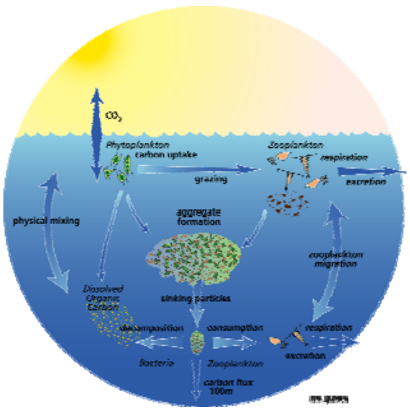
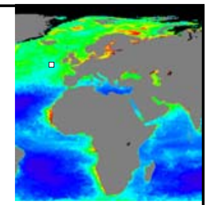


Food web structure is a key determinant on carbon fluxes:

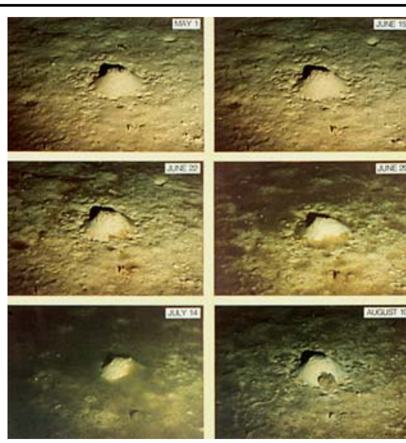
1) Cell size and geometry influence sinking rate
2) Zooplankton repackage material and vertically migrate
3) Small cells support longer food webs = more carbon recycled to CO_2

Zooplankton repackage plankton into rapidly sinking fecal material



Sedimentation of diatom-rich salp fecal pellets > 1 mm long, 350 µm wide, 10 µg C per pellet---these things sink FAST...

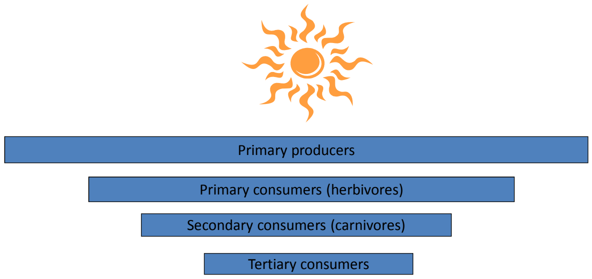
Direct aggregation and pulsed export is also important



Flux of labile phytodetritus to the deep North Atlantic

Why do we care about biomass?

- Information on biologically stored energy
- Quantify the amount of carbon held in marine biota (carbon budgeting purposes)
- Identify how much “material” is available to at each step of the food chain.



Biomass

(mg C L^{-1})

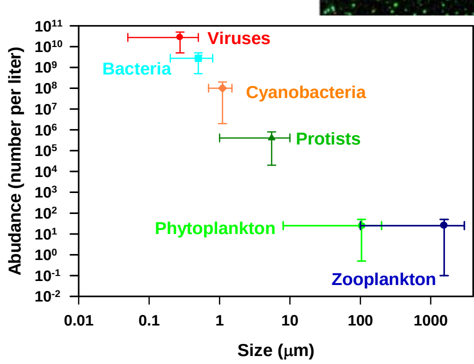
The way biomass is distributed among trophic levels in the food web provides clues to the efficiency of energy transfer through the ecosystem .

Note: this is a static depiction-it does not provide information on how fast biomass turns over within each trophic level.

In a "typical" liter of seawater…

Fish	None
Zooplankton	10
Diatoms	1,000
Dinoflagellates	10,000
Nanoflagellates	1,000,000
Cyanobacteria	100,000,000
Prokaryotes	1,000,000,000
Viruses	10,000,000,000

High abundance does not necessarily equate to high biomass. Size is important.

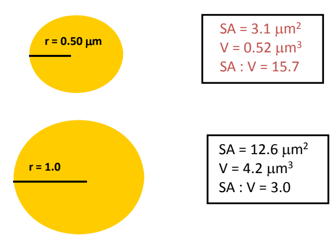


Why are pelagic organisms so small?

Consider a spherical cell:

SA= $4\pi r^2$

V= $4/3\ \pi r^3$



The smaller the cell, the larger the SA:V
Greater SA:V increases cell's ability to absorb nutrients from dilute solution.
This might allow smaller cells to out compete larger cells for limiting nutrients.

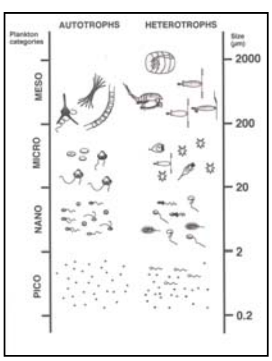
- "Typical" concentrations of inorganic nutrients in the open sea:
  - Subtropical North Pacific:
    - Nitrate+nitrite 1-10 nM (0.001-0.01 µM)
    - Phosphate 10-40 nM (0.01-0.04 µM)
- "Typical" concentrations of inorganic nutrients in soils:
    - Nitrate+Nitrite 5-100 µM
    - Phosphate 5-30 µM

How do we measure plankton biomass?

- **Count and measure individuals and calculate carbon**
- **Weigh (either dry or wet) cells and calculate biomass**
- **Estimate living carbon using some biomolecule proxy (DNA, ATP, chlorophyll)**

Particulate carbon

- **Technique: combust (oxidize) organic material and measure resulting CO_2.**
- **Need to concentrate cells: typically glass filters (usually ~0.7 µm pore size) or tangential flow (Fukuda et al. 1998)**
- **Measurements include living cells and detritus.**



Zooplankton

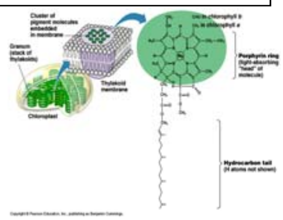
- Small zooplankton are usually enumerated by microscopy and converted to cell carbon
- Larger zooplankton can be weighed for approximation of carbon.

Primary consumers (herbivores)

Secondary consumers (carnivores)

Phytoplankton carbon

- Phytoplankton carbon determinations are most often derived from measurements of chlorophyll; this requires a conversion factor.
- Phytoplankton carbon can also be estimated based on cell size and abundances (microscopy and/or flow cytometry).




Primary producers

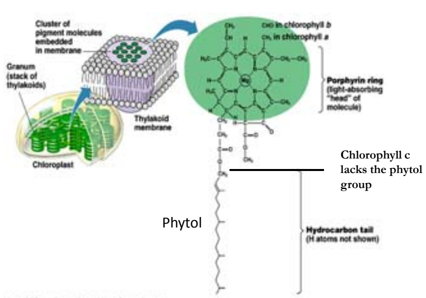
Light harvesting photosynthetic pigments

- Chlorophylls
- Carotenoids
- Biliproteins

- Recently discovered photoreceptor proteins (Proteorhodopsin and Bacteriorhodopsin) serve as proton pumps, but do not appear to harvest energy for oxygenic photosynthesis.

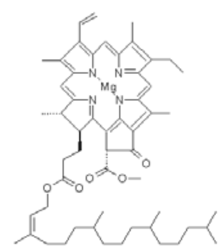
Chlorophylls

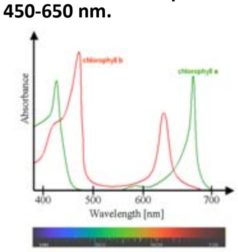
- Cyclic tetrapyrole with a magnesium atom chelated in the center of the ring



- All oxygen evolving photosynthetic plankton contain Chlorophyll *a* (peak absorption 465 and 665 nm)

- Chl *a*, *b*, and *c* all absorb strongly in the red (between 440-465 nm) and blue wavelengths (~645-665 nm). The presence of Chl *b* and *c* increases the absorption between 450-650 nm.

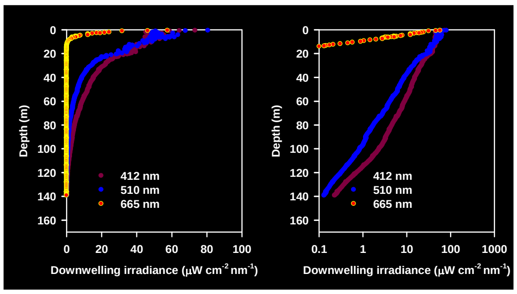


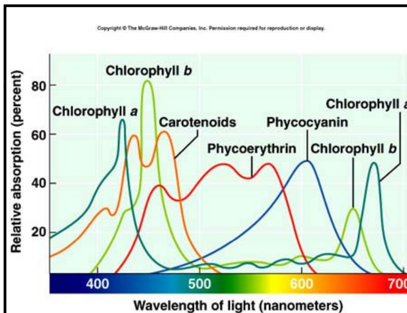


The exponential decay of light with depth:

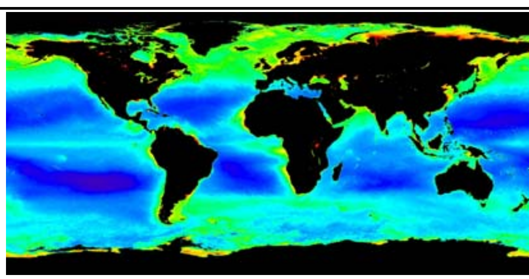
$$I_Z = I_0 e^{-kZ}$$

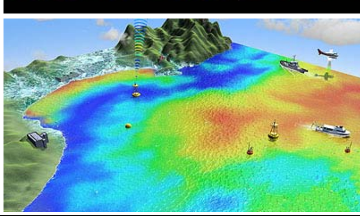
I_Z = light at depth Z (units of mol quanta m^{-2} s^{-1})
I_0 = light at surface of ocean (incident irradiance; units of mol quanta m^{-2} s^{-1})
k = attenuation coefficient (units of m^{-1})



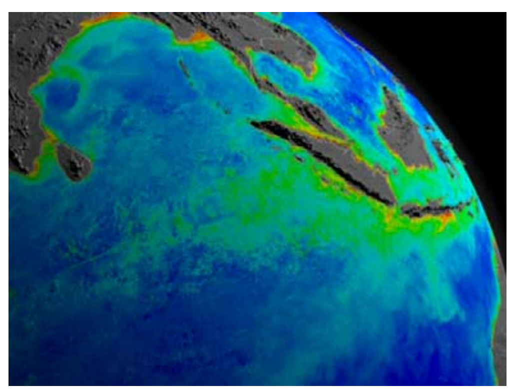


Carotenoids and biliproteins extend the spectral region able to support plankton growth; thus light forms an important environmental control on phytoplankton evolution.



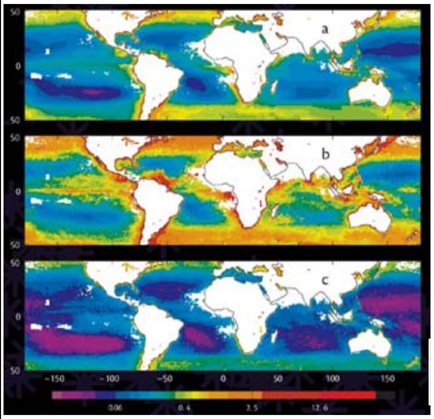


If we can determine phytoplankton biomass from chlorophyll, we can use various remote sampling technologies



1) Physically forced dynamics (ENSO, Amazon plume, upwelling, etc.)
2) Seasonality
3) Event scale variability

7 years of ocean chlorophyll from satellites



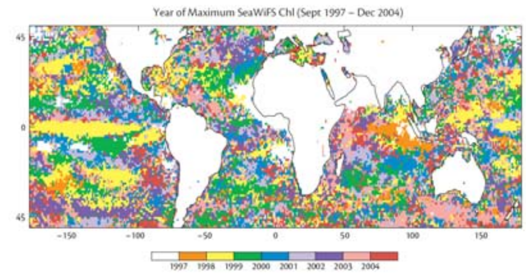
Mean

Maximum

Minimum

High latitudes are highly variable, central gyres more stable

Biological variability in space and time



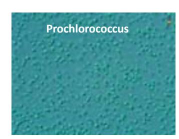
Spatially coherent interannual variability in selected ecosystems, but most ocean ecosystems appear highly variable in space and time

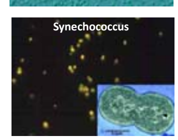
Major divisions and classes of photosynthetic plankton in the ocean

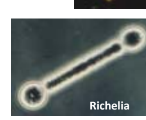
- Prokaryotes
  - Cyanobacteria
- Eukaryotes:
  - Chlorophyta (green algae); include the following classes:
    - Chlorophyceae
    - Prasinophceae
    - Euglenophyceae
  - Chromophyta (brown algae); include the following classes:
    - Chrysophyceae
    - Pelagophyceae
    - Prymnesiophyceae
    - Bacillariophyceae (diatoms)
    - Dinophyceae (dinoflagellates)
    - Cryptophyceae (crytophytes)
    - Phaeophyceae (phaeophytes)
  - Rhodophyta (red algae)-mostly macrophytes

Marine cyanobacteria

- **Cyanobacteria:** major groups of cyanobacteria in the oceans include: *Prochlorococcus*, *Synechococcus*, *Trichodesmium*, *Crocosphaera*, *Richelia*
  - Wide range of morphologies: unicellular, filamentous, colonial
  - Some species fix N_2
  - Hugely abundant in the open sea – often dominate photosynthetic biomass and production



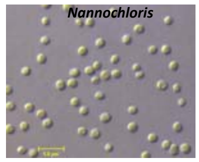




Many images from: http://www.sb-roscoff.fr/Phyto/gallery/main.php?g2_itemId=19

Chlorophyta (green algae)

- Chlorophytes
  - Contain Chl *b*
  - Uncommon in open ocean; mostly freshwater.
  - Very diverse (more than 7000 species described)
  - Can be single cells or colonies, coccoid or flagellated
  - *Chlorella, Chlamydomonas, Dunaliella*
- Prasinophytes
  - Contain Chl *b*
  - Predominately unicellular
  - Relatively common, but not abundant in ocean
  - Can be single cells or colonies, coccoid, biflagellated, or quadri-flagellated


Nannochloris


Prasinophyceae

Chromophyta (brown algae)

- Pelagophytes
  - Contain Chl *c*
  - Very common in open ocean.
  - Coccoid or monoflagellated

Pelagomonas

- Chrysophytes
  - Contain Chl *c*
  - Relatively rare in open ocean
  - Mostly bi-flagellated (flagella of unequal length)


Dictyocha

- Cryptophytes
  - Contain Chl *c*
  - Contain carotenoid alloxanthin
  - Contain phycoerythrin or phycocyanin
  - Flagellated unicells


Rhodomonas salina

Images from: http://planktonnet.sb-roscoff.fr/index.php#search

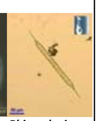
Chromophyta (brown algae)-Cont.

- Prymnesiophytes
  - Mainly biflagellates
  - Very common in open ocean
  - 2-5 µm
  - Some species form $CaCO_3$ plates (coccoliths)


Emiliana huxleyi

- Bacillariophytes
  - Ubiquitous
  - All contain Chl *c* and carotenoid fucoxanthin
  - Rigid silica-impregnated cell wall
  - Many form colonies
  - 2 prominent cell morphologies: centric and pennate

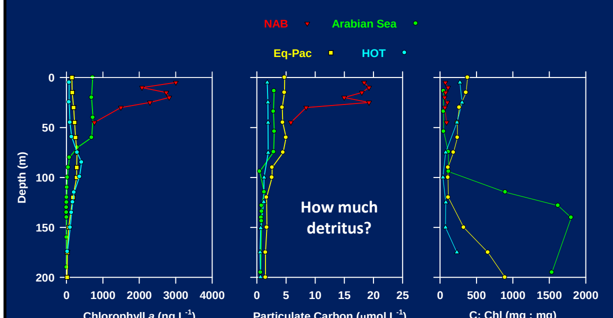

Coscinodiscus

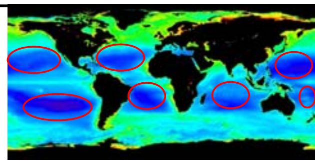

Rhizosolenia

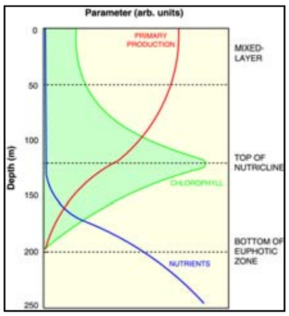
- Dinophytes
  - Possess the carotenoid peridinin
  - Widely distributed (estuaries, open ocean)
  - Mostly unicellular and autotrophic, but colorless heterotrophs can also be abundant
  - 2 flagella
  - Many are bioluminescent and some case toxic red tides blooms

Carbon to Chlorophyll Conversions

- Chlorophyll concentrations can vary depending on physiological and environmental history of the cells







In the ocean gyres, chlorophyll concentrations are low in the surface water, greater at depth (80-150 m). In contrast, most of the production (=synthesis of biomass) occurs in the well-lit upper ocean.