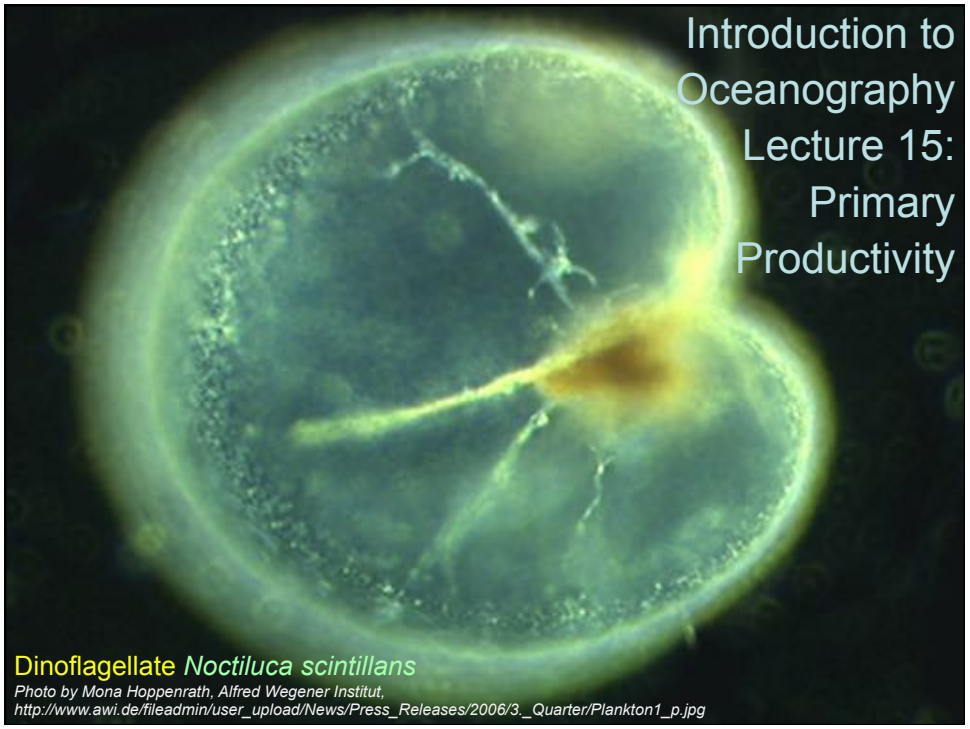
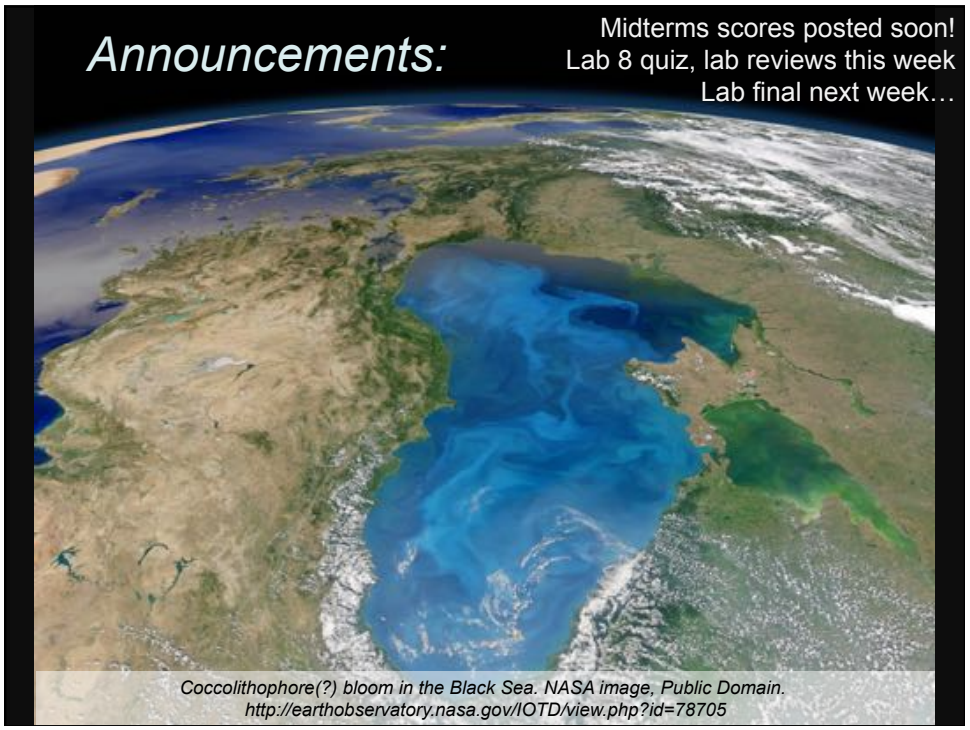


Dinoflagellate *Noctiluca scintillans*

Photo by Mona Hoppenrath, Alfred Wegener Institut, http://www.awi.de/fileadmin/user_upload/News/Press_Releases/2006/3._Quarter/Plankton1_p.jpg



Coccolithophore(?) bloom in the Black Sea. NASA image, Public Domain. http://earthobservatory.nasa.gov/IOTD/view.php?id=78705

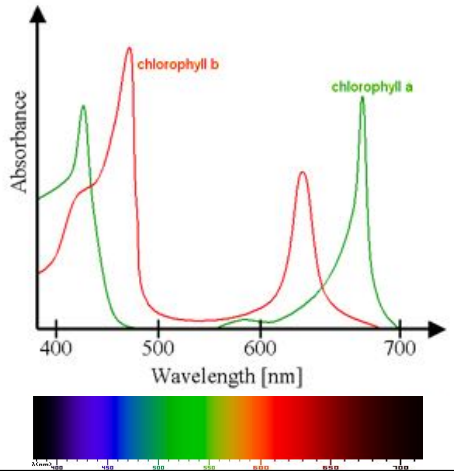
Photosynthesis

Living systems require chemical energy

Chlorophyll: a green pigment that captures photons and transfers their energy to electrons, an through a series of steps creates carbohydrate molecules (chemical energy) and oxygen.

Chlorophyll looks green because it absorbs red and blue light, and reflects green light

Sargassum algae, NOAA, Public Domain, http://oceanexplorer.noaa.gov/explorations/02sab/logs/aug09/media/lines.html



Adapted from figure by Aushulz, Wikimedia Commons, Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:Chlorophyll_ab_spectra2.PNG

Photosynthesis Reaction

sunlight

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$$

Carbon dioxide + *water* *(yields)* *Glucose (a sugar)* + *Oxygen*

Typically, ~100 grams carbon/ year / meter^2 is fixed to sugar in the open ocean

This 100 grams/year/meter^2 is "*Primary Production*": The rate of new organic carbon creation by autotrophs.

How can we measure productivity?

Color-imetry! (yes, it means what you think)

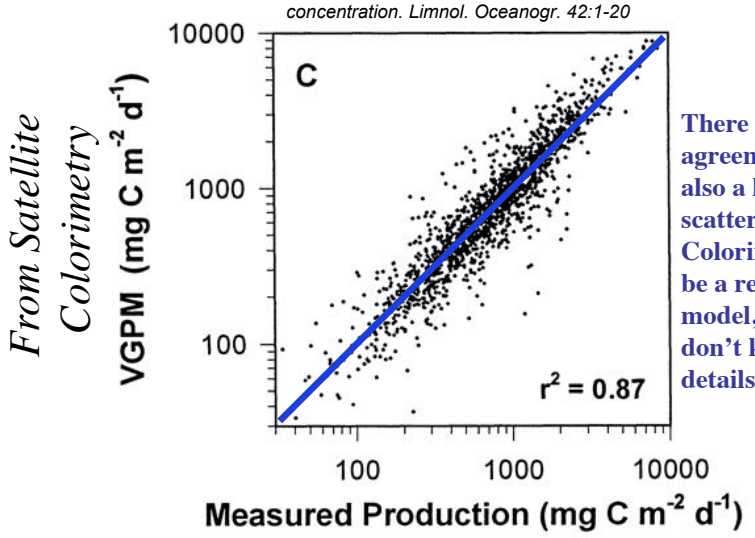
- Chorophyll enables photosynthesis by absorbing blue and red light. Green light is reflected or scattered.
- Green ocean implies lots of chlorophyll
- Lots of chlorophyll implies lots of productivity!
- Satellites like SEASTAR can measure color from space. This makes colorimetry ideal for global ocean surveys, if it works. This technique will be bad for long-lived plants (chlorophyll is present even when big plants aren't active, I.e. spruce trees)

HYPOTHESIS: Green color in the ocean correlates with primary productivity.

PREDICTION: Productivity estimated from color should be the same as productivity measured by "weighing" uptake of inorganic carbon.

Colorimetry compared with "weighing"

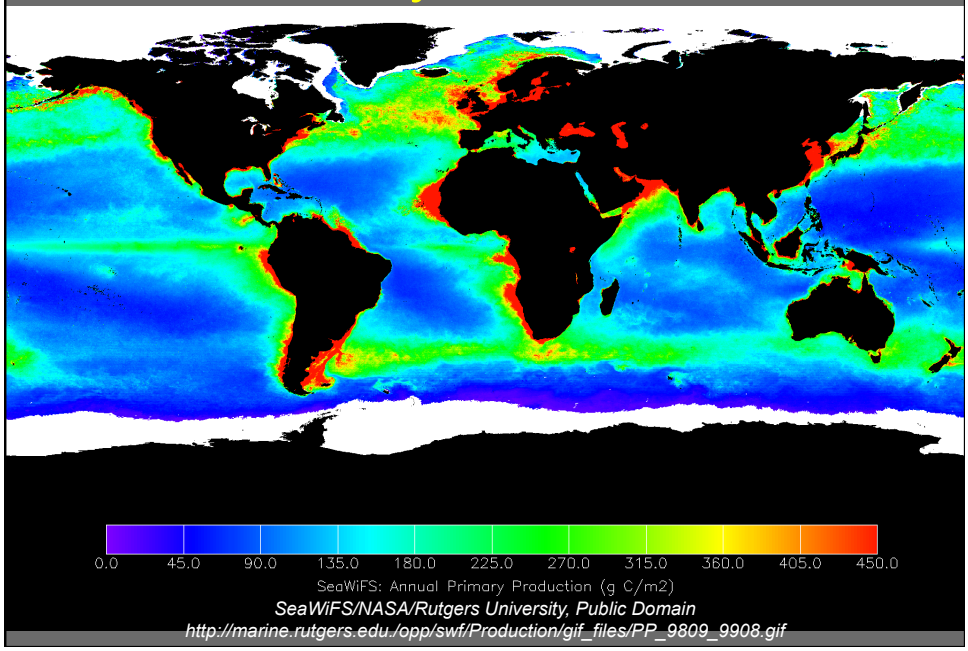
M.J. Behrenfeld & P.G. Falkowski. 1997. Photosynthetic rates derived from satellite-based chlorophyll concentration. Limnol. Oceanogr. 42:1-20



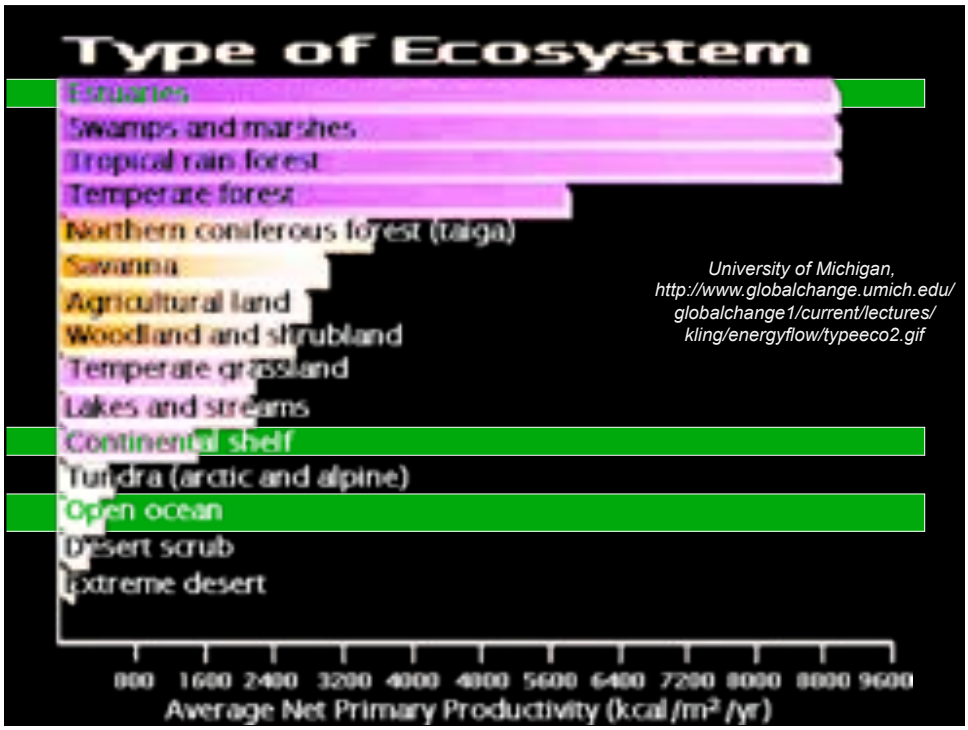
There is good agreement, but also a lot of scatter. Colorimetry may be a reasonable model, but we still don't know all the details!

From Measured uptake of inorganic ^{14}C

Productivity from SeaWiFS



SeaWiFS/NASA/Rutgers University, Public Domain
http://marine.rutgers.edu./opp/swf/Production/gif_files/PP_9809_9908.gif



University of Michigan,
http://www.globalchange.umich.edu/globalchange1/current/lectures/kling/energyflow/typeeco2.gif

Primary Production

1. Amount depends on:
   a. Driving Energy (Solar or chemical)
   b. Nutrients
2. <u>Regions of Highest Productivity</u>
   a. Continental margins: Upwelling (Ekman pumping) and vertical mixing common along margins. Also close to rivers, dust sources
   b. Equatorial Divergences
   c. Antarctic Divergence
   d. Northern Pacific & Northern Atlantic
      i. Deepwater upwelling in Pacific; Divergence within subpolar Arctic/Atlantic gyres

Primary Production

3. <u>Regions of Lowest Productivity</u>
   a. Interiors of subtropical gyres
      i. This is where ocean water is stably stratified
      i.e., surface water stays at the surface
      --- Strong, stable pycnocline, little vertical mixing. Few nutrients are brought up to the surface.
      --- These are the "deserts" of the ocean, most nutrients lost as dead organisms sink into the deep ocean

Primary Production

4. Primary Producers (Autrotrophs)
    a. Eukaryotic Algae (Seaweeds & Single celled photosynthesizers)
        i. Benthic (coastal): minor component
            i. Seaweeds
        ii. Pelagic phytoplankton: primary component
            i. Diatoms, dinoflagellates, coccolithophores, etc.
    b. Cyanobacteria: blue-green algae
    c. Picoplankton / Archea(?)
    d. Chemosynthetic Bacteria: Use inorganic compounds to get energy
        i. They oxidize compounds such as H_2S (Hydrogen sulfide)

Abalone, Oregon Coast Aquarium, photo by Little Mountain 5, Wikimedia Commons, Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:Abalone_OCA.jpg

Ocean Habitats

- Where do organisms live in the oceans?
  - Biozones
    - Benthic vs. Pelagic
      - Sea floor vs. Free-floating/free-swimming
  - Light Zones
    - Photic, Dysphotic, Aphotic

Habitat

1. Pelagic (oceanic): live in the water column
2. Benthic: Live in or on ocean bottom

Whale shark, Georgia aquarium, Zac Wolf, Creative Commons A S-A 2.5, http://commons.wikimedia.org/wiki/File:Whale-shark-enhanced.jpg

Coral polyp, Nick Hobgood, Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:Euphyllia_glabrescens_%28Hard_coral%29_with_polyps_extended.jpg

Ocean Habitats

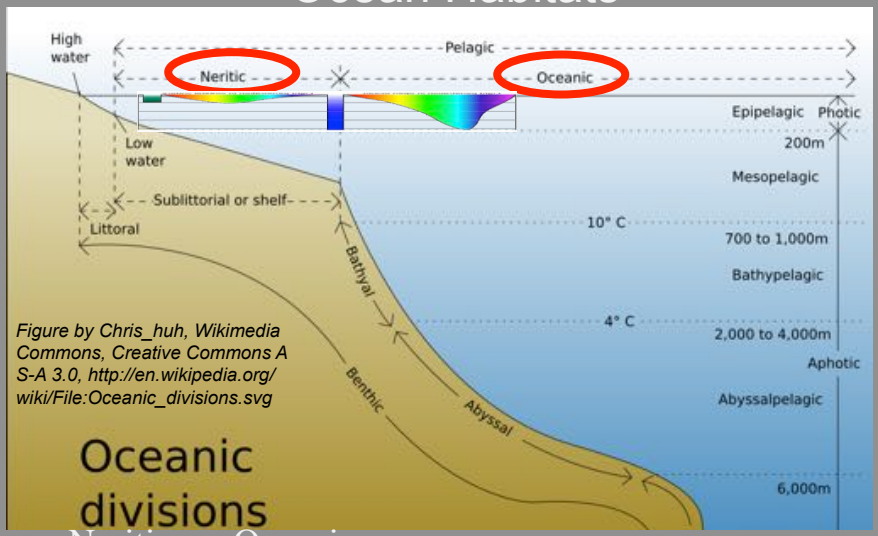


Figure by Chris_huh, Wikimedia Commons, Creative Commons A S-A 3.0, http://en.wikipedia.org/wiki/File:Oceanic_divisions.svg

- Neritic vs. Oceanic
  - –Shelf waters vs. deep waters
  - –Neritic/Sublittoral: photic zone reaches to sea floor

Light zones

Photic Zone: lit by sunlight, ~ 100 - 500m deep

Euphotic Zone:

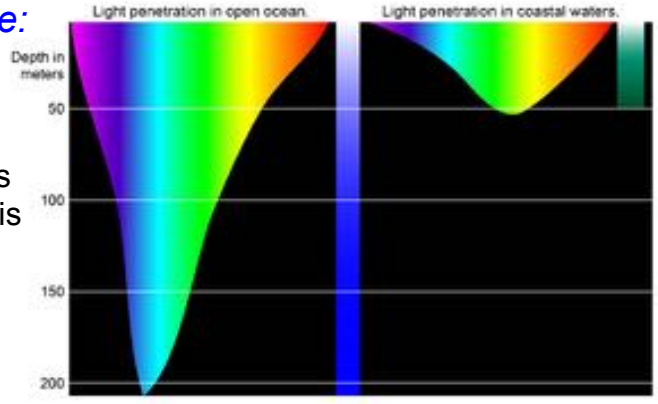
autotrophs capture more energy than they use; net fixation of carbon; net production of O_2

Disphotic Zone:

Not enough light for profitable photosynthesis (photosynthesis < respiration)

Aphotic Zone:

Permanent darkness



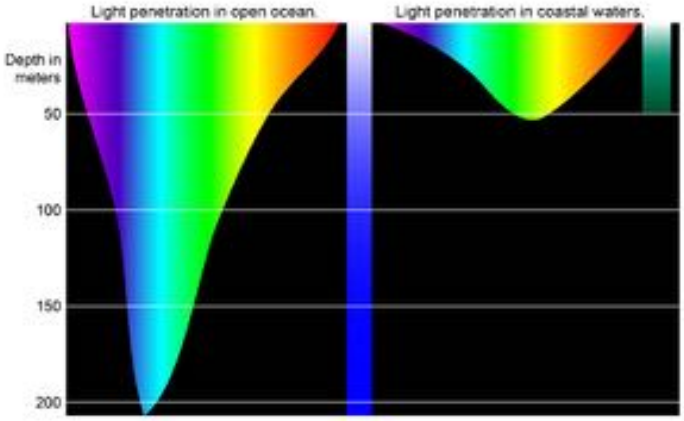
NOAA, Public Domain, http://oceanexplorer.noaa.gov/explorations/04deepscope/background/deeplight/media/diagram3_600.jpg

Photic Zone

Coastal waters typically have more suspended sediments, nutrients: higher productivity

Open ocean typically has clearer water, & deeper but less productive photic zone

Deserts of the ocean



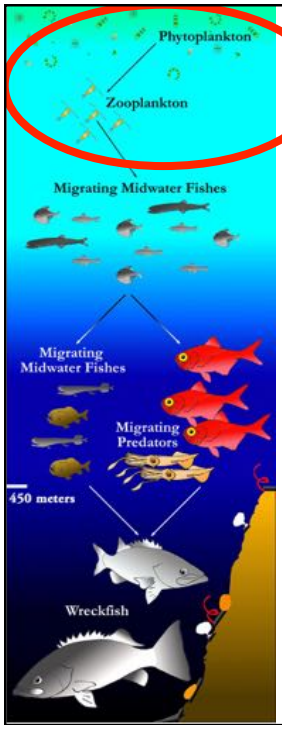
NOAA, Public Domain, http://oceanexplorer.noaa.gov/explorations/04deepscope/background/deeplight/media/diagram3_600.jpg

Photo Stefani Drew, Creative Commons A S-A 2.0, http://commons.wikimedia.org/wiki/File:Jelleyfish.jpg

Plankton

- **Definition**: Drifting or weakly swimming organisms suspended in the water column
- Horizontal position depends dominantly on the currents in which they are embedded
- Planktonic = A drifting ***lifestyle***
  - Jellyfish to microscopic bacteria

Photo E. Schauble, UCLA



PLANKTON

Open ocean (and many coastal) food webs start with plankton

Food web of Charleston Bump, NOAA/Weaver and Sedberry, 2001, Public Domain, http://oceanexplorer.noaa.gov/explorations/03bump/background/lifeonbump/media/foodweb.html

Majority of Plankton are Small

photo Peter Parks, http://www.nikonsmallworld.com/detail/year/2007/5

Sampling Plankton

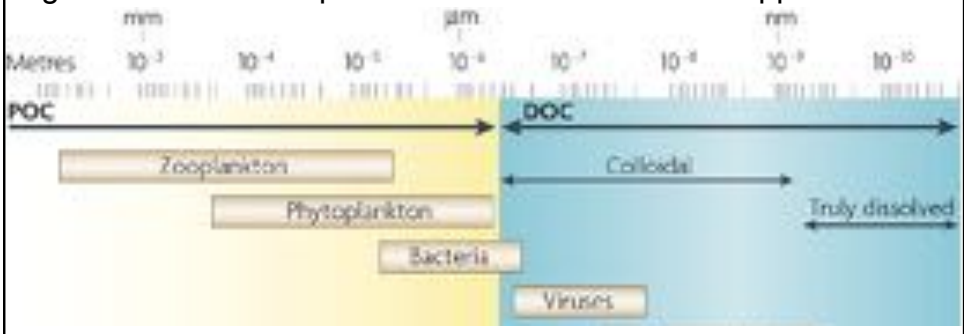
- Net only samples plankton larger than mesh size

NOAA, Public Domain, http://oceanexplorer.noaa.gov/explorations/02sab/logs/aug07/media/plnet.html

Preparing for a plankton tow in the arctic, NOAA image, Public Domain, http://www.arctic.noaa.gov/aro/russian-american/photo-gallery/Plankton-Nets-Photo-K-Iken.JPG

Sampling Plankton

Significant fraction of plankton are too small to be trapped in nets



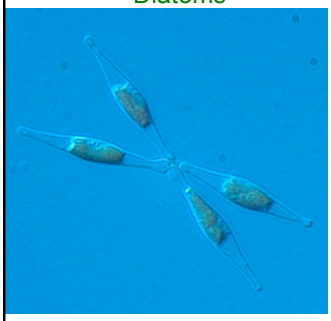
Azam and Malfatti, Nature Reviews Microbiology 5, 782-791, doi:10.1038/nrmicro1747

Smallest plankters can only be captured with centrifuges, special filters.

Phytoplankton

- ~ 4000 species of phytoplankton presently described
- New species continually being discovered
- Dominant phytoplankton:

Diatoms

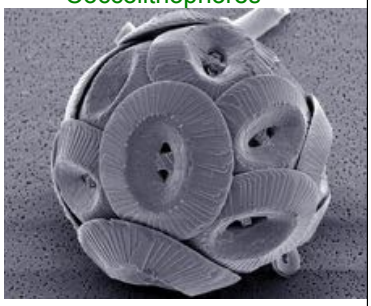


Alessandra de Martino and Chris Bowler, PLoS, Creative Commons A 2.5, http://commons.wikimedia.org/wiki/File:Phaeodactylum_tricornutum.png

Dinoflagellates

Minami Himemiya, Creative Commons A S-A 3.0, http://en.wikipedia.org/wiki/File:Ceratium_furca.jpg

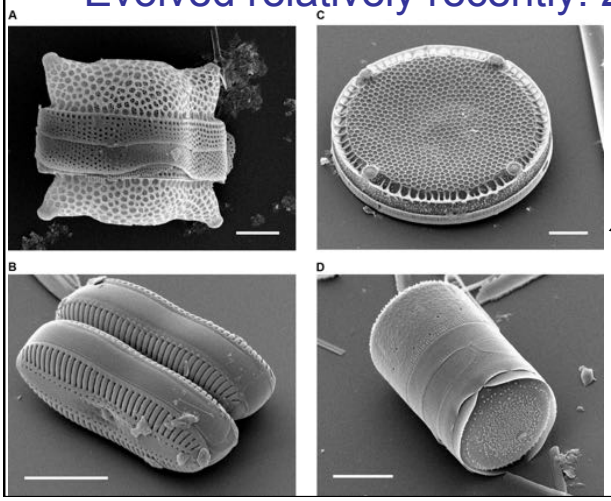
Coccolithophores



Richard Lampitt, Jeremy Young, Creative Commons A S-A 2.5, http://commons.wikimedia.org/wiki/File:Coccolithus_pelagicus.jpg

DIATOMS

- Autotrophic planktonic algae (Bacillariophyceae)
- Most abundant single plankton group
- Evolved relatively recently: 200 Mya



NOTE!
White bar = $2x10^{-5}$ m

Mary Ann Tiffany, PLoS, Creative Commons A 2.5, http://commons.wikimedia.org/wiki/File:Diatoms.png

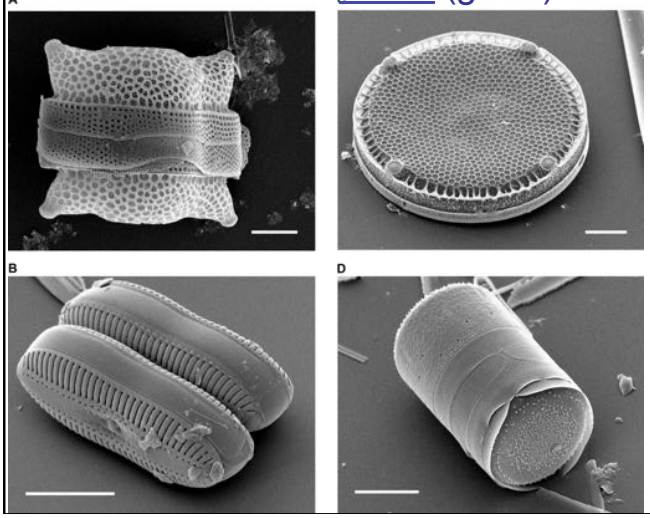
DIATOMS

Pillbox morphology (2-200 $x10^{-6}$ m):

Transparent, rigid shell (i.e., Frustule)

Silica (glass) shell: two nested halves

Photosynthetic material inside frustule

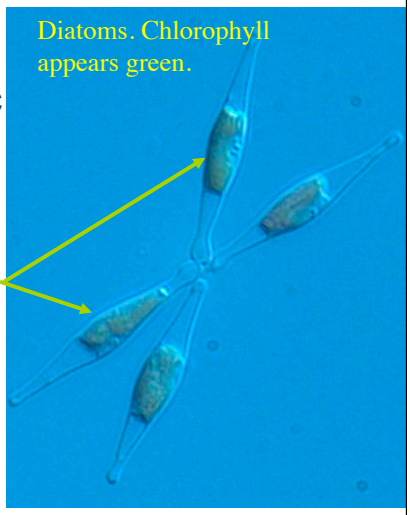


Mary Ann Tiffany, PLoS, Creative Commons A 2.5, http://commons.wikimedia.org/wiki/File:Diatoms.png

Diatoms

Extremely efficient photosyntheic conversion of sunlight to chemical energy

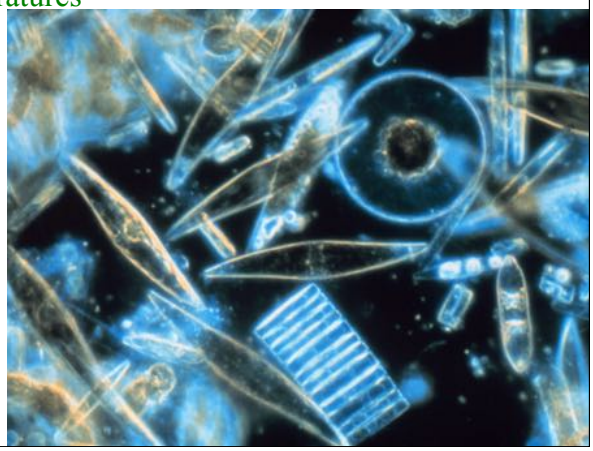
- Chloroplasts within frustule
  - Fixes Carbon, releases Oxygen
- Tiny holes in frustule allow gas/water exchange with ocean
- Frustule surface may also increase CO_2 availability
- *Skeletons used to make filters*
  - *"cold filtered, never pasteurized"*



Alessandra de Martino and Chris Bowler, PLoS, Creative Commons A 2.5, http://commons.wikimedia.org/wiki/File:Phaeodactylum_tricornutum.png

Diatoms

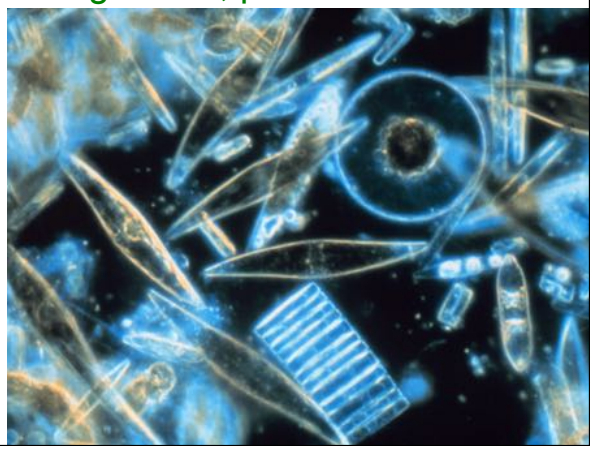
- Typically found in areas of
  - High sunlight
  - Temperate to Polar Waters
    - Cold water temperatures



Antarctic diatoms, photo Gordon T. Taylor, Stony Brook University/NOAA, Public Domain, http://commons.wikimedia.org/wiki/File:Diatoms_through_the_microscope.jpg

Diatoms

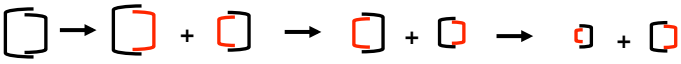
- Can't swim, but have 3 ways to stay near surface
  - Small size, formation of chains, colonies further increases drag
  - Control density: salt regulation, produce/store low density oils
  - Surface current turbulence



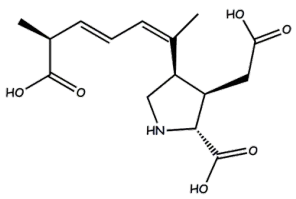
Antarctic diatoms, photo Gordon T. Taylor, Stony Brook University/NOAA, Public Domain, http://commons.wikimedia.org/wiki/File:Diatoms_through_the_microscope.jpg

Diatoms

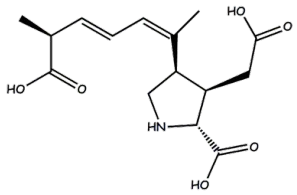
- Reproductive Cycle
  - [(Asexual)^n, sexual]^m



  - Critical minimum size requires sexual reproduction
  - Cycle can lead to rapid diatom blooms
  - Can also form **resting spores** when conditions are bad
  - Some species release *domoic acid*, a toxin for mammals (including us!).



domoic acid



domoic acid

Toxins can be fatal to animals near the top of the food chain (fish, sea birds, humans, cows etc.)

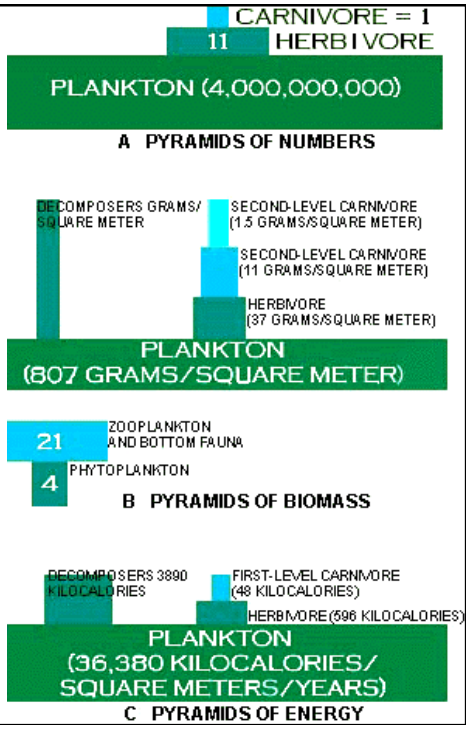


Figure from U. Michigan Global Change Program, http://www.globalchange.umich.edu/globalchange1/current/lectures/kling/energyflow/energyflow.html

DINOFLAGELLATES

- 2nd most abundant plankton group
- Unicellular algae (Pyrrophyceae) that do not form chains as diatoms do
  - exist singly, cellulose (organic) cell walls rather than mineral skeleton.

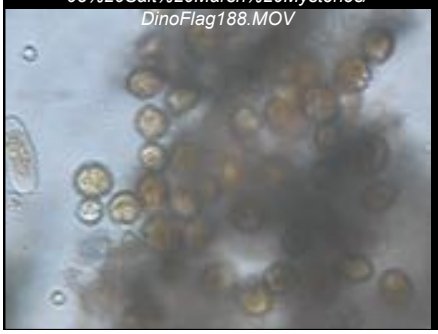
Ceratium longipies, Photo by Mitchell Sogin, UNH Marine Biological Lab, http://www.eos.unh.edu/newsl_0708/dinoflagellate.shtml

Dinoflagellates

- Possess two flagella: **motile**
  - 1 flagellum for translation, other for rotation
- Transverse groove: **girdle**, separates anterior & posterior halves

Ceratium longipies, Photo by Mitchell Sogin, UNH Marine Biological Lab, http://www.eos.unh.edu/newsl_0708/dinoflagellate.shtml

Movie by Wayne Lanier, http://www.hikingwithafieldmicroscope.com/00%20CONTENTS/08%20Salt%20Marsh%20Mysteries/DinoFlag188.MOV



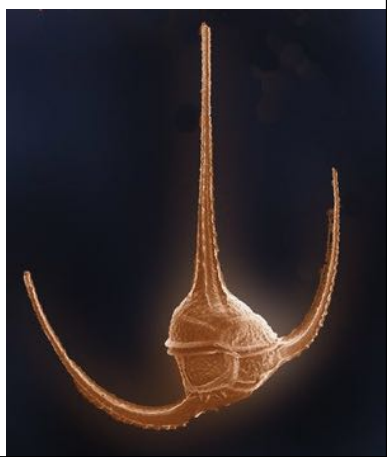
Dinoflagellates

- Variety of feeding strategies:

  Some are autotrophic (photosynthesis)

  Some are heterotrophs without chloroplasts

  Some are **mixotrophs**
  - Can photosynthesize but also feed on other plankton



Ceratium longipies, Photo by Mitchell Sogin, UNH Marine Biological Lab, http://www.eos.unh.edu/newsl_0708/dinoflagellate.shtml

Dinoflagellates

- Rapid reproduction in warm, nutrient rich waters
  - Can result in blooms: **Red Tides**
- Can produce a range of chemicals
  - **Bioluminescence** and **strong** neurotoxins
  - As with domoic acid & mercury, organisms that feed on dinoflagellates concentrate toxins

Noctiluca scintillans, Maria Antónia Sampayo, Instituto de Oceanografia, Faculdade Ciências da Universidade de Lisboa, Creative Commons A S-A 3.0

Photo by catalano82, Flickr, Creative Commons A 2.0, http://commons.wikimedia.org/wiki/File:Dinoflagellate_luminescence.jpg

Red tide near La Jolla, CA, P. Alejandro Díaz and Ginny Velasquez, Public Domain, http://commons.wikimedia.org/wiki/File:La-Jolla-Red-Tide.780.jpg

Dinoflagellates

- Post-Bloom:
  - After nutrients are exhausted:
    - Bloom ceases
    - Bacterial decomposition (ie, bacterial respiration) of deceased bloomers removes oxygen from water column
      - Anoxic conditions: **Post bloom fish kills**

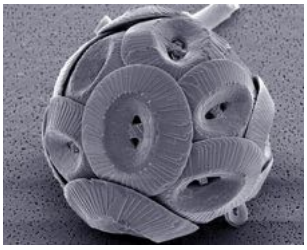
Dinoflagellates

Fish kill during *Karenia brevis* bloom, Florida

Woods Hole Oceanographic Institute Photo, http://www.cop.noaa.gov/stressors/extremeevents/hab/features/florida_0406.html

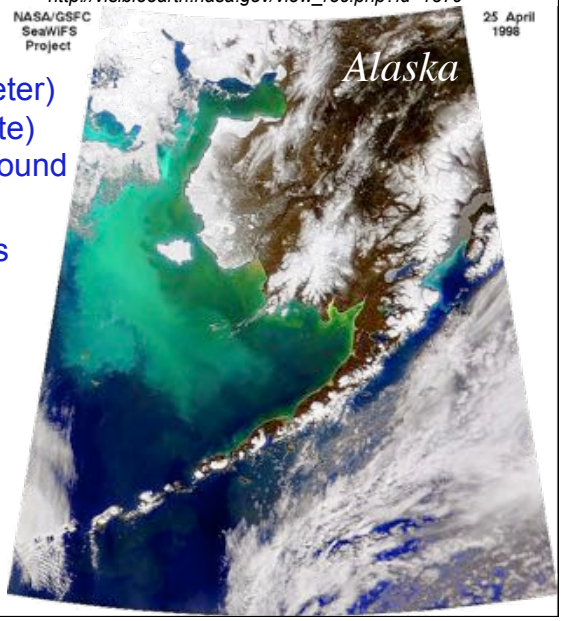
COCCOLITHOPHORES

- Abundant single-celled autotrophic plankton
- Tiny (3 - 50 micron diameter) $CaCO_3$ (calcium carbonate) shells, about 30 shells around each individual
- Leading calcite producers in the oceans



Richard Lampitt, Jeremy Young, The Natural History Museum, London, Creative Commons A 2.5

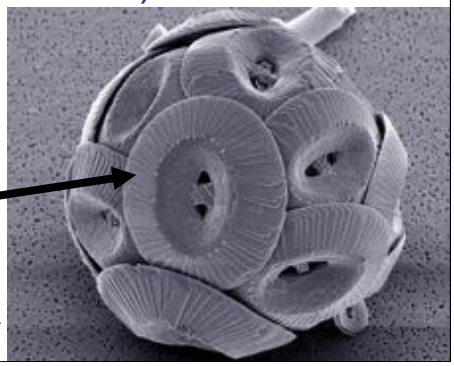
SeaWiFS/NASA, Public Domain, http://visibleearth.nasa.gov/view_rec.php?id=1379



Coccolithophores

- External shell of many calcareous plates called coccoliths
- Chalk is an uplifted ocean sediment composed dominantly of coccolith shells (ie, the White Cliffs of Dover)

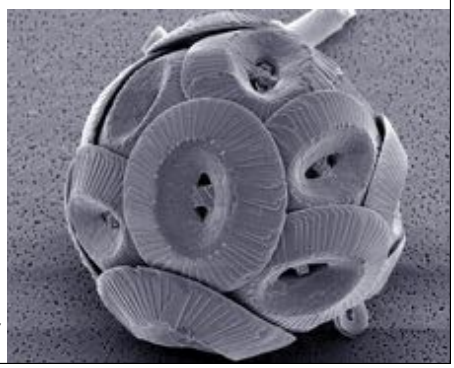
Coccoliths



Richard Lampitt, Jeremy Young, The Natural History Museum, London, CC A 2.5, http://commons.wikimedia.org/wiki/File:Coccolithus_pelagicus.jpg

Coccolithophores

- Thrive in warmer waters (low nutrients) & in low light conditions, where others do not
- Maximum abundances at ~ 100m depth in clear tropical waters

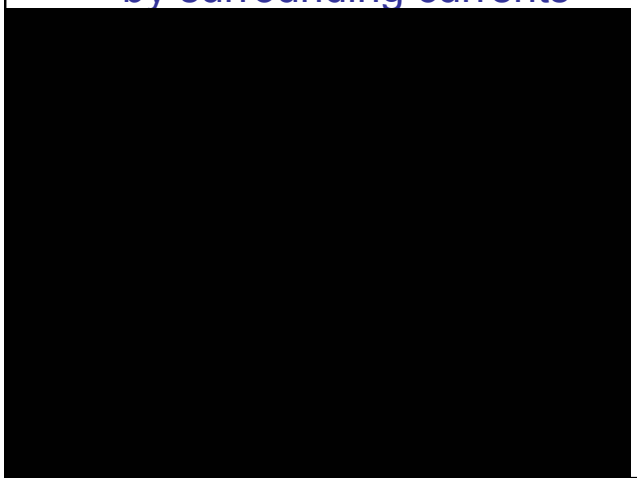


Richard Lampitt, Jeremy Young, The Natural History Museum, London, CC A 2.5, http://commons.wikimedia.org/wiki/File:Coccolithus_pelagicus.jpg

Paraeuchaeta norvegica, a copepod, photo Hege Vestheim, University of Oslo, http://oceanworld.tamu.edu/resources/oceanography-book/marinefoodwebs.htm

Zooplankton

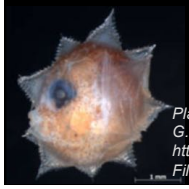
- Definition: Animals (heterotrophs) capable of movement but still controlled by surrounding currents



NOAA, Public Domain(?), http://oceanexplorer.noaa.gov/explorations/02arctic/logs/mis_sum_pelagic/media/jellyfish_320.mov

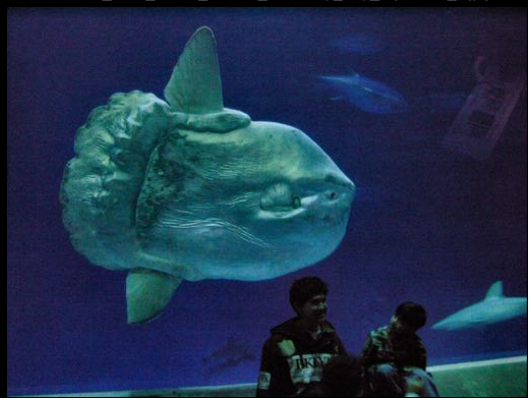
Zooplankton

- Types:
  - **Holoplankton**: permanently planktonic
  - **Meroplankton**: temporarily planktonic (ie, fish larvae, lobster larvae, etc.)
- Feeding Styles
  - Herbivores: eat plants
  - Carnivores: eat other animals
  - Detritivores: eat dead organic material
  - Omnivores: mixed diets



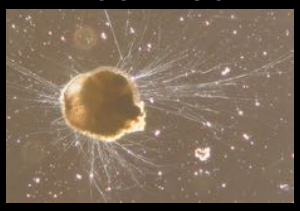
Planktonic sunfish larva (Mola mola), G. David Johnson, CC A S-A 3.0, http://commons.wikimedia.org/wiki/File:Molalavdj.jpg

Nektonic adult sunfish (Mola mola), Fred Hsu, CC A S-A 3.0, http://commons.wikimedia.org/wiki/File:Mola_mola_ocean_sunfish_Monterey_Bay_Aquarium_2.jpg



Zooplankton

- Major Zooplankton:
  - Foraminifera



Scott Fay, UC Berkeley, CC A S-A 2.5, http://en.wikipedia.org/wiki/File:Live_Ammonia_tepida.jpg

  - Radiolaria

Living Classrooms Foundation's Weinberg Education Center, http://www.livingclassrooms.org/lbo/biofilm/creature.html

  - Ostracod

Anna Syme, CC A S-A 3.0, http://en.wikipedia.org/wiki/File:Ostracod.JPG

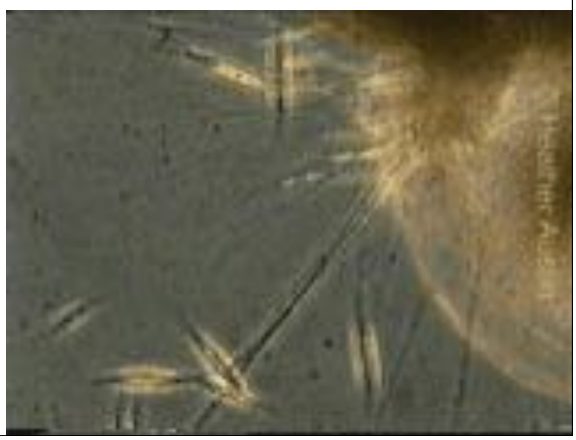
(Also dinoflagellates)

  - Copepod

Hege Vestheim, University of Oslo, http://oceanworld.tamu.edu/resources/oceanography-book/marinefoodwebs.htm

Foraminifera

- Heterotrophic , single-celled plankton
- Calcium carbonate shells (test) & spines
  - Testate amoeba
- Pseudopodia used to capture prey
- Prey includes bacteria, phytoplankton or small zooplankton



Movie by Heather Austin, U. St. Andrews, http://www.eforams.icsr.agh.edu.pl/index.php/Image:ApertureB1e.gif

Foraminifera

Photo by Howard Spero, UCSC, http://earthguide.ucsd.edu/earthguide/imagelibrary/orbulinauniversa.html

Radiolaria

Single-celled plankton

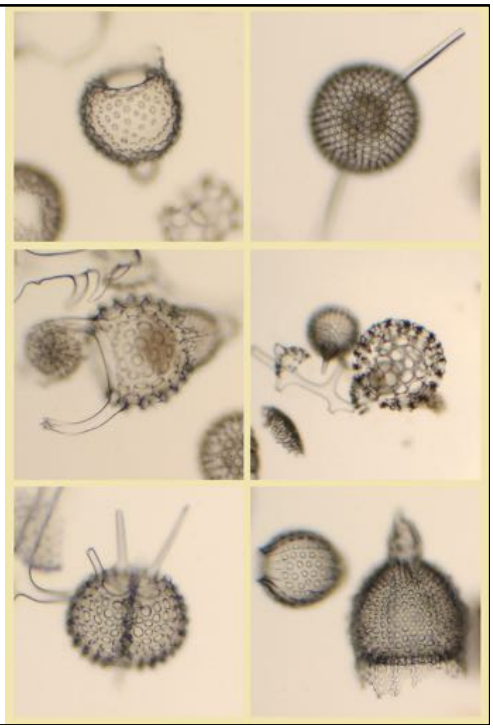
Silica tests (shells)
~ average 5×10^{-5} m

Branched pseudopodia for food capture

Carnivorous/Omnivorous

- Food: zoo- & phytoplankton (diatoms), detritus

Sometimes possess symbiotes such as dinoflagellates



Luis Fernández García, CC A S-A 2.5, http://commons.wikimedia.org/wiki/File:Radiolaria_varios.jpg

Radiolaria Sedimentary Fossils

Eocence radiolarians (34-56 million years old), Ocean Drilling Program/NSF image, http://www-odp.tamu.edu/public/life/199/week2.html

Ostracods

- Two clam-like shells
- Crustaceans: 0.5mm - 25 mm
  - 2mm is typical
- Originated around 550 Mya!
- Some are bioluminescent
- Consume plankton, many are also bottom-dwelling scavengers.

Danielopolina mexicana – actually a cave-dweller
http://www.tamug.edu/cavebiology/fauna/PhotoGallery/Yucatan/Yucatan-sm-crustaceans-1.html

Copepod

- Crustacean: average sizes 0.5 - 15 mm
  - Max size ~ 25 mm
  - ~ 9000 known species
- Voracious feeder/filterer
- Forms key food for many other larger plankton and nekton

Photo Alfred Wegener Institute, http://www.awi.de/fileadmin/user_upload/News/Press_Releases/2006/3._Quarter/Plankton3_p.jpg

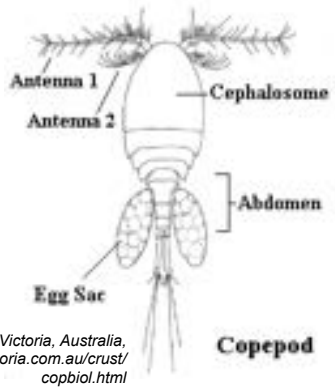
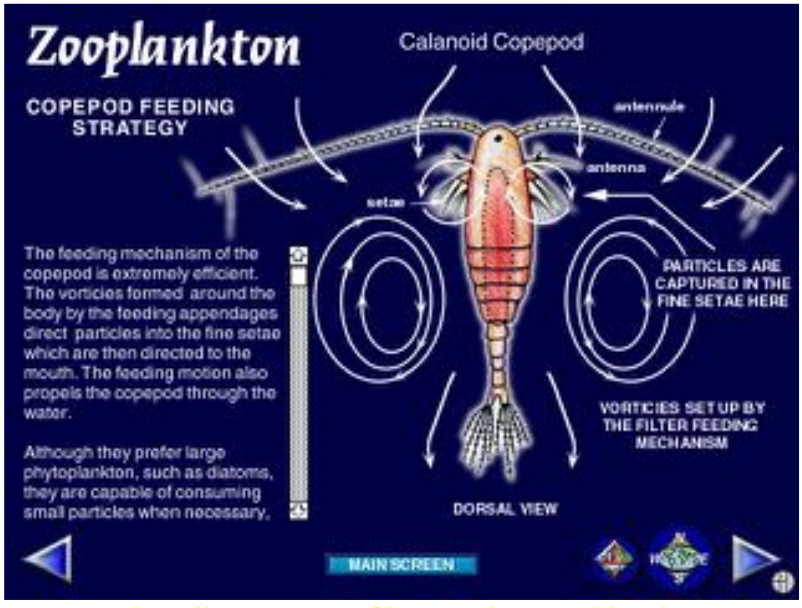
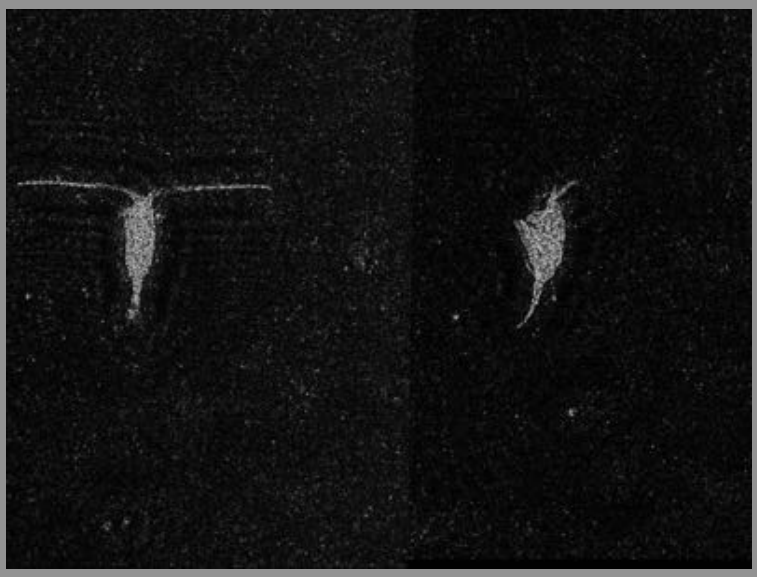


Image from Museum Victoria, Australia, http://museumvictoria.com.au/crust/copbiol.html



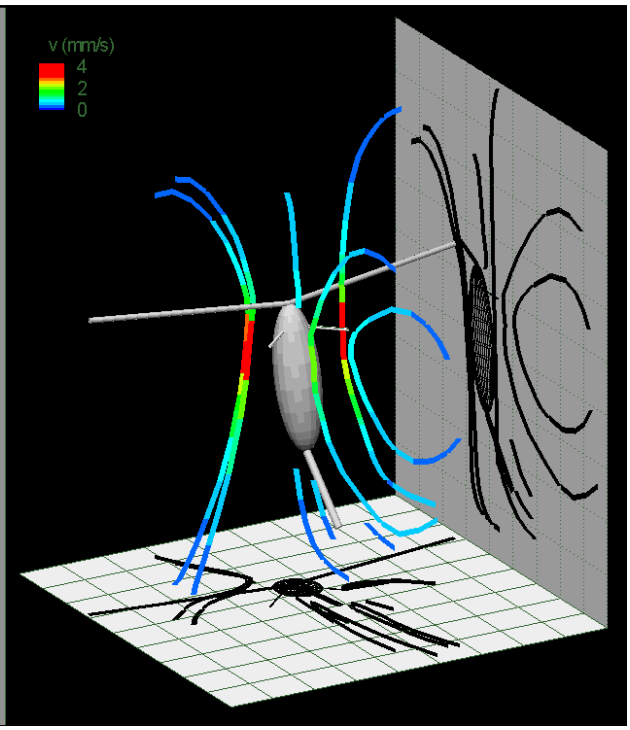
http://www.seaprofiles.com/copepod.html

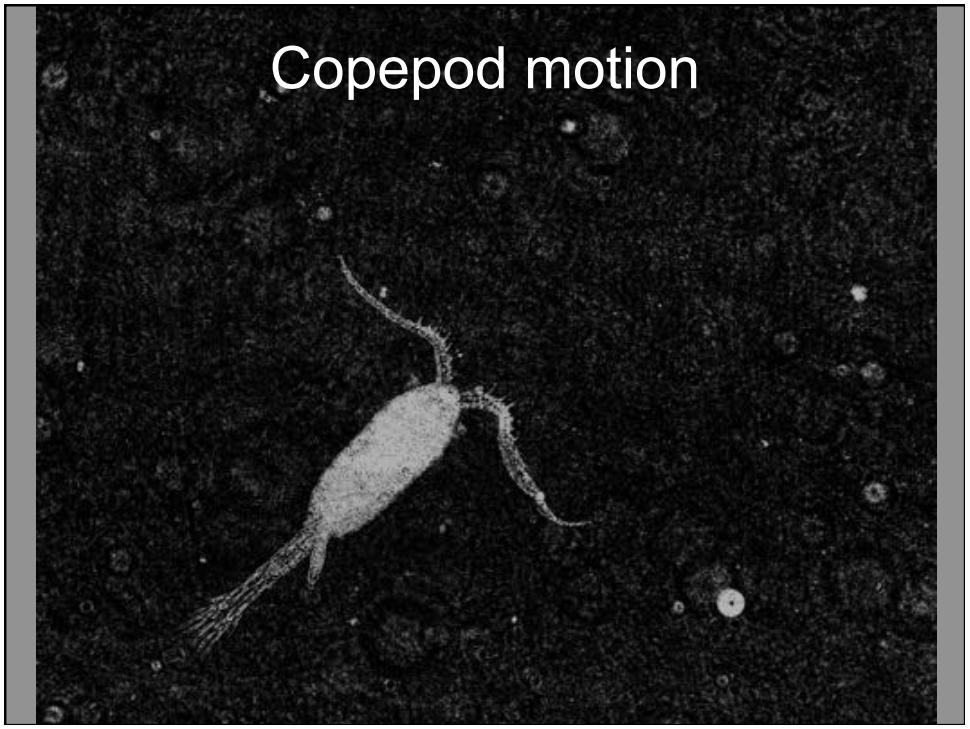
Copepod motion



http://jeb.biologists.org/cgi/content/full/206/20/3657/DC1

Reconstructed feeding currents





Questions

http://www.ianskipworth.com/suig/