Chs 8, 15, & SR

Production and Phytoplankton

Objectives

- Report on last week's nutrient data
- Understand how we define and measure *productivity* in lakes
- Understand phytoplankton morphology, physiology, and classification
- Understand phytoplankton's role in aquatic systems/general patterns
- Overview of Thursday's lab and assignment

Outline

- I. Lake Ecosystem Concept and Terminology
- II. Ecosystem Interrelationships and Production
  - Food webs and structure
  - Productivity and how we measure it
- III. Phytoplankton
  - Morphology and Physiology
  - Taxonomy and diversity
  - Phenology and dynamics
- IV. Lab techniques
  - Identification and diversity

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Lake Ecosystem Concept

- Relationships of organisms within lakes (Forbes, 1887; Lindeman 1942)
- History of lakes being viewed as closed systems
  - Microcosms: functionally isolated from the rest of the landscape and biosphere
  - WHY?

- Review:
- What are sources of nutrients from outside an aquatic system called ?

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  - Allochthonous (allochthony)
- Within the system?

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- Within the system?
  - Autochthonous

- Review:
- What are sources of nutrients from outside an aquatic system called ?
  - Allochthonous (allochthony)
- Within the system?
  - Autochthonous -> Production!

Lake Ecosystem Concept

- Relationships of organisms within lakes (Forbes, 1887; Lindeman 1942)
- History of lakes being viewed as closed systems
  - Microcosms: functionally isolated from the rest of the landscape and biosphere
- Despite foundational work in lakes for understanding interrlationships within ecosystems, know that basin inputs are v important

Lake Ecosystem concept

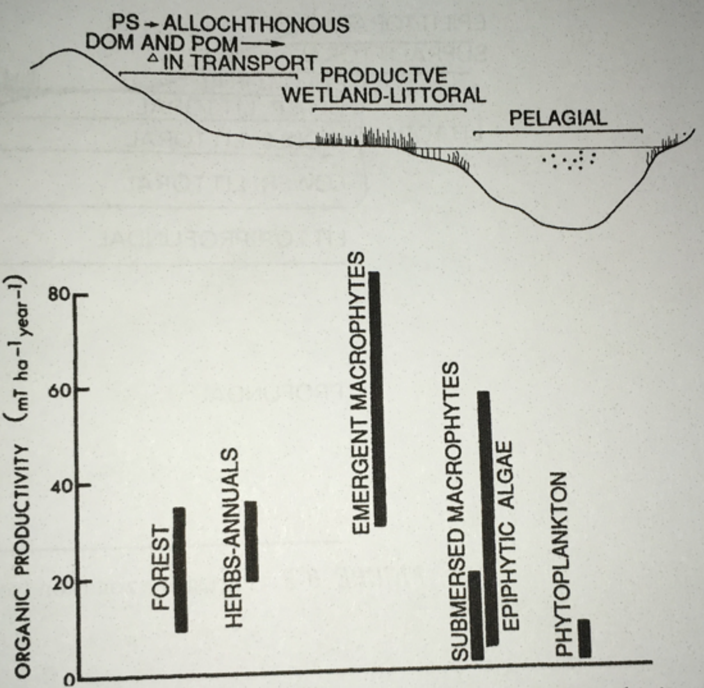
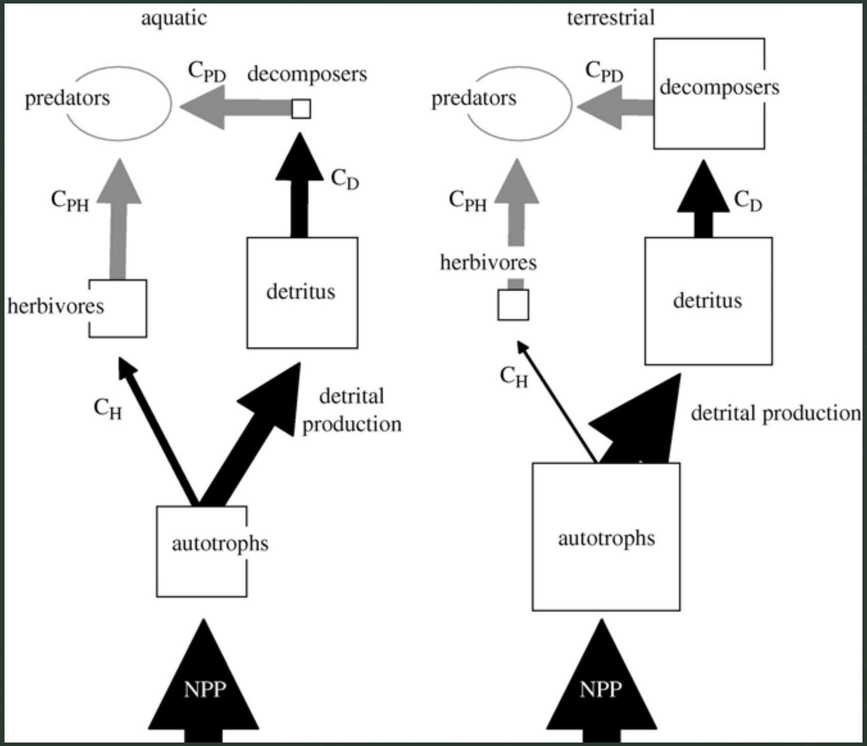


FIGURE 8-1 The lake ecosystem, showing the drainage basin with terrestrial photosynthesis (*PS*) of organic matter, movement of nutrients and dissolved (*DOM*) and particulate (*POM*) organic matter in surface and groundwater flows towards the lake basin and chemical and biotic alteration of these materials en route, especially as they pass through the highly productive and metabolically active wetland–littoral zone of the lake per se (net organic productivity in metric tons per hectare per year).

Ecosystem Interrelationships

- Phytoplankton is responsible for autotrophy in aquatic systems!
  - Via photosynthetic production



Ecosystem Interrelationships

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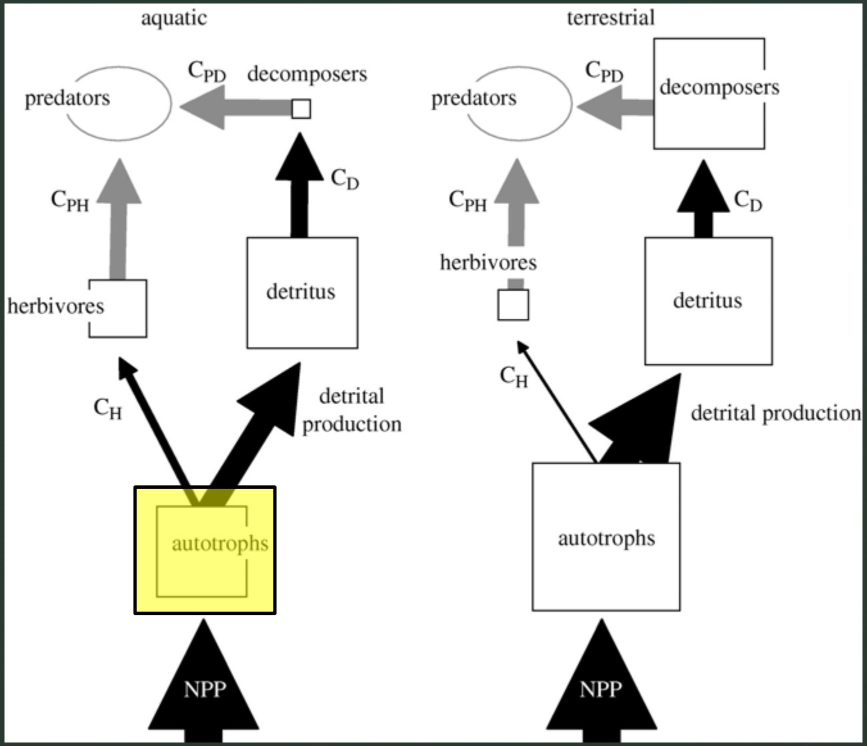


Productivity

- What is production?

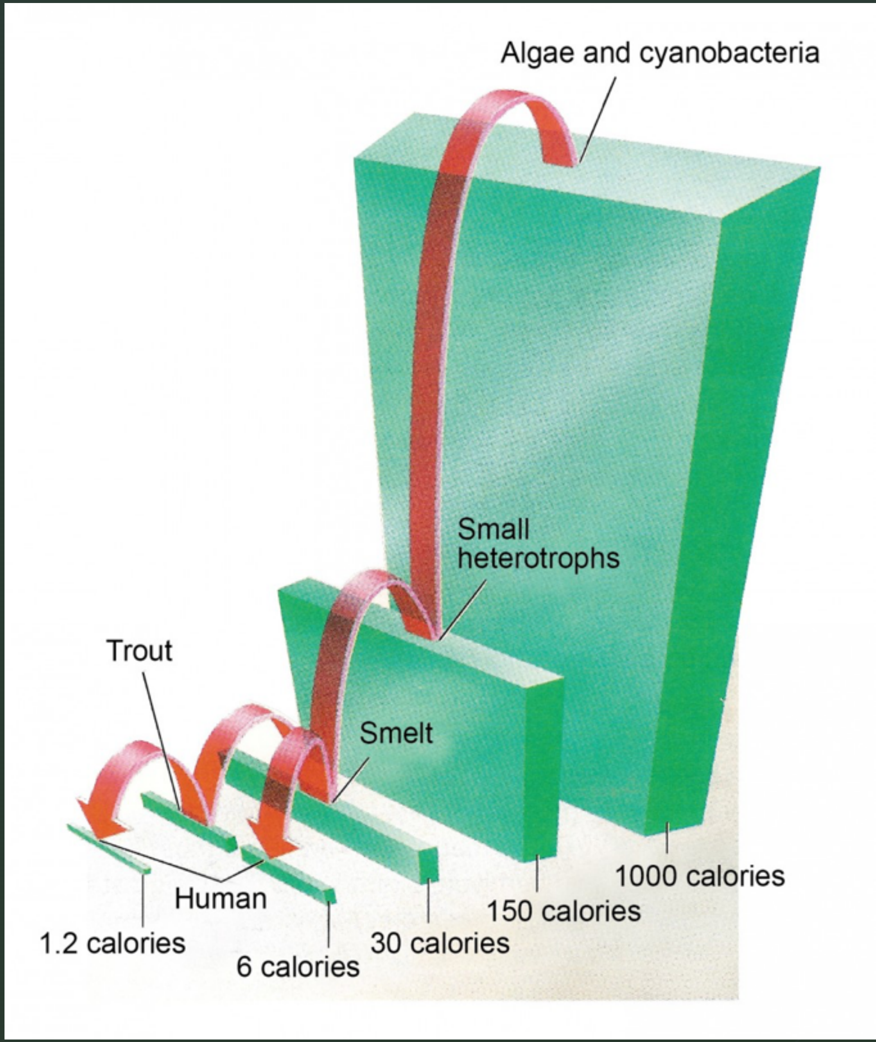
Productivity

- What is production?
  - Thienemann, 1931: maximum growth and development of organisms under optimal conditions,
  - Dussart, 1966: potential of organisms or organic matter per unit volume or surface area per unit time
  - Wetzel, 2001: realized or actual production of organisms, a functional group of organisms in a community, or an ecosystem
    - More specifically: the flow or flux of mass or energy over time; its dimensions are mass area^{-1} time^{-1} (e.g., g m^{-2} yr^{-1})
- Production: increase in biomass of new organic material formed over a period and includes any losses attributable to respiration, excretion, secretion, injury, death, or grazing.
  - Primary production: production by photosynthesis (mixotrophy does not count)

Production Terminology

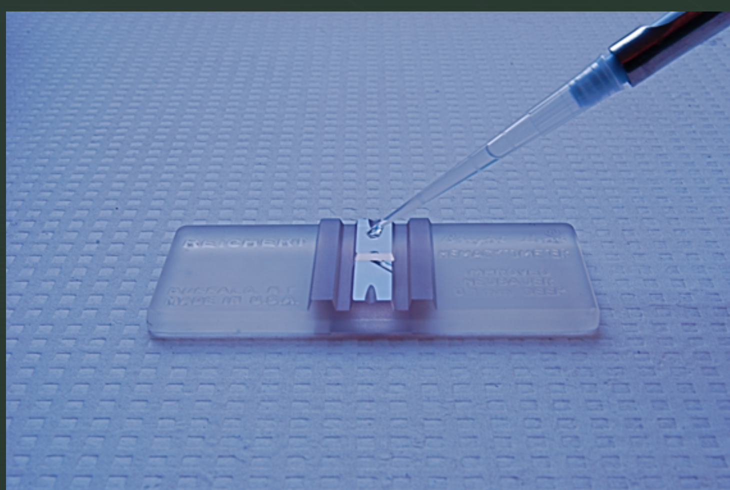
- Biomass: mass/weight of all living material in a unit area/volume at a given instant in time; product of mean individual weight and density, e.g., mass per unit volume, g mL^{-1}
- Yield: crop (or biomass) expressed as a rate
  - N.B., time scales matter! Daily, weekly, annual
- Gross production: all changes in biomass, including losses to predation and non-predation over time
- Net Production: gross production less losses over time

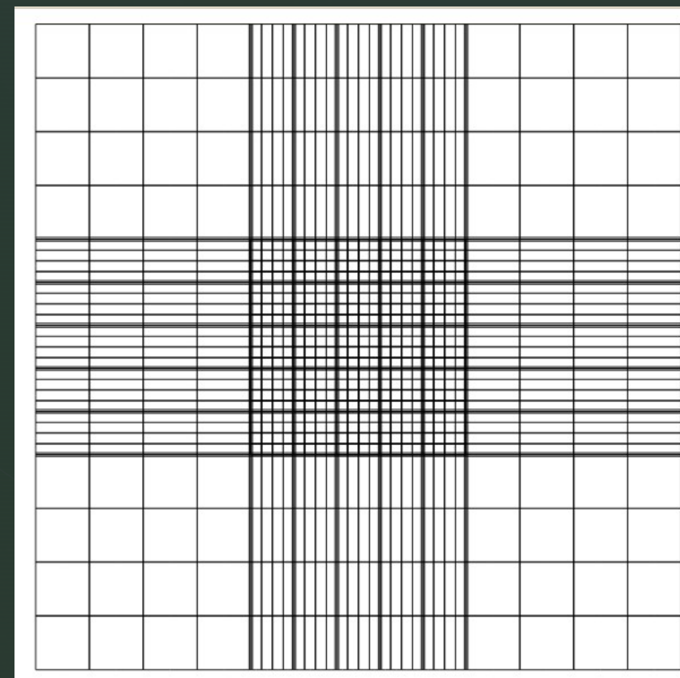
How do we measure *production*?



How do we measure *production*?

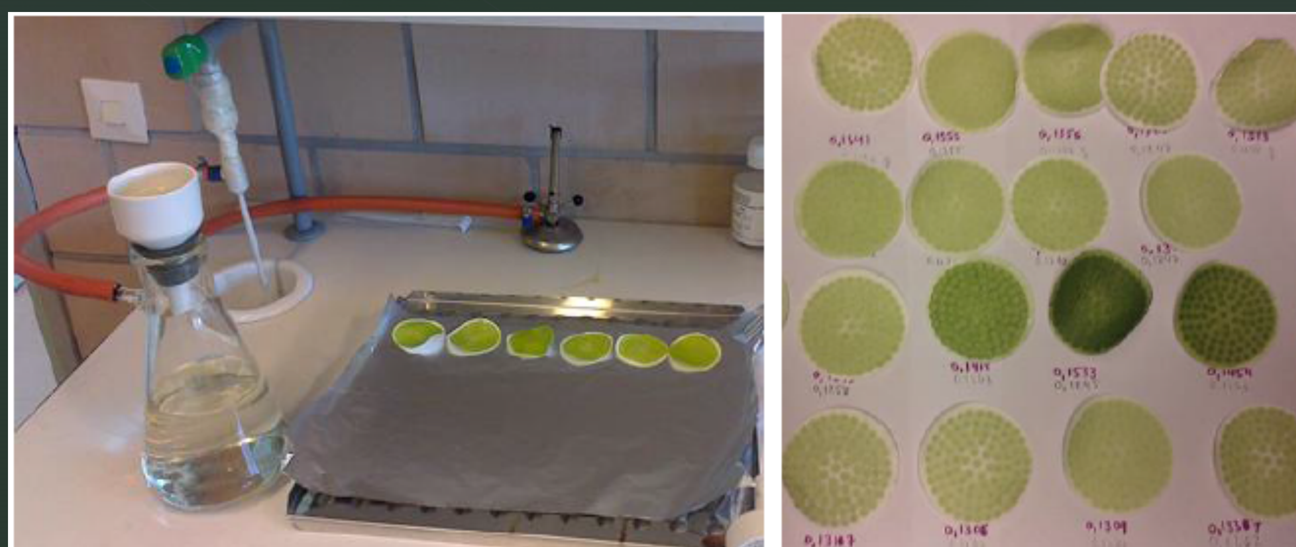
- Enumeration/biovolume
  - Counting per volume
  - Hemocytometer





How do we measure *production*?

- Weight/Mass
  - Wet-weight, usually a no-go
  - Dry-weight per volume (ash-free dry weight for larger orgs)



How do we measure *production*?

- Cellular constituents (organic carbon)
  - Organic carbon content of cells
    - Plants very stable (40-60% of ash-free dry weight)
      - Works for green algae, assumed to work for photosynthetic species
    - Cyanos much lower (20-30%)

How do we measure *production*?

- Other methods:
  - Oxygen production/consumption in light and dark bottles
  - pH drops
  - Carbon
  - Conductivity
  - Chlorophylls/pigments

How do we measure *production*?

- Production/Biomass ratios (P/B): temporary storage of mass/energy
- Represents turnover rate of energy flow/biomass

TABLE 8-3 Mean and Range of P/B Ratios among Trophic Groups of Freshwater Ecosystems[a]

	Mean	*Range*
Bacteria	141.0	73–237
Phytoplankton	113.0	9–359
Herbivorous Zooplankton	15.9	0.5–44.0
Carnivorous Zooplankton	11.6	1.5–30.4
Herbivorous Benthic Invertebrates	3.7	0.6 ≥ 200
Carnivorous Benthic Invertebrates	4.8	1.0–80

[a] After data of Saunders *et al.* (1980), Brylinsky (1980), and Benke (1993).

Production Summary

- Aquatic systems are open and *need* inputs from surrounding ecosystems.
- Productivity is low to intermediate in the terrestrial, highest in wetland interface, and lowest in open water lake (generally).
- Production is the flux of energy or mass over time.
- Primary production can be measured in many ways, some better than others.

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Tangent Terminology

- The complicated linguistics of Limnology (Wetzel 2001):
  - Alga(e): synonymous with phytoplankton, but differentiates by community
    - Periphyton (biofilms): epipelic, epilithic, epiphytic, epizooic, epipsammic (more to come in Benthos/Macrophyte lecture)
    - Metaphyton: algae/phytoplankton in littoral zone
    - Phytoplankton: assemblage of small plants or photosynthetic bacteria having no or very limited powers of locomotion; more or less subject to distribution by water movement

Terminology
(Linguistics with Larry)

- The complicated linguistics of Limnology (Bowman 2017):
  - Phytoplankton: assemblage of small *photosynthetic or mixotrophic organisms* having no or very limited powers of locomotion; more or less subject to distribution by water movement (Wetzel 2001)
  - Algae (*Latin*: seaweed): eukaryotic floaty/clingy/growy things
    - Greens, Reds, Euglenoids, Diatoms, Browns, Goldens, Yellow-greens, dinos
    - Photosynthetic
  - Cyanobacteria: prokaryotic/bacterial floaty/clingy/growy things
    - Formerly known as blue-green algae
    - Capable of photosynthesis *and* nitrogen fixation
- Why are these semantics important?
  - All phytoplankton were classified under *Plantae* for decades (when only one group actually falls into that clade, green algae)
  - Modern sequencing tells us about history of Earth and taxonomy

Terminology

- What we can say:
- Derrida's *Cogito et histoire de la folie* (1963)
  - *différance:* conceptual differentiation and deferral of meaning in process of signification
- Ergo, Phytoplankton is *not*:
  - Non-photosynthetic bacteria, non-photosynthetic protista, animalia, embryophtya, fungi… that live in water

Phytoplankton

- Photoautotrophic microbiota
  - Functionally the major synthesis of new organic material
- Pigments
  - Chlorophylls (A+C)
    - Chlorophyll a is primary photosynthetic pigment of life (A+C)
    - Chlorophyll b gathers light energy, transmits to Chl a (A)
  - Carotenoids (A) probably function like Chl b; b-carotene (C)
  - Xanthophylls (A + more C)
  - Biliproteins (mostly C + some A)

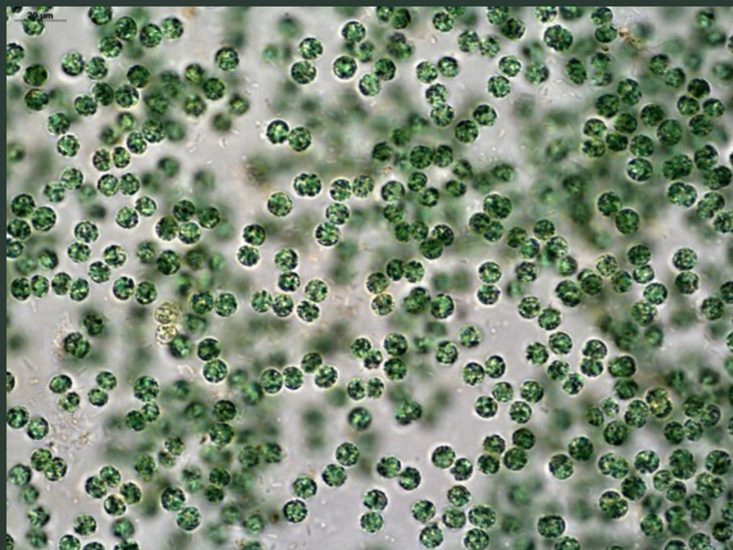
Taxonomy

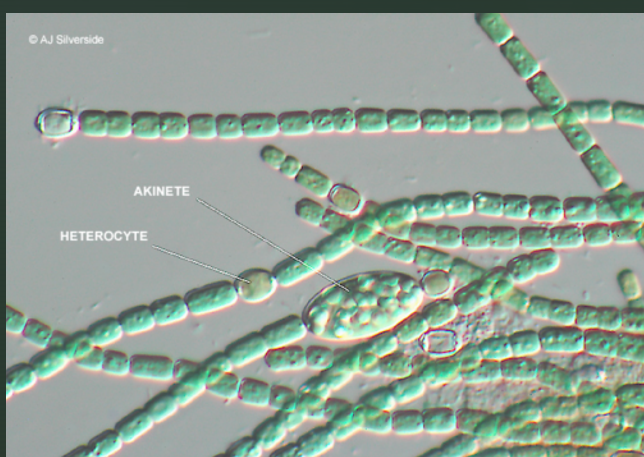
- Cyanobacteria (Cyanophyta *blue-green*; Myxophyceae *slime*)
- Algae
  - Greens (Chlorophyta; true ‘plants’)
  - Heterokonts (Heterokonta/‘protista’)
    - Yellow-greens (Xanthophyceae)
    - Golden-browns (Chrysophyceae)
    - Diatoms (Bacillariophyceae)
    - Browns (Phaeophyceae)
  - Cryptomonads (Cryptophyta)
  - Dinoflagellates (Dinoflagellata)
  - Euglenoids (Euglenophyta)
  - Reds (Rhodophyta)

Cyanobacteria

- Simple, prokaryotic cells
- Nuclear membrane, mitochondria, and chloroplasts
- Reproduce by binary fission
- Structurally and physiologically = bacteria; Functionally = plants/algae
- Can produce toxins (cyanotoxins); often used as dietary supplements and alternative, renewable fuel source
- Unicellular, filamentous, colonial—most in mucilaginous sheaths
- Heterocysts- sites of nitrogen fixation
- Examples: *Anabaena*, *Microcystis*, *Gloeotrichia*, *Spirulina*

Cyanobacteria

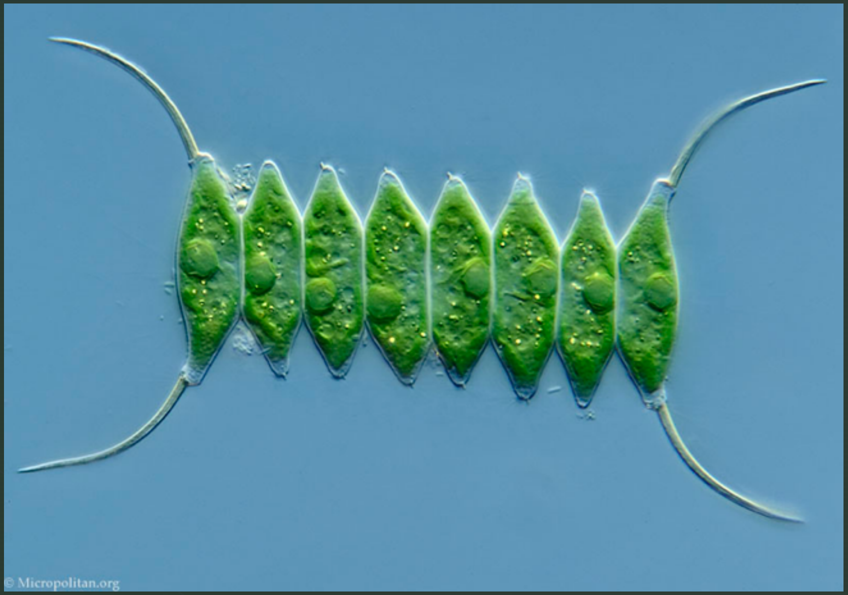


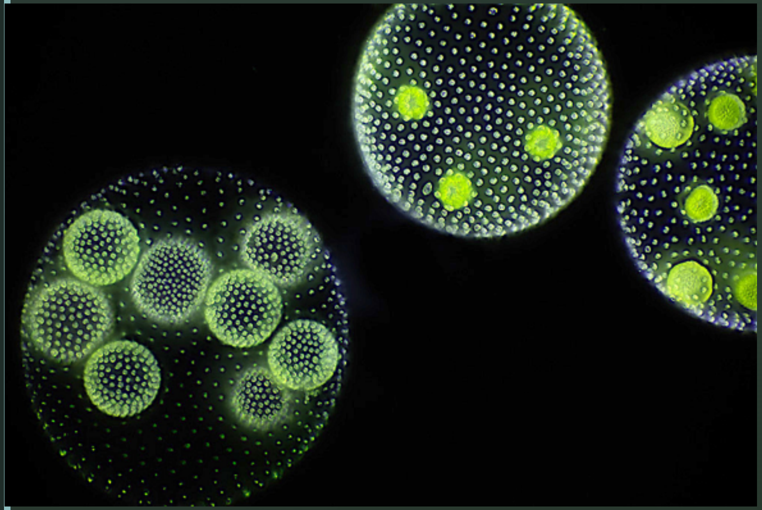


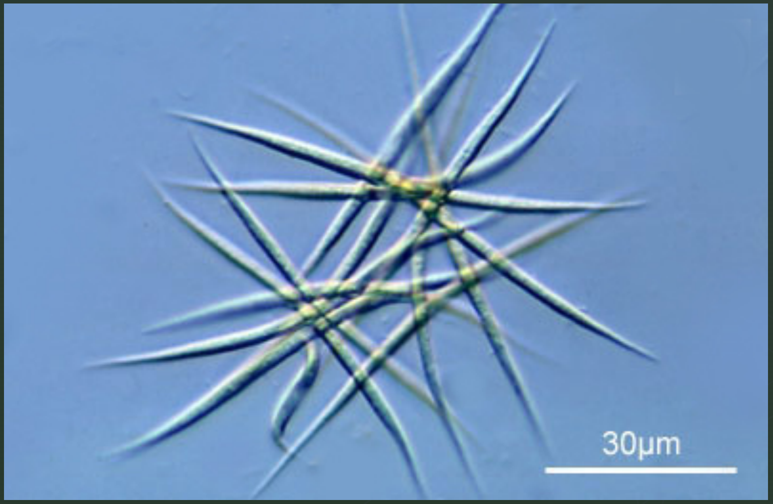
Greens (Chlorophyta)

- Almost exclusively freshwater (~7000 spp)
- Unicellular, multicellular, and colonial
- Asexual and sexual reproduction
- All have motile flagellated swimming cells
- Widely adapted and symbiotic (lichens, watermelon snow &c.)
- Some species heterotrophic, free-living, or parasitic
- Examples: *Chlamydomonas, Volvox, Scenedesmus, Ankistrodesmus, Prototheca* (human pathogen)

Greens (Chlorophyta)







Heterokonts

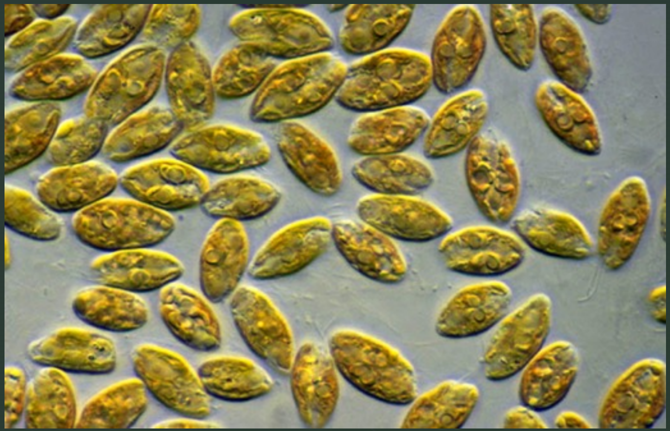
- Generalities: Cellular division at night; asex and sex; huge diversity
- Yellow-greens: mostly epiphytic
- Golden-browns: some possess delicate siliceous or calcareous shells/plates, very small as individuals, but colonial species dominate oligotrophic lakes under certain conditions, esp. *Dinobryon* and *Uroglena* (effective phosphate use, and many are heterotrophic consuming huge amounts of bacteria/microcrustacea); usually cold & low-light adapted (high-latitudes)
- Diatoms: hugely important, mostly sessile and littoral-associated; silicified cell walls (defining characteristic); two groups (Centrales=radial; Pennales= bilateral); usually unicellular
- Browns: large and primitive, none are planktonic (mostly marine or benthic)

Heterokonts

Cryptomonads

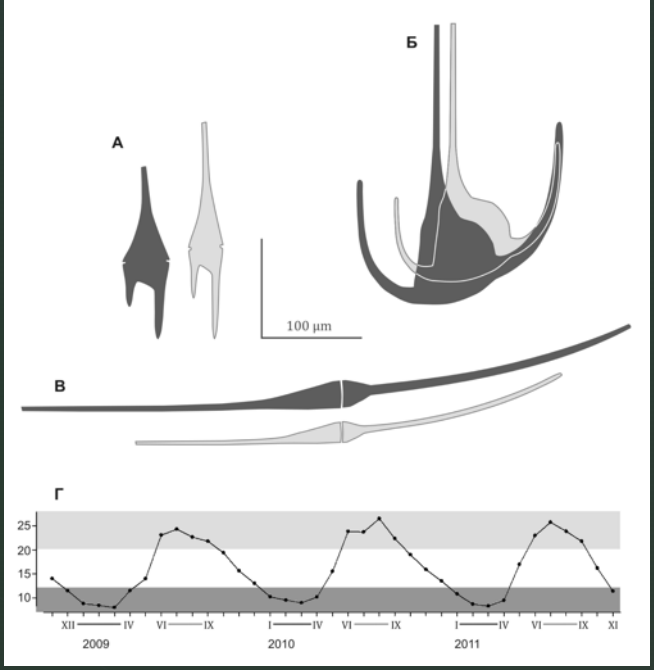
- Naked, unicellular, motile microflagellates
- Low diversity, mostly *Cryptomonas, Rhodomonas,* and *Chroomonas*
- 2 flagella; wide spectrum of color, only asex is known
- Important stabilizing force in lakes
- Ecology: intermittent numerical dominance, high nutritional quality, short turnover time, grow/reproduce in low light, effective pulse growth timing

Cryptomonads

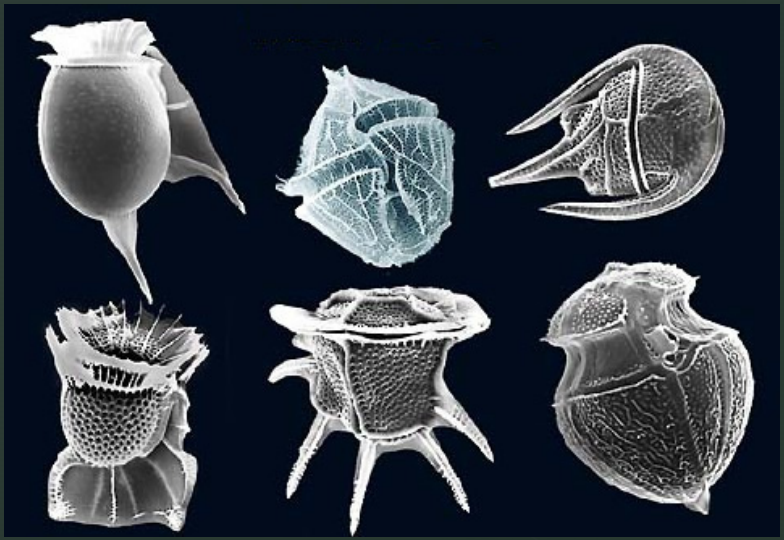


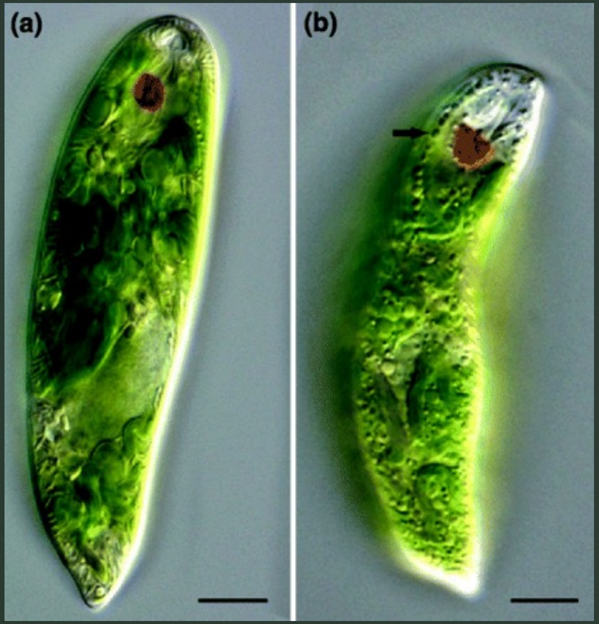
Dinoflagellates, Euglenoids, and Reds

- Dinos
  - Unicellular, flagellated, motile
  - Sex or asex (with diapausing spores)
  - Seasonal polymorphism (increased temps); less viscous water, more buoyant
  - Infamous red tides
- Euglenoids
  - Few are planktonic; unicellular; 1-3 flagella; most are facultative heterotrophs; eye spot
  - Most abundant when ammonia and DOC levels are high, e.g., during turnover, polluted lakes, farm ponds
- Reds
  - None are planktonic; >95% are marine

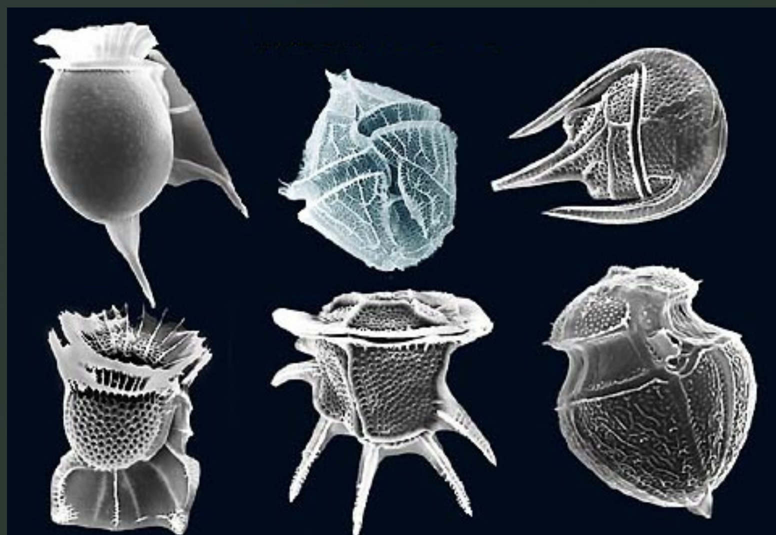


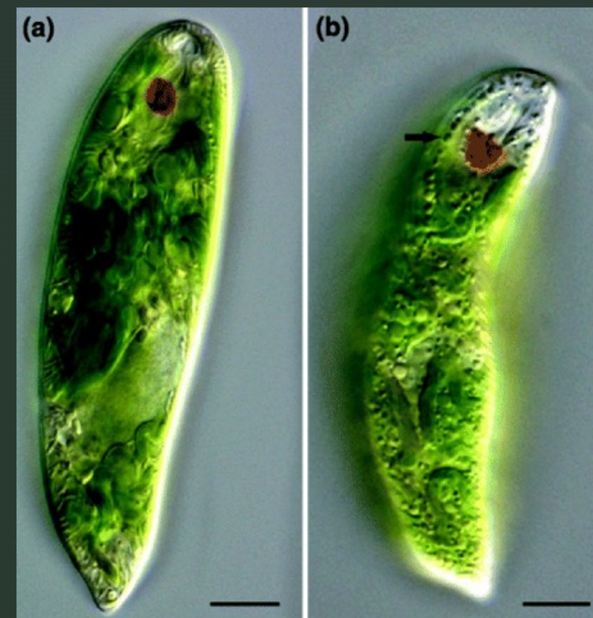
Dinoflagellates, Euglenoids, and Reds

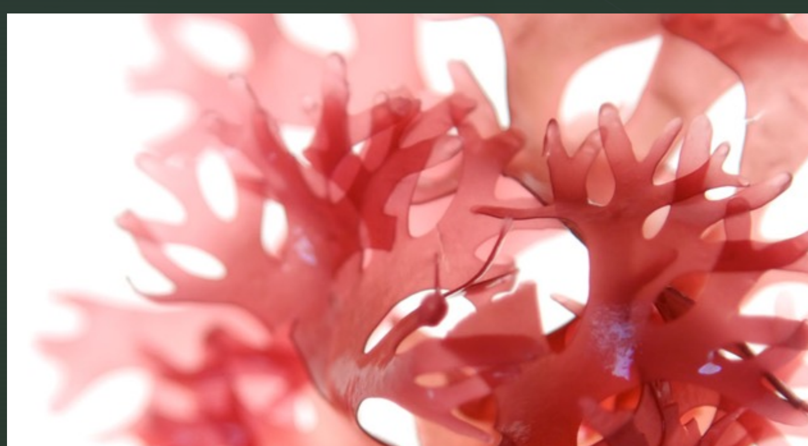


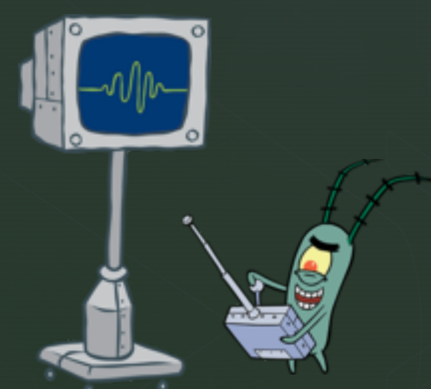


Dinoflagellates, Euglenoids, and Reds









Phenology and Dynamics

- Coexistence
  - “Paradox of the Plankton” (Hutchinson, 1961)
  - Multi-specific equilibria exist in open water of lakes
    - Niche overlap? Uniform conditions? Commensalism? Symbiosis? Selective grazing?
    - ”Contemporaneous disequilibrium” (Richerson et al., 1970)

Phenology and Dynamics

TABLE 15-4 Characteristics of Common Major Associations of the Phytoplankton in Relation to Increasing Lake Fertility[a]

General lake trophy	Water characteristics	Dominant algae	Other commonly occurring algae
Oligotrophic	Slightly acidic; very low salinity	Desmids *Staurodesmus, Staurastrum*	*Sphaerocystis, Gloeocystis, Rhizosolenia, Tabellaria*
Oligotrophic	Neutral to slightly alkaline; nutrient-poor lakes	Diatoms, especially *Cyclotella* and *Tabellaria*	Some *Asterionella* spp., some *Melosira* spp., *Dinobryon*
Oligotrophic	Neutral to slightly alkaline; nutrient-poor lakes or more productive lakes at seasons of nutrient reduction	Chrysophycean algae, especially *Dinobryon*, some *Mallomonas*	Other chrysophyceans, (e.g., *Synura and Uroglena*); diatom *Tabellaria*
Oligotrophic	Neutral to slightly alkaline; nutrient-poor lakes	Chlorococcal *Oocystis* or chrysophycean *Botryococcus*	Oligotrophic diatoms
Oligotrophic	Neutral to slightly alkaline; generally nutrient poor; common in shallow Arctic lakes	Dinoflagellates, especially some *Peridinium* and *Ceratium* spp.	Small chrysophytes, cryptophytes, and diatoms
Mesotrophic or eutrophic	Neutral to slightly alkaline; annual dominants or in eutrophic lakes at certain seasons	Dinoflagellates, some *Peridinium* and *Ceratium* spp.	*Glenodinium* and many other algae
Eutrophic	Usually alkaline lakes with nutrient enrichment	Diatoms much of year, especially *Asterionella* spp., *Fragilaria crotonensis, Synedra, Stephanodiscus,* and *Melosira granulatea*	Many other algae, especially greens and cyanobacteria during warmer periods of year; desmids if dissolved organic matter is fairly high
Eutrophic	Usually alkaline; nutrient enriched; common in warmer periods of temperate takes or perennially in enriched tropical lakes	Cyanobacteria, especially *Anacystis* (= *Microcystis*), *Aphanizomenon, Anabaena*	Other cyanobacteria; euglenophytes if organically enriched or polluted

[a] After Hutchinson (1967).

Phenology and Dynamics

- Many phytoplankton are auxotrophic (need vitamins that they cannot synthesize), particularly B_{12}

TABLE 15-6 General Requirements for Vitamins among the Algae and Cyanobacteria[a]

Algal groups	*Biotin*	*Thiamine*	*Vitamin B_{12}*	*Predominant vitamin requirements*
Cyanobacteria	0	0	++	B_{12}
Rhodophyceae	0	0	++	B_{12}
Bacillariophyceae	0	+	++	B_{12}
Xanthophyceae	0	0	0	None
Phaeophyceae	0	0	+	None
Chlorophyceae	0	+	++	B_{12}
Chrysophyceae and Haptophyceae	–	++	+	Thiamine
Cryptophyceae	–	–	+	None
Dinophyceae	+	0	++	B_{12}
Euglenophyceae	–	–	+	None

[a] After discussion of Provasoli and Carlucci (1974).
++ = required in many species; + = few species; – = requirement rare; 0 = no known requirement.

Phenology and Dynamics

- General trends for dimictic temperate zone lakes
  - Under-ice and midwinter conditions, often dominated by small and motile species, small greens, and some diatoms
    - *Rhodomonas* and *Cryptomona*, *Chlamydomonas*, and *Synedra, Tabellaria,* and *Fragilaria*
  - Summer ‘clearwater’ phase
    - High temps, high water column stability, high light, low nutrients, high predation
    - Filtration rates of the system outpace replacement rates, increases in inedible and less-readily grazed algae

Phenology and Dynamics

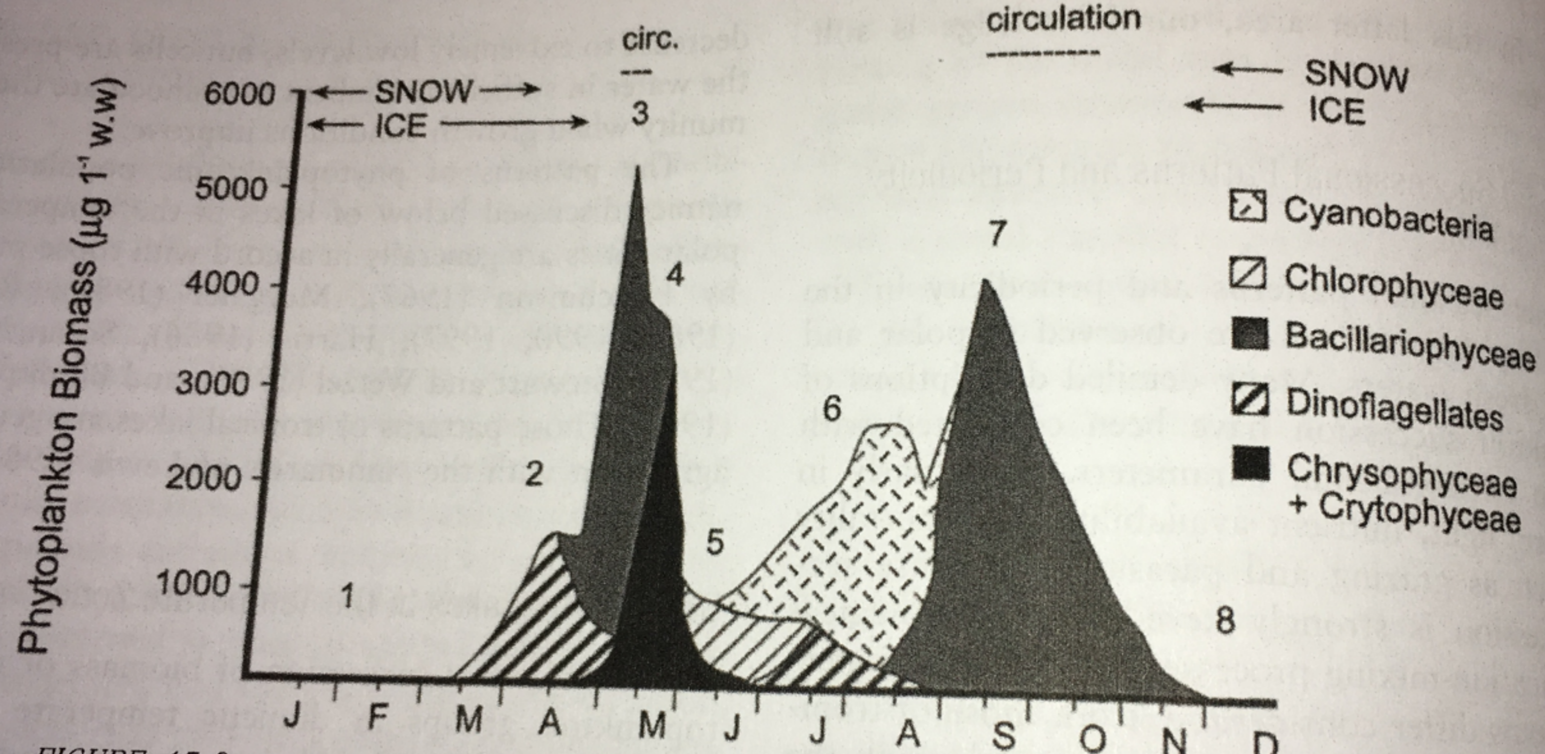


FIGURE 15-9 Model of biomass development and seasonal succession of major phytoplankton groups in a typical temperate lake of moderate productivity. Numbers refer to the eight seasonal periods discussed in the text. (Data from Lake Erken, Sweden; diagram modified from Blomqvist *et al.* (1994.)

1. midwinter; 2. late winter; 3. spring circ; 4.initial summer strat; 5. summer clearwater phase; 6. latter summer strat; 7. fall circ; 8. late autumn decline

Phenology and Dynamics

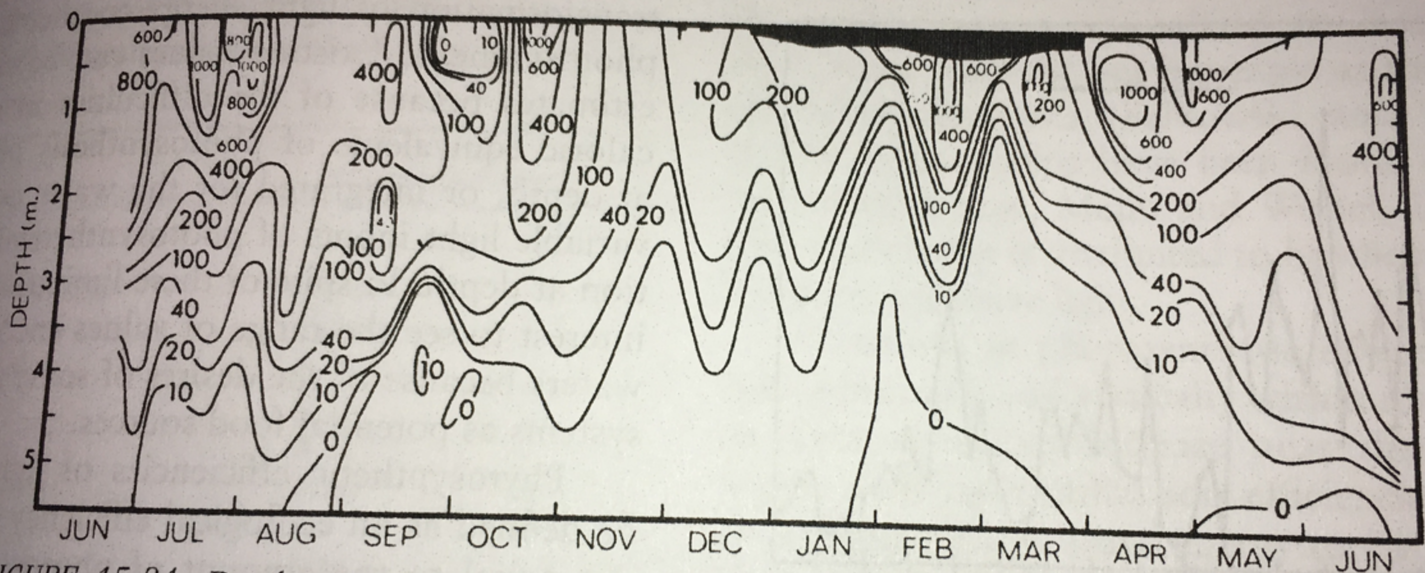


FIGURE 15-24 Depth–time distribution of the *in situ* rates of production of phytoplankton in mg C m^{-3} day^{-1}, Wintergreen Lake, Michigan, 1971–1972. Opaque area = ice cover to scale. (From Wetzel *et al.*, unpublished data.)

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Lab techniques

- http://fmp.conncoll.edu/Silicasecchidisk/CarolinaKey_Information.html
- http://cfb.unh.edu/phycokey/phycokey.htm

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