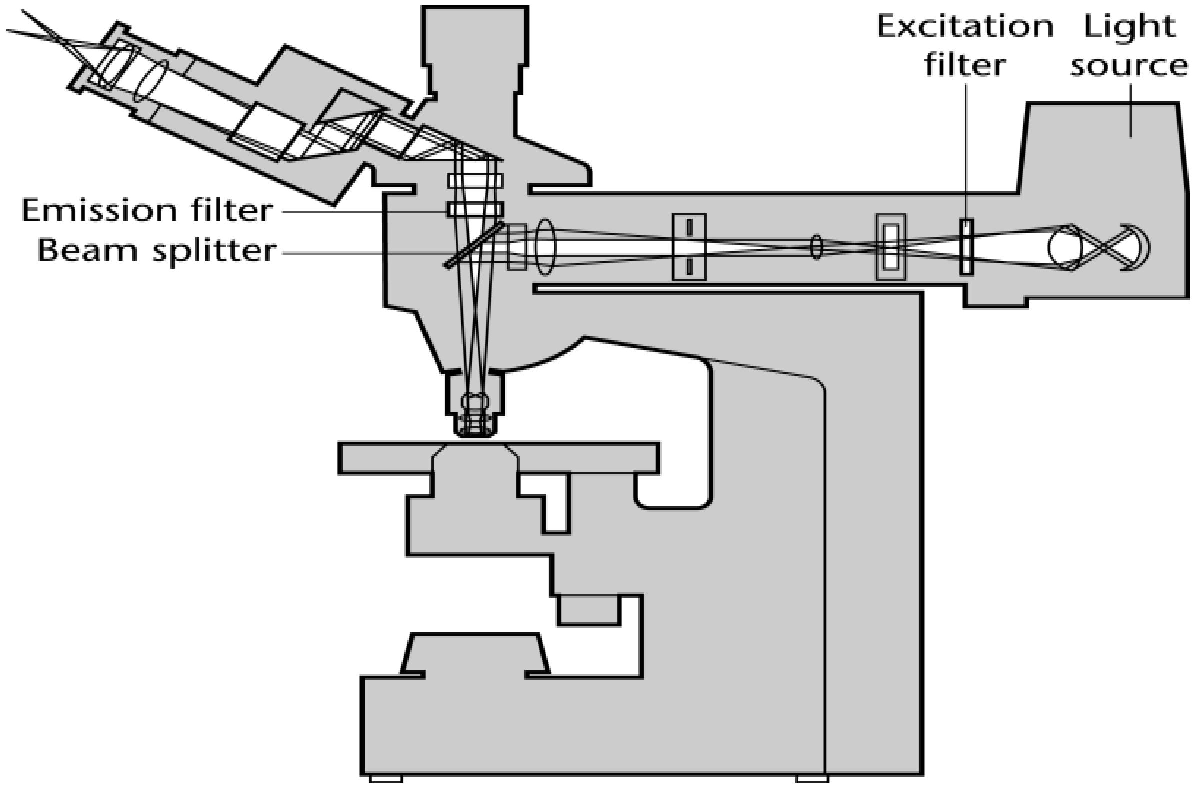
# EBS 566/666: Lecture 16. Zooplankton

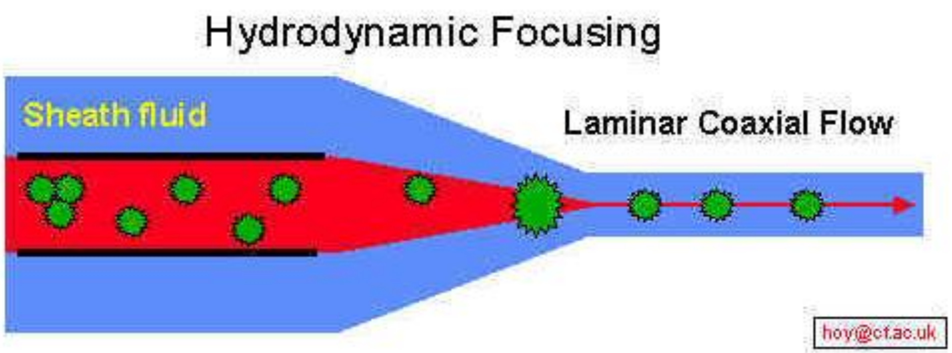
Topics:

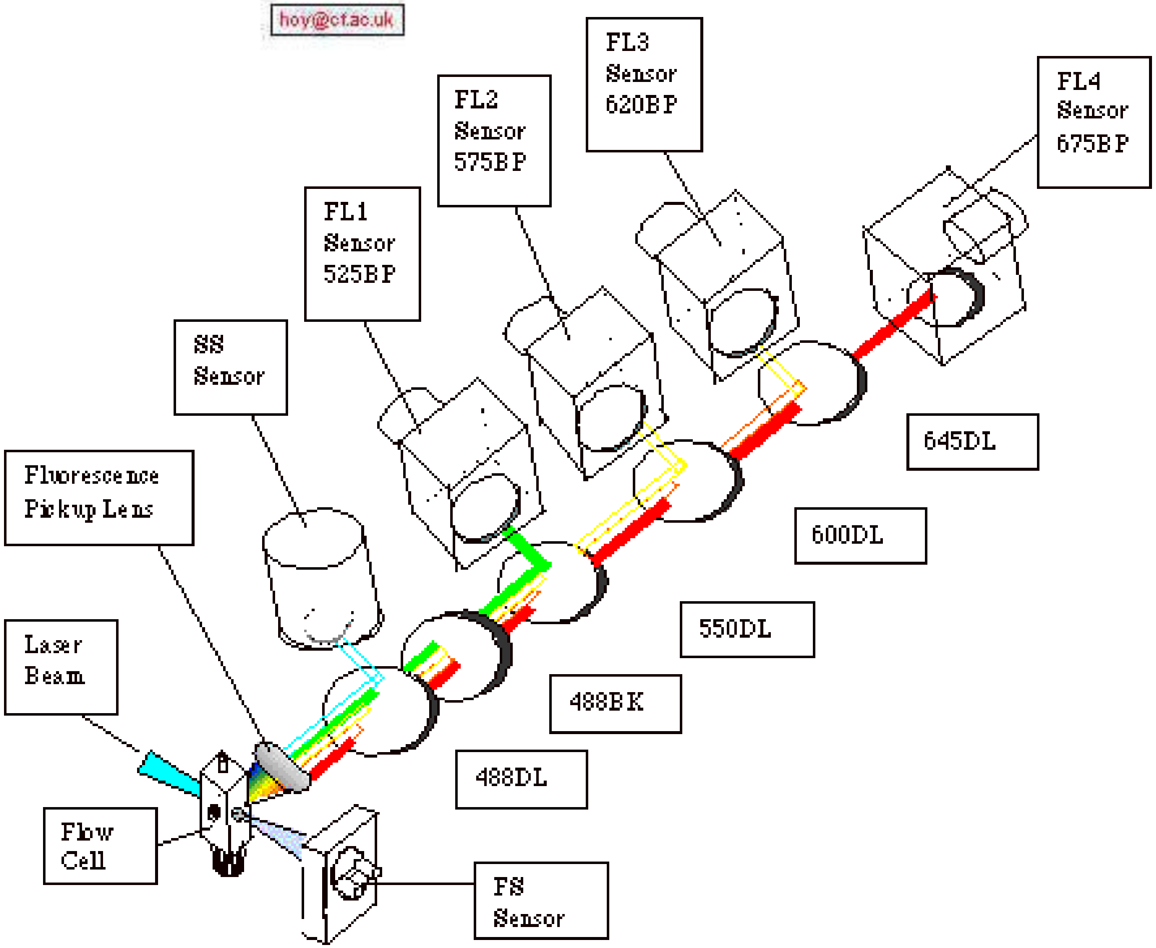
1. Measuring phytoplankton
2. Primary production
3. Fate of primary production
4. Zooplankton groups
5. Feeding
6. Secondary production

# Epifluorescence microscopy



# Flow cytometry



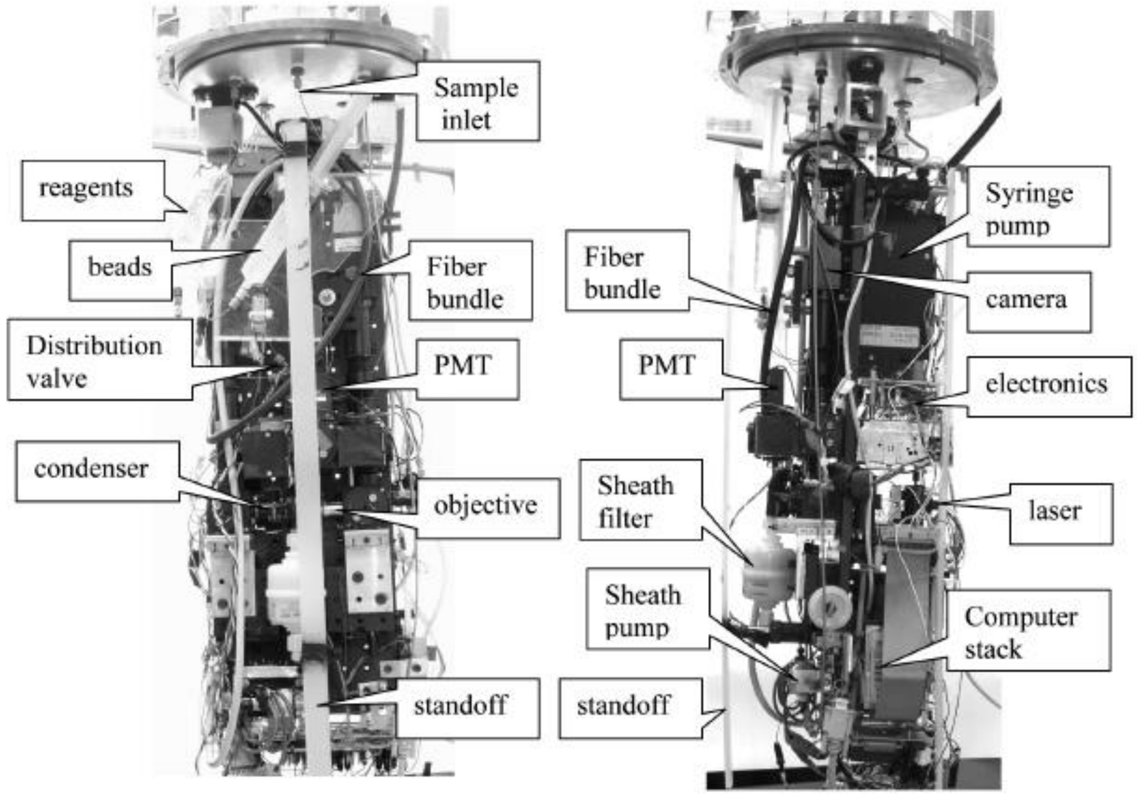



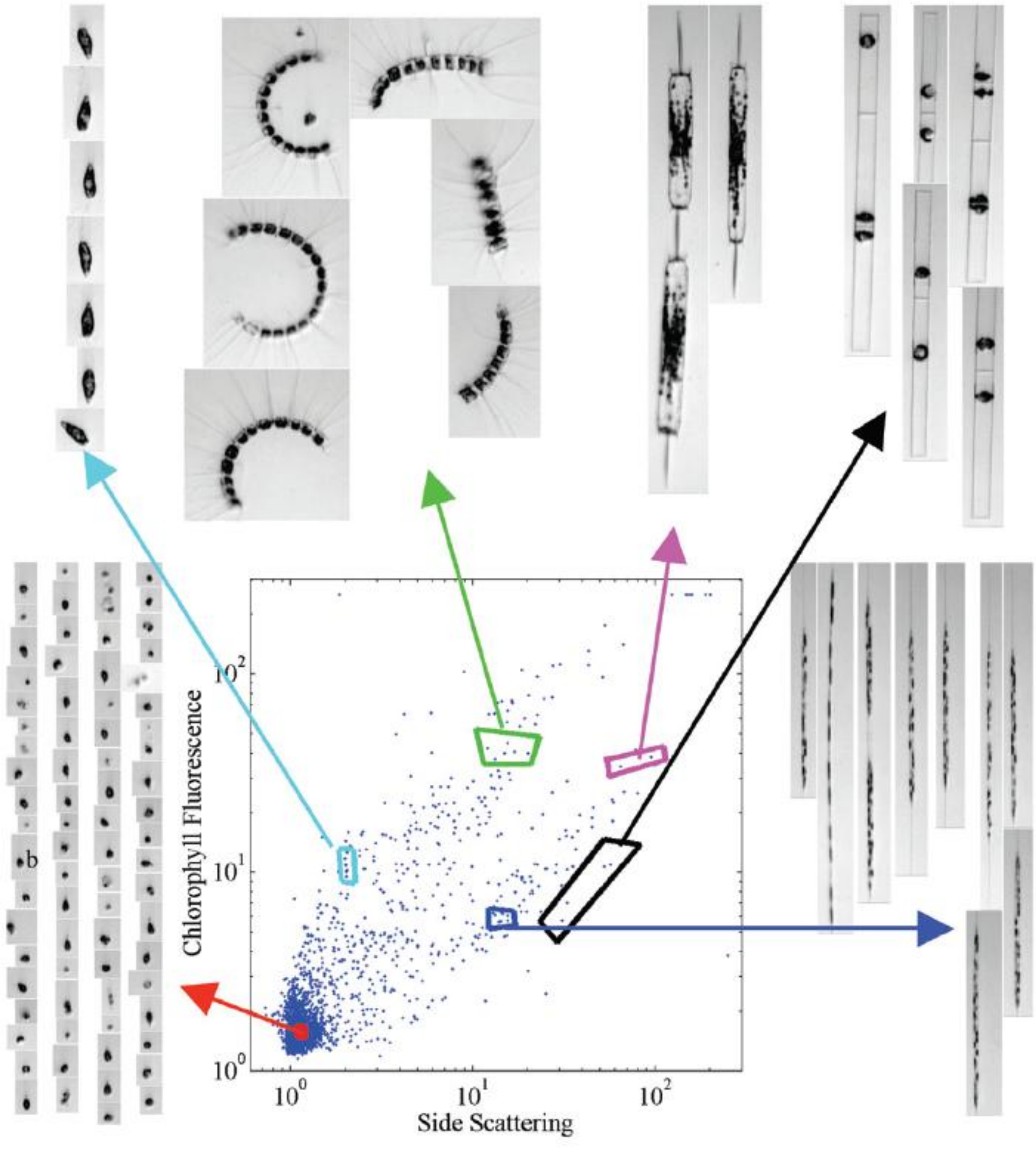
**CytoBuoy**

- CytoSense (benchtop)
- CytoSub (submersible)


Olson and Sosik, Woods Hole Oceanographic Institution

FlowCytobot and Imaging FlowCytobot

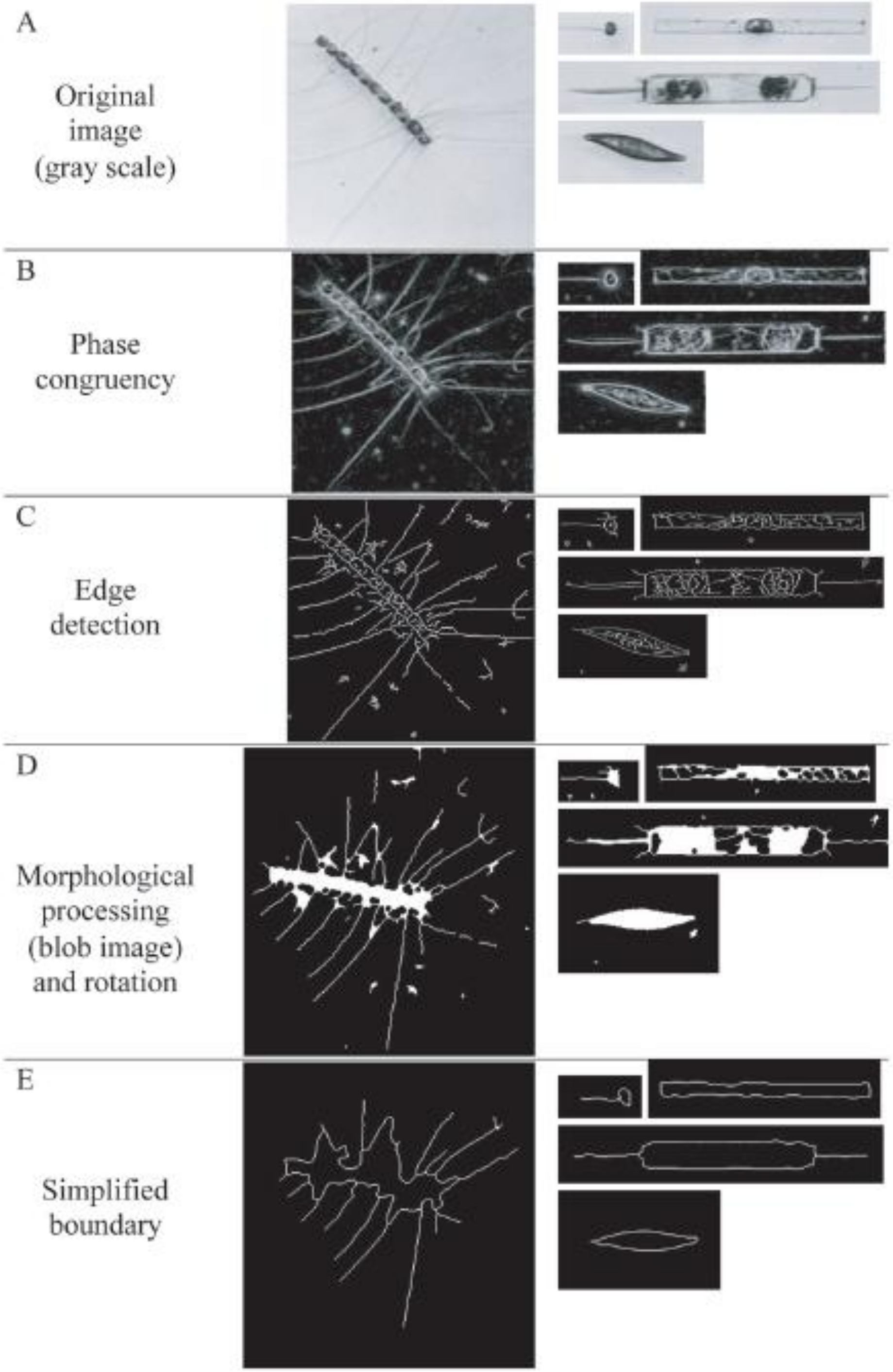




Chlorophyll Fluorescence
Side Scattering
$10^0$
$10^1$
$10^2$
b

# Image processing steps for Flow CytoBot

Sosik & Olsen, 2007



# FlowCAM: Flow Cytometer And Microscope

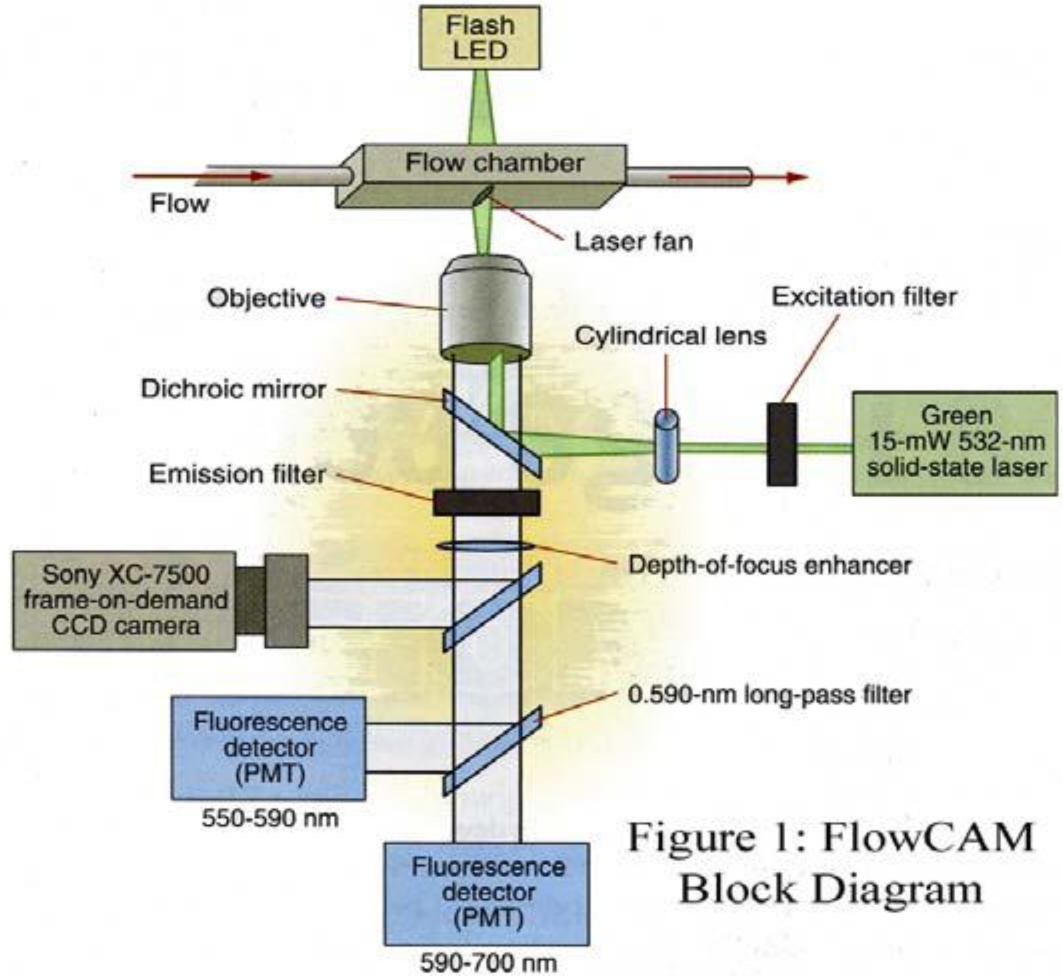
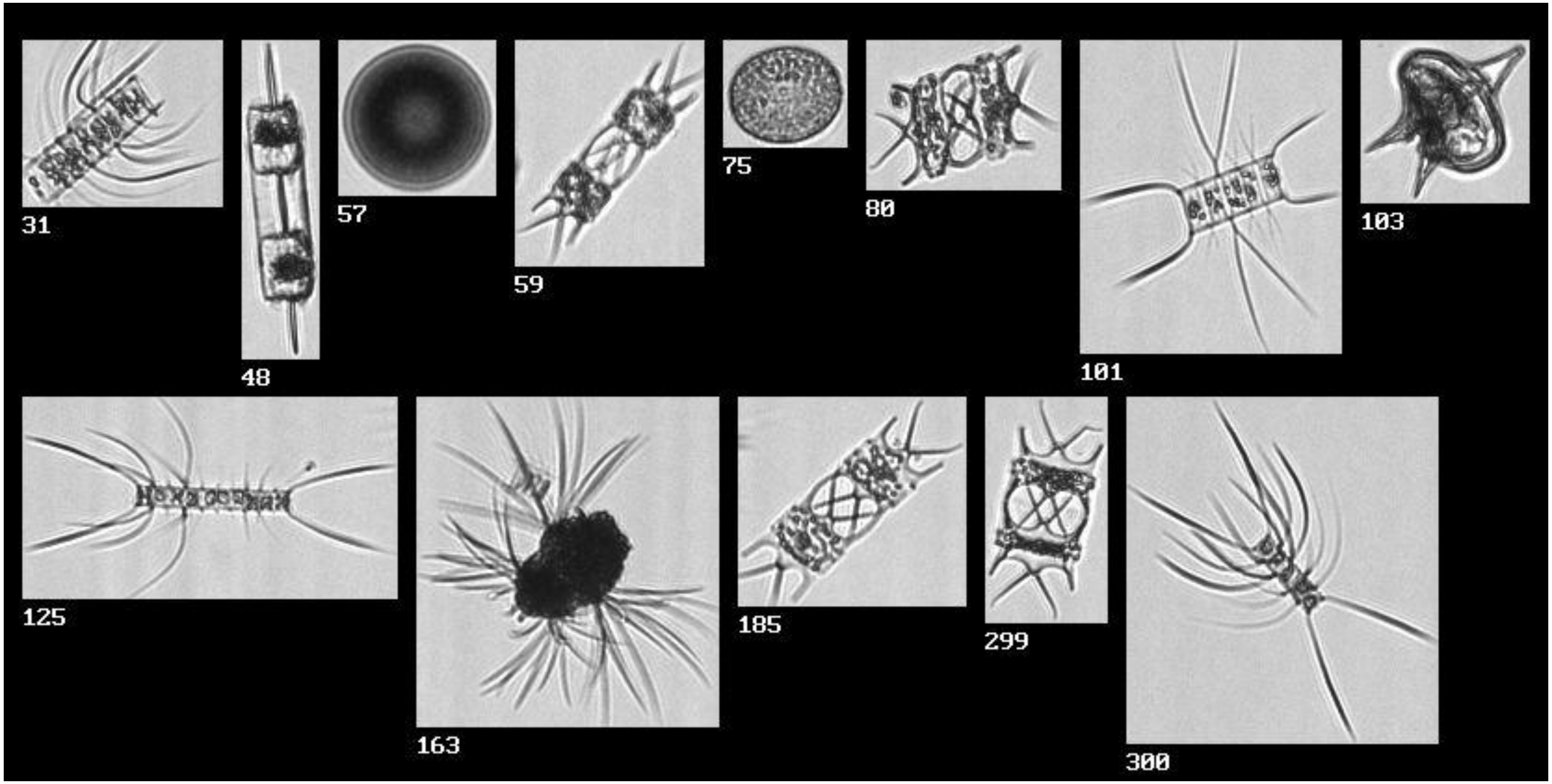
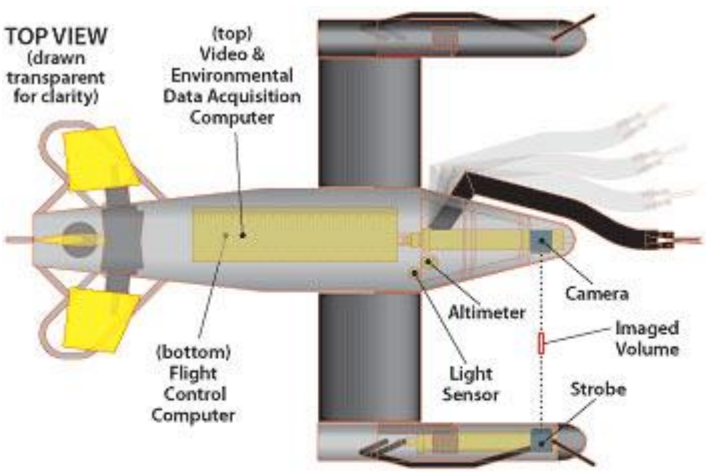


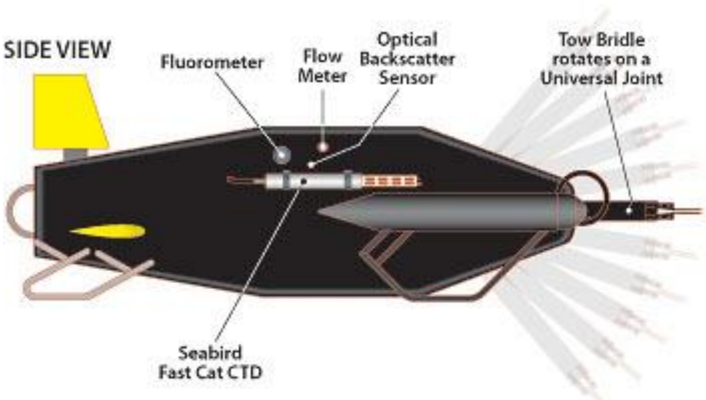

Figure 1: FlowCAM Block Diagram

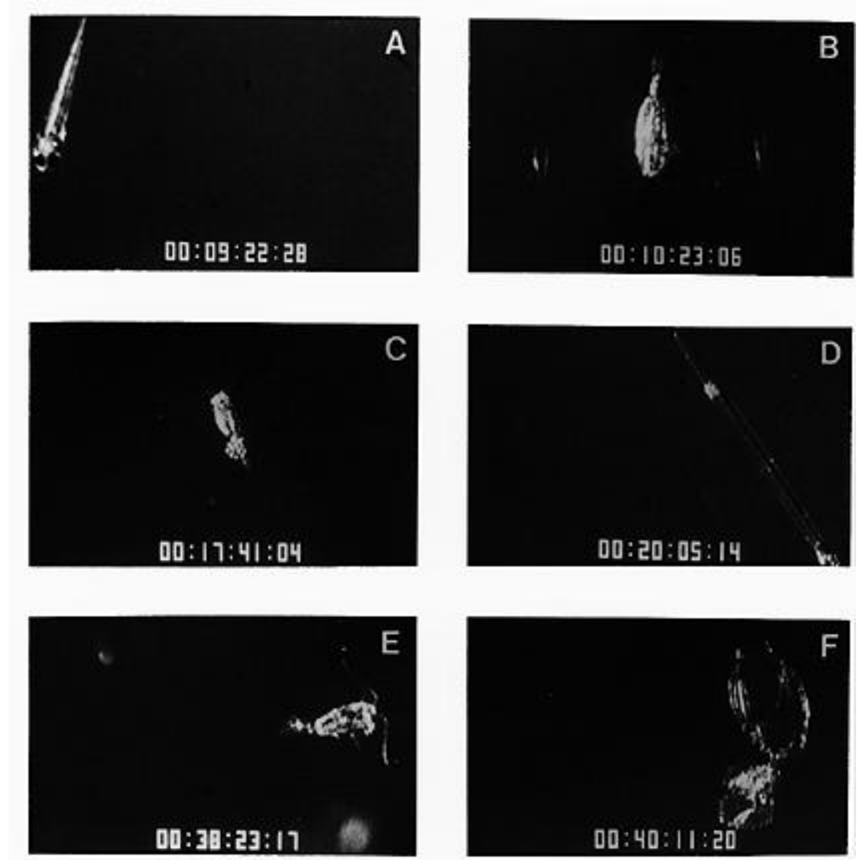
FLUID IMAGING TECHNOLOGIES

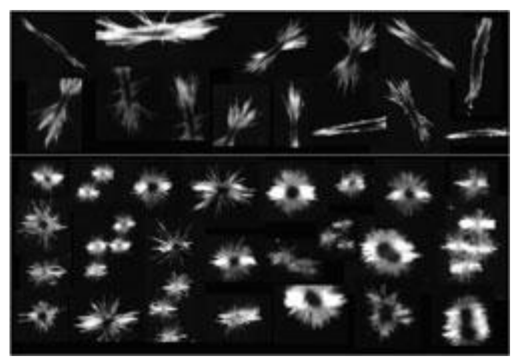
# Marine sample from the coast of Oregon



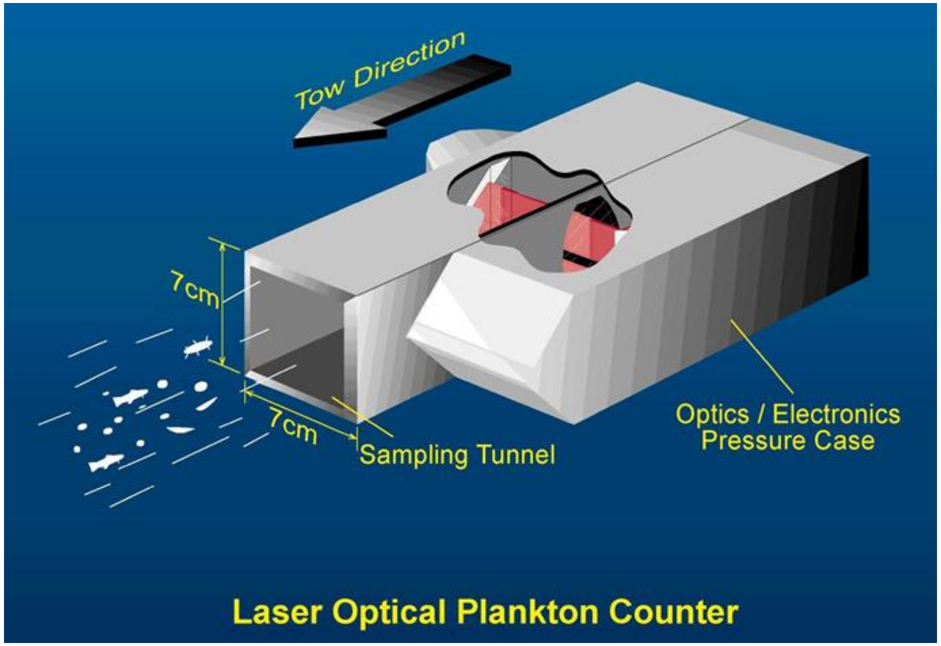


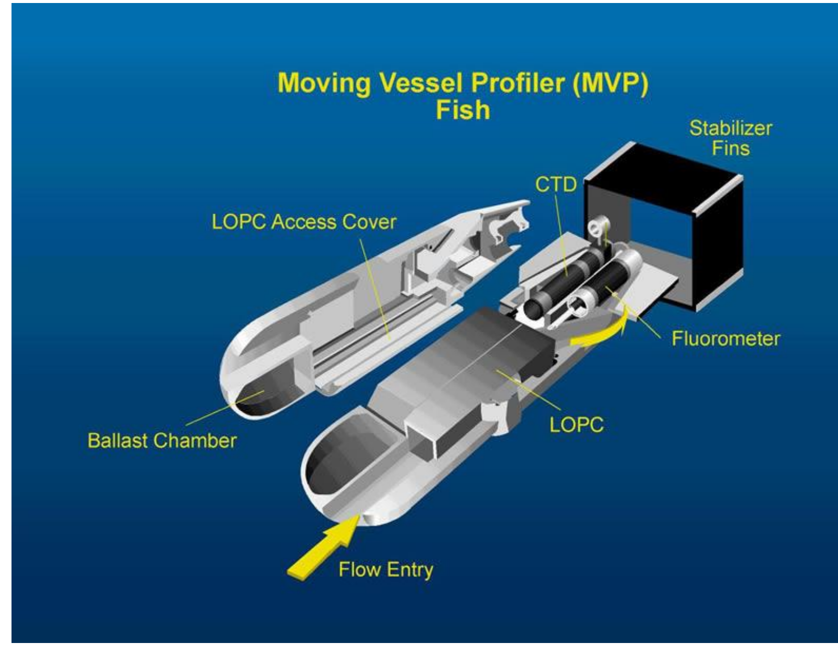



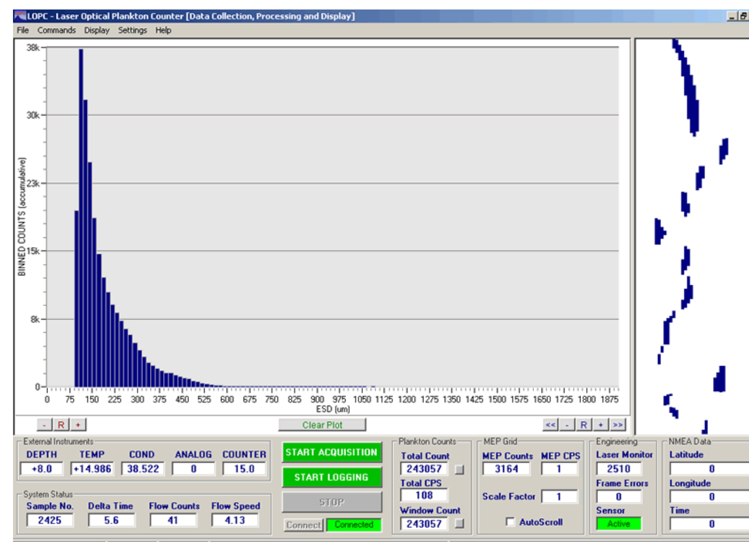
# Video Plankton Recorder




( A ) Wide Tunnel LOPC - Batfish Tow

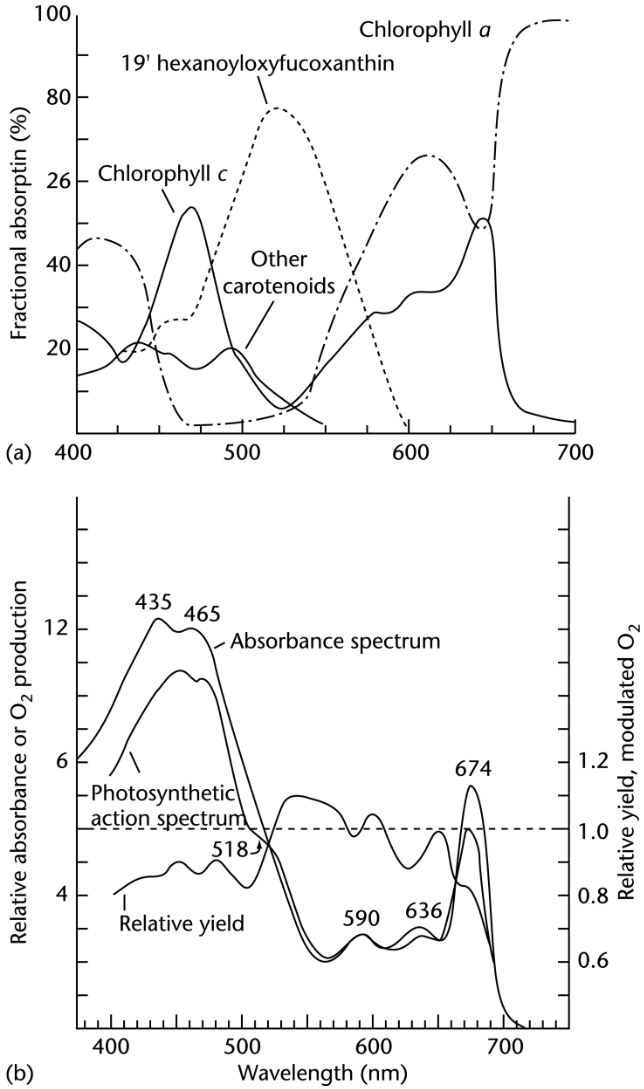
Shape profiles obtained from an LOPC mounted on a Batfish vehicle towed at 8 knots. Silhouettes show profiles of euphausiids and copepods of a variety of sizes. Credit: ©Alex Herman, Bedford Institute of Oceanography.

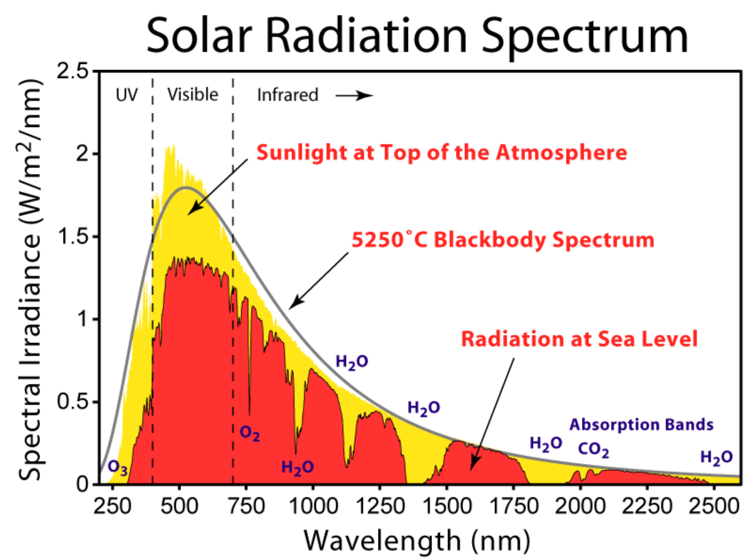


# Primary production

- Fixation of inorganic carbon using energy from the sun to make organic carbon (through the process of photosynthesis)
- **Primary production** = organic matter produced (speak of a *rate* of primary production)
- Primary productivity = rate of organic matter production – *never* say ‘rate’ of primary productivity (‘rate’ is implicit)
- Generally measured using a tracer of carbon uptake ($H^{14}CO_3^-$ or $H^{13}CO_3^-$) or by appearance of oxygen (since oxygen evolution is the product of photosynthesis)
- Geochemical ways: apparent oxygen utilization, etc.

# There is a correspondence between spectra of pigment absorption, wavelengths of solar radiation, and absorption by water

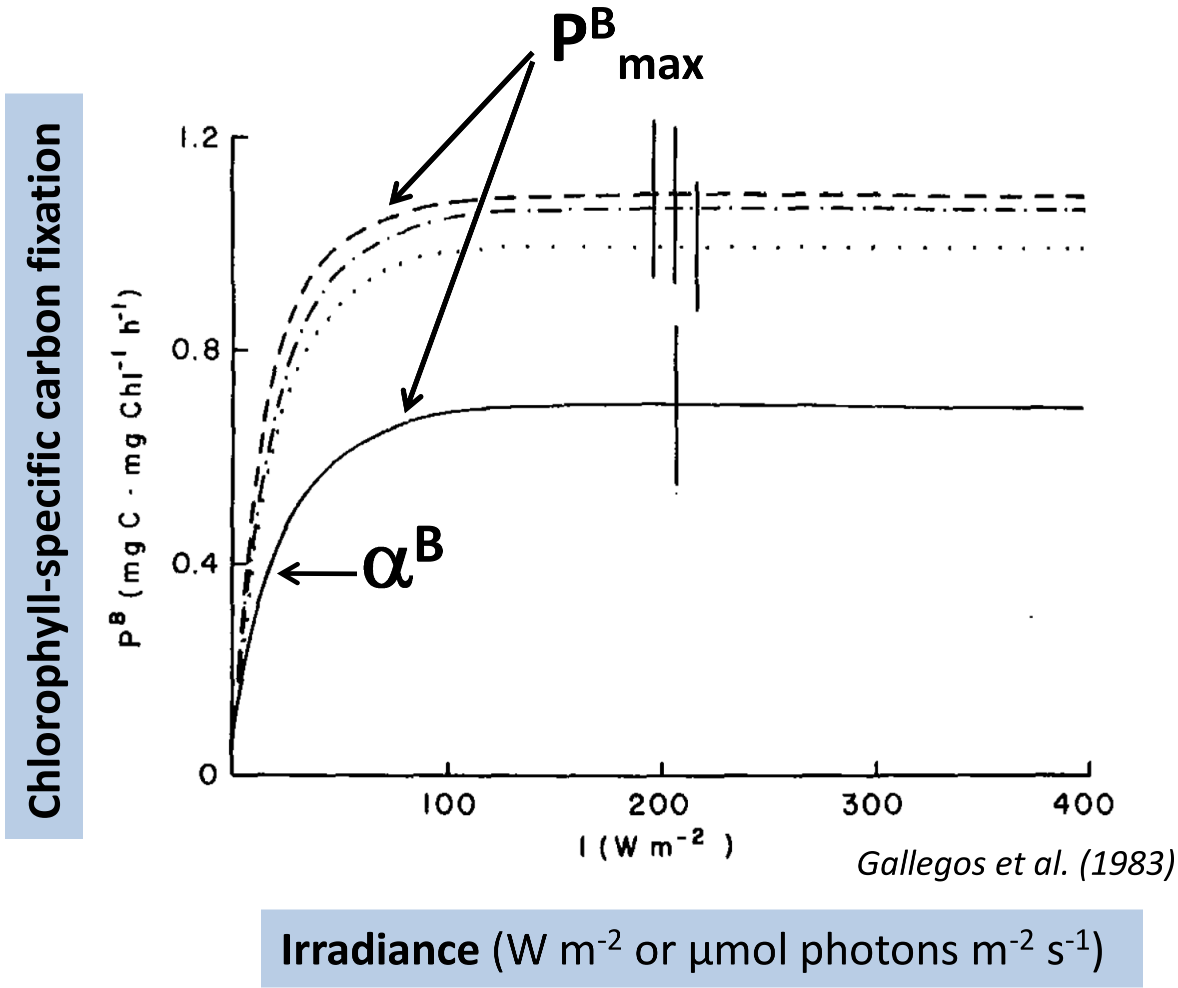


# Photosynthesis vs. irradiance (P vs. E) curves

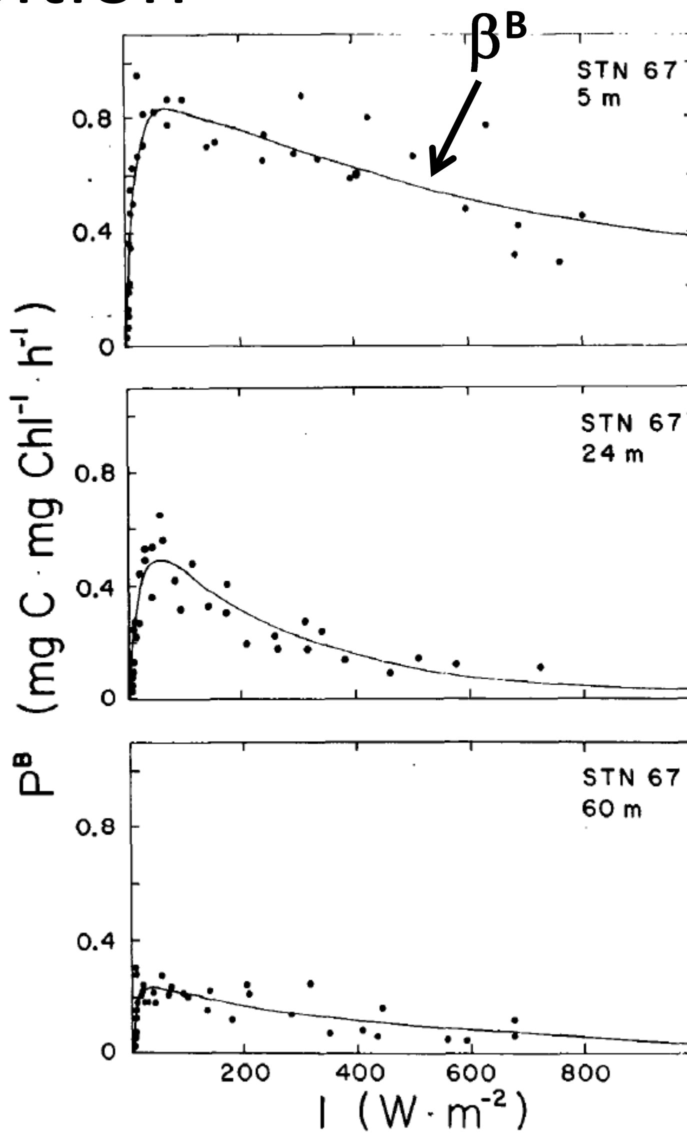
- Alpha ($\alpha^B$): initial slope of the PE curve
- $P^B_{max}$: maximum chlorophyll-specific rate of C-fixation

Beta ($\beta$)



# Photoinhibition

- $\beta^B$: slope of the PE curve that reflects photoinhibition
- Photoinhibition: light-induced reduction in photosynthetic capacity caused by damage to photosystems



# New production

- Dugdale & Goering, 1967
  - Ratio of uptake of nitrogen species used tells us about what is getting exported in a steady-state system (‘f ratio’)
  - ‘new’ nitrogen is nitrate (and $N_2$ gas), while regenerated nitrogen is ammonium and organic nitrogen (e.g. urea)
  - This concept may be losing favor as we discover many complexities in the nitrogen cycle (e.g. nitrification)

$$f\,ratio = \frac{\rho NO_3^-}{\rho NO_3^- + \rho NH_4^+}$$

# Fate of primary production

- Sinking (Smetacek, 1970)
  - Senescence and remineralization at depth
  - Burial
- Grazing (Landry & Hassett, 1982)
  - Most grazing accomplished by microzooplankton, not meso- or macrozooplankton (Strom et al, 2001)
- Programmed cell death (Bidle and others)

# Sinking

- Phytoplankton sink in two ways:
  - As ‘particles’ (governed by Stokes’ law):

    $V = 2/9\ gr^2(\rho' - \rho)/\rho\nu$
  - Through buoyancy regulation (controlled by ion exchange and lipids)
- Phytoplankton density > seawater (cytoplasm density is 1.03-1.10 g $cm^{-2}$ compared to 1.021-1.028 g $cm^{-3}$; $SiO_2$ is 2.6 g $cm^{-3}$; calcite/aragonite has density of 2.70-2.95 g $cm^{-3}$)
  - For a given excess density and viscosity, a sphere will increase its sinking speed in proportion to the square of the radius

# Viscosity and drag

- Viscosity: a measure of the resistance of a fluid which is being deformed by either shear stress or tensile stress (‘thickness’ of a fluid; resistance to flow)
- Reynolds number: ratio of the *inertial force* to the *viscous force* acting on a body
  - Inertial force: force necessary to accelerate a body from its velocity at time *0* to its velocity at time *t*, or to stop the body traveling at constant speed under its own inertia
- $Re = \rho v L/\mu$

  Re = Reynolds #, $\rho$ is density; v is velocity of fluid across solid object; L = linear dimension; $\mu$ is dynamic viscosity

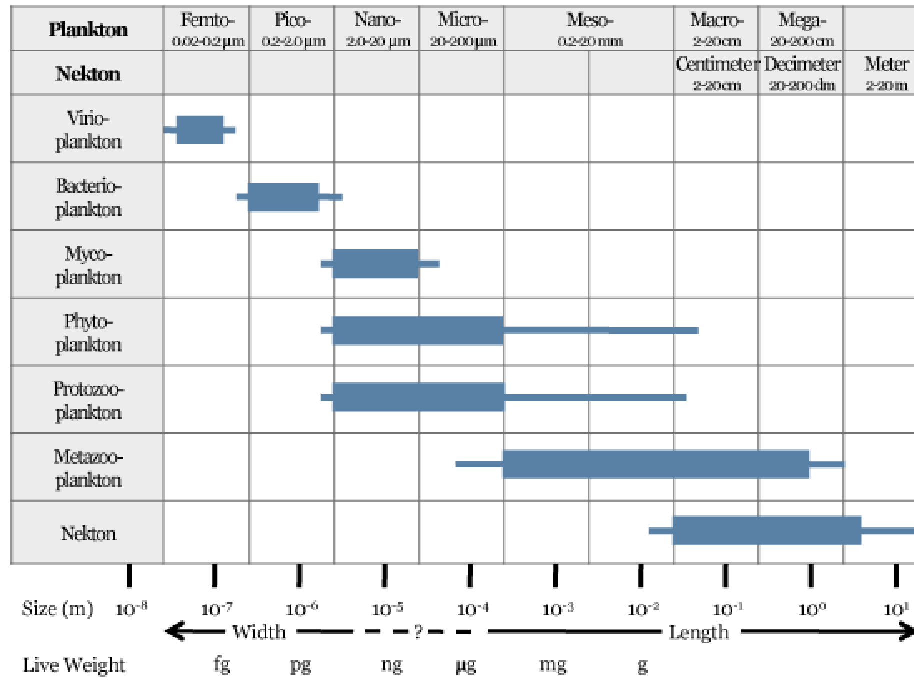
# Zooplankton – who are they?

## Size

- Megazooplankton (20-200 cm)
- Macrozooplankton (2-20 cm)
- Mesozooplankton (0.2-20 mm)
- Microzooplankton (20-200 µm)

## Life habit

- Holoplankton – planktonic throughout lifecycle
- Meroplankton – some time spent in the plankton, generally as larvae



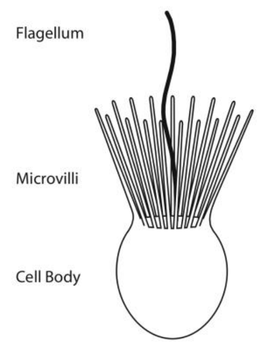

From Sieburth et al, 1978)

J.M. Sieburth, V. Smetacek, J. Lenz. 1978. Pelagic Ecosystem Structure: Heterotrophic Compartments of the Plankton and Their Relationship to Plankton Size Fractions. Limnology and Oceanography, Vol. 23, No. 6. (Nov., 1978), pp. 1256-1263

# Major groups of zooplankton

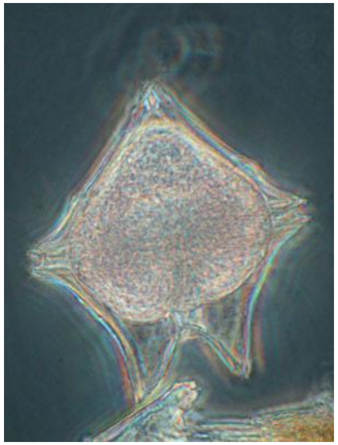
**Microzooplankton (Protists)**

- Microflagellates
- Ciliates
- Dinoflagellates
- Actinopoda (amoebae)

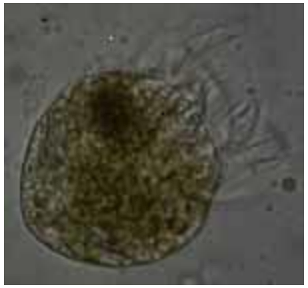



www.tolweb.org


Microflagellates



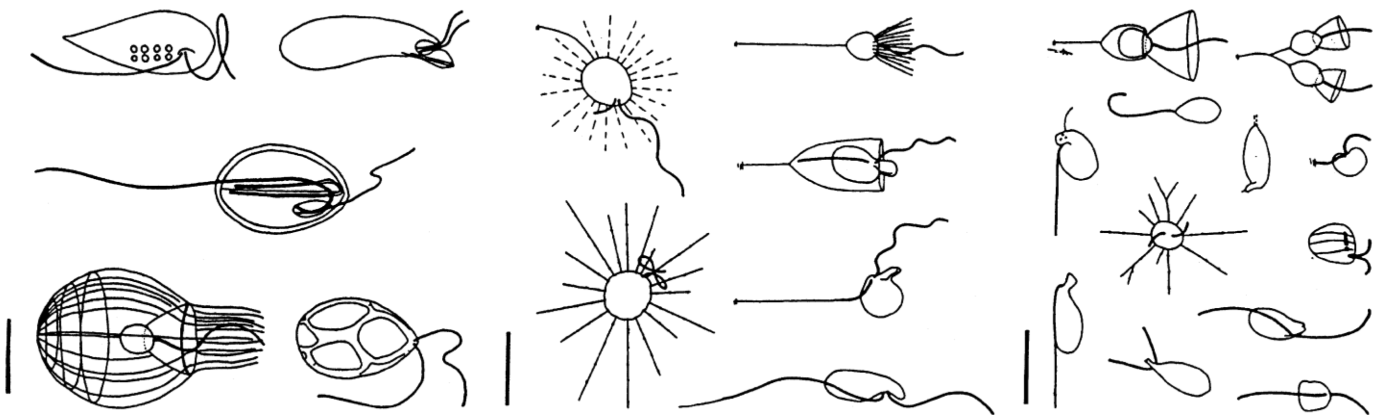
www.cimt.ucsc.edu



www.biosci.ohiou.edu /faculty/currie


www.eol.org

# microflagellates



# Ecological importance of microzooplankton

- Important consumers of phytoplankton (herbivores) and bacteria (bacterivores)
- Exhibit rapid growth rates
- Help explain the HNLC phenomenon in the northeast subarctic Pacific
- Highly diverse group, important in studies of evolution

# Rhizopoda

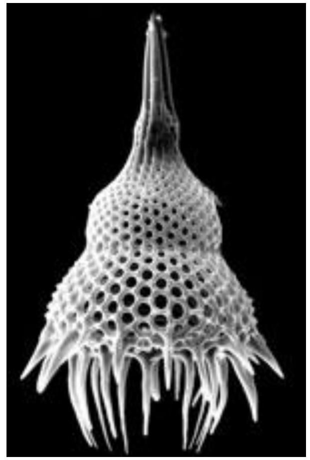
**Actinopoda**

- Heliozoa
- Acantharia
- Phaeodaria
- Radiolaria

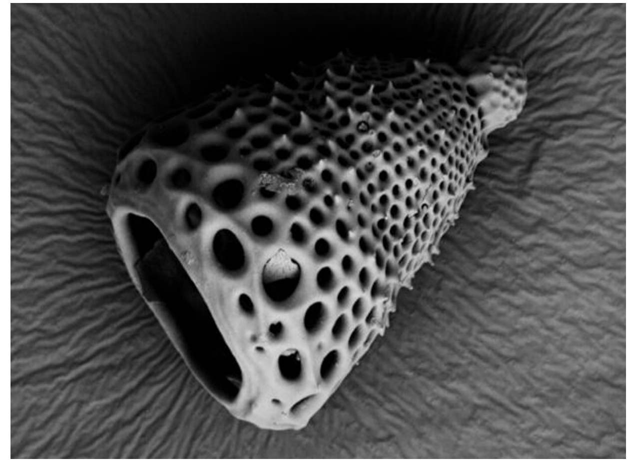
**Granulreticulosa**

- Foraminifera

Radiolaria

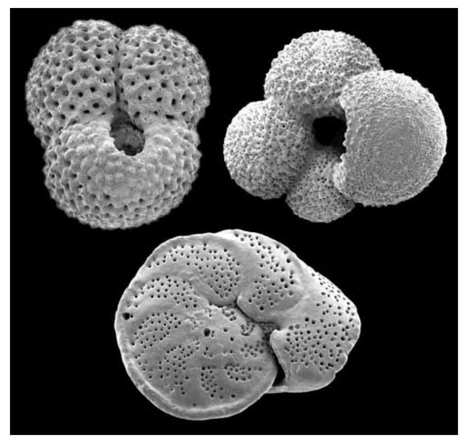


www.radiolaria.org

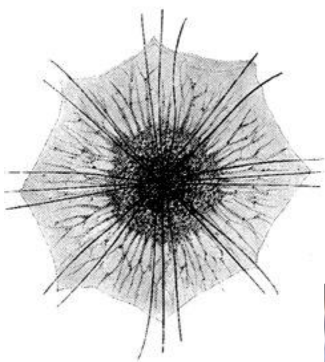


http://academics.hamilton.edu/biology/kbart


Foraminifera

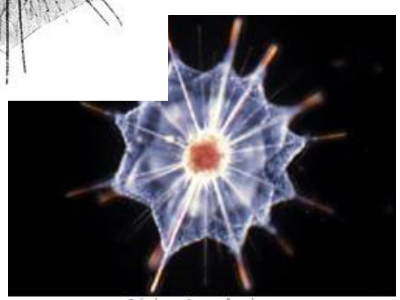


www.teara.govt.nz

Acantharians

www.usc.edu



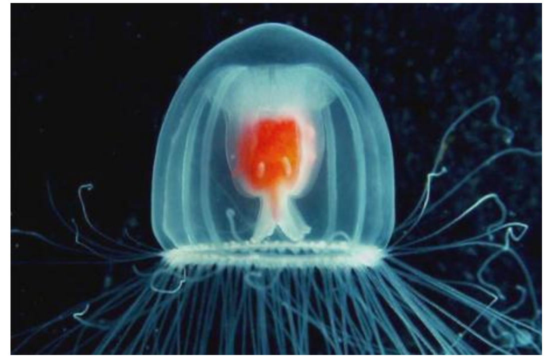
Living Acantharian

Move mouse pointer over images on the side

# Jellies

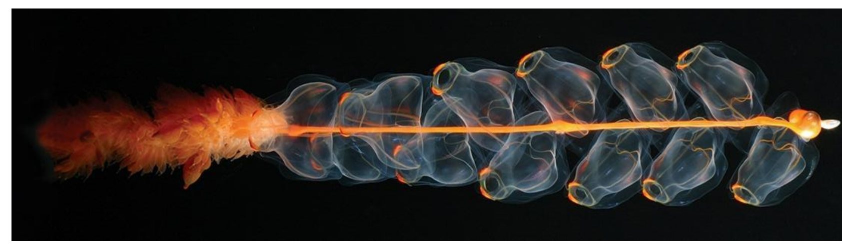
**Cnidaria**

- Gelatinous zooplankton
- Have nematocysts
- simple organization
  - Hydrozoa
  - Scyphozoa
  - Siphonophora
    - Portuguese man-of-war



http://inabsurdis.files.wordpress.com

http://www.cryptosula.nl



http://www.naturalisme.dk

**Ctenophora**

# Significance of jellies

- Fishing
- Human health
- Climate



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Originally published Sunday, August 3, 2008 at 12:00 AM

E-mail article | Print view

**Rise in jellyfish swarms hints at oceans' decline**

Blue patrol boats crisscross the swimming areas of beaches here with their huge nets skimming the water's surface. The yellow flags that...

By ELISABETH ROSENTHAL
*The New York Times*


http://www.cnn.com


**Japanese fishing trawler sunk by giant jellyfish**

A 10-ton fishing boat has been sunk by gigantic jellyfish off eastern Japan.

By Julian Ryall in Tokyo
Published: 7:00AM GMT 02 Nov 2009

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# Worms

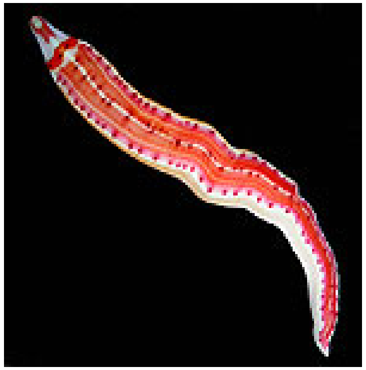
- Platyhelminthes
- Nemertes
- Annelida
- Nematoda
- Chaetognatha



www.starfish.ch

K. Osborn, UCSD

www.wildsingapore.com



http://www.nmnh.si
.edu

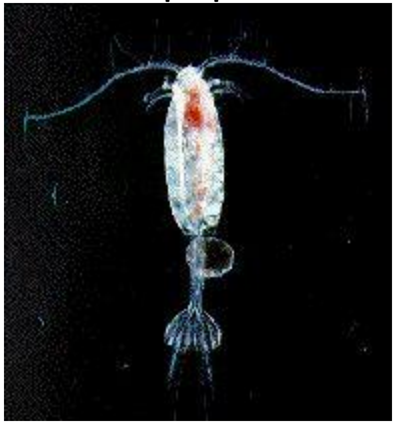
# Molluscs

- Opisthobranchs
  - Euthecosomata – pteropods (winged foot)
    - Aragonite shells
    - Mucous ‘float’
  - Pseudothecosomata – pteropods with gelatinous shell
  - Gymnosomata – unshelled pteropods
    - carnivorous
- Prosobranchs – benthic snails
  - Calcite shells

# Arthropods

- Branchiopoda
- Ostracoda
- Copepoda
- Cirripedia
- Amphipoda
- Mysidacea
- Euphausiacea
- Decapoda

copepod



euphausiid

ostracod

mysid

amphipod

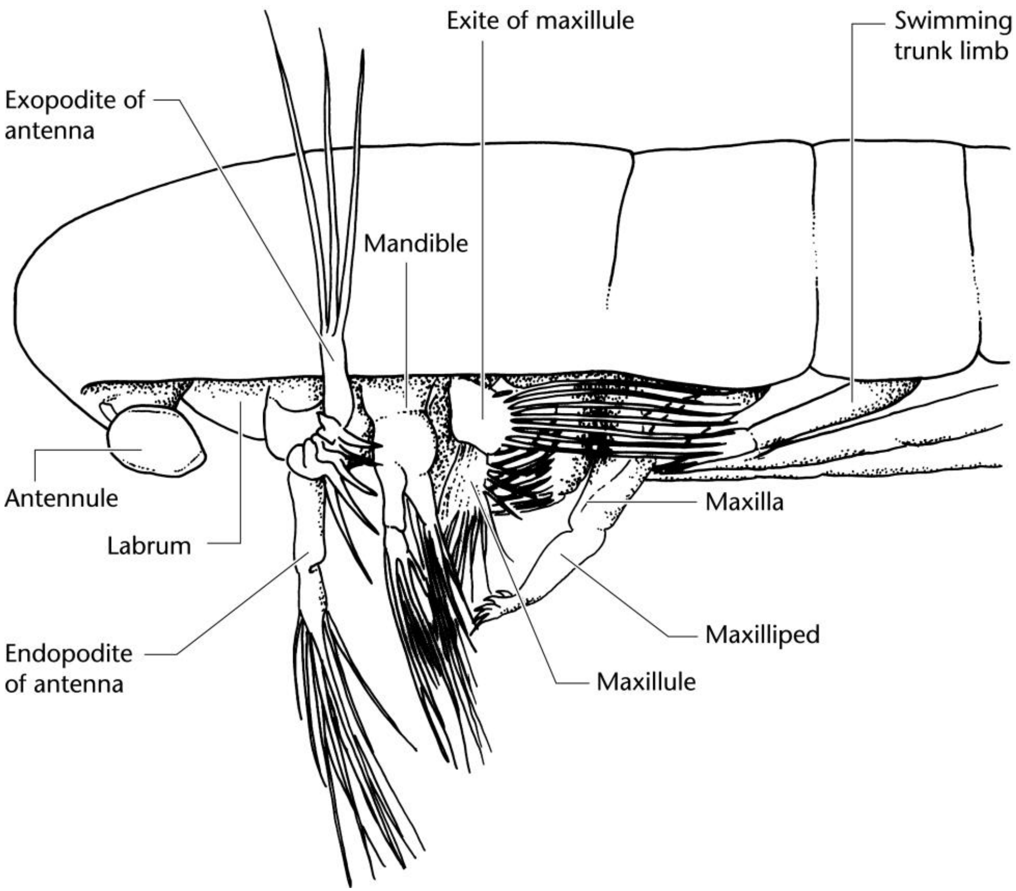
Branchiopoda


Cirripedia

Decapoda

*Calanus finmarchicus*

R. Jones, UNH



Naupliar and copepodite stages

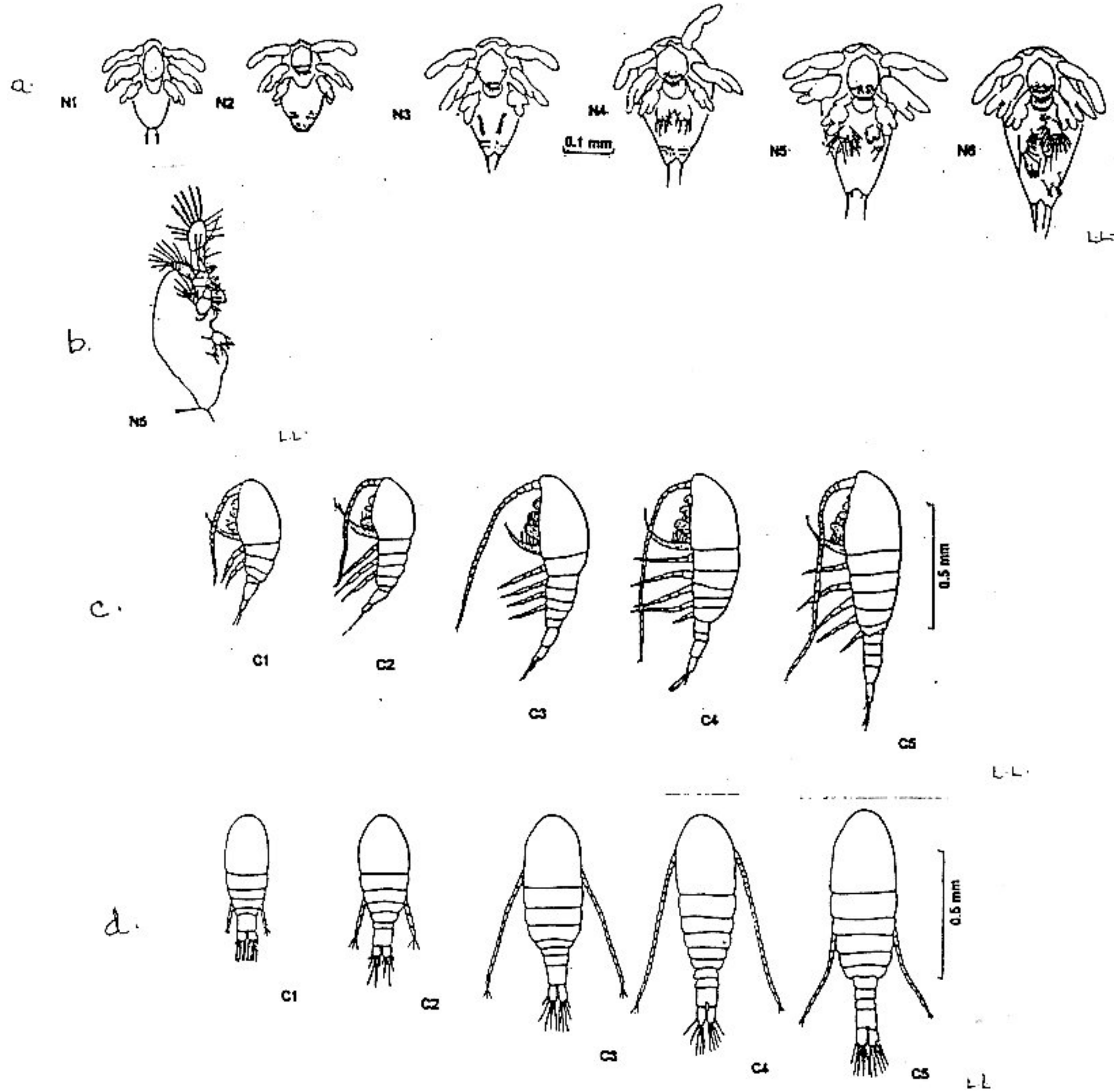
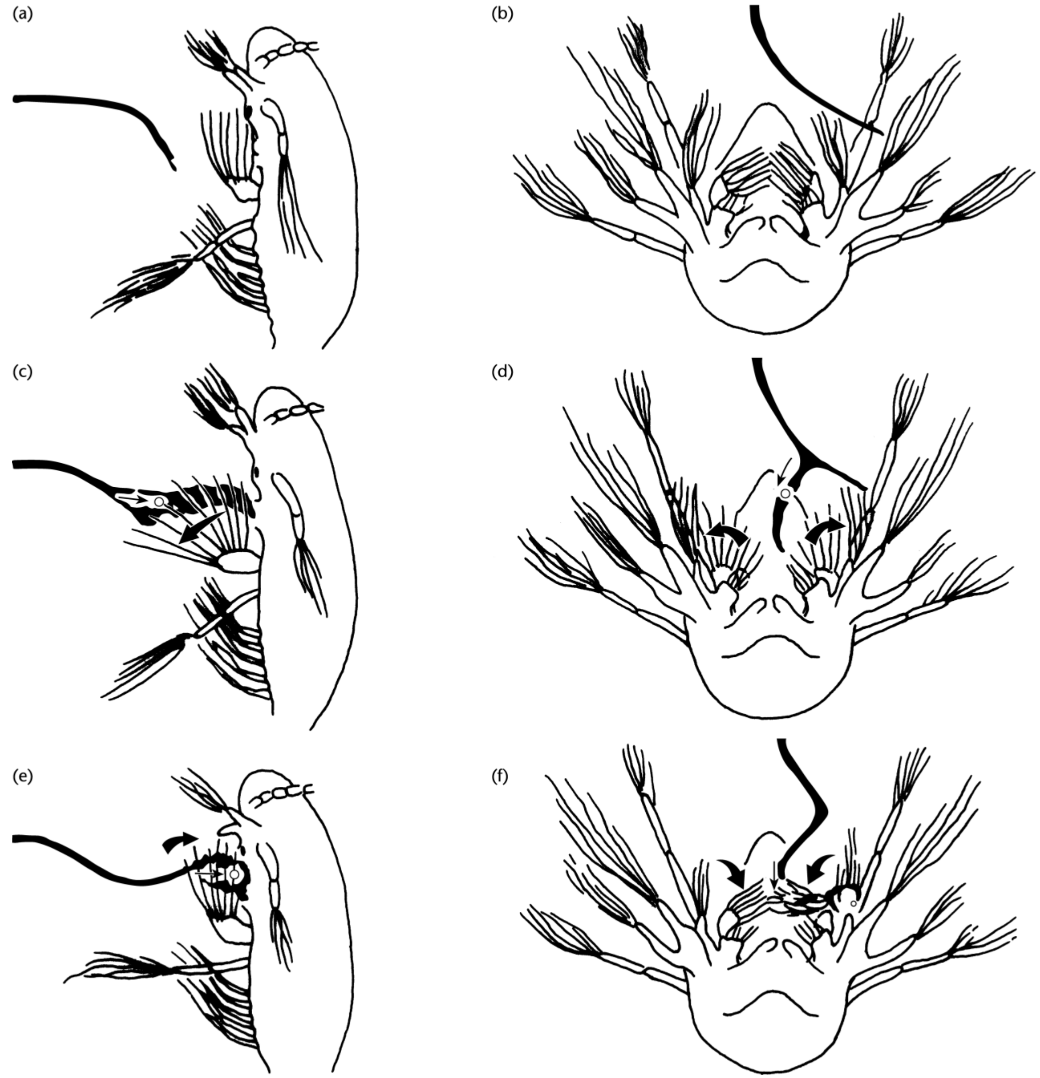



Figure 3. Naupliar and copepodite stages of *Diaptomus* spp. (a.) N1 - N6, naupliar stages of *D. kenai* M.S. Wilson, ventral view (after Green and Northcote 1982). (b.) N5, nauplius stage 5 of *D. gracilis* Sars, lateral view (after Gurney 1931). (c.- d.) C1 - C5, copepodite stages of *Diaptomus* sp. (modified from Shih and Maclellan 1977 and Einsele 1989). (c.) lateral view (d.) dorsal view

# Feeding

**Observations about copepod feeding (Koehl & Strickler, 1981)**

- Copepods live in a viscous world where flow is laminar
- Bristled appendages behave as solid paddles rather than open rakes
- Particles can neither be scooped up nor left behind because appendages have thick layers of water adhering to them
- Water and particle movement stops immediately when an animal stops beating its appendages

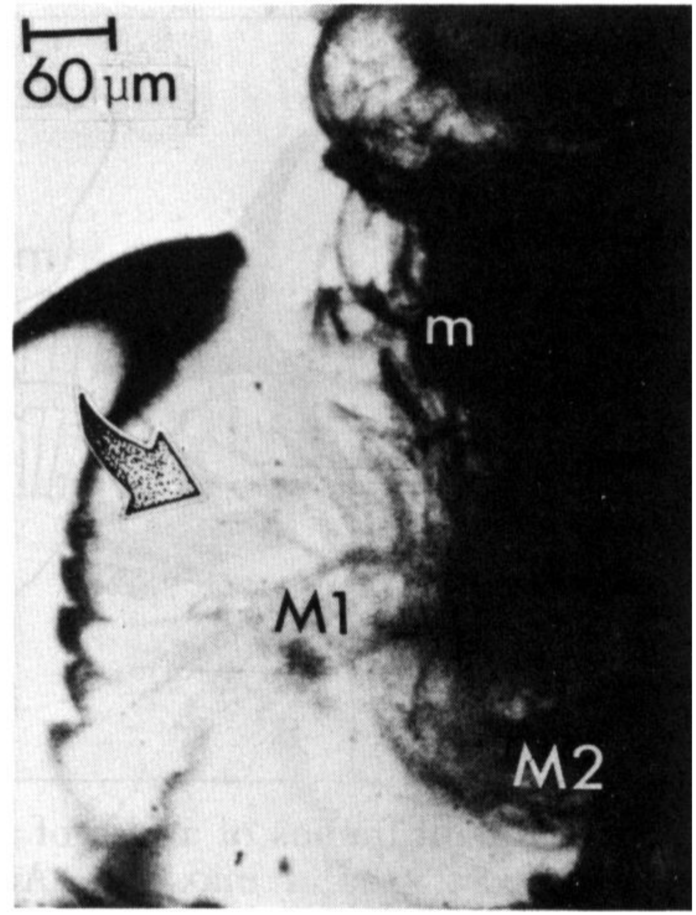



$Re = \rho\, v\, L/\mu$

**Observations about copepod feeding (Koehl & Strickler, 1981)**

- Bristled appendages behave as solid paddles rather than open rakes

$Re = \rho v L/\mu$




From Koehl and Strickler, 1981 (Fig. 5)

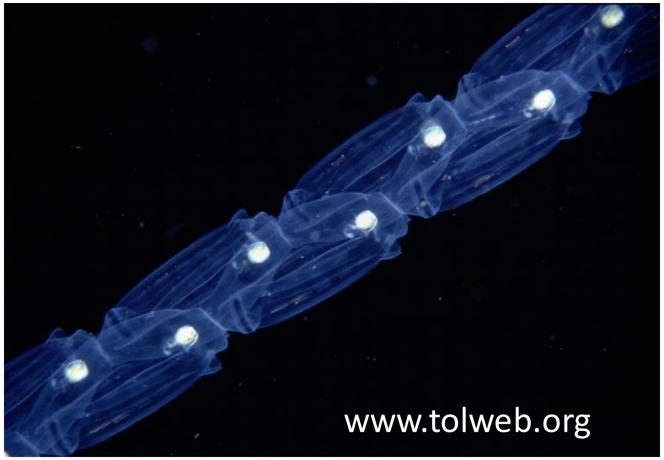
*Black is dye being pushed out of the page by first maxilla (M1)*
*Note: dye does not flow between the setae*

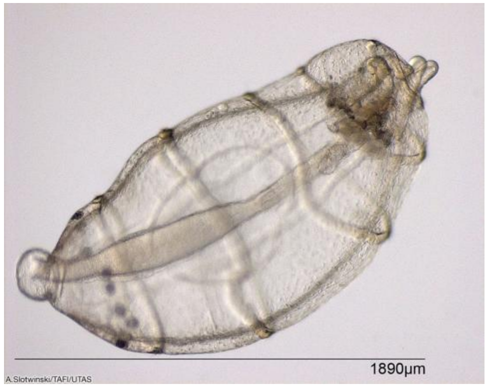
-Detection of food is thought to be olfactory, although mechanical disruption may be important as well
-can reject food by reversing the motions used in feeding

# Urochordata

- Salpidae
- Doliolidae
- Appendicularia

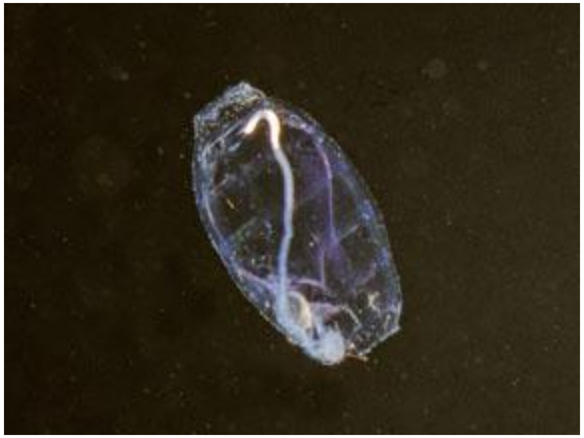
Salps



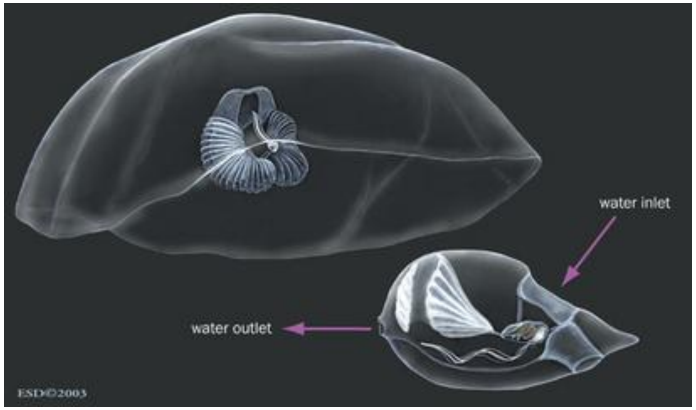

http://www.tafi.org.au

Doliolid



www.jellieszone.com

Appendicularia




http://animaldiversity.ummz.umich.edu

**Vertebrata**

Fish – fish larvae are zooplankton (icthyoplankton)

http://www.pac.dfo-mpo.gc.ca/sci/OSAP

# Feeding rates

- Frost equation (Frost, 1972)

- $\ln(N_t/N_0) = (\mu - FC/V)\, t$

  - $N_t$ = # plants left after the expt period
  - $N_0$ = # plants started with
  - F = clearance rate (volume cleared by each animal)
  - C = # animals
  - V = container volume
  - t = time
  - μ = growth rate of plants

**Influences on clearance and ingestion rates**:

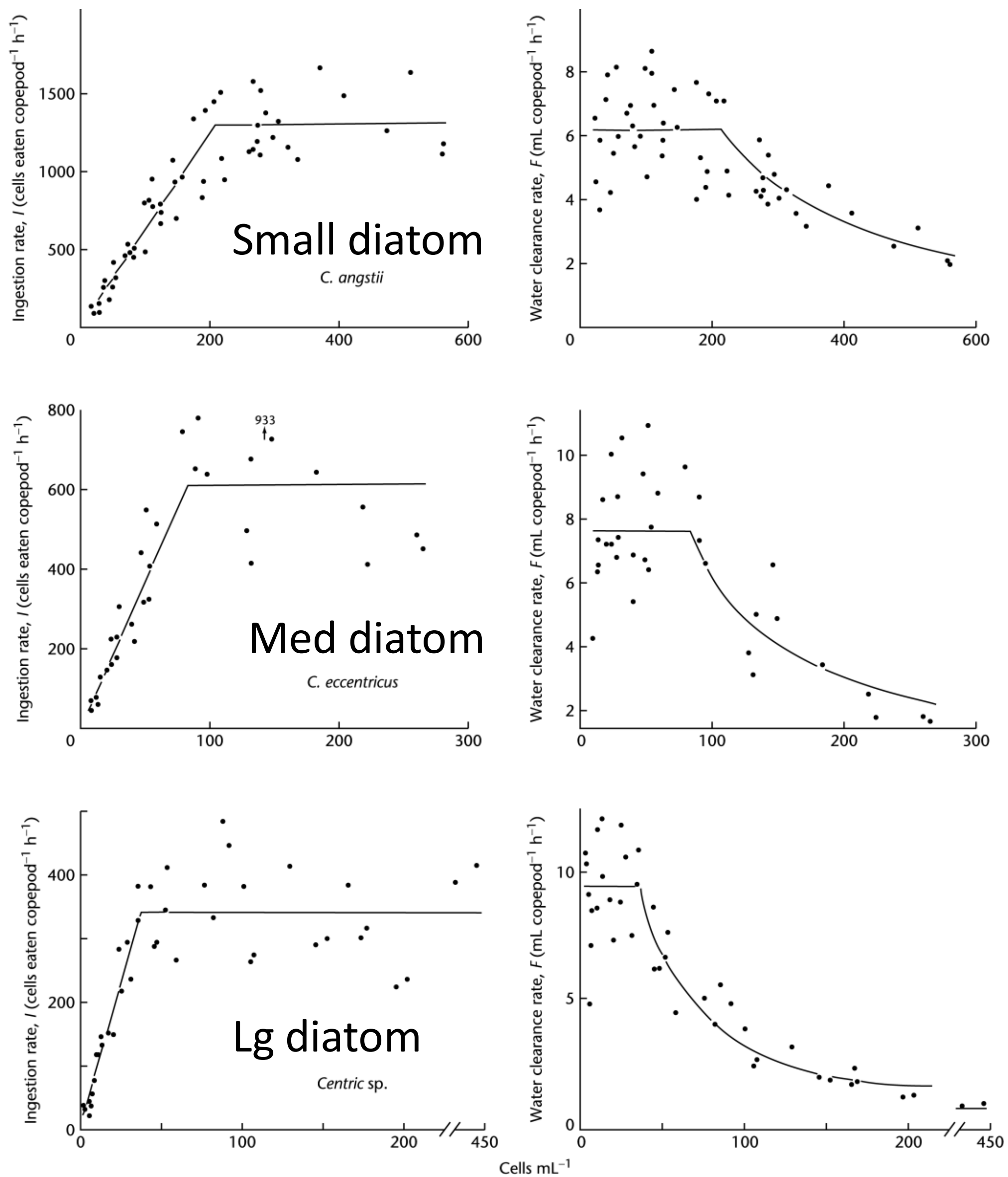
- Food density, container volume, food particle size, animal size, life cycle stage, previous feeding history, type of food, temperature

# Effect of food density: the functional response

Ingestion rate ($I = F\ N_{mean}/V$)

*(F is clearance rate; $N_{mean}$ is mean plant concentration; V is container volume)*

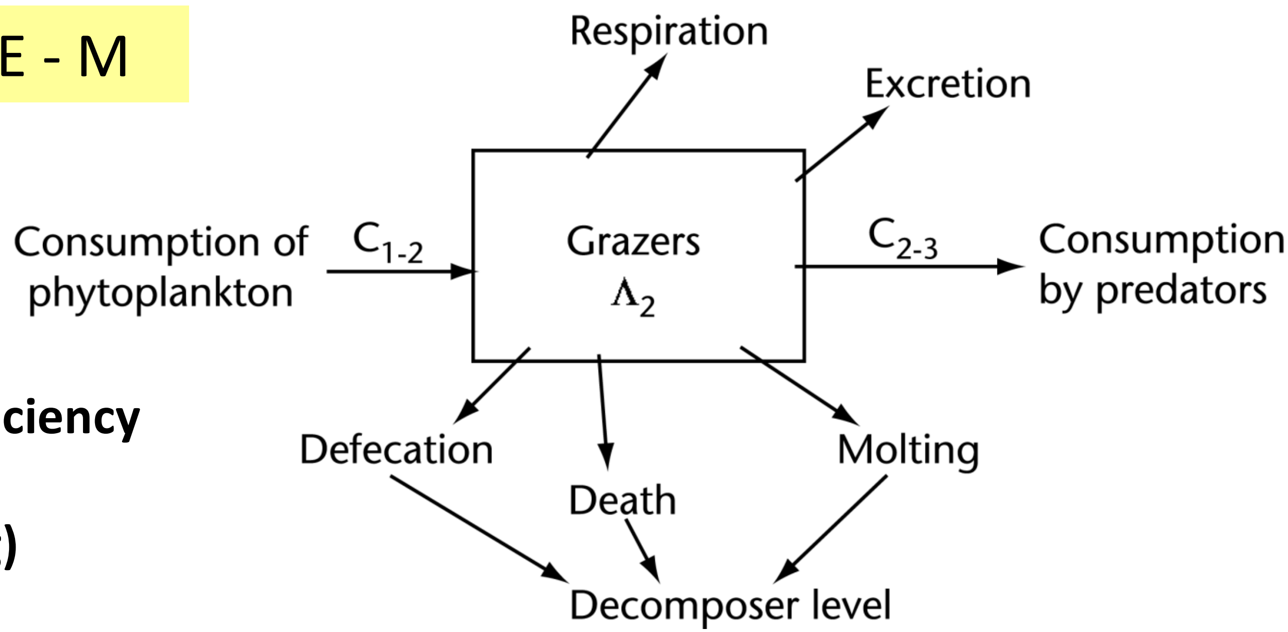
- At low food conc'n, filtering rates do not change much;
- Ingestion rate remains nearly constant once 'saturation' is reached;
- Maximum ration is achieved more rapidly for large cells compared to small ones.



# Secondary production ($2^oP$)

- Rate of change in the biomass of herbivores plus that removed by predation
- Herbivore growth (growth x biomass)

$$2^oP = \Gamma A - R - E - M$$




**$\Gamma$ = grazing rate**
**A = assimilation efficiency**
**R = respiration**
**E = ecdysis (molting)**
**M = mortality**

# Herbivore growth

- Growth x biomass to give $2^oP$
- Allometry: Rate = $a(\text{Weight})^b$

Growth

- **(1) Vidal (1980)**: based on temperature, food availability, size of individual → Chapman-Richards growth equation:

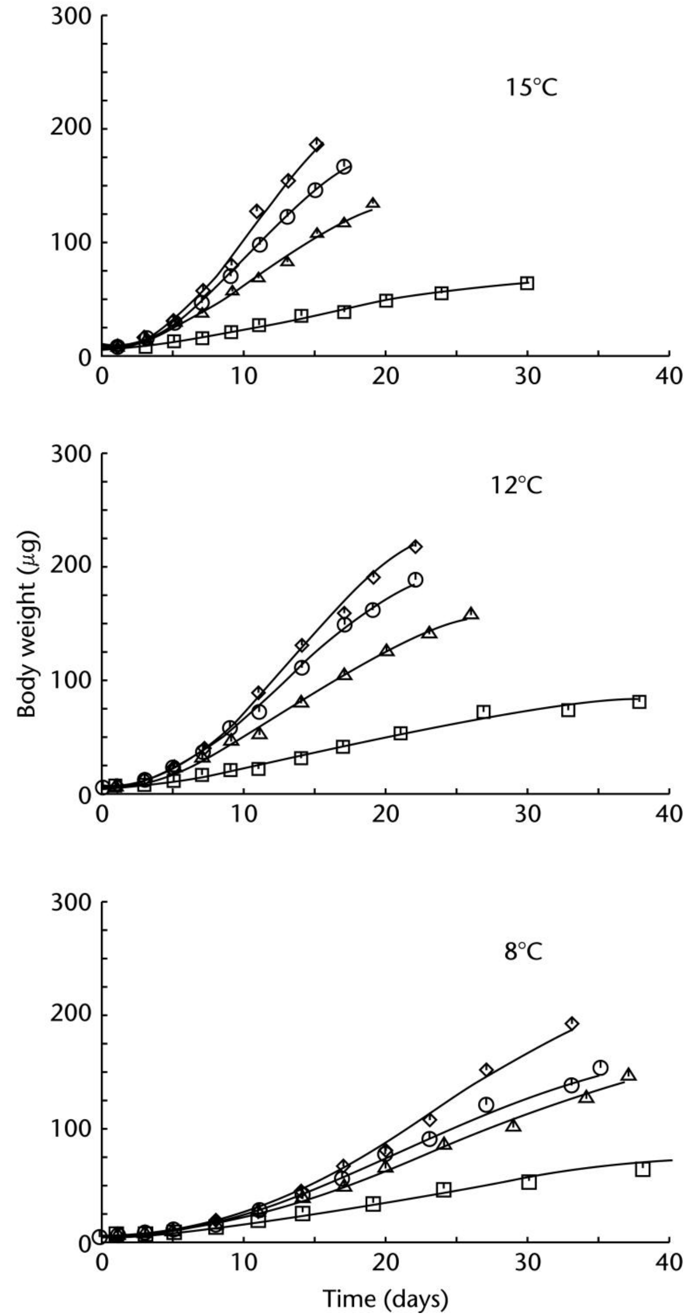
$$W_t = W_{max}(1+Be^{-kt})^{-m}$$

  - $W_t$ = dry body weight of a copepod at time t, $W_{max}$ is max weight attained at maturity
  - *B, K, m* define initial weight, slope, and inflection point of the sigmoid weight vs. time curve, respectively
- Produces Ivlev curve:

$$G = G_{max}(1 – \exp[d_G(P-P_G)])$$

- $G_{max}$ = max growth rate, $d_G$ is slope of the curve, P is food conc'n, $P_G$ is value of P when G = 0

# Sigmoidal growth curves



# Herbivore growth

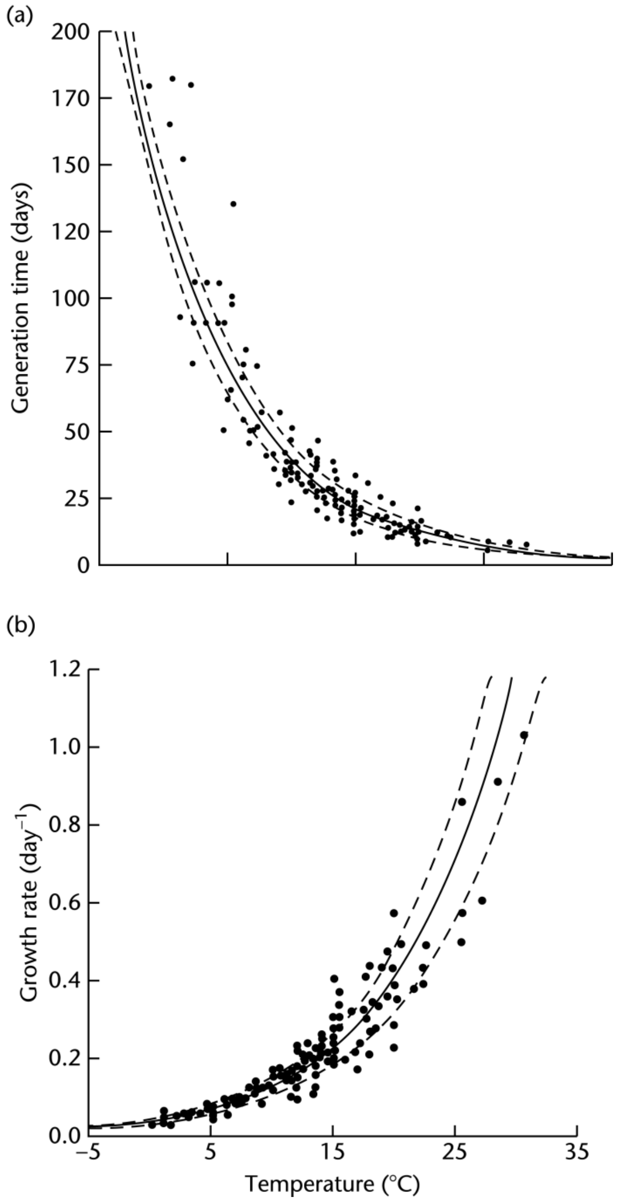
- (2) Jensen (1919) equation:

$$2^o P = \sum_{i=1}^{adult} G_i B_i$$

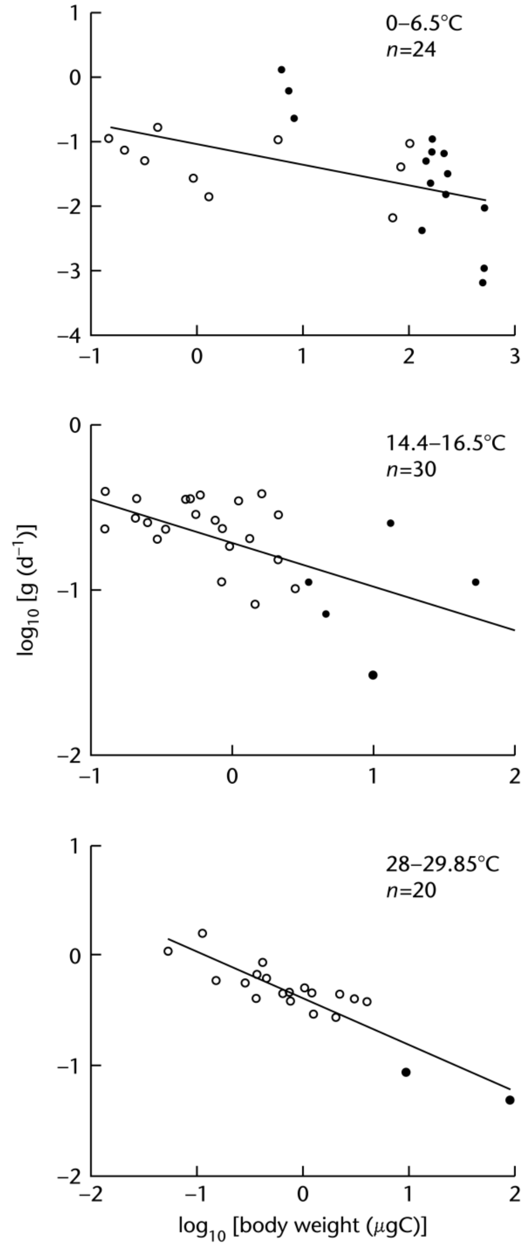
  - i = life cycle stage
  - $G_i$ = weight-specific growth rate of ith stage
  - $B_i$ = mean biomass of life cycle stage in the habitat
- Measure growth of different stages separately

# Controls on secondary production

- Temperature (Huntley-Lopez model)
- Hirst and others: development time, body size, spawning mode, food availability → not dependent on temperature
- No consensus




Huntley and Lopez, 1992




Hirst and Sheader, 1997

# Phenology

The relationship between a periodic biological phenomenon and climatic conditions

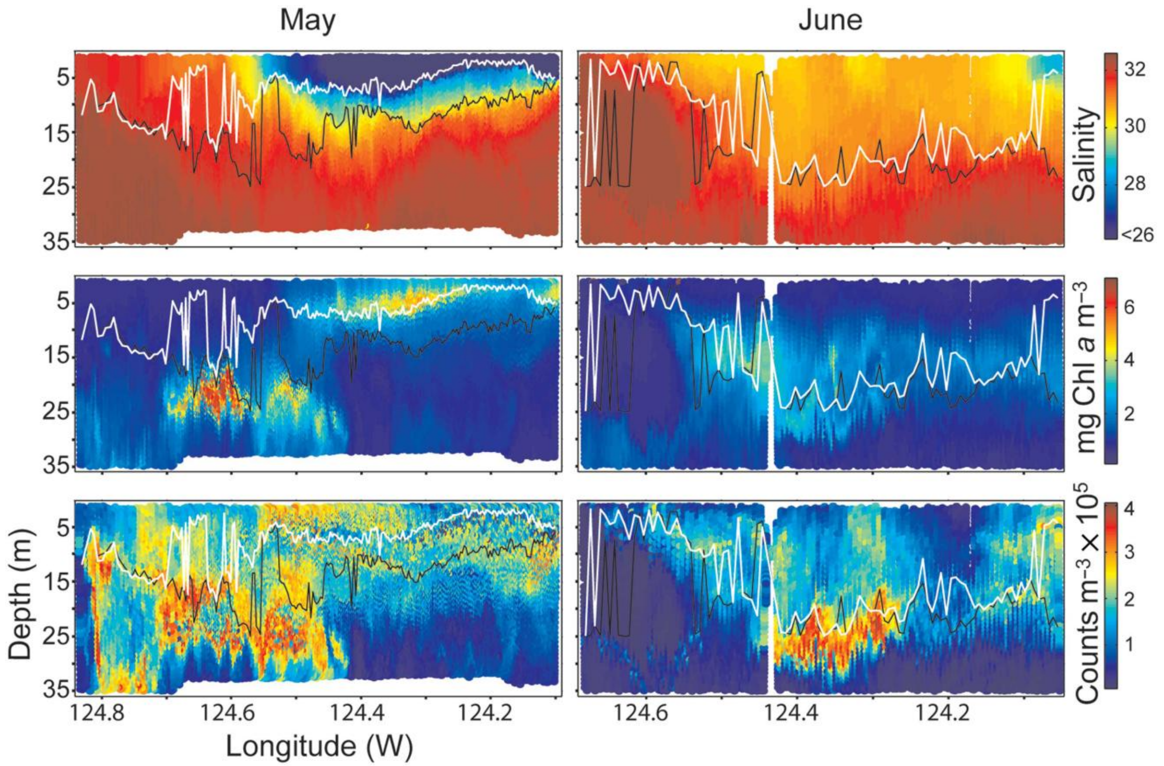
- For zooplankton:
  - **Feeding** (match-mismatch hypothesis, D.H. Cushing)
  - **Diapause**: means to survive predictable, unfavorable or adverse environmental conditions, such as temperature extremes or reduced food availability
    - Often observed in arthropods

# Other important behavior patterns

- Diel vertical migration
- Creators of turbulence in low-turbulence environments (Kunze et al., 2006; Katija & Dabiri, 2009)- more when we talk about bio-physical coupling
- Aggregation at or near fronts

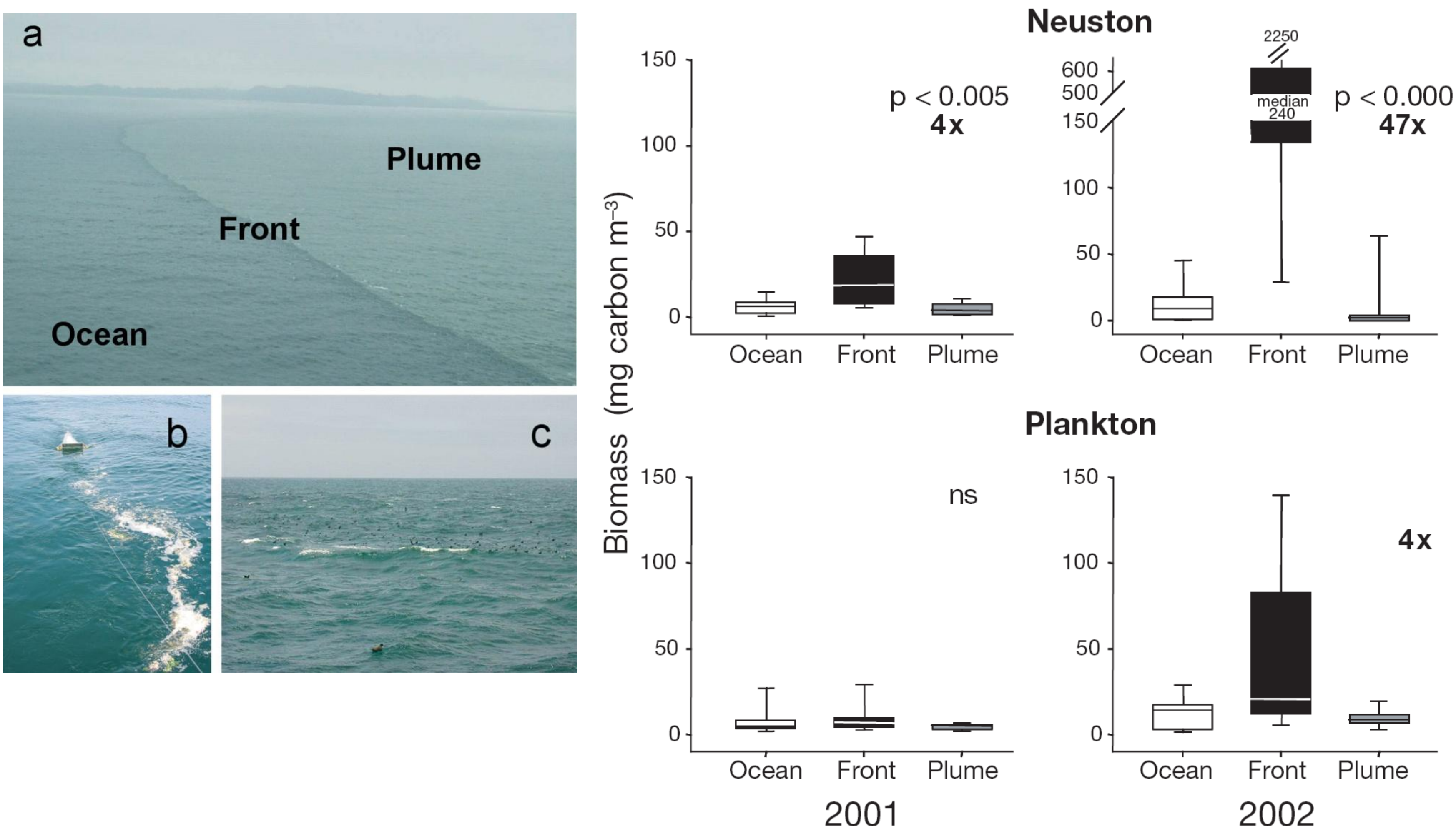
# Zooplankton in the Columbia River plume

Peterson & Peterson, 2008 (ICES J. Mar Sci)




*Peterson & Peterson* (2008), Figure 2. Salinity (top), Chl a (middle), and zooplankton abundance (bottom) along cross-shelf transects (indicated by arrows in Figure 1) just south of the Columbia River mouth during the May (left) and June (right) surveys. The pycnocline (solid white line) and thermocline (solid black line) are shown in each panel.

# Zooplankton accumulate at fronts, especially near the surface




Morgan et al. (2005), Mar. Ecol. Prog. Ser., 299: 19-31.