Food Webs Overview

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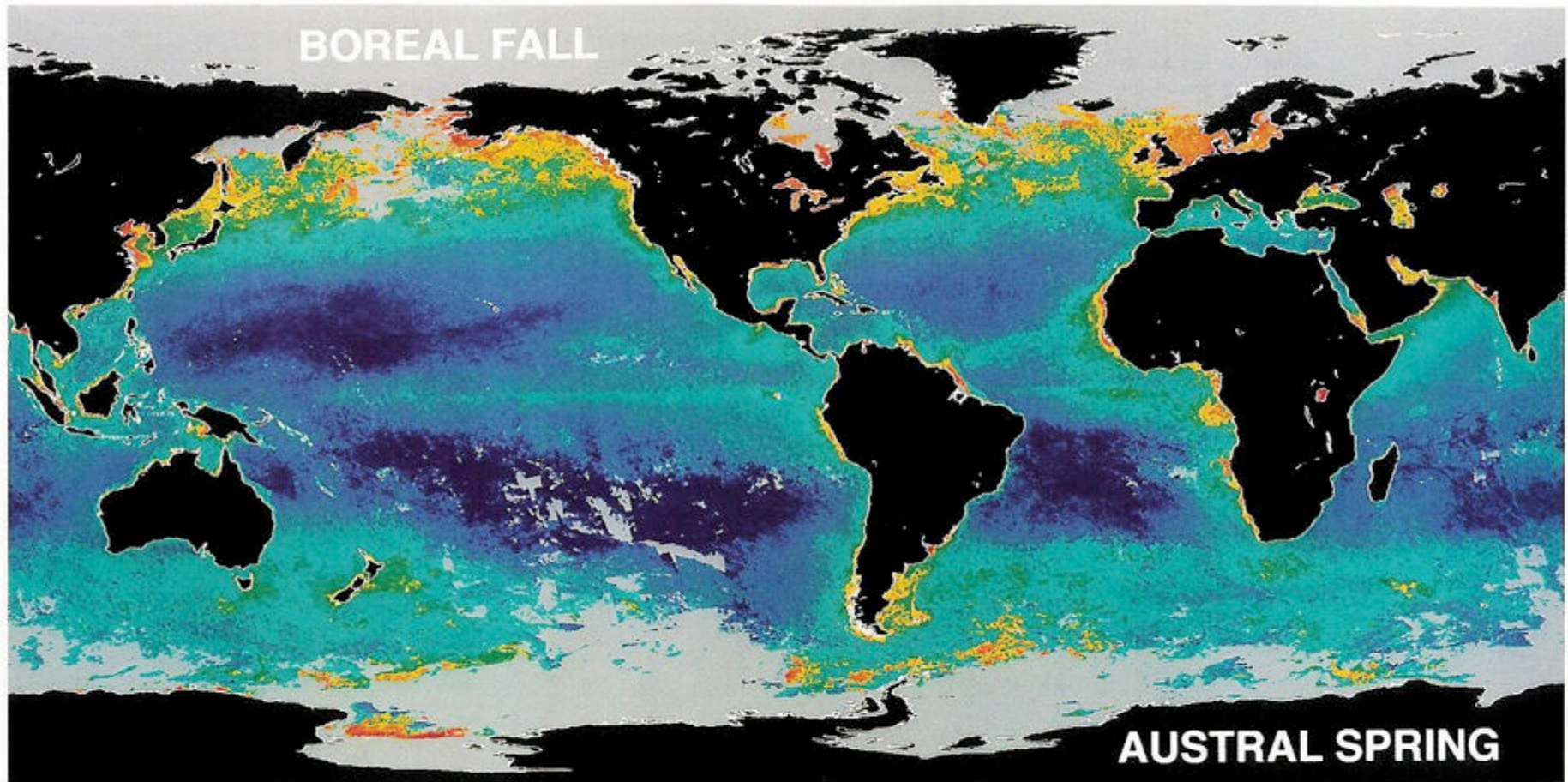selph@hawaii.edu

Today's Lecture

- Global View of Ocean Ecosystems
- Physical and Chemical Forcing
- Phytoplankton Size as Structuring Agent
- Food web major players

COLOR PLATE 2 Climatological (1978–1986) seasonal sea surface chlorophyll field obtained with Coastal Zone Color Scanner sensor for boreal fall (September–November). Color is a log scale for chlorophyll: purple = <0.06 mg Chl m^{-3}, orange-red = 1–10 mg Chl m^{-3}. Provided by NASA/Goddard Space Flight Center.

Why isn't chlorophyll the same everywhere?

Basic Zones of Plankton Distribution

- Polar -- Arctic, Antarctic Circumpolar

- Subpolar -- Subarctic, Subantarctic

- Temperate -- "Transition Zone"

- Subtropical Gyres -- Northern & Southern

- Equatorial -- Tropical

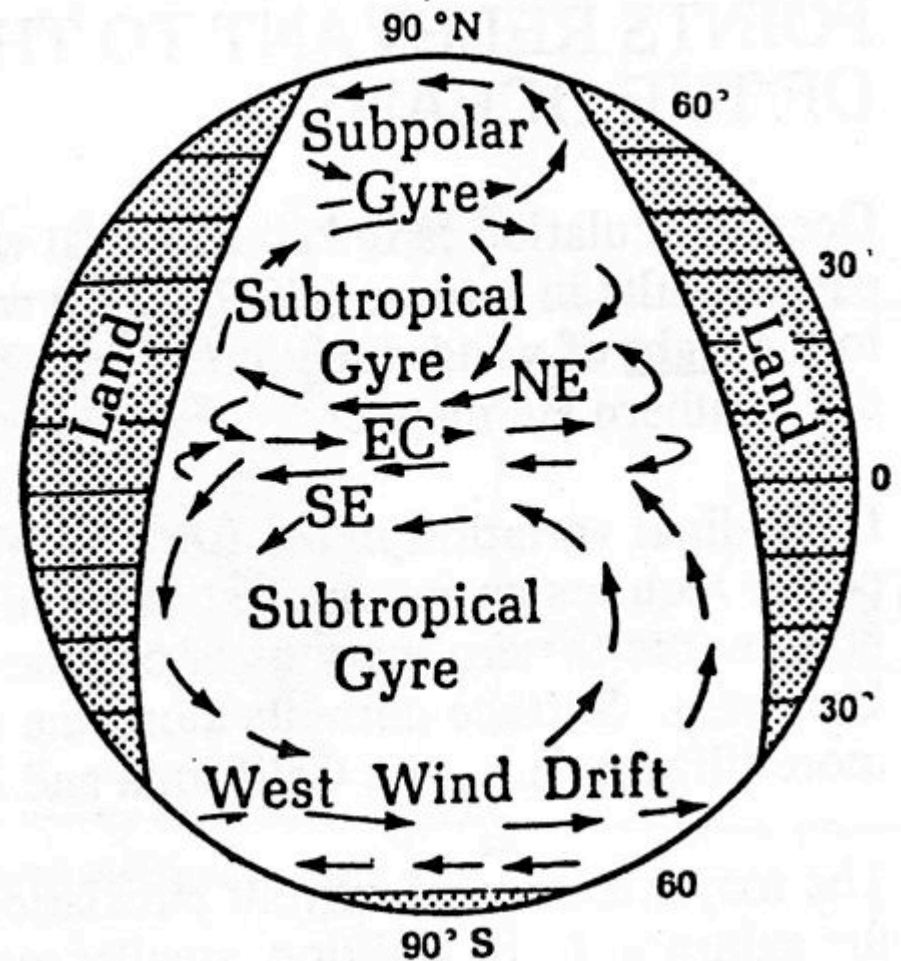- Eastern Tropical Pacific

- Warm-Water Cosmopolitan

These provinces have unique hydrographic characteristics and appear to be self-sustaining ecosystems
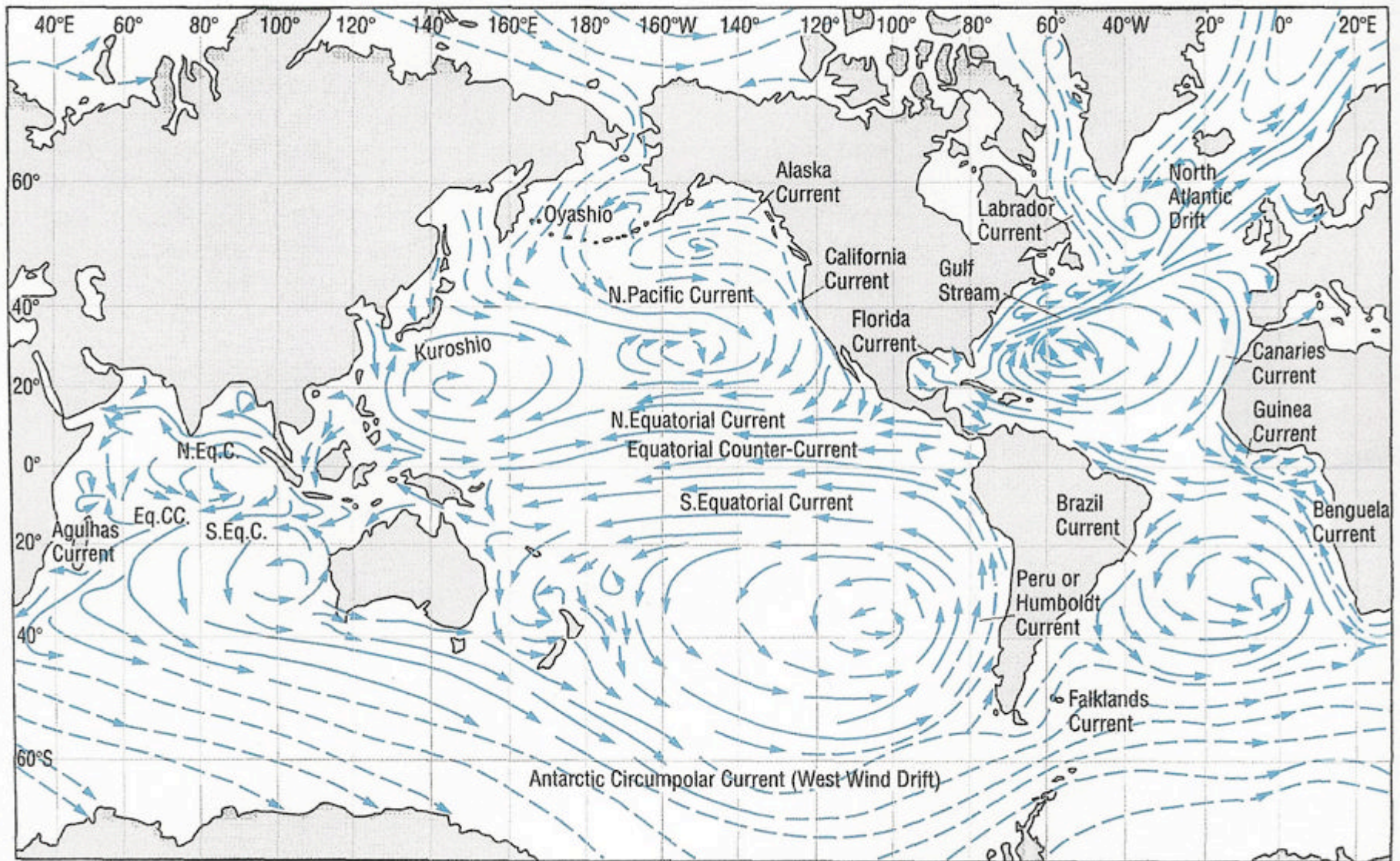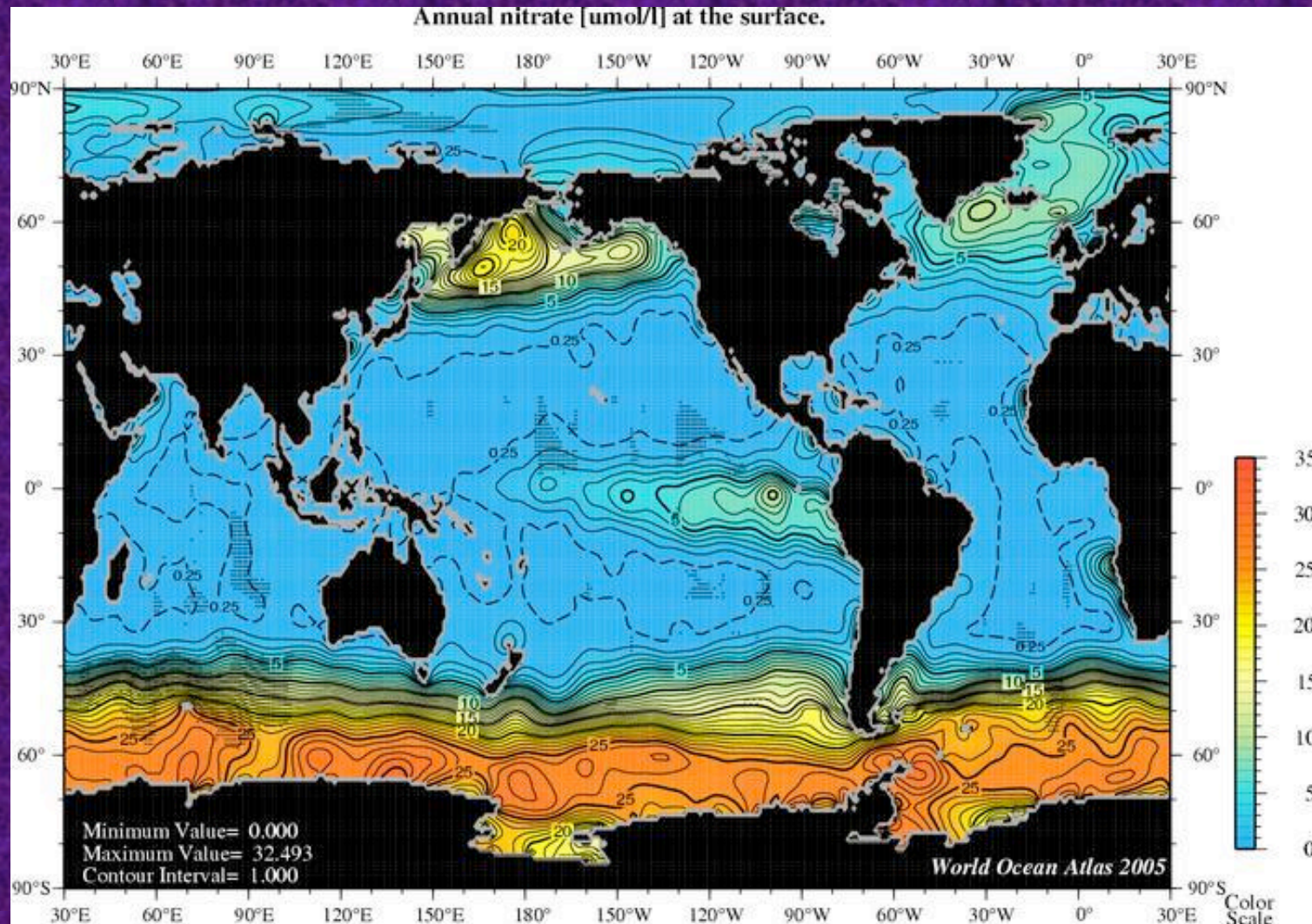
Winds and Currents
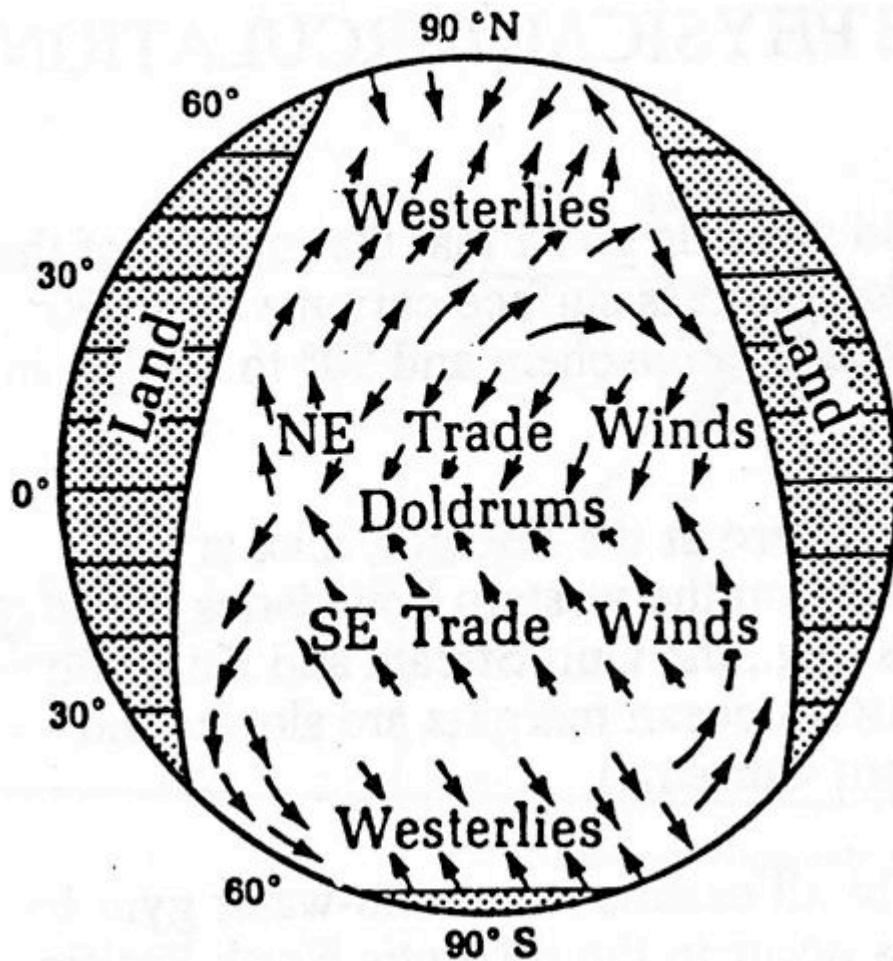
Main Ocean Current Systems

Figure 2.19   The major surface currents of the oceans in northern winter. Dashed arrows indicate cool currents; solid arrows show warm currents.

Lalli & Parsons 1997

Surface Nitrate Concentrations
Annual Averages

Annual nitrate [umol/l] at the surface.

Minimum Value= 0.000
Maximum Value= 32.493
Contour Interval= 1.000

World Ocean Atlas 2005

http://www.nodc.noaa.gov

Light varies with Latitude

http://www.xpeditiononline.com/climatepage.html
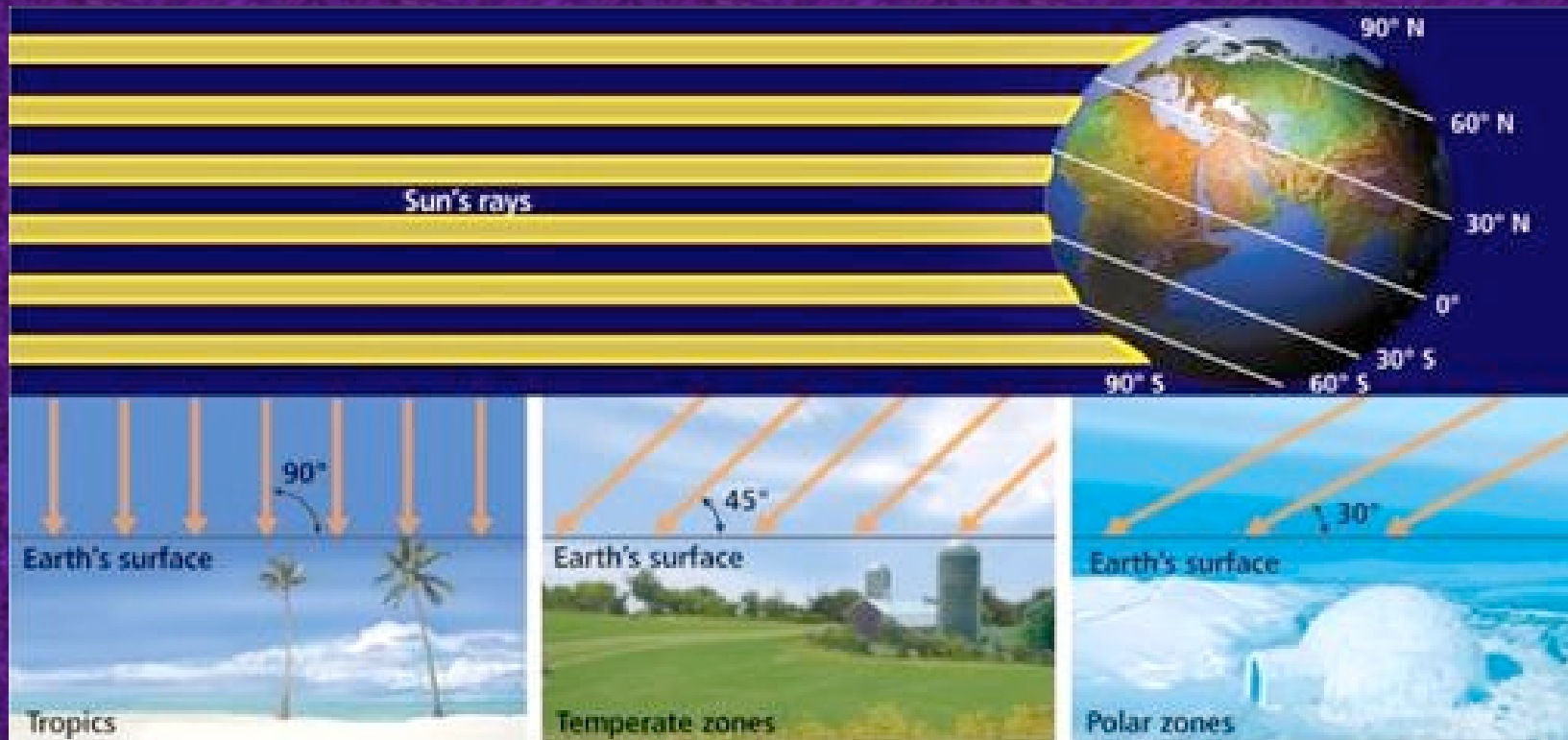
Light and Nutrients

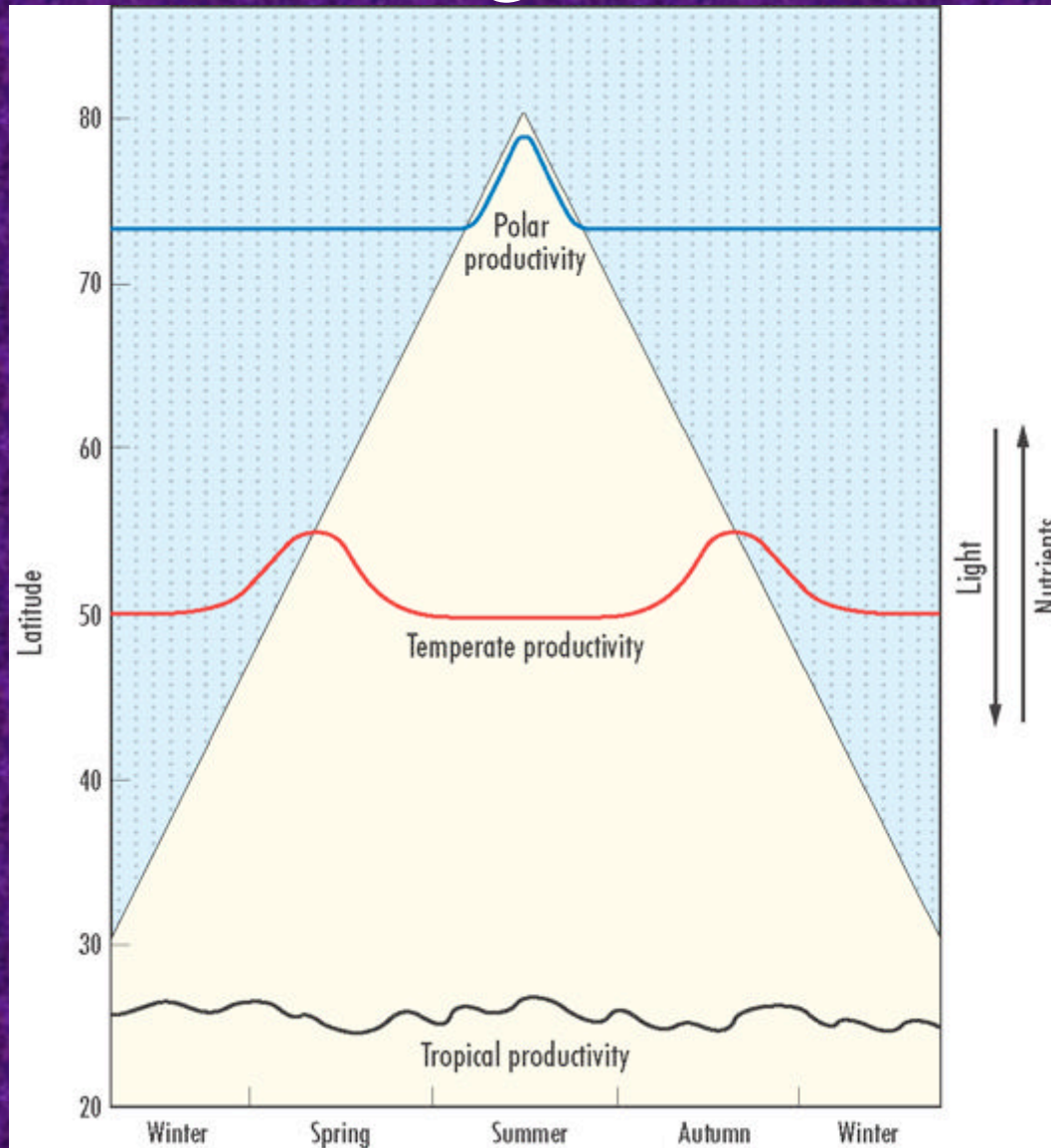**Light** increases from the poles towards the equator

Surface **nutrients** increase from the equator towards the poles

Phytoplankton **productivity** varies with latitude as well

What nutrients are we usually most concerned with and why?

Required nutrient elements: carbon, nitrogen, phosphorus, oxygen, silicon, magnesium, potassium, calcium

Trace element nutrients: iron, manganese, zinc, etc.

Redfield Ratio: "Healthy" phytoplankton have a molar C:N:P ratio of 106:16:1 (or a C:N ratio of 6.6)

Life requires energy and certain raw materials

- **Energy**: sunlight is the primary driver
- **Raw materials**: dissolved inorganic nutrients
- **Photosynthesis**: biochemical reactions that use the raw materials and light to synthesize the organic matter found in all living things
- **Heterotrophs** then consume phytoplankton (or organic matter derived from phytoplankton) and thereby the organic matter is transferred to other components of the ecosystem

Elemental Stoichiometry

Phytoplankton tend to have a **constant molar ratio of elements** because all cells are made up of essentially the same components

Nucleic acids: *DNA, RNA*

Proteins: *essential machinery of cells (enzymes)*

Carbohydrates: *sugars and starches*

Lipids and fats: *cell walls and all internal membranes, energy storage*

100 um

Rhizosolenia chain (with Chaetoceros chain behind)

Heterotroph Stoichiometry

At low trophic levels (primary and secondary consumers), elemental stoichiometry also tends towards constancy

Elemental ratios are different than in autotrophs however, as cellular machinery is used to break down consumed food

Later in course: differences in elemental stoichiometry between predator and prey directly impacts what is recycled back to the mineral phase

Limiting Nutrients

Concept: as phytoplankton grow, one of the many nutrient elements that they require will be limiting first: when that element runs out, growth will stop till more is available

In the ocean, the limiting nutrients are usually

nitrate or iron

because of their low concentrations **relative** to other required nutrients

Microbial Abundances

1 drop of seawater
(~1 ml)

10 million viruses

1 million bacteria
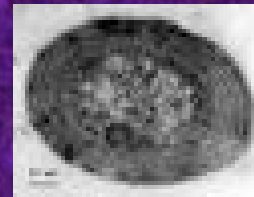and archaea

1000 eukaryotes

The Phytoplankton Players (Autotrophs)

1° Producers

Photosynthetic bacteria (**Cyanobacteria**):

Prochlorococcus:

40°N - 40°S, but not abundant/present in coastal higher-nutrient systems

Synechococcus:

*wider latitudinal range, including coastal systems, but not in polar (Arctic or Antarctic) systems*

Halosphaera minor
Ostenfeld

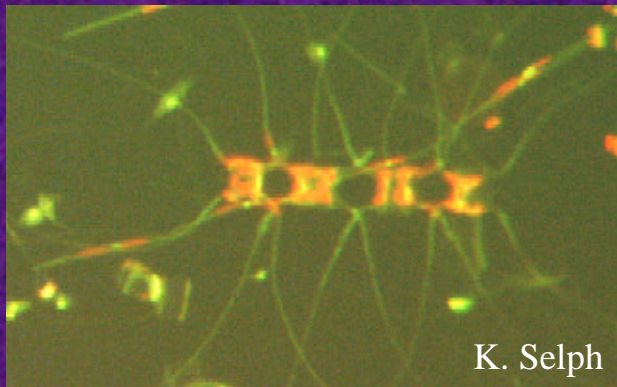Eukaryotic single-celled algae:
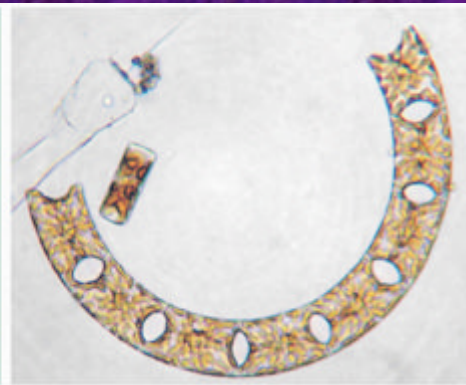
Pico & nano-eukaryotes (<2 - 20 μm)

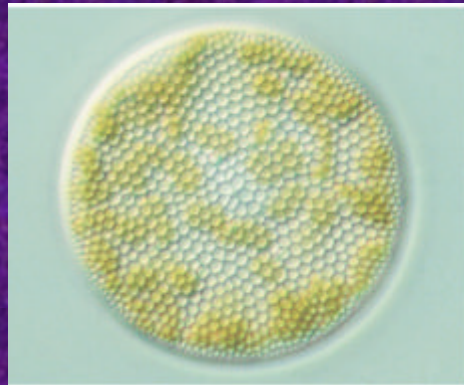*Dinoflagellates (~10 - 200 μm)*

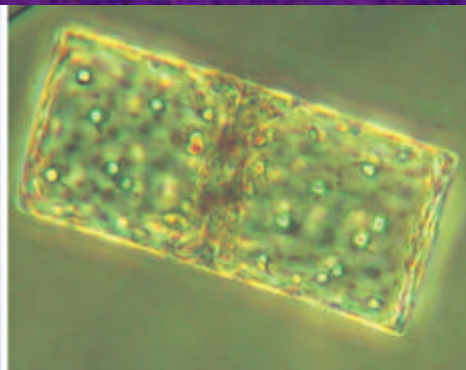*Diatoms (~5 um to chain lengths up to mm size range)*

Important in coastal/high nutrient systems, present but otherwise not usually a large component of community
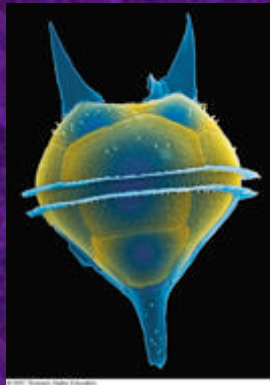
A Selection of Diatoms (Autotrophic Eukaryotes)

K. Selph
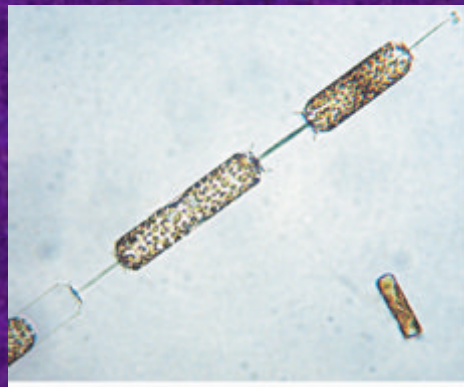
Kaiser et al. 2005

Great variety of sizes/shapes of phytoplankton

0.6 - 0.8 μm

0.8 - 1.4 μm

2 - 5 μm

5 - 20+ μm

5- 50+ μm
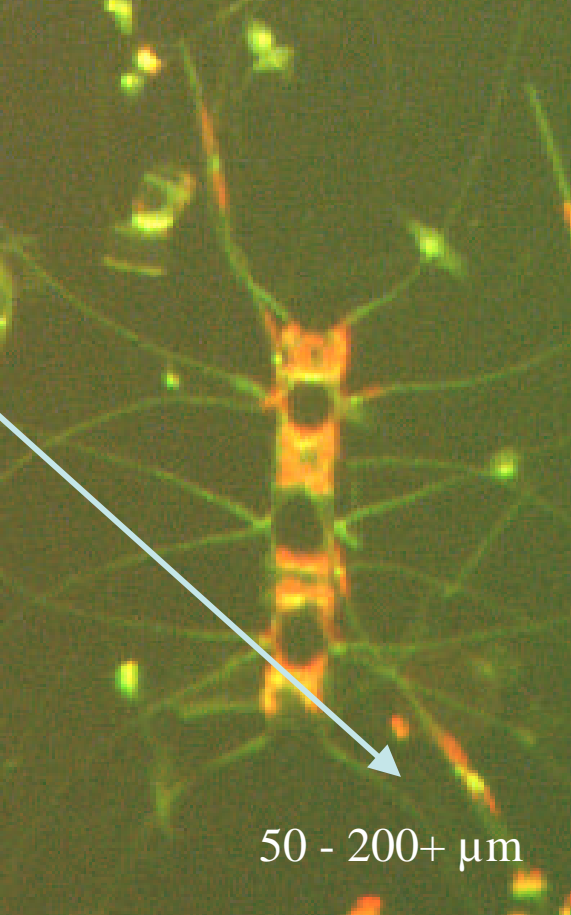
50 - 200+ μm

Surface-Volume Ratio

$S = 4 \Pi r^2$

r

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

r

$S = 2ab + 2bc + 2ac$

a

b
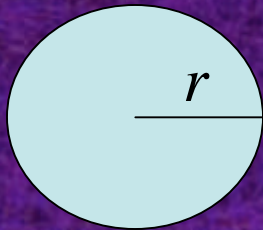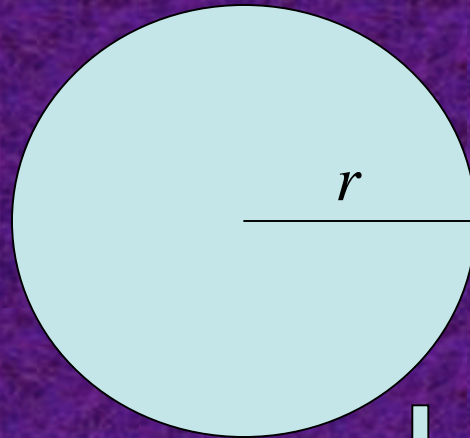
c
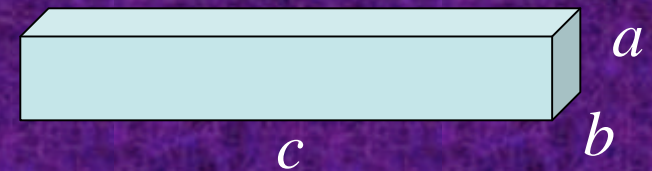
$V = abc$

Nutrient transport proteins are located on surfaces

Gases must cross surfaces to penetrate to the interior

Spines add drag -- help keep cells in lit layer
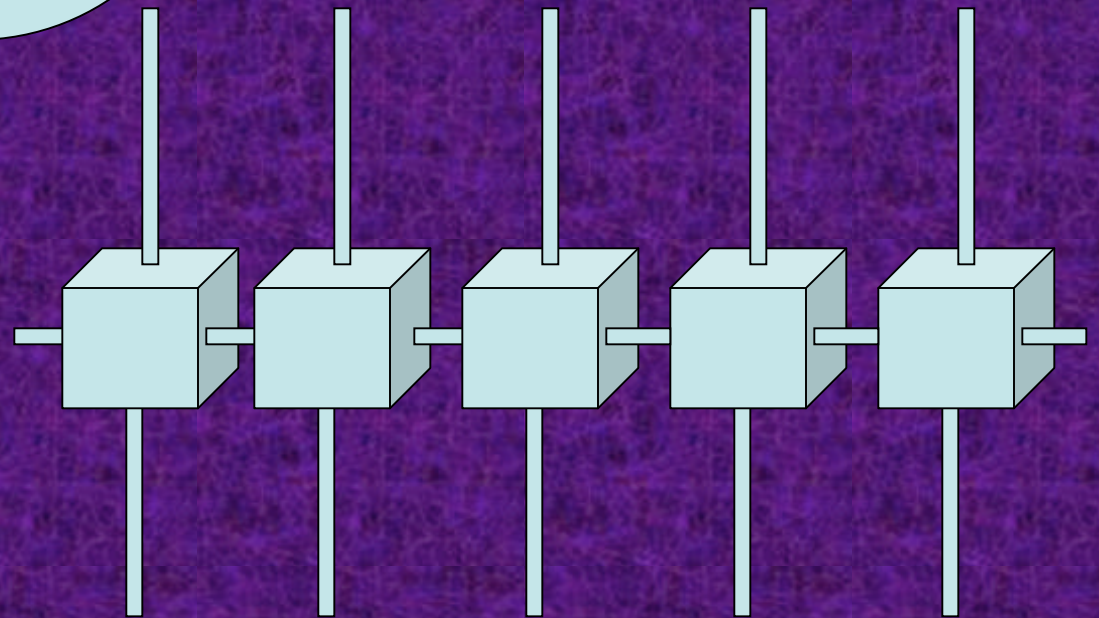
Adaptive strategies

Low nutrient concentrations

  small cells favored: higher S:V ratio

  leads to better uptake capability at a lower nutrient concentration
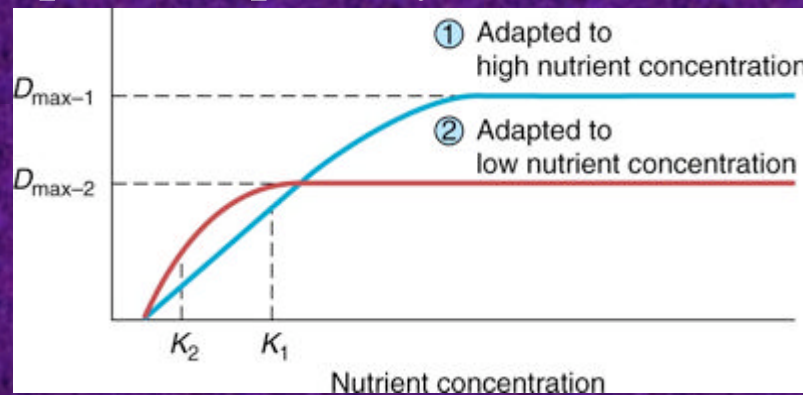
Levinton 2009

High nutrient concentrations

  larger cells favored, having higher growth rates

  varied shape allows better S:V ratio despite larger cell size

  varied shape also can function as predator defense

COLOR PLATE 2 Climatological (1978–1986) seasonal sea surface chlorophyll field obtained with Coastal Zone Color Scanner sensor for boreal fall (September–November). Color is a log scale for chlorophyll: purple = <0.06 mg Chl m^{-3}, orange-red = 1–10 mg Chl m^{-3}. Provided by NASA/Goddard Space Flight Center.

Why don't chlorophyll distributions tell us the whole story?

Why study consumption?

$$\frac{\text{monthly accum PP carbon}}{\text{1 day's 1° production}}$$

$$\frac{\text{standing stock of PP}}{\text{monthly 1° production}}$$

FIGURE 3.1 This figure shows how (i) monthly accumulation of phytoplankton carbon (top) is generally about one-half of 1 day's primary production and (ii) that standing stock (bottom) is equivalent to 0.02–0.10 of the monthly primary production or about one-half to 3 days productivity. The figure is based on CZCS data as described in the text; the analysis is split between oceans (A, I, P, and S) and biomes.

Longhurst 1998

- Standing stock is only a small fraction of production: need to understand consumption to get whole picture.

PP = phytoplankton

median: middle line of box
range: top & bottom bar

1° Consumers: Microzooplankton (Eukaryotes)

Flagellates
www.bigelow.org

Ciliates

100 um
Heterotrophic dinoflagellate
Dinoflagellates

Protist grazers

- *a.k.a.* protozoans -- single celled organisms

Note: Protists can be autotrophs OR heterotrophs OR mixotrophs *(e.g., diatoms, coccolithophorids, dino-flagellates, "picoeukaryotes", etc.)*

NOT PROTISTS: *Prochlorococcus, Synechococcus*, other bacteria

2°Consumers

- Heterotrophic bacteria and archaea
  - DOC produced as a by-product of grazing*

- Other protists (ciliates/dinoflagellates) -- many are omnivores

- Metazoans
  - usually metazoans are 3° consumers or higher, however

2°- 4° Consumers

Copepods -- most common (numbers and biomass)

Well-studied: easily caught with nets and seen with low power microscopes or the naked eye

Specialized feeding appendages

- Filter or Suspension feeders (usu. herbivores)
- Raptorial feeders (usu. carnivores)

Euphausiids (krill) -- Shrimp-like

Some herbivorous, some carnivorous

Significant populations in Antarctic waters

Chaetognaths (arrow worms)

- Ambush predators -- mainly feed on copepods
- Common, 1 - 10 cm

- Sensory hairs to detect vibrations of prey
- Once prey captured, it is injected with a neurotoxin

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haddock@lifesci.ucsb.edu

Sagitta euneritica

Gelatinous Zooplankton

- Definition based on water content: diverse groups

- *Herbivores*: body adapted to filter large quantities of water (sacks of jelly), e.g., salps, doliolids and appendicularians

- *Carnivores*: sticky tentacles, e.g., tentaculate ctenophores and medusae. Also, lobate ctenophores capture prey using lobed feeding surfaces

GELATINOUS ZOOPLANKTON (Jelly Plankton) - taxonomically diverse grouping sharing a common strategy - high water-content bodies and/or secreted mucus nets increase effective size of animal and its food gathering capability relative to other zooplankton of comparable organic biomass. Many of the oceanic representatives of these groups are very fragile and disintegrate when captured with nets.

CTENOPHORES - "comb jellies" characterized by bands of joined cilia (comb rows) around body surface. Tentaculate forms have two tentacles with special sticky cells (colloblasts) to entangle prey; the tentacles are "set" like nets. Lobate types capture prey contacting their large lobed feeding surfaces.
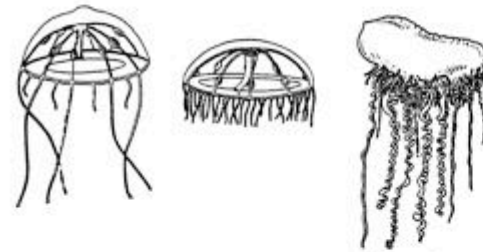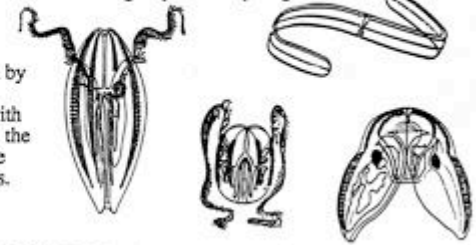
MEDUSAE - Voracious carnivores, food captured by tentacles armed with paralyzing nematocysts. Most coastal (neritic) species alternate generations between attached (benthic) hydroid form which is asexual and a free-swimming, sexual medusae. Most oceanic forms do not have an attached hydroid generation. Siphonophores, the order containing the Portugese man-of-war (*Physalia*), is particuarly significant in oceanic waters. In these pelagic hydroids, several types of "individuals" perform different "jobs" within the colony.

SALPS - barrel-shaped animal with muscle bands that contract to force water into a buccal opening and out of an atrial opening (jet-propulsion). Ciliary-mucus, filter-feeders - particles in the water current entering the buccal opening are captured on a net of mucus strands which is continuously being passed backward along the gill bar to the esophagus for ingestion. Alternation of sexual (colonies) and asexual (solitary) generations. Salps are chiefly oceanic; dense coastal plankton may clog their feeding mechanism. High food gathering and reproductive capability, sometimes occur in dense swarms.
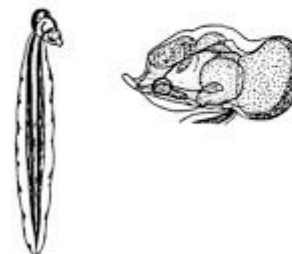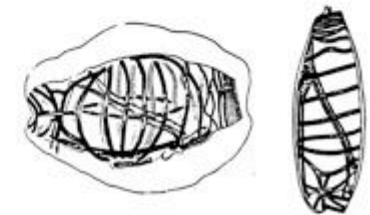
APPENDICULARIANS (LARVACEANS) - mature forms retain appearance of tadpole chordate larvae, head with tail. Body enclosed in feeding "house". Undulations of tail cause water to enter house through coarse filter where fine particles are concentrated and conveyed to pharynx (mouth?) by a complex collection apparatus (not a simple net). The house is abandoned periodically (predator disturbance or clogged filter) and a new house is built. Old larvacean houses are an important component of "marine snow" in some areas.

Fish

- **Role of fish eggs, larvae and juveniles in open ocean food webs: prey and predator, depending upon life cycle stage**
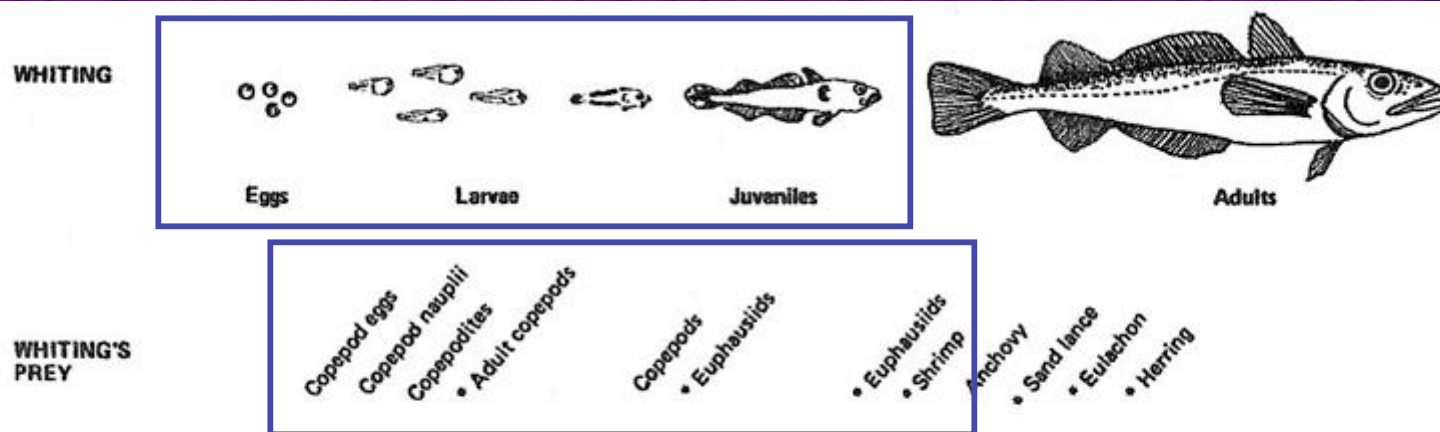

Figure 6.11. Pacific whiting prey fish eaten at various life history stages. (Asterisk indicates major prey species.) Modified from Livingston and Bailey (1985). Mar. Fish. Rev. 42(2):16–22.

Differences in organisms between biomes and oceans

TABLE 4.1 Differences in the Composition of Mesozooplankton Between Biomes and Between Oceans [a]

Biomes	Oceans	Taxonomic groups									Trophic groups					
		Medusae	*Siphophora*	*Chaetognatha*	*Ostracoda*	*Copepoda*	*Euphausidae*	*Pteropoda*	*Appendicularia*	*Thaliacia*	*Coelentrate predators*	*Raptorial predators*	*Micro-herbivores*	*Macro-herbivores*	*Omnivores*	*Detritivores*
POLAR	Arctic	0.07	0.00	9.15	3.30	69.31	0.04	10.08	0.30	0.00	0.08	19.23	0.32	64.57	12.36	3.45
POLAR	Antarctic	0.39	1.49	8.08	2.79	65.86	15.29	3.38	0.06	0.06	1.69	24.22	0.11	47.69	23.79	2.51
WESTERLIES	North Atlantic	1.24	0.94	2.89	1.21	53.07	31.57	3.66	0.07	1.22	1.68	31.75	0.99	20.86	43.79	0.93
WESTERLIES	North Pacific	5.35	4.40	8.21	1.61	40.19	29.01	3.43	0.15	0.39	8.02	33.05	0.45	22.08	35.08	1.32
WESTERLIES	Southern Indian	3.25	0.00	7.41	4.72	34.36	39.24	1.75	0.03	0.23	2.55	36.15	0.60	16.47	40.53	3.70
TRADES	Atlantic	0.86	8.90	6.56	0.60	32.96	23.91	4.00	0.04	6.03	13.61	29.35	8.46	22.48	25.27	0.84
TRADES	Pacific	1.27	10.90	10.46	2.18	29.13	40.78	1.20	0.20	0.93	17.20	38.26	1.63	17.18	22.65	3.08
TRADES	Indian	3.81	5.73	9.97	5.06	32.28	25.84	3.37	0.07	1.72	12.08	31.52	2.27	21.78	25.95	6.40
COASTAL	North Atlantic	0.14	0.45	7.51	0.17	74.84	7.96	1.24	0.00	0.26	0.62	16.96	0.27	44.49	37.49	0.18
COASTAL	North Pacific	1.71	5.36	11.29	0.67	35.37	27.39	1.66	0.22	2.00	7.99	18.99	2.51	24.18	45.57	0.76

[a] Taxonomic and aggregated trophic groups of plankton are expressed as percentage of carbon biomass. Data from 1500 samples, representing all oceans and latitudes, processed by the Smithsonian Museum Plankton Sorting Center, Washington, D.C.

Longhurst 1998

Why should we care that ecosystems differ?

- *Oceans: an important global sink for CO_2*
  - Surface ocean gases are in equilibrium with atmosphere
  - **Photosynthesis** reduces dissolved CO_2 in ocean water to organic carbon (thus more CO_2 is drawn into the ocean from the atmosphere)
  - High phytoplankton growth rates means lots of CO_2 is reduced to organic carbon daily
  - But, most phytoplankton biomass turned over on a daily basis -- so most organic carbon converted back to CO_2 via **respiration** by heterotrophic organisms
- *The rates of growth/mortality and the amount of carbon that the ocean sequesters depends upon the structure and function of an ecosystem*

POC Transformations: Organisms and their wastes

- Consumer waste products
  - CO_2 (respiration)
  - Excretion of low MW material (e.g., amino acids, etc.)
  - Egestion of "dissolved" organic matter
- Heterotrophic Protist Waste
  - POC to DOC or CO_2 - major remineralization role
- Metazoan Wastes
  - POC to DOC or CO_2 - lesser role than protists
  - POC to packaged POC/DOC - vertical flux
  - Vertical Migrants - transport of wastes to deep waters

100 um

Rhizosolenia, Nitzschia, Pseudonitzschia

Fecal Pellets

Not all fecal pellets are created equal…

salp

copepod

euphausiid

1 mm

D. Steinberg, VIMS

Yields of Fish from Ecosystems

The structure of ecosystems also governs fish yields, since every step in the food chain reduces the amount of organic carbon available to the next higher trophic level
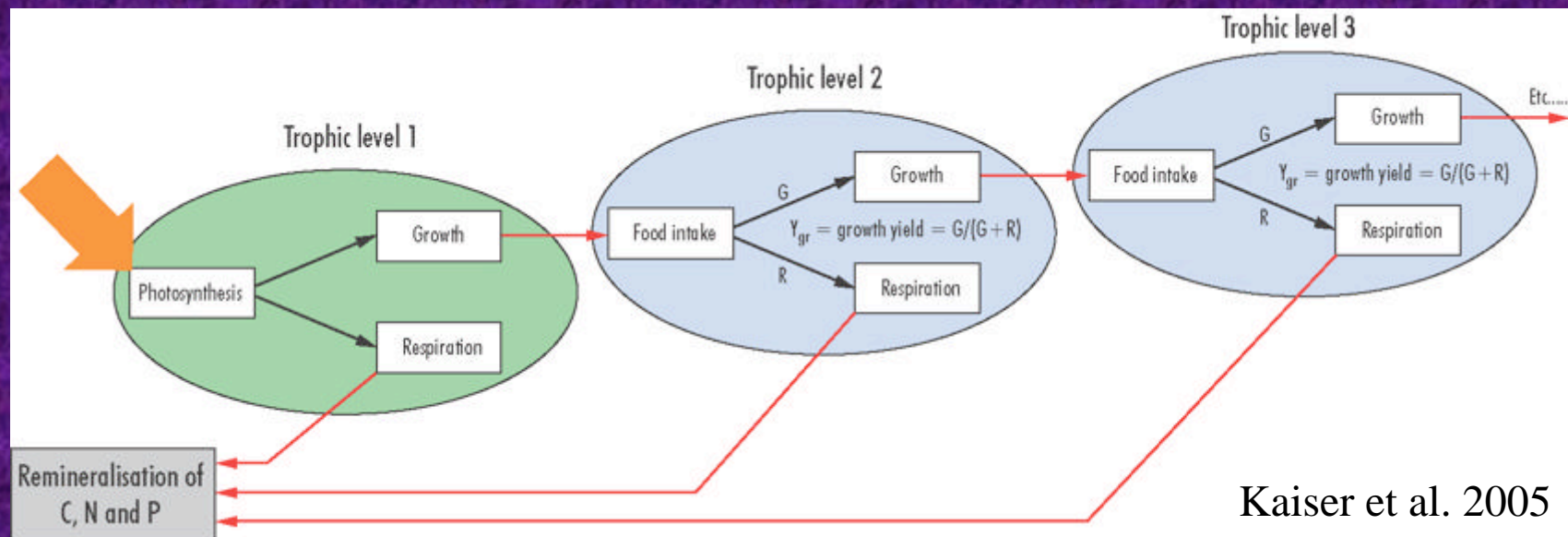

Pauly & Christensen 1995

Trophic Transfer Efficiency

TTE (or Trophic Yield) = *Amount of production at trophic level (X+1) relative to production at trophic level X*

Because of losses to metabolism/egestion at each step, longer food chains result in less yield to the top predator

How to apply to actual food chain?

Overall Food Chain Efficiency = TTE(2)*TTE(3)*TTE(4)*TTE(n)

Kaiser et al. 2005

Simplified Biological Pump