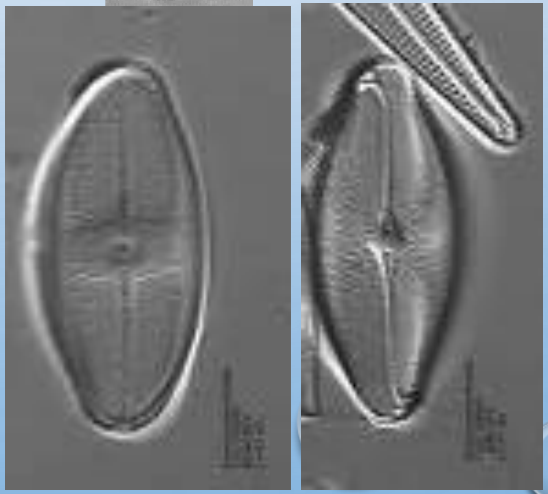




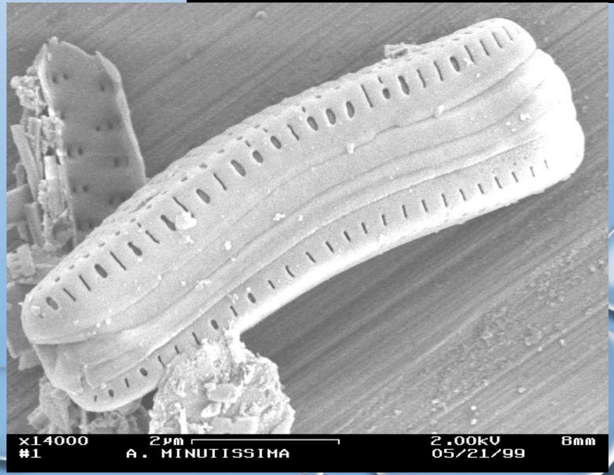
Cocconeis



Psammothidium

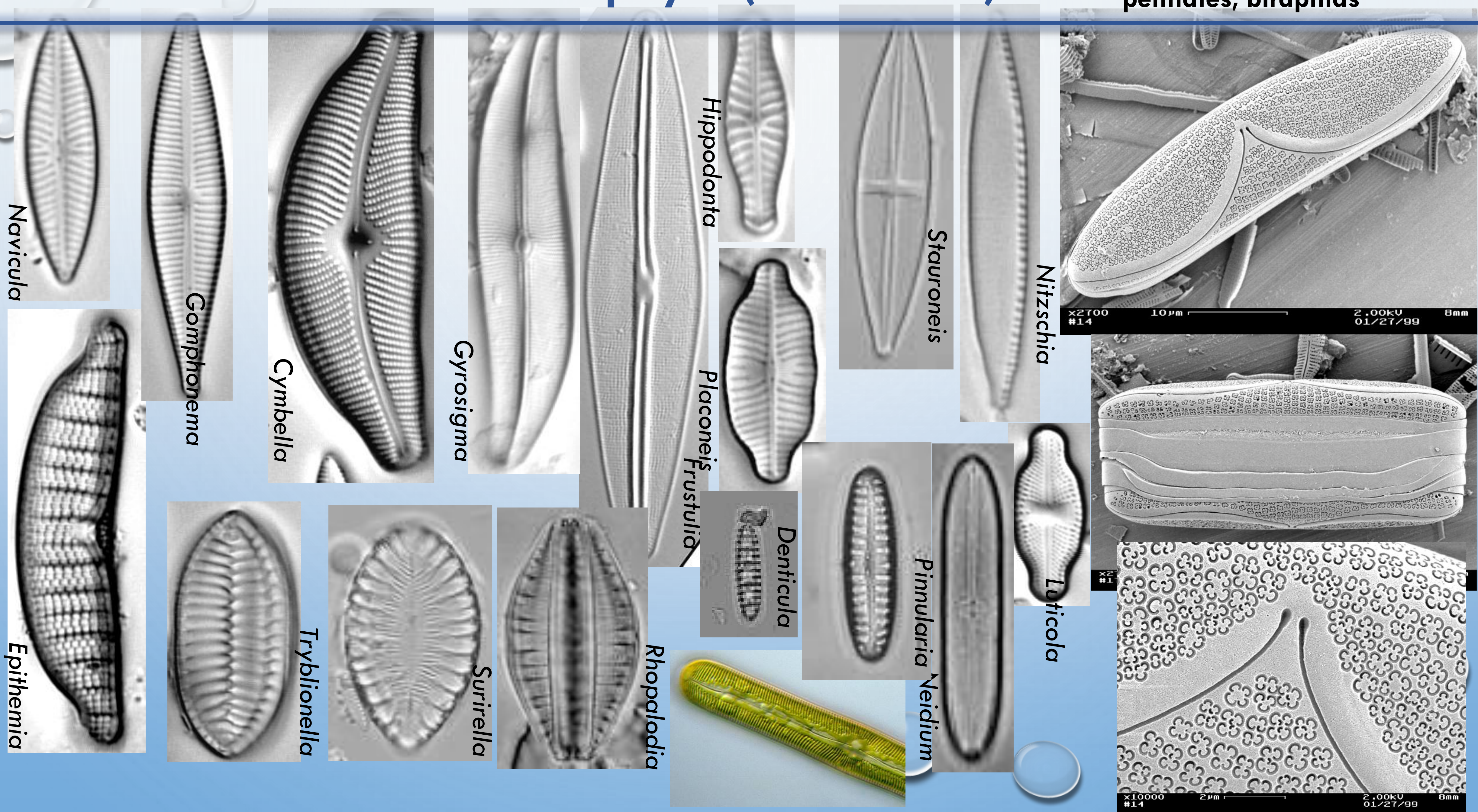


Eucocconeis

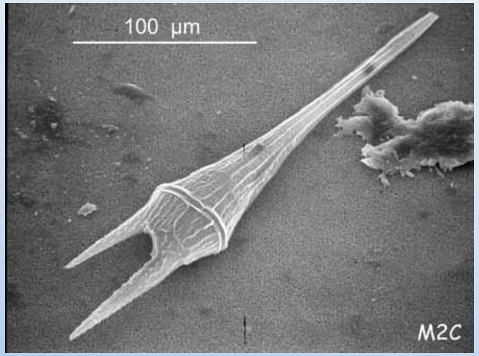


Bacillariophyta (= Diatoms)

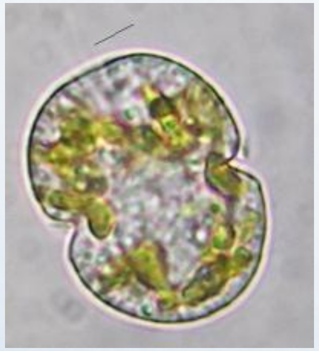
Morphological classification – pennates, biraphids



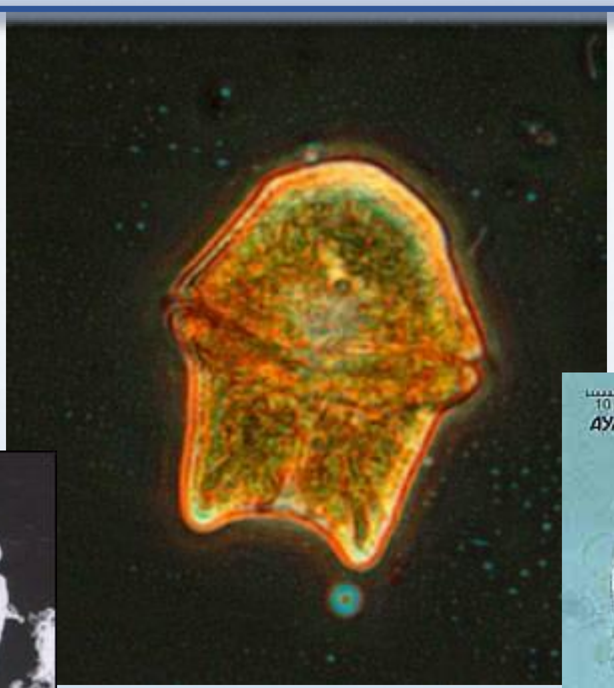
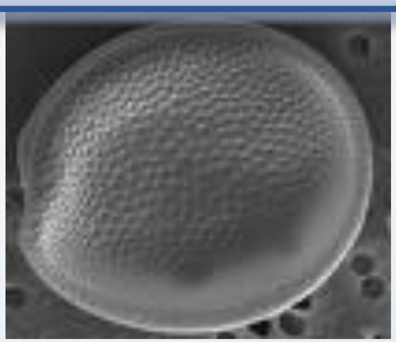
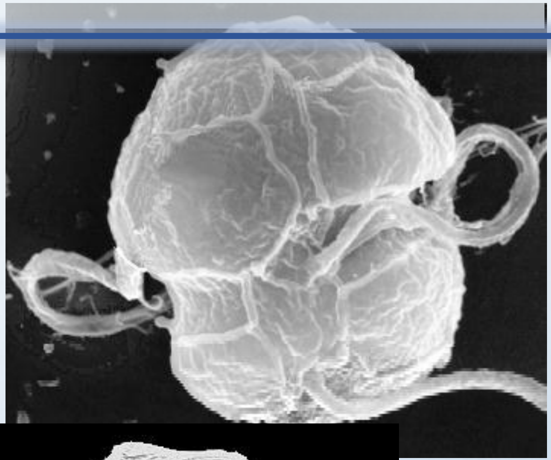
Dinophyta (= Dinoflagelates)

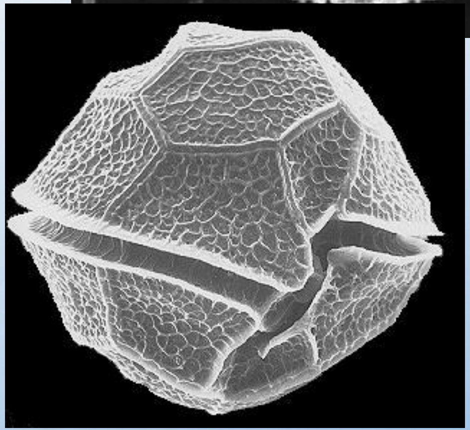



Ceratium

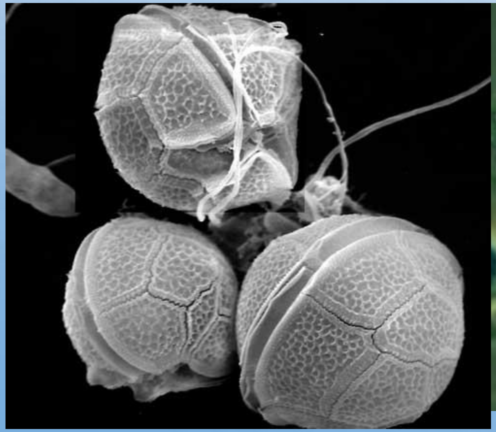



Gymnodinium

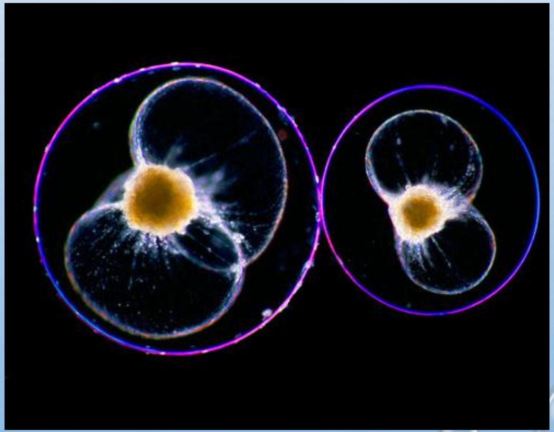




Peridinium

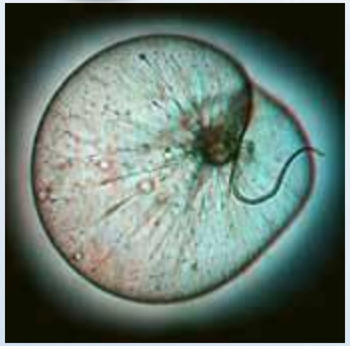



Gonyaulax

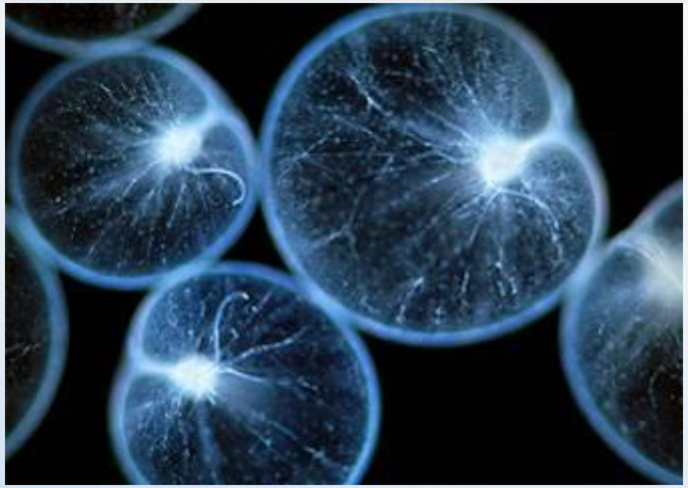


Pyrocystis

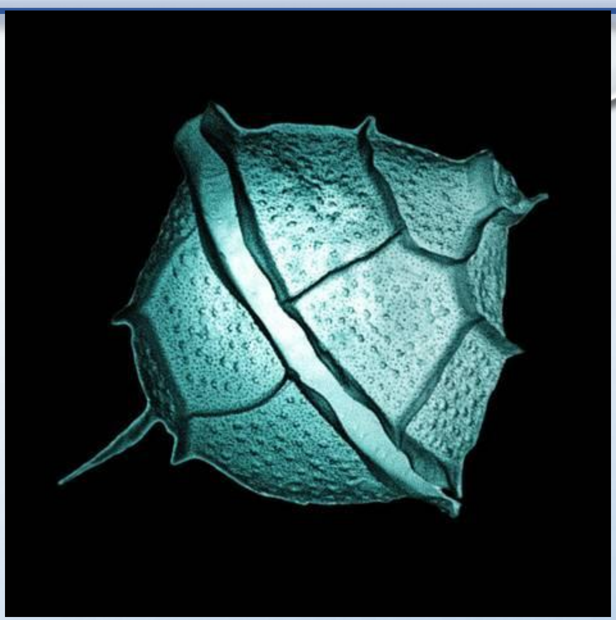
Dinophyta (= Dinoflagelates)

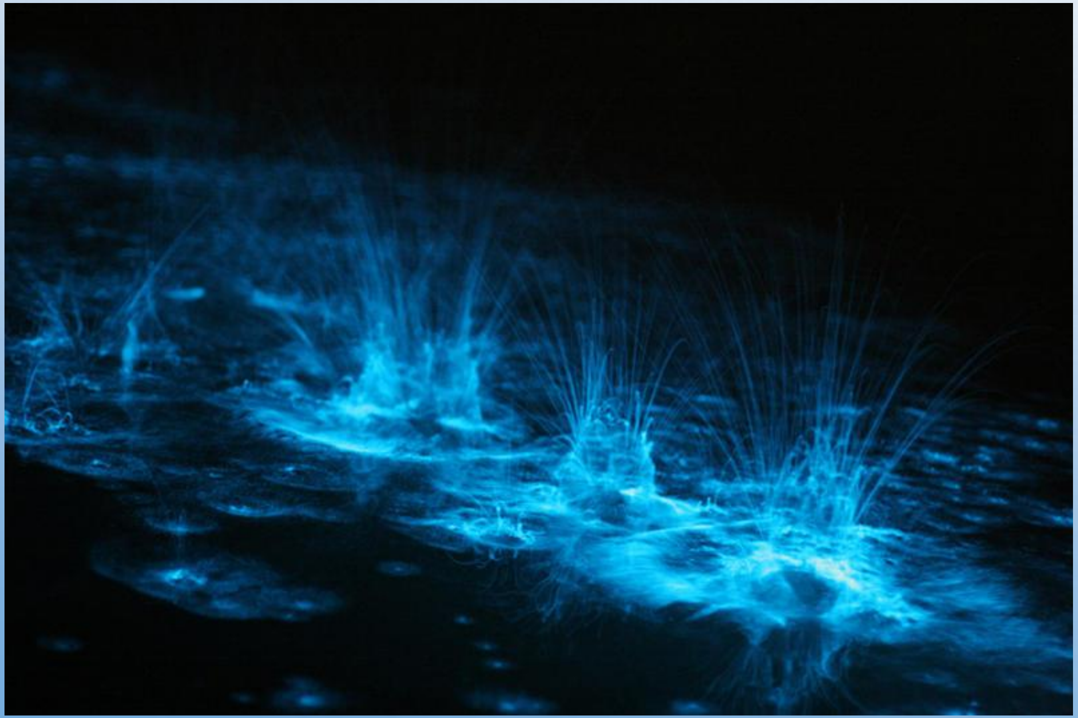


Noctiluca

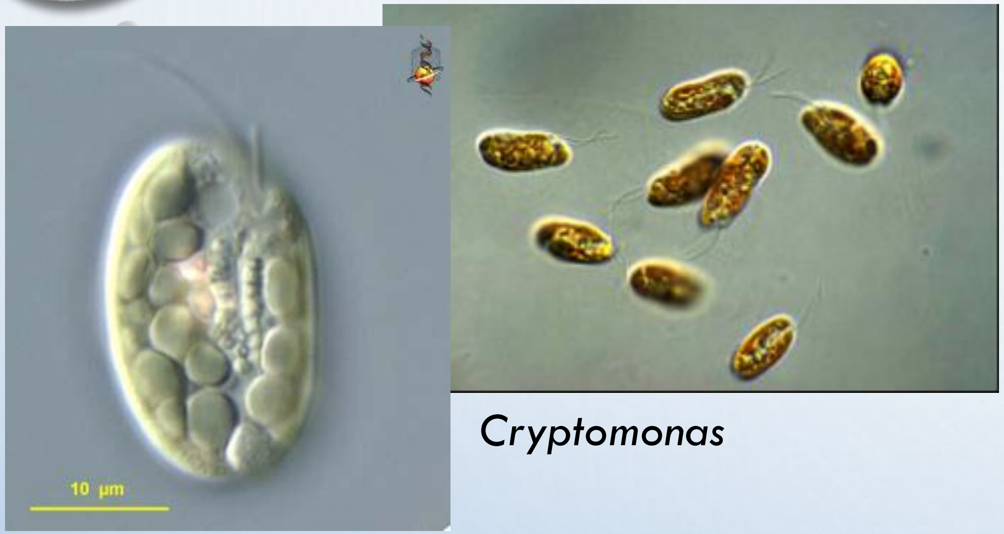


Pyrodinium



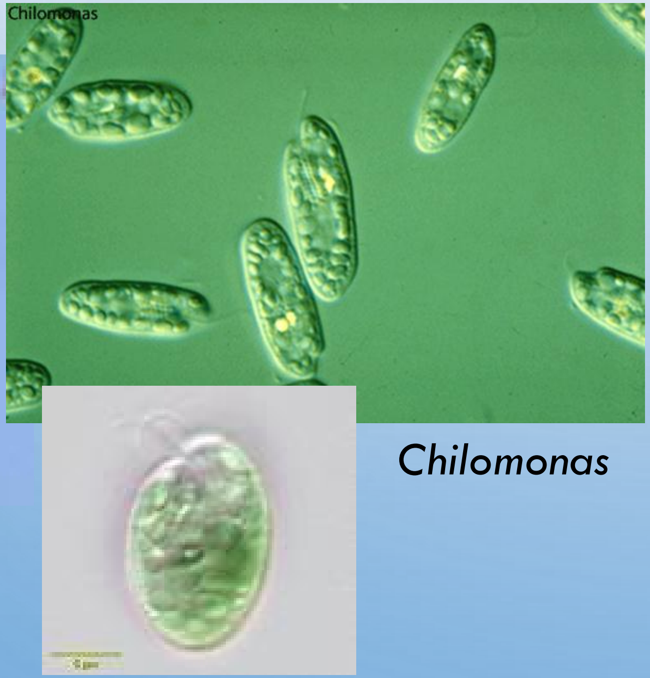


Cryptophyta

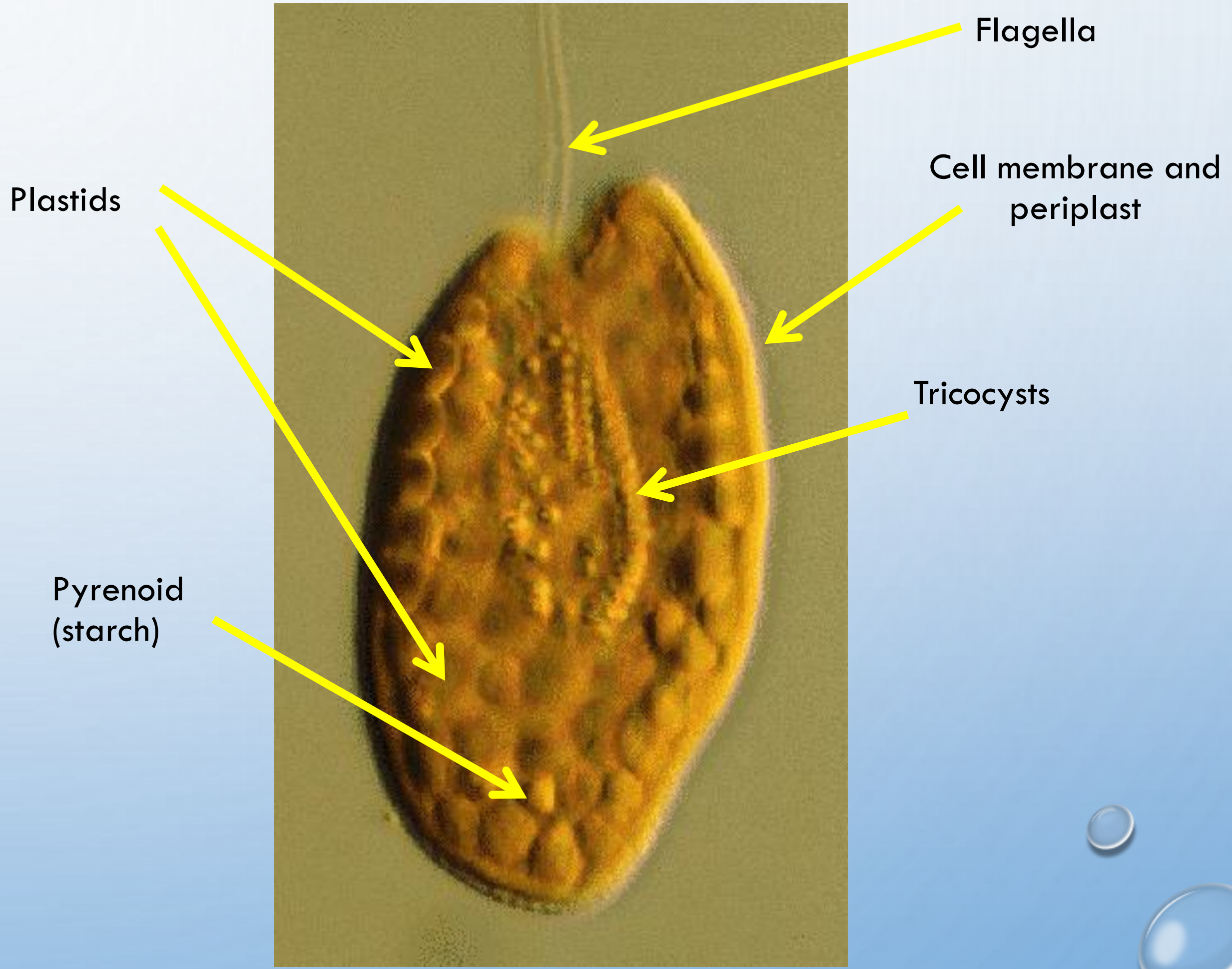


Cryptomonas

Chroomonas



Chilomonas



Factors influencing algal development - *Nutrients*

Essential Nutrients

- **Inorganic:** C, H, O, P, K, N, S, Ca, Fe
- **Organic:** vitamins such as B12, biotine and tyamine
- **Trace elements:** Na, Co, Mn, Cu, Zn, Mo, B.

These nutrientes are naturally present in water, however, some result from the metabolism of other organisms such as bacteria, fungi, fish or even other algae, contributing to ecological succession in the algal community.

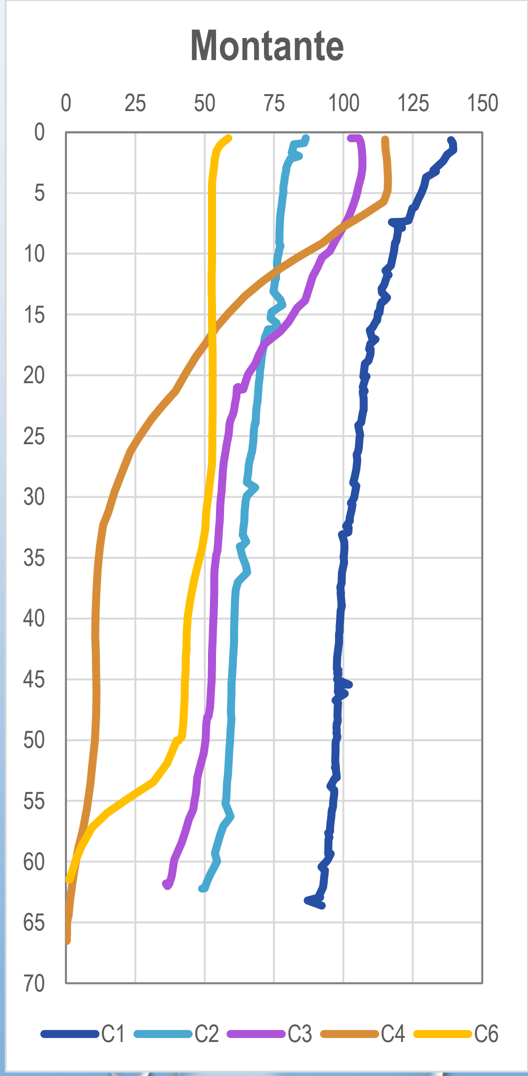
Ecological succession is generally originated by changes in environmental parameters (e.g. temperature, nutrient loads, contamination, tides, etc.), that can create adverse conditions for some species and be favorable for others.

Factors influencing algal development – *Water chemistry*

Salinity: Algae are highly sensitive to salinity! Very few marine algae can survive in freshwaters and *viceversa*. Salinity affects the **osmotic pressure** inside the cell.

pH: Algae are highly adapted to pH and only survive under specific ranges. CO_2 dissolves into water can exist as CO_2 (low pH), bi-carbonate (HCO_3^-) (neutral) and carbonate (CO_3^{2-}) (high pH). And algae cannot use carbonate!

Oxygen: Dissolved oxygen in the water highly influences the presence of algae. Oxygen, apart of being used in cellular respiration is also related to photosynthesis, so, when more algae are present, the dissolved oxygen concentration increases!!



Dissolved oxygen (% sat.)

Factors influencing algal development – *Physical parameters*

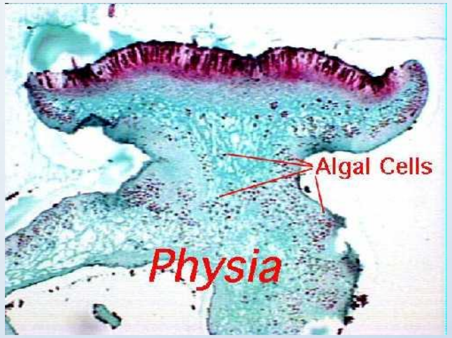
Light: Algae are commonly present in the photic zone. However, too much light can cause the photooxidation of chlorophyll. Photosynthetically active radiation (PAR) is the spectral range that photosynthetic organisms can use for photosynthesis.

Substrate: The substrate characteristics are important for the establishment and maintenance of algal communities (chemical composition, hardness, light exposure, etc.).

Temperature: Algae can survive in a wide range of temperatures. Some can survive under ice, whilst others can inhabit thermal waters with temperatures near the boiling point.

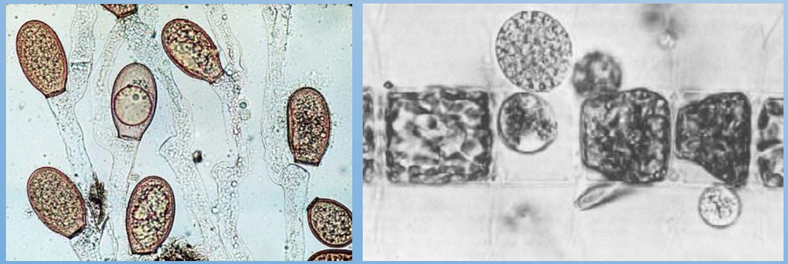
Factors influencing algal development – *Biological parameters*

- Competition: Light, space, substrate, nutrients
- Symbionts: Lichens, zooxanthellae and zoochlorellae
- Epiphytism: Red algae are epiphytic by excellence
- Endophytism: Several red algae
- Predation: Protozoans, invertebrates, mollusks, fish, etc.
- Parasitism: chytrids, fungi, protozoans, insects, etc.

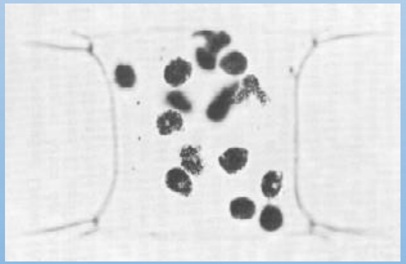


Lichens

Corals



chytrids



amoebas

Phycomycetes

Integrated definition of inland aquatic systems

An area of temporarily or permanently waterlogged or inundated land, natural or artificial, with water that is standing or running, ranging from fresh to saline, and where inundation by water influences the biota ecological processes occurring at any time

Modified standing waters - Reservoirs

- Reservoirs are impoundments created by humans. They are being constructed on an unprecedented scale in response to the exponential water demands for human activities. Such massive alterations of large drainage systems will result in major modifications in topography and regional climate that are not yet fully recognized or even partially understood.
- A great need exists to carefully plan the construction of reservoirs, because deleterious effects may exceed expected benefits.
- The morphometry of these systems generally possess large areas where phytoplankton and macrophyte vegetation grow. Such communities radically alter the productivity of the system.
- Moreover, small reservoirs generally receive high nutrient inputs, which further increases their productive capacity.

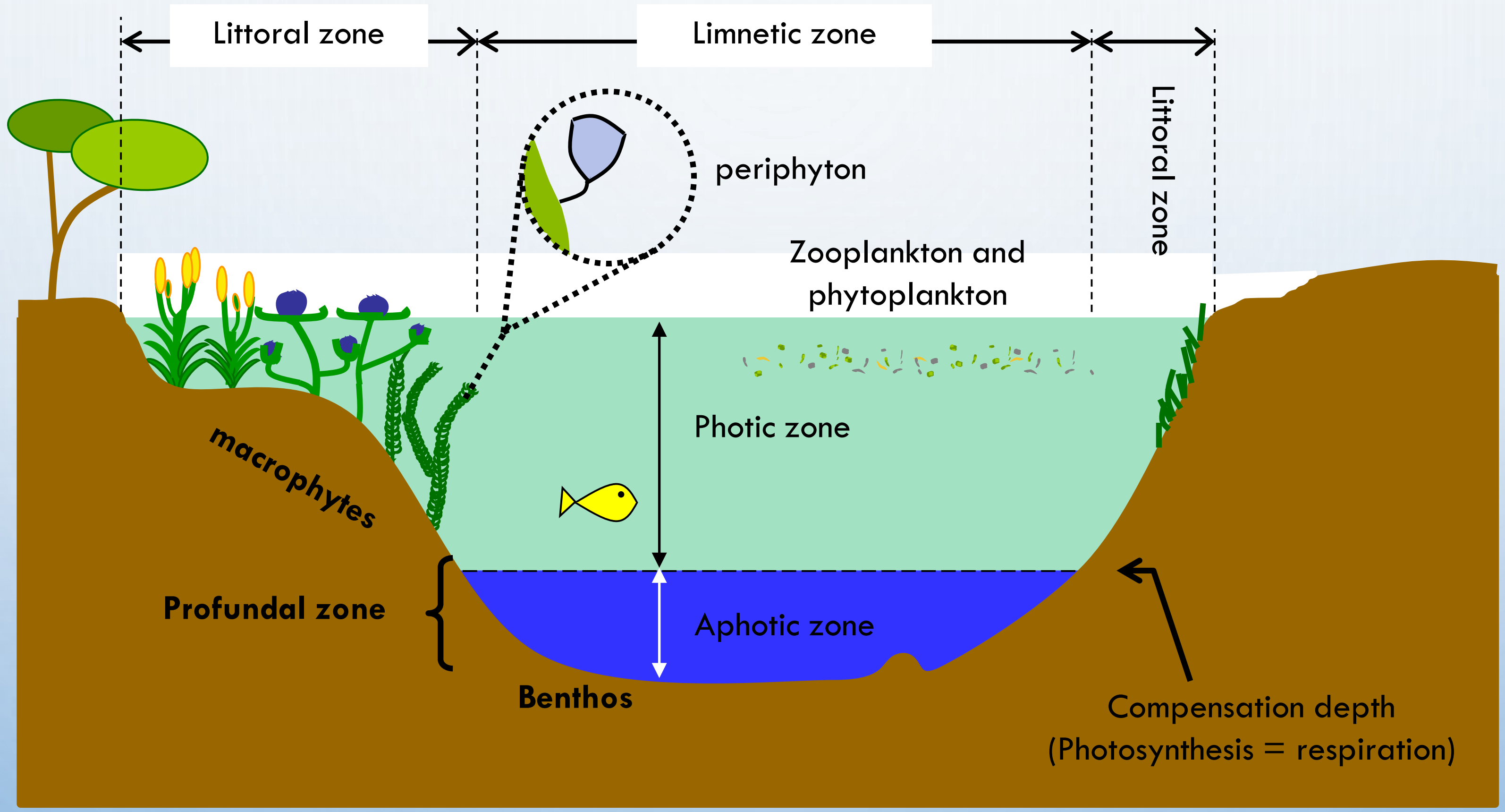
Most reservoirs are relatively short-lived because of the extensive sediment load delivered by affluents.

Modified standing waters - Reservoirs

- They can be considered as a **hybrid between a river and a lake.**
- In the **tail area the system acts as river** in contrast to the **zone near the dam where the system operates as a lake**.
- Although, they form an own system with different characteristics from those they would have if a river or a lake were directly linked together.
- Among other typical characteristics, we can mention the asymmetric morphology of the basin, the shorter water renewal times compared with lakes and the fluctuations in level greater and independent of the natural regime of the river.



Modified standing waters – Lacustrine zonation



Photosynthetic activity mostly takes place in the **euphotic zone.**
It extends from the surface down to a depth where light intensity falls to 1% of that at the surface, called the euphotic depth.

Trophic status

Although there are no universally accepted definitions of oligotrophic and eutrophic states, various attempts have been made to quantify them.

Assessment of trophic status can be made using one or more of the following methods:

- **Nutrient concentration** (TP); **Phytoplankton biomass** (Chl *a*);
- **Rate of primary production** (PP); **Water transparency** (Secchi disk)

Oligotrophic

	TP ($\mu g\ l^{-1}$)	Chl *a* ($\mu g\ l^{-1}$) Maximum	PP ($mg\ C\ m^{-2}\ d^{-1}$)	Secchi depth (m) Maximum
Ultra-oligotrophic	<4	<2.5	<30	>6
Oligotrophic	4-10	2.5-8	30-100	3-6
Mesotrophic	10-35	8-25	100-300	1.5-3
Eutrophic	35-100	25-75	300-3000	0.7-1.5
Hypereutrophic	>100	>75	>3000	<0.7

Trophic status

Oligotrophic

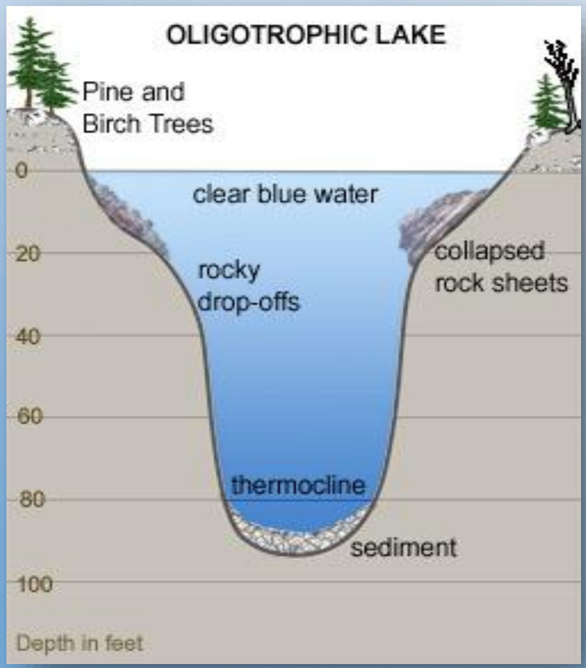
- Low nutrients (P&N)
- Low algal concentration
- Less decomposition
- Clear water
- Highly oxygenated waters

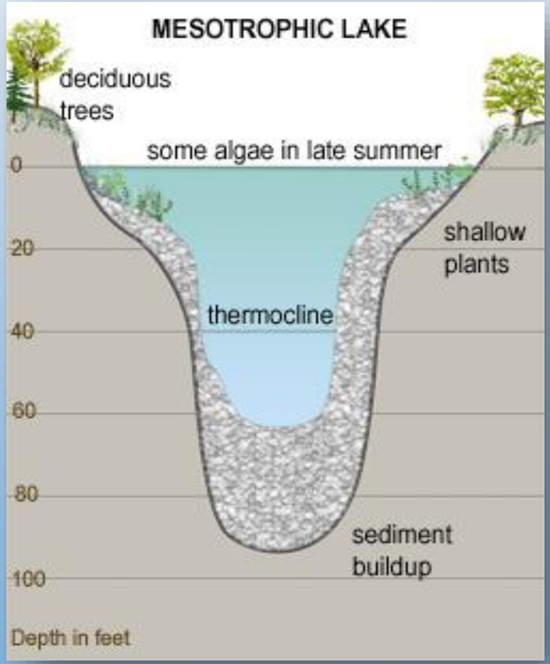
Mesotrophic

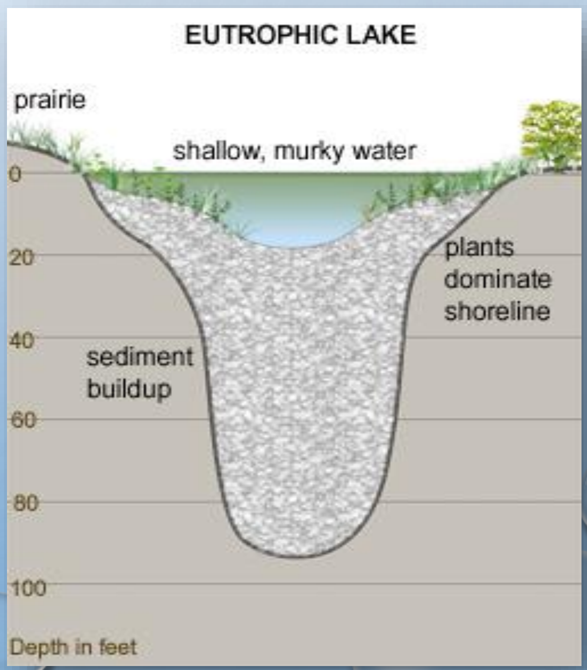
- Intermediate level of productivity
- Stratification
- Oxygen concentration high at the surface, bottom layer anoxic during summer

Eutrophic

- High nutrient levels
- High primary production
- Murky, green water
- Usually shallow
- Lots of plants and algae

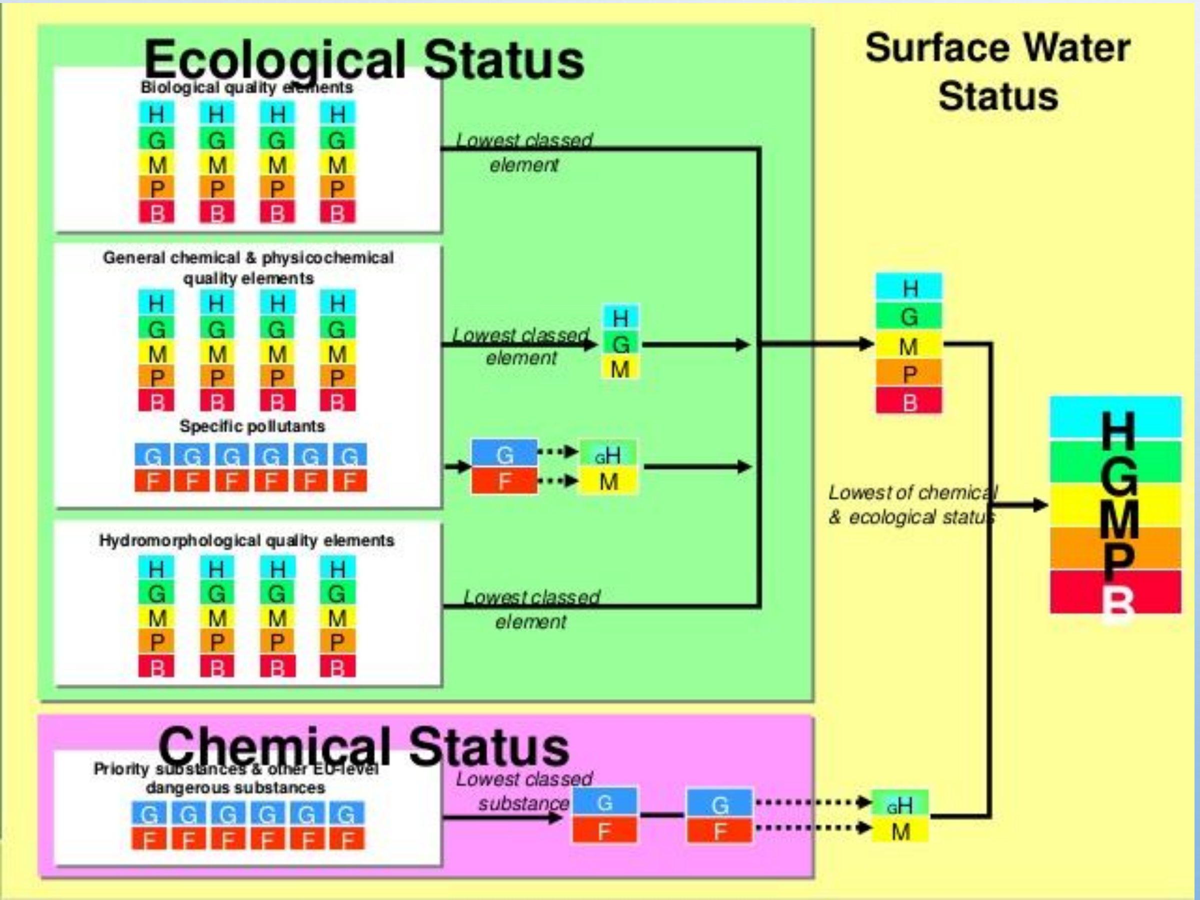






Water Framework Directive

Purpose of the **WFD** is to establish a framework for the protection of inland surface waters, estuaries, coastal waters and groundwater.



Heavily Modified Water Bodies (HMWB)

A water body resulted from physical alterations by human activity, which substantially change its character

Ecological potential represents the degree to which the quality of the water body's aquatic ecosystem approaches the maximum it could achieve, given the heavily modified and artificial characteristics of the water body that are necessary for the use or for the protection of the wider environment.

Maximum Ecological Potential is defined as the state where "the values of the relevant biological quality elements reflect, as far as possible, those associated with the closest comparable surface water body type, given the physical conditions, which result from the heavily modified characteristics of the body" (WFD Annex V 1.2.5).

Water Framework Directive

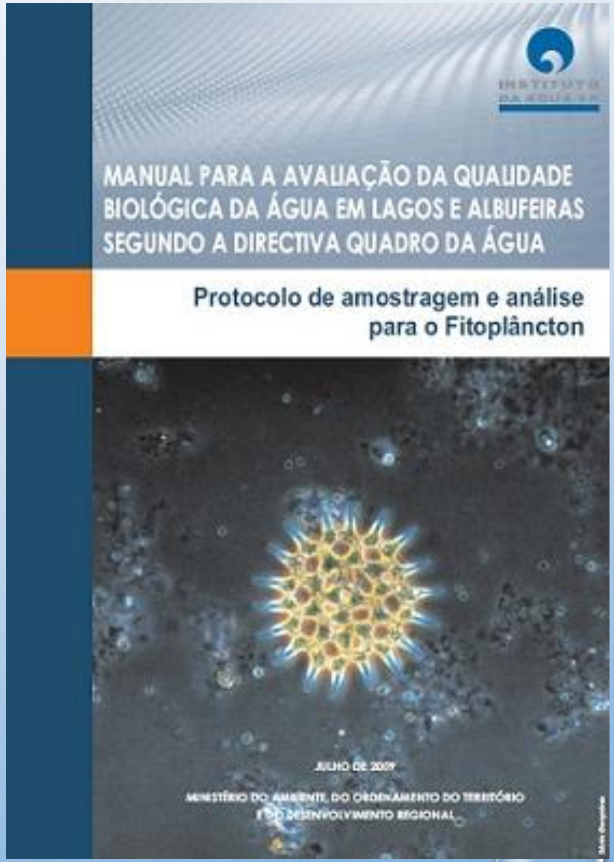
Physicochemical Elements	Parameters
Transparency	Sechi disk depth (m) Total suspended solids (mg/L) Colour /scale Pt-Co) Turbidity (NTU)
Temperature	Temperature profile (°C)
Oxygenation	Dissolved O_2 profile (mg O_2/L) O_2 profile (O_2 % saturation) Biochemical O_2 Demand (mg O_2/L) Chemical oxygen demand (mg O_2/L)
Salinity	Electrical conductivity 20 °C (µS/cm)
Acidification	pH (escala de Sorensen) Alcalinity (mg HCO_3/L) Hardness (mg $CaCO_3$/L)
Nutrients	Nitrates (mg NO_3/L) Nitrites (mg NO_2/L) Ammonia (mg NH_4/L) Total nitrogen (mg N/L) Ortophosphates (mg PO_4/L) Total Phosphorus (mg P/L)

Parameters	Limits for the Good Ecological Potential	
	North	South
Dissolved Oxygen	$\geq$ 5 mg O_2/L	$\geq$ 5 mg O_2/L
Oxygen (% saturation)	Between 60% and 120%	Between 60% and 140%
pH	Between 6 and 9	Between 6 and 9
Nitrates	$\leq$ 25mg NO_3/L	$\leq$ 25mg NO_3/L
Total Phosphorus	$\leq$ 0,05 mg P/L)	$\leq$ 0,07 mg P/L)

Water Framework Directive

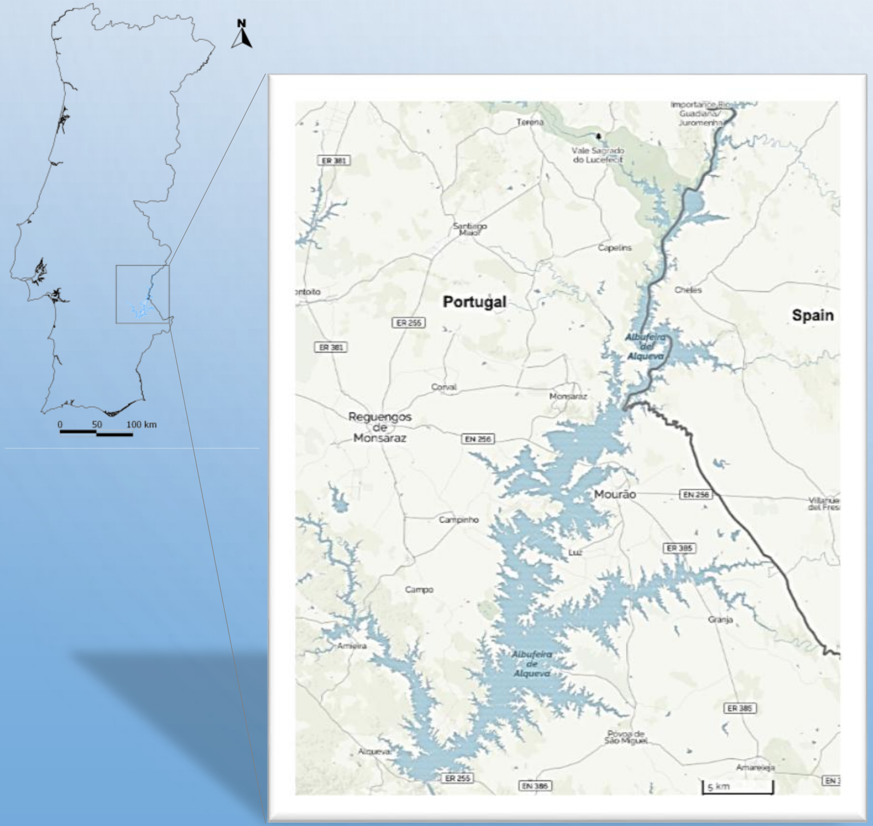
Phytoplankton

Type	Component	Indicator	Reference value	Good/ Moderate
North	Biomass	Chlorophyll *a* (mg/m^3)	1,7	7,9
		Total Biovolume (mm^3/L)	1,20	2,80
	Composition and abundance	Cyanobacteria Biovolume (mm^3/L)	0,02	0,80
		Índice de Grupo de Algas (IGA)	2,00	37,60
South	Biomass	Chlorophyll *a* (mg/m^3)	1,6	9,50

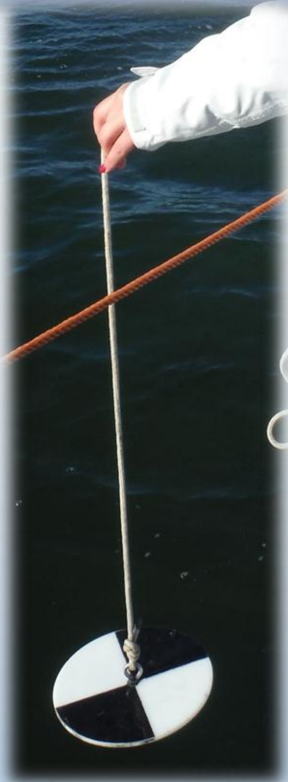


Alqueva as a case study

- Located in the **Guadiana river;**
- Closure of floodgates on 8 February, 2002;
- **Largest artificial water reservoir in Western Europe,** also called the **Great Lake;**
- Built with the objective of **irrigation** for the entire Alentejo area and **production of electricity,** in addition to other complementary activities;
- Classification in terms of **trophic state:** **Mesotrophic;**
- Classification in terms of **circulation:** **Warm monomictic**
- Ecological Potential: **Good**

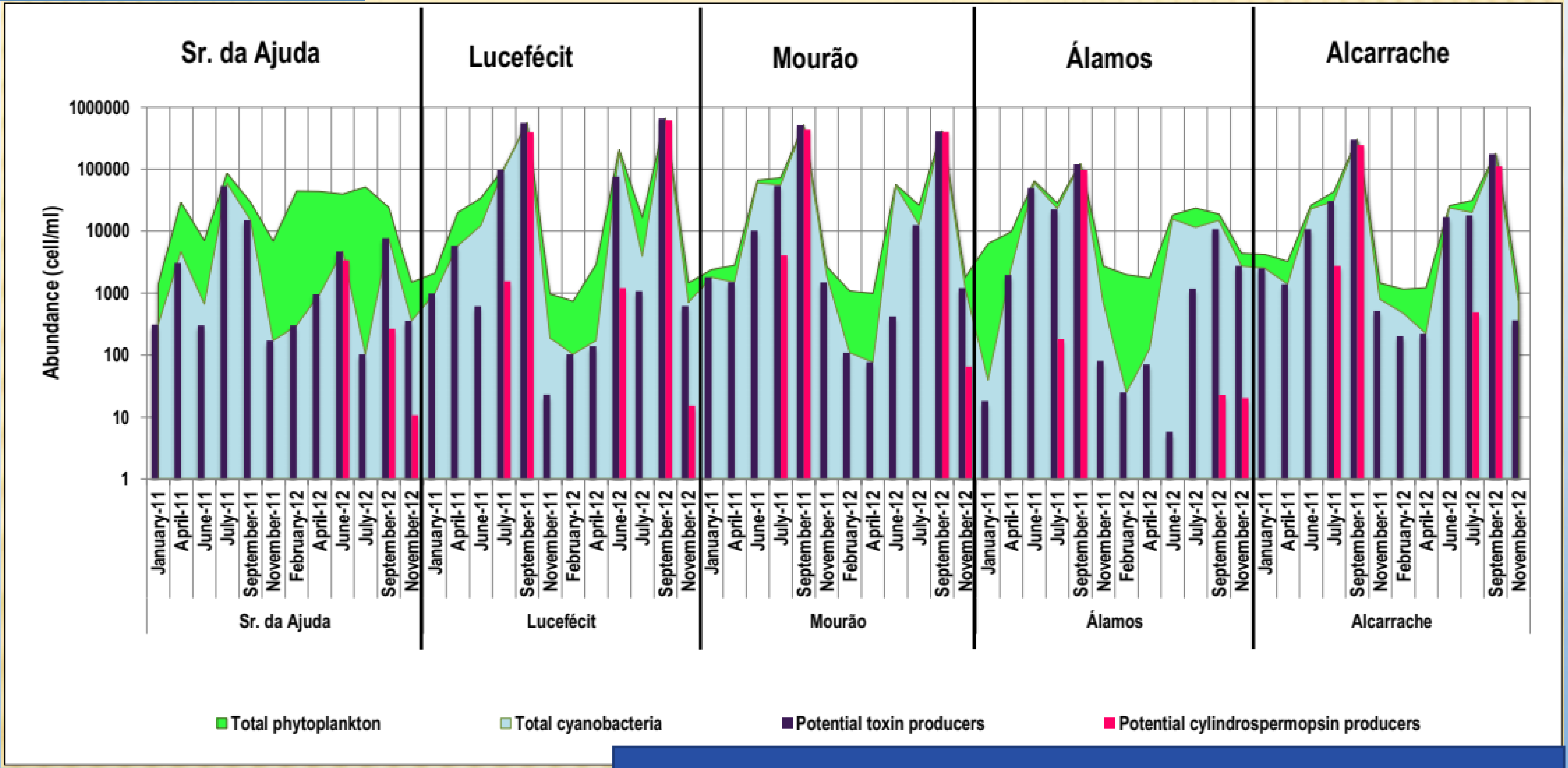


Alqueva as a case study - *methods*



Alqueva and the Algae – *historical data*

Phytoplankton data for Alqueva 2011-2012

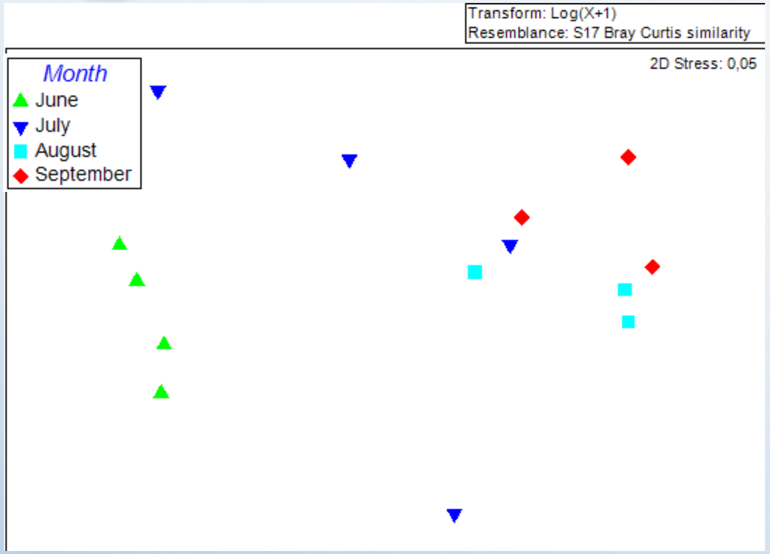


Current studies in Alqueva concentrate on phytoplankton (water column).

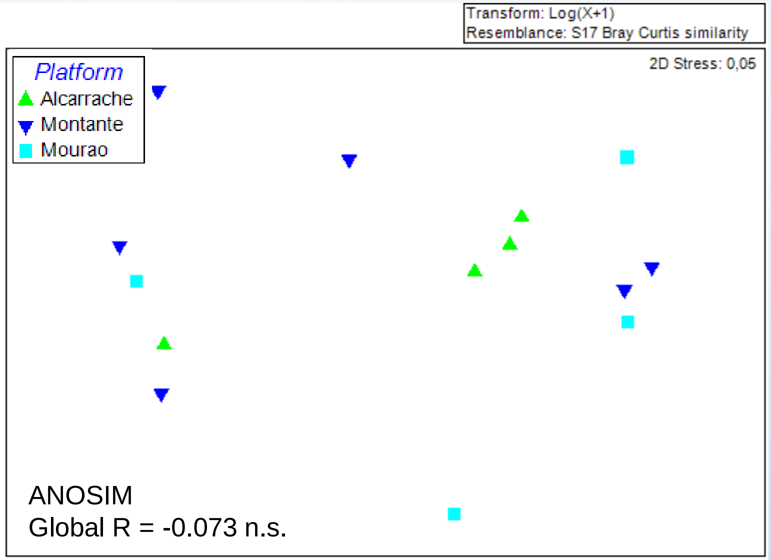
Planktonic cyanobacteria dominate during the warm months (spring and summer).
Apparently, the densities of cyanobacteria during the rest of the year are low.

Risk	Guiding value (cells. Cyan./mL)	Chl. *a* (Cyan. dominant)
Relativamente baixo	20.000	10 µg/L
Moderado	100.000	50 µg/L
Elevado	Florescência	-----

Alqueva and the Algae – *ALEX 2014*

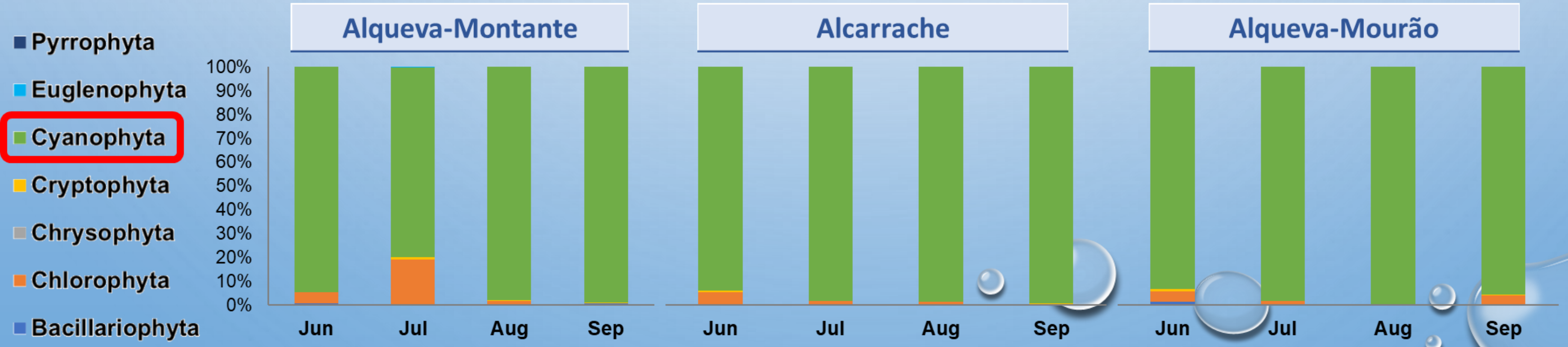


ANOSIM
Pairwise Tests R
Jun/Jul=0.563*
Jun/Aug=1.000*
Jun/Sep=1.000*
Pairwise Tests R
Jul/Aug=0.111 n.s.
Jul/Sep=0.286 n.s.
Aug/Sep=0.000 n.s.



Succession of phytoplankton species, mainly cyanobacteria, thus representing a **temporal dynamics**, typical of reservoirs that are **not under the influence of severe anthropogenic pressure**

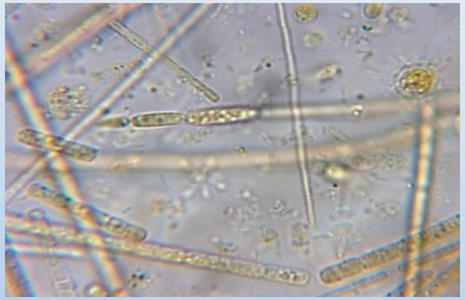
Cyanobacteria dominated in abundance throughout the experiment, whilst **Chlorophyta** were the **taxa richest group**



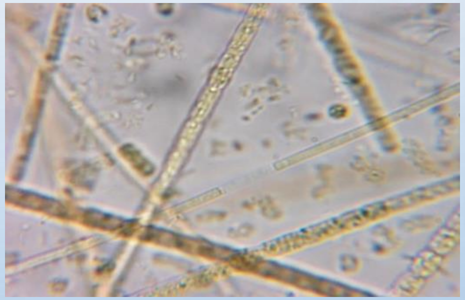
Cyanobacterial bloom in Alqueva reservoir

June 2014 Next to dam walls

Anabaena catenula

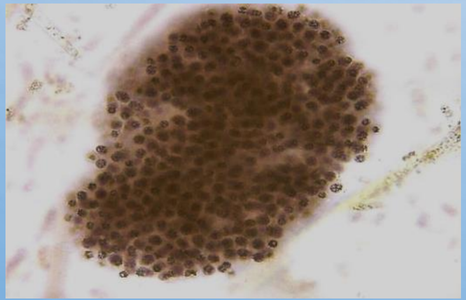


Cylindrospermopsis sp.

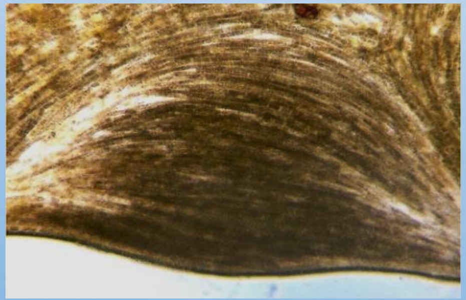


Lyngbya sp.

Oscillatoria sp.



Microcystis aeruginosa



Aphanizomenon flos-aquae

Woronichinia naegeliana

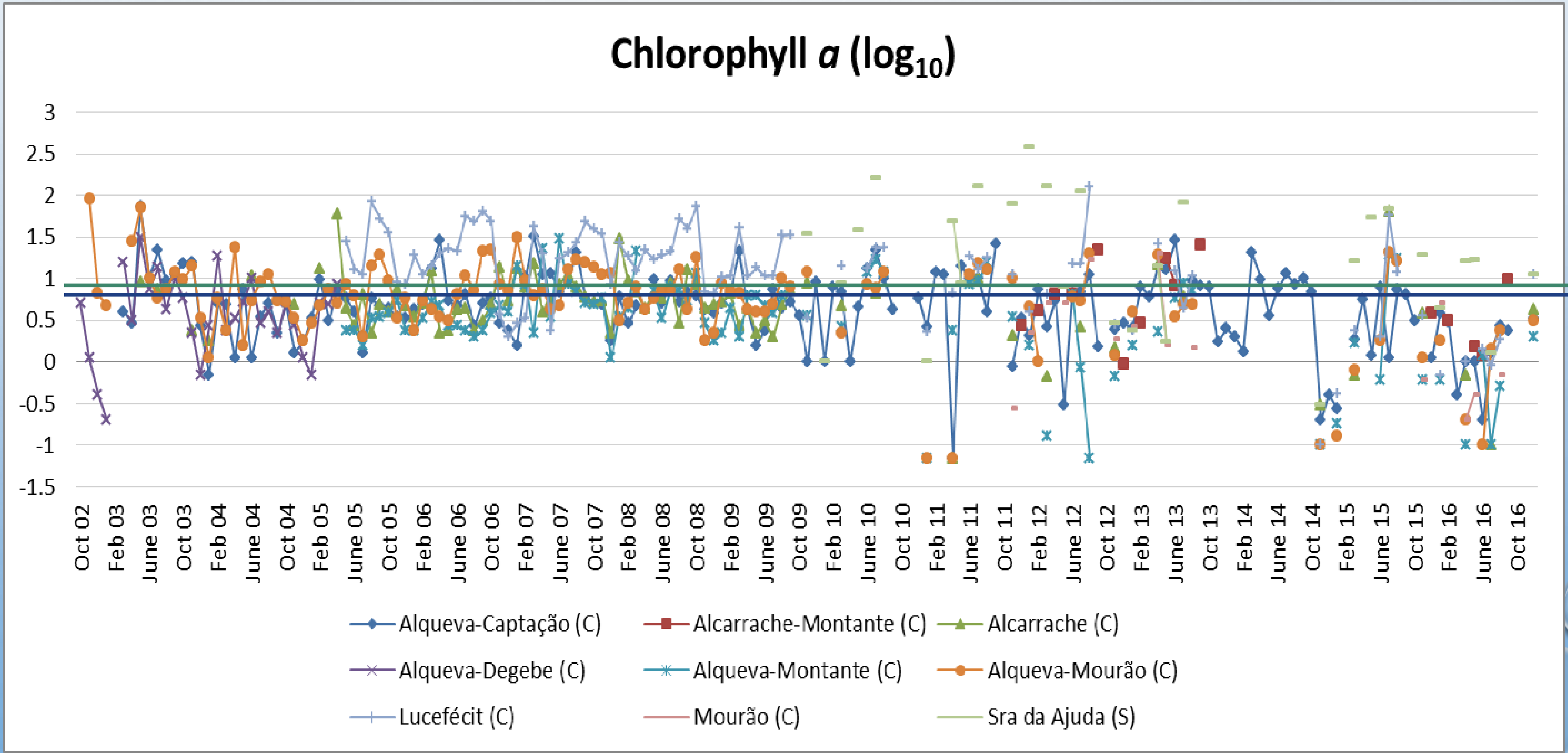
Microcystis aeruginosa

Alqueva and the Algae – *historical data*

Limit for Good Ecological Potential ≤ 9.5 µg/L

Lower limit for eutrophy: 8 µg/L

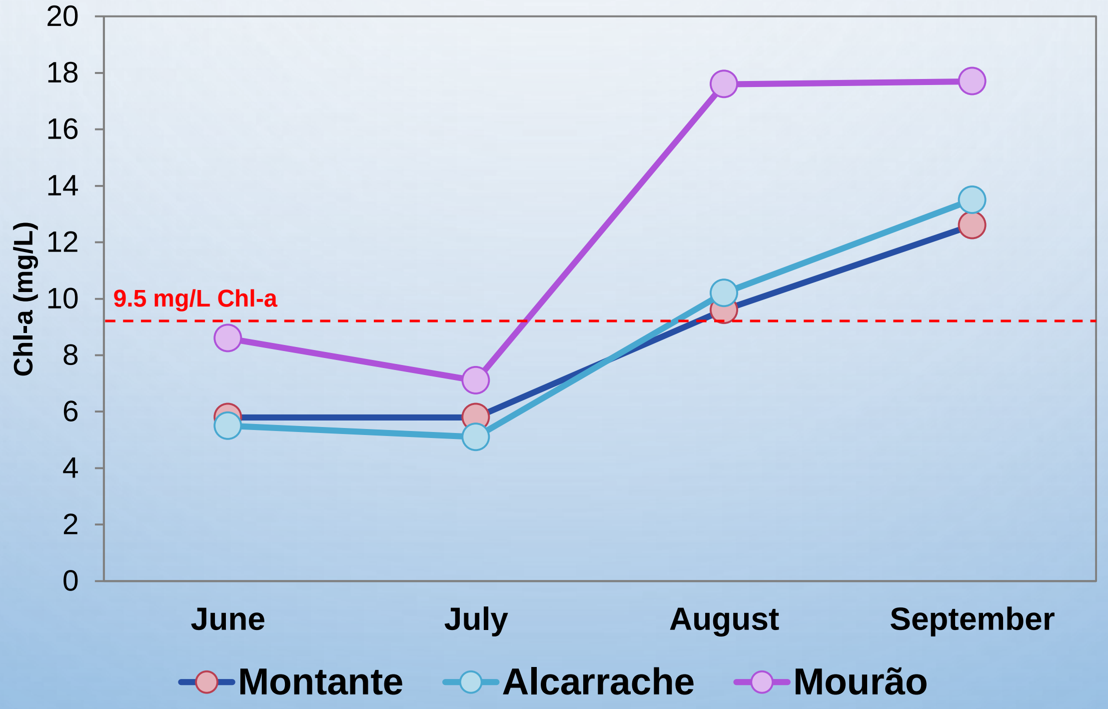
Mean values of Chl. *a* for Alqueva 2002-2016



Alqueva and the Algae – *ALEX Summer 2014*

Chlorophyll-*a* over time

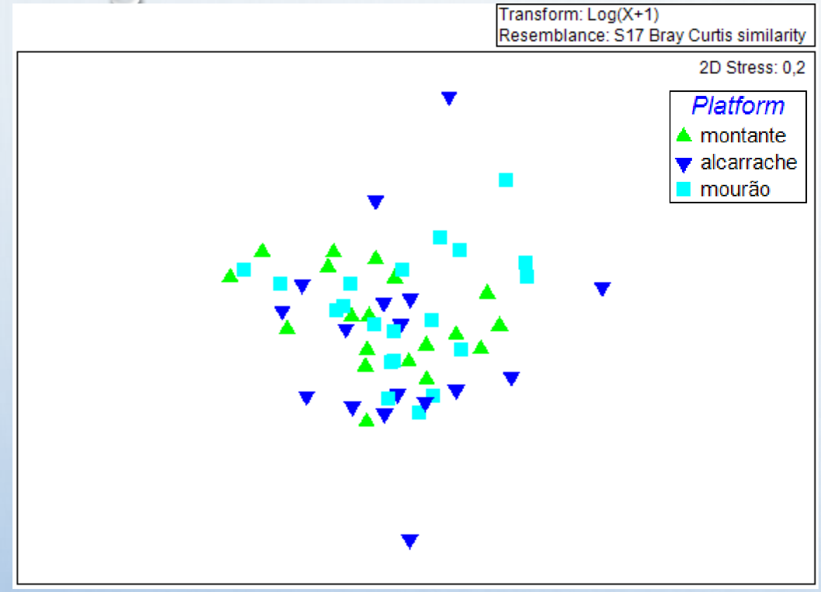
Water Frame Work Directive (reservoirs for South Portugal)	**Good Ecological Potential ≤ 9.5 mg/L**
	Limit for **Eutrophic state ≤ 8 mg/L**

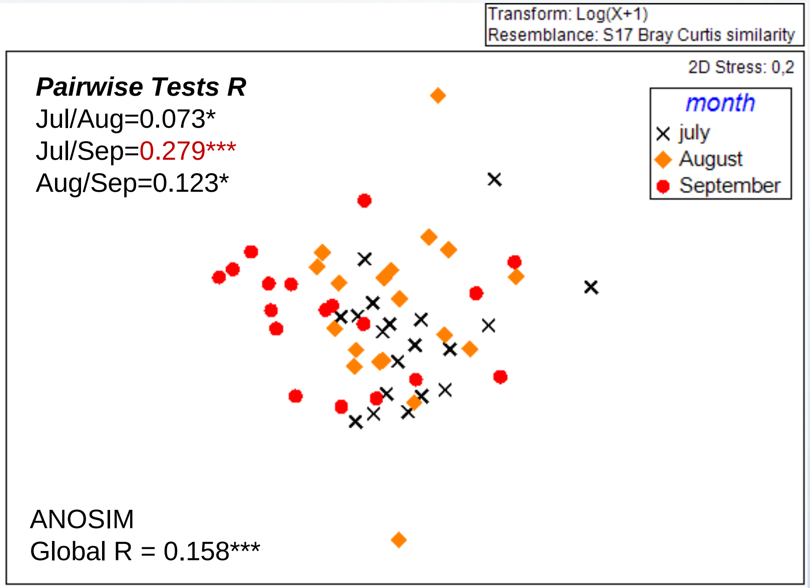


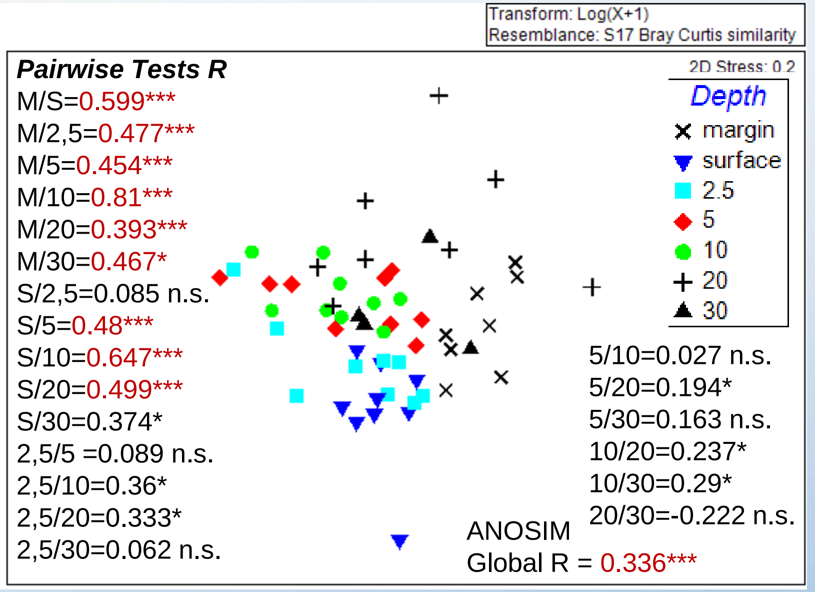
- ➢ In **August** and **September,** Chlorophyll *a* levels **higher than 9.5 mg/L** at **all sampling sites;**
- ➢ **Mourão** with the **highest values.**

Alqueva and the Algae – *ALEX Summer 2014*

Diatoms





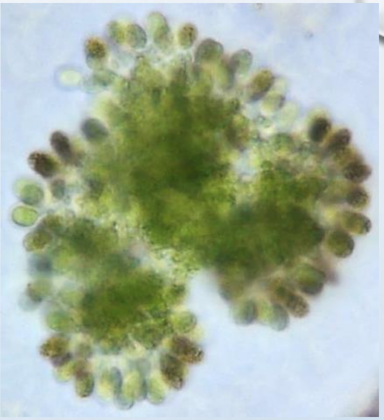


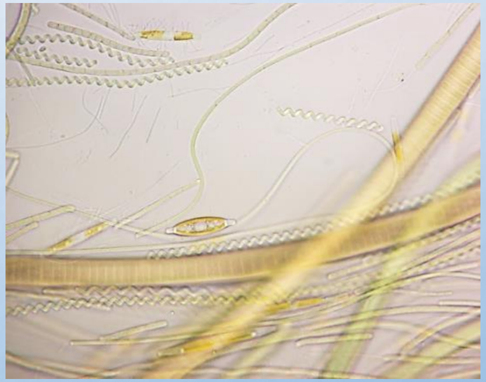
- no differences among platforms
- no significant differences between sampling dates, even though there are some shifts in relation with month
- margin littoral assemblages were significantly different from lacustrine platforms, independently of the depth
- gradual shift in diatom assemblages with depth

Understudied blooms in Southern Portugal: benthic Cyanobacteria

<u>Identified toxic species</u>

Limnothrix redeckei
Oscillatoria limosa
Phormidium tergestinum
Spirulina subsalsa
Woronichinia naegeliana



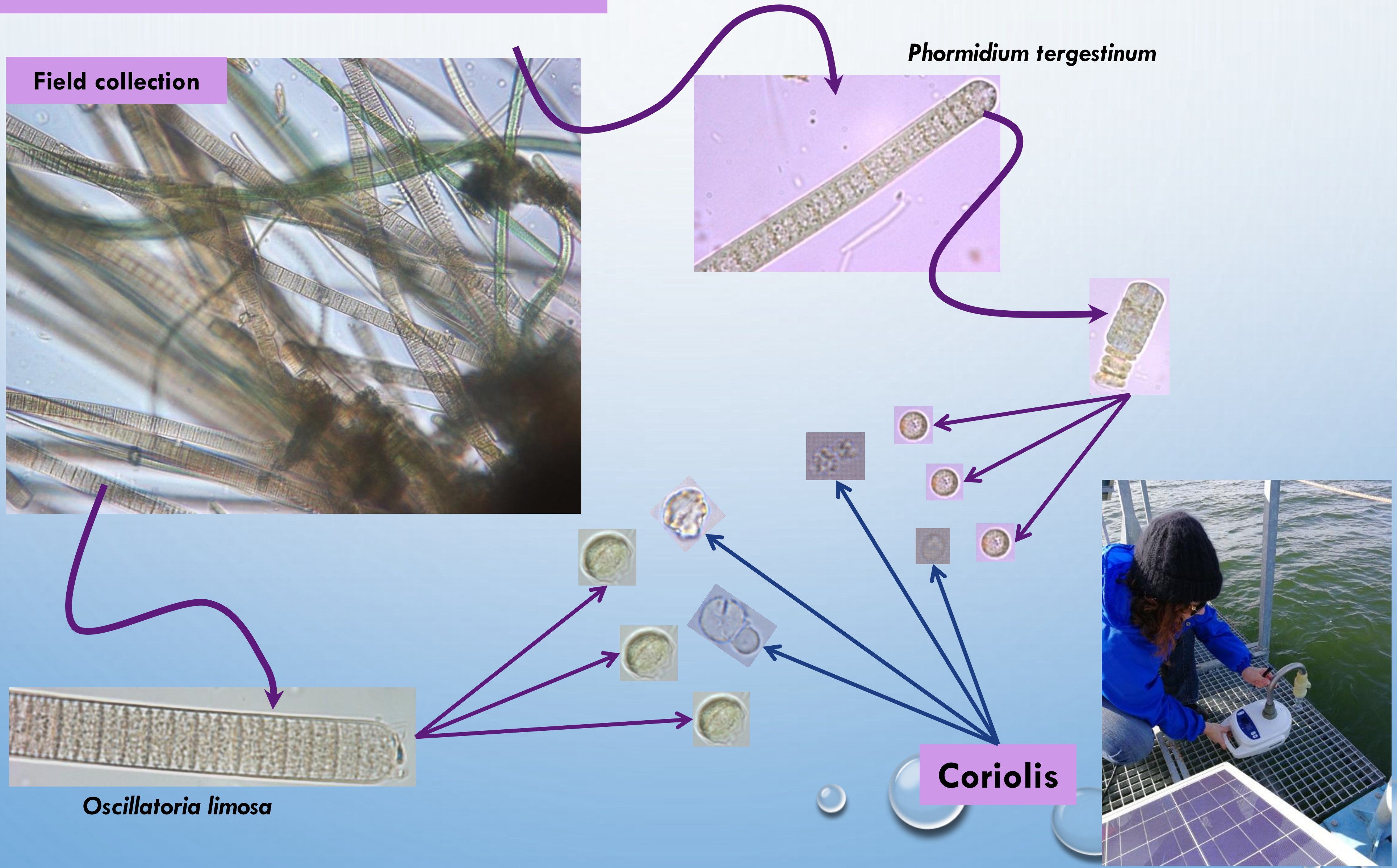


<table>
<tr><th>Localities</th><th>Water and Intracelular (µg/L)</th><th>Intracelular (µg/L)</th><th>Limit (µg/L)
TDI (µg/kg)</th></tr>
<tr><td>Mourão (stones)</td><td>1.13</td><td>1.04</td><td rowspan="5">1 / 0.04</td></tr>
<tr><td>Mourão (floating mat)</td><td>1.41</td><td>1.33</td></tr>
<tr><td colspan="3">Other critical localities</td></tr>
<tr><td>Beach of Monsaraz</td><td>1.47</td><td>1.40</td></tr>
<tr><td>Beach of Liberdade</td><td>1.77</td><td>1.67</td></tr>
</table>

Concentrations of total microcystins in Alqueva determined by ELISA. Data from January and February, 2018.

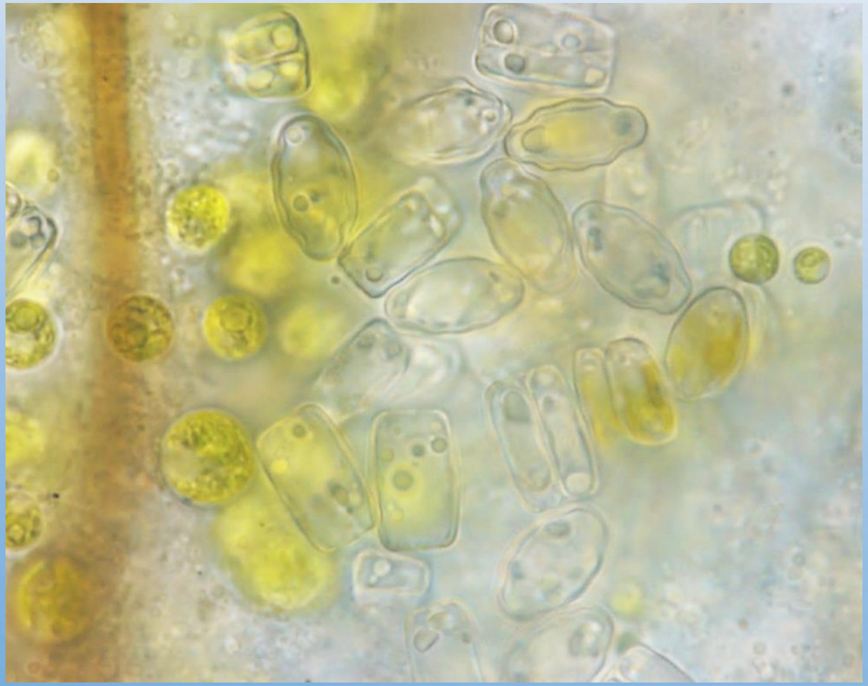
Alqueva and the Algae – *Are algae able to fly?*

A possible mechanism for release into air



Alqueva and the Algae – *Are algae able to fly?*

Air sample, roof top of the Water Laboratory, University of Évora (BG 11 medium)



First Workshop "Taxonomy and Ecology of Cyanobacteria"

September 10-15, 2018

Laboratório da Água

Main Facilitators

Prof. Jeffrey R. Johansen

Department of Biology, John Carroll University, University Heights, Ohio, USA

Prof. Dr. Célia L. Sant'Anna

Phycological Studies Nucleus, Institute of Botany, São Paulo, Brazil

UNIVERSIDADE DE ÉVORA
ESCOLA DE CIÊNCIAS E TECNOLOGIA
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