

# *Food Webs Overview*

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Biological Oceanography

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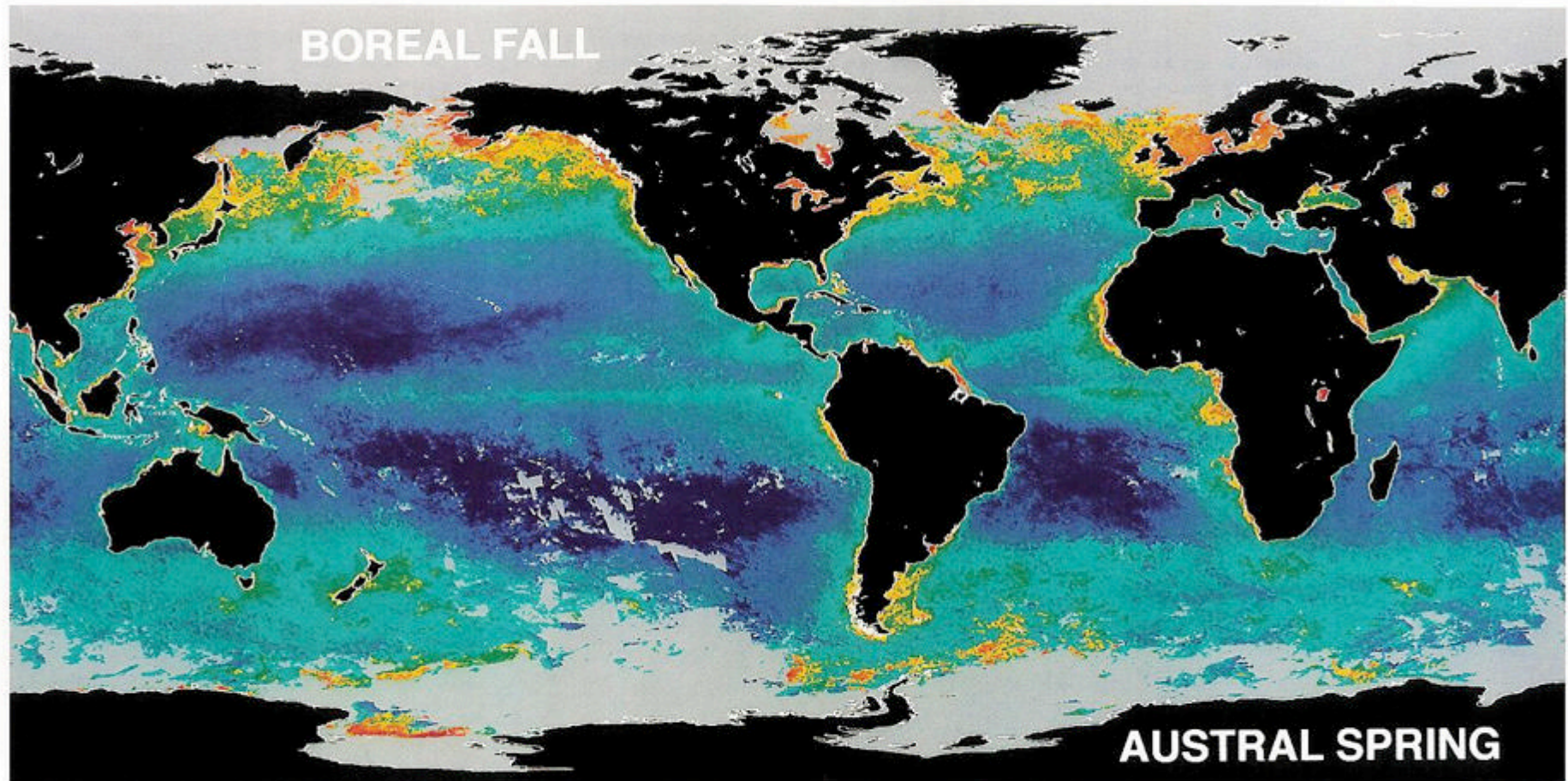




# Today's Lecture

- 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 =  $<0.06 \text{ mg Chl m}^{-3}$ , orange-red =  $1\text{--}10 \text{ mg Chl m}^{-3}$ . Provided by NASA/Goddard Space Flight Center.

Why isn't chlorophyll the same everywhere?



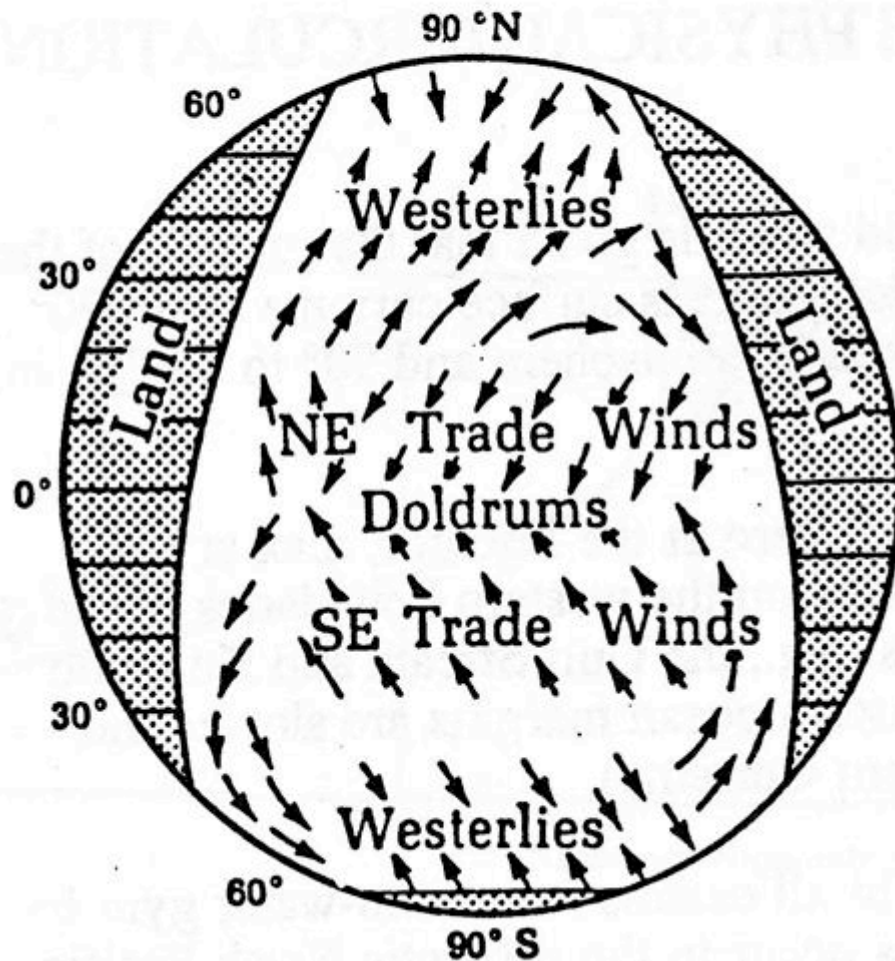
# Basic Zones of Plankton Distribution

- Polar -- Arctic, Antarctic Circumpolar
- Subpolar -- Subarctic, Subantarctic
- Temperate -- “Transition Zone”
- Subtropical Gyres -- Northern & Southern
- Equatorial -- Tropical
- Eastern Tropical Pacific
- Warm-Water Cosmopolitan

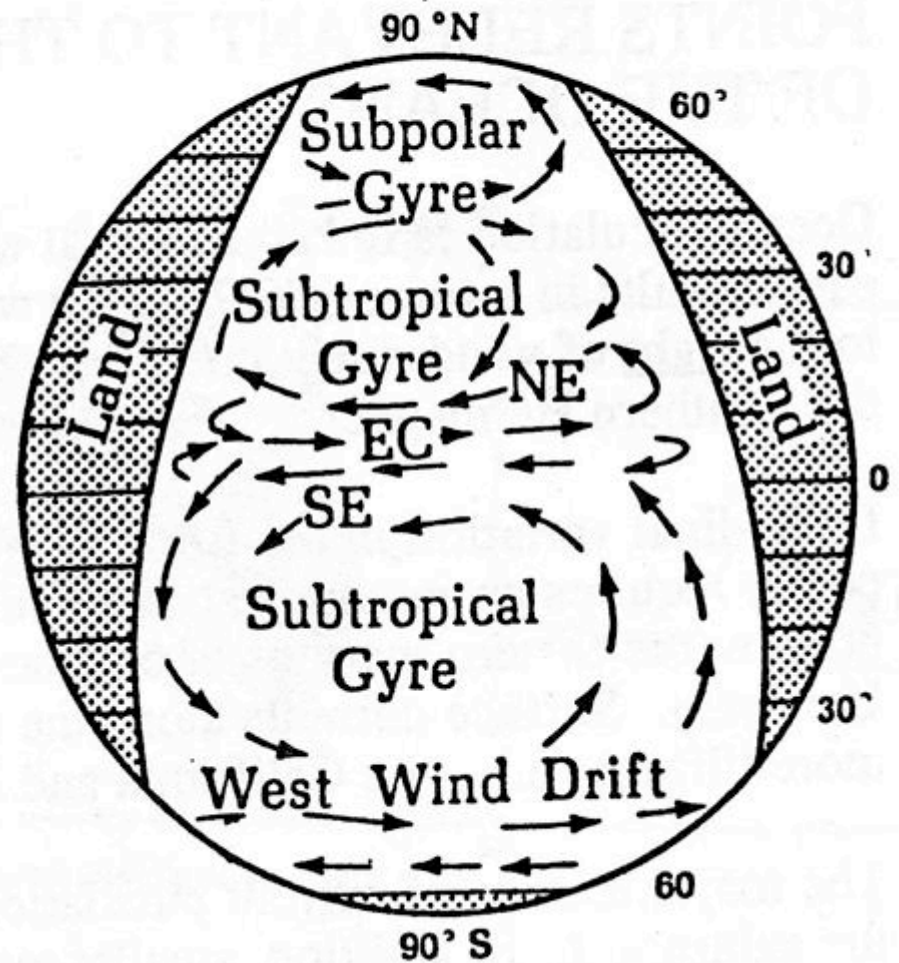
*These provinces have unique hydrographic characteristics  
and appear to be self-sustaining ecosystems*

# Winds and Currents

PLANETARY  
WIND PATTERN



OCEAN CURRENT  
PATTERN





# Main Ocean Current Systems

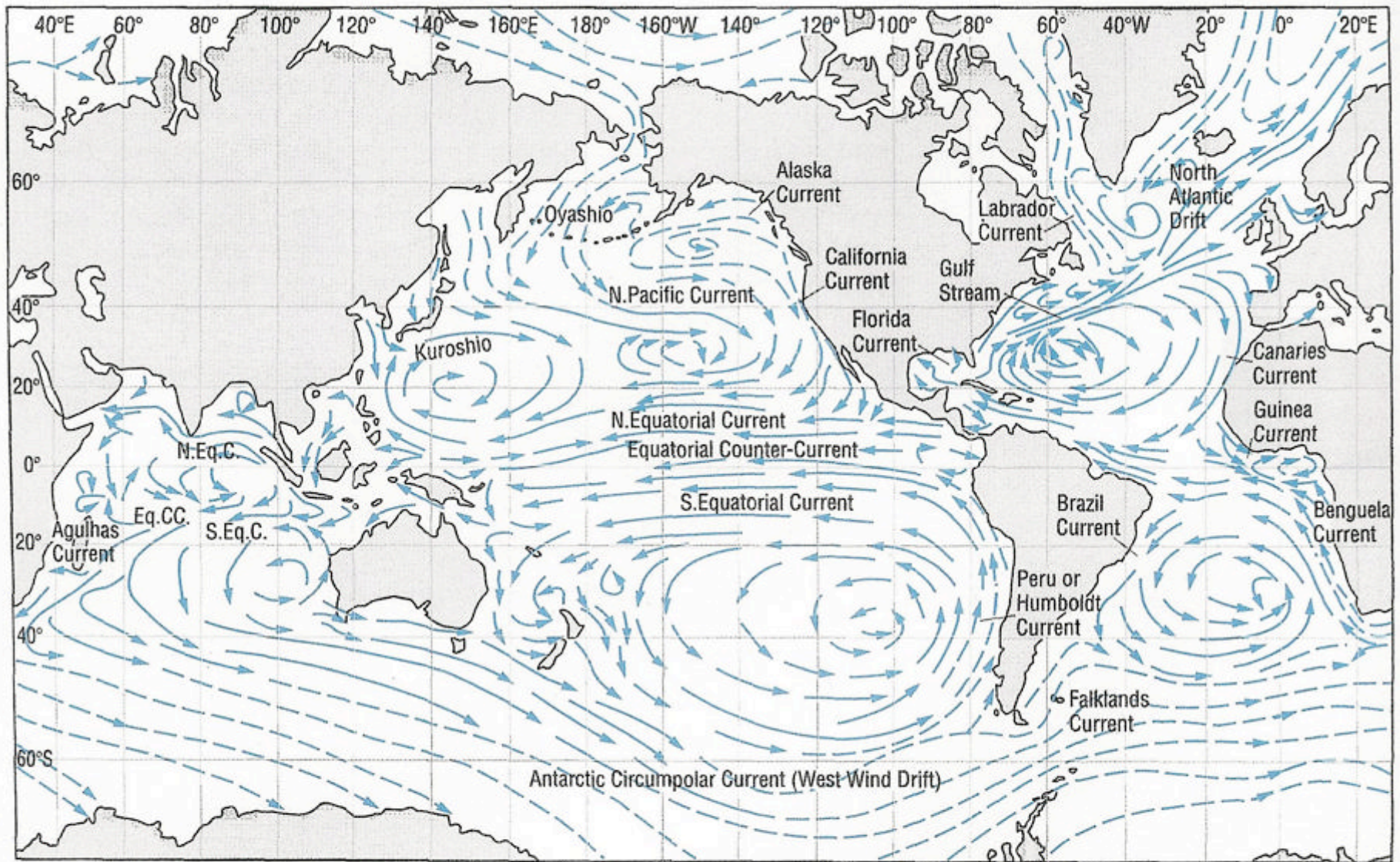


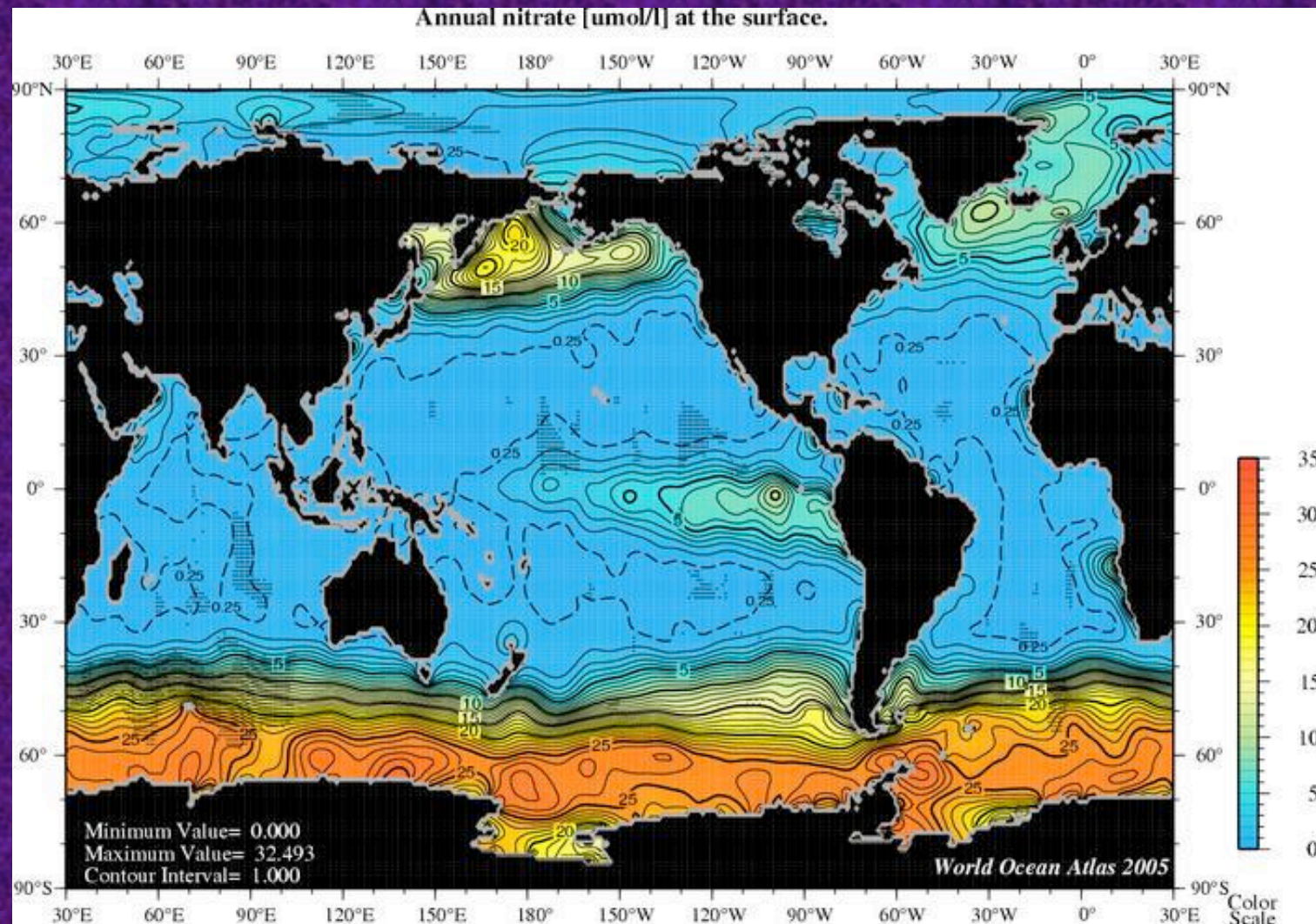
Figure 2.19 The major surface currents of the oceans in northern winter. Dashed arrows indicate cool currents; solid arrows show warm currents.

Lalli & Parsons 1997



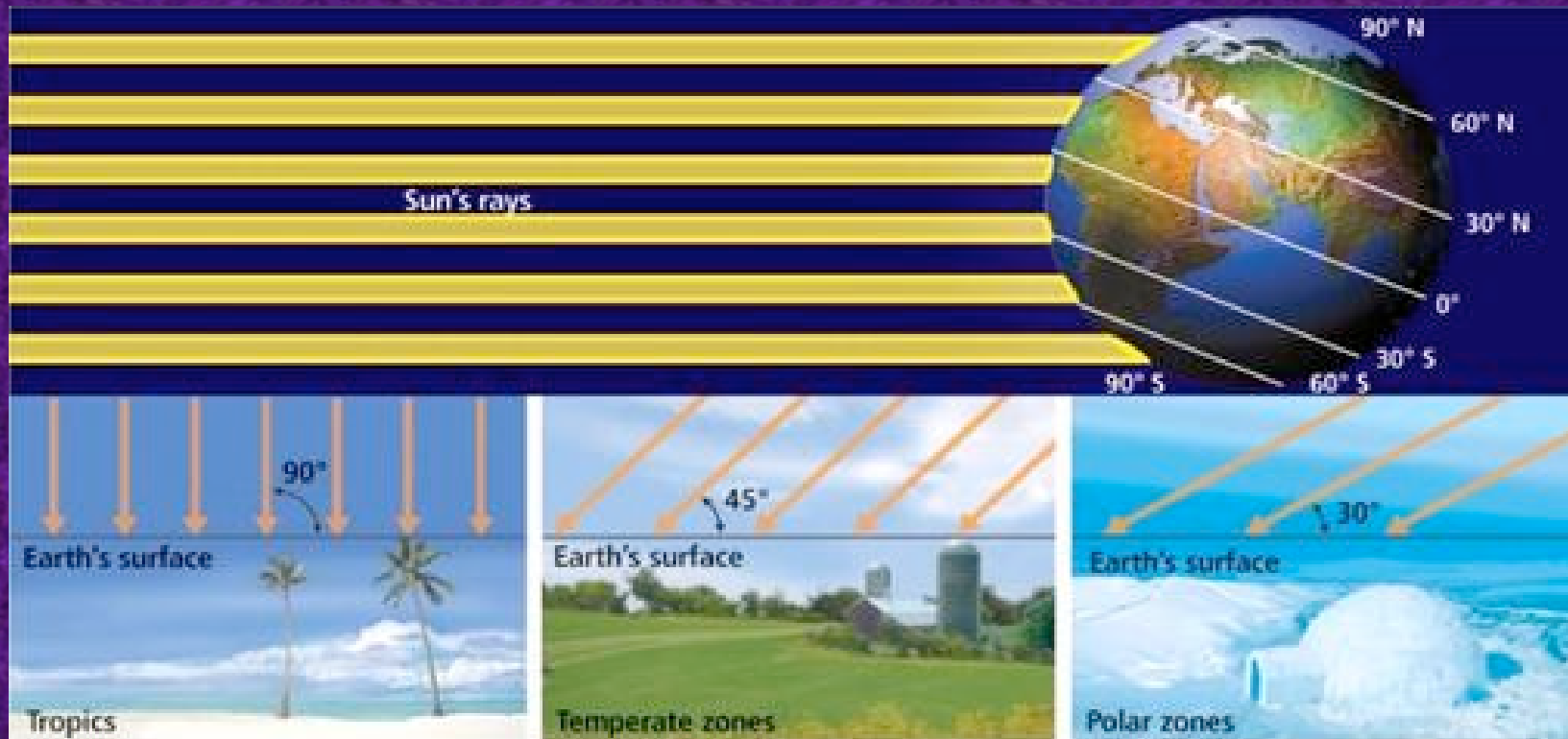
# Surface Nitrate Concentrations

## *Annual Averages*



<http://www.nodc.noaa.gov>

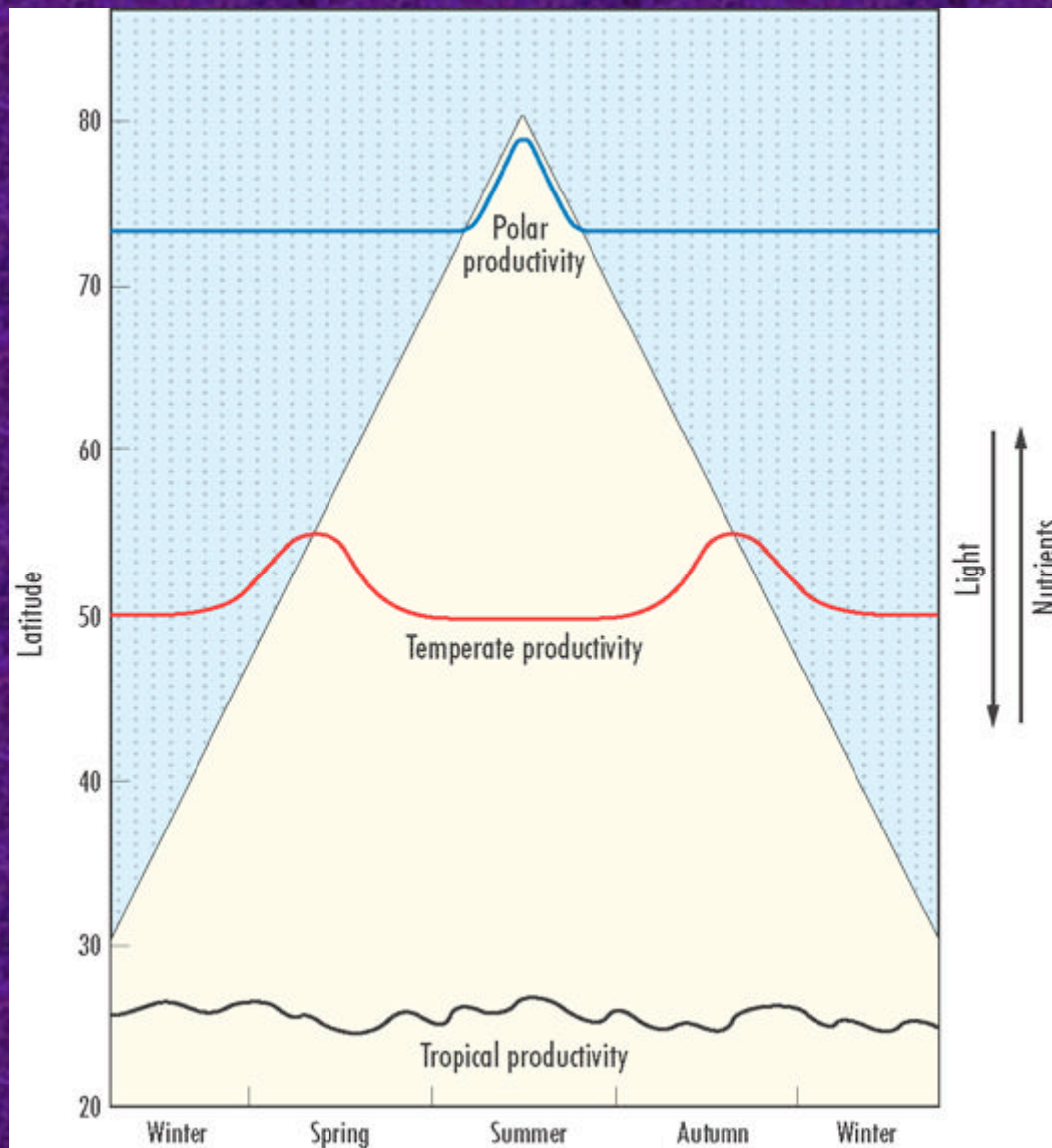
# Light varies with Latitude



<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  $\mu\text{m}$

*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



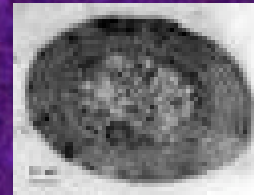
# The Phytoplankton Players (Autotrophs)

## 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*



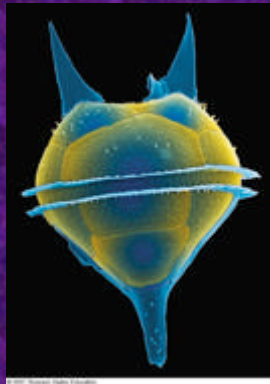
Eukaryotic single-celled algae:

*Pico & nano-eukaryotes (<2 - 20 μm)*

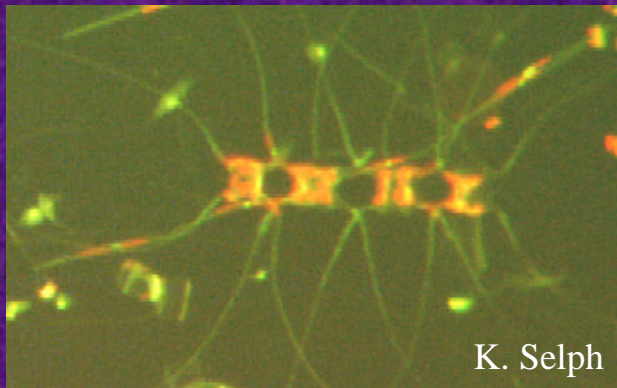
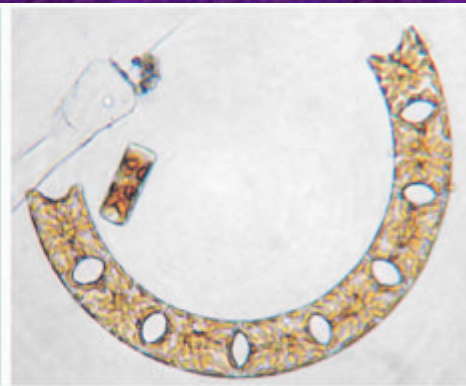
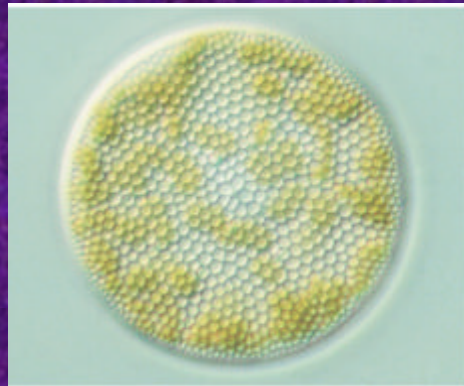
*Dinoflagellates (~10 - 200 μm)*

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

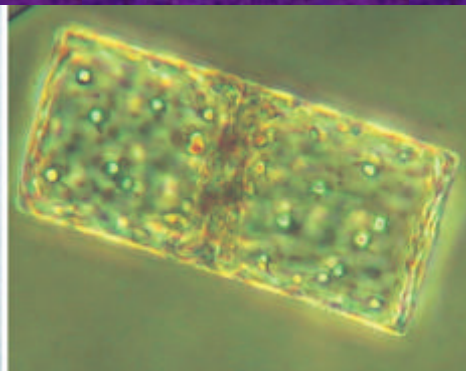
*Important in coastal/high nutrient systems, present but  
otherwise not usually a large component of community*



# A Selection of Diatoms (Autotrophic Eukaryotes)



K. Selph



Kaiser et al. 2005



# Great variety of sizes/shapes of phytoplankton



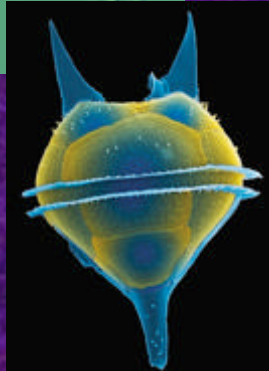
0.6 - 0.8  $\mu\text{m}$



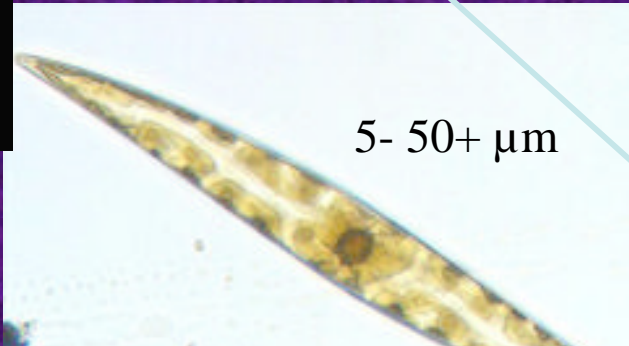
0.8 - 1.4  $\mu\text{m}$



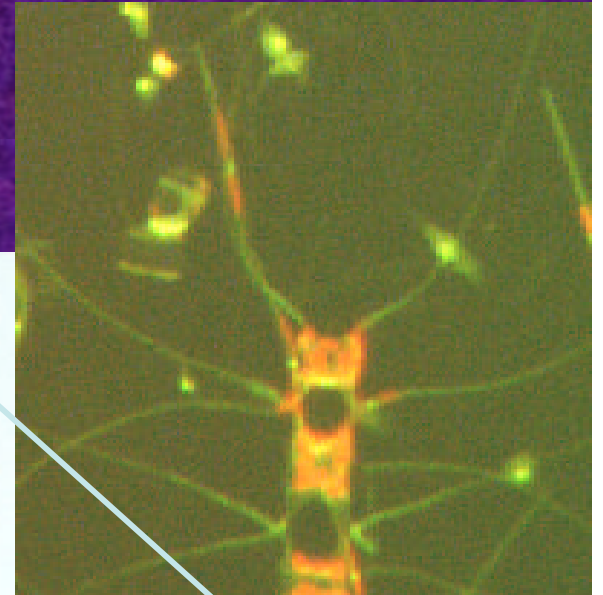
2 - 5  $\mu\text{m}$



5 - 20+  $\mu\text{m}$



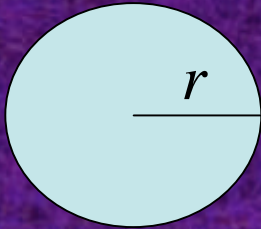
5- 50+  $\mu\text{m}$



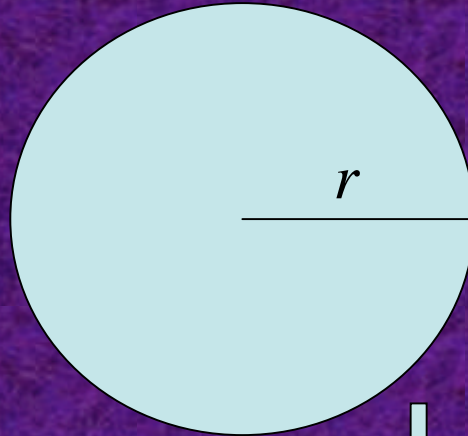
*Different ecosystems are characterized by a dominance of either large ( $>5 \mu\text{m}$ ) or small ( $<5 \mu\text{m}$ ) phytoplankton*

# Surface-Volume Ratio

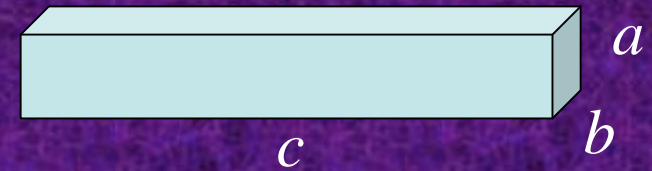
$$S = 4 \pi r^2$$



$$V = \frac{4}{3} \pi r^3$$



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

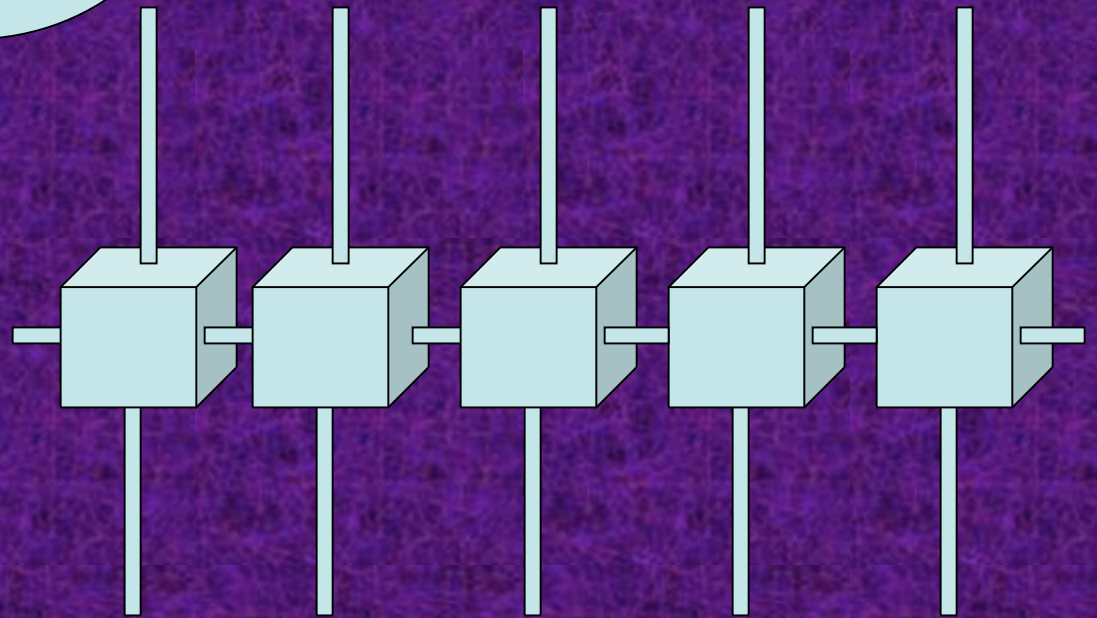


$$V = abc$$

*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*



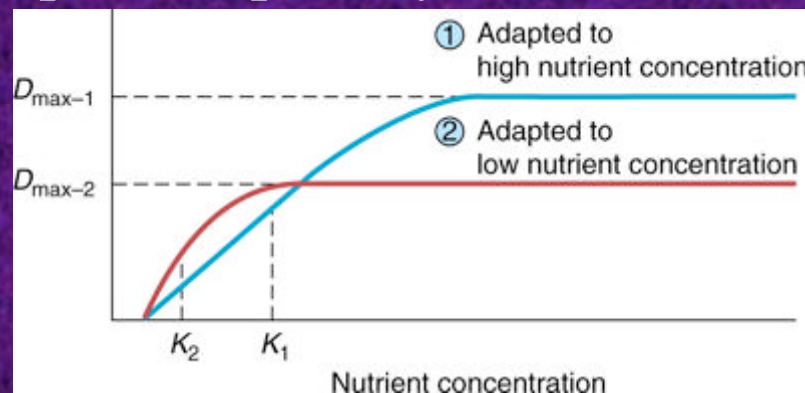


# Adaptive strategies

## 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

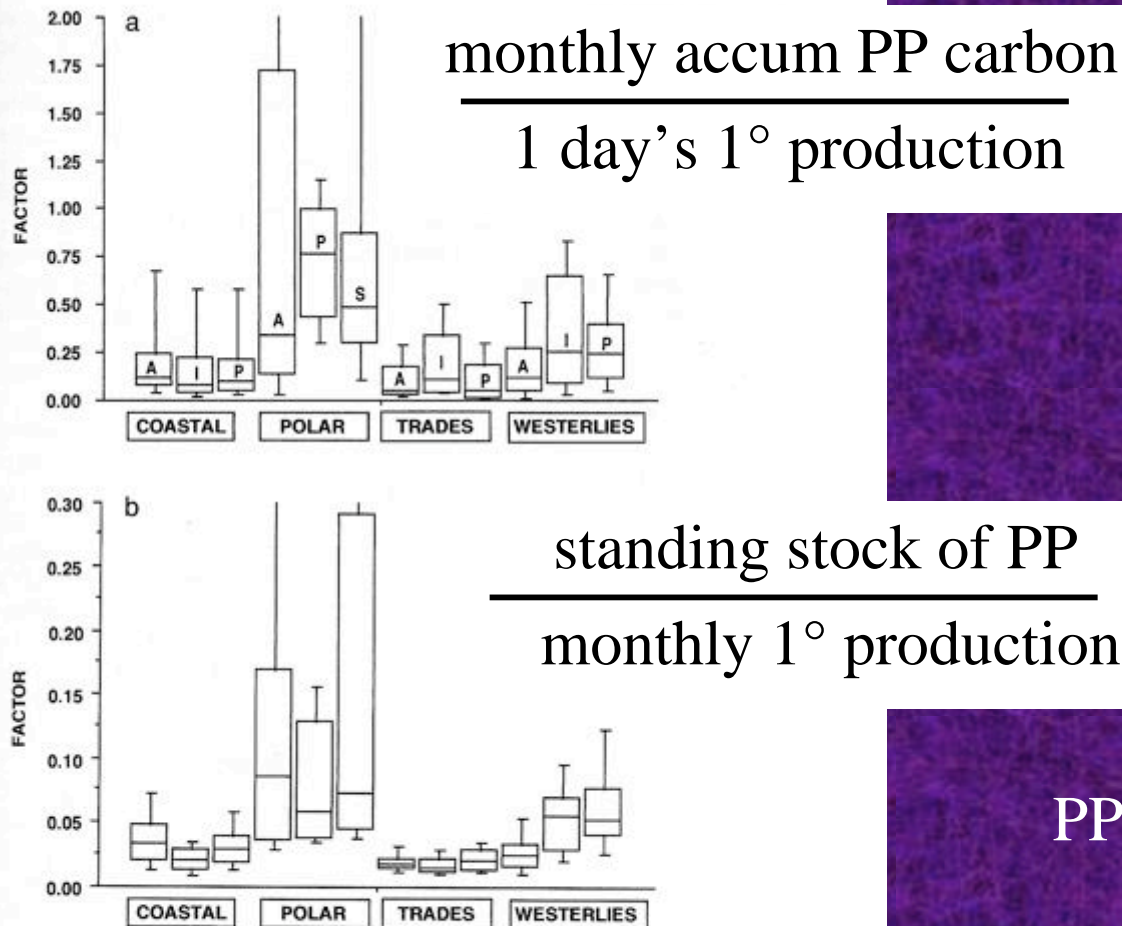
larger cells favored, having higher growth rates

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

varied shape also can function as predator defense

# Why study consumption?

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



**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

PP = phytoplankton

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



# 1° Consumers: Microzooplankton (Eukaryotes)

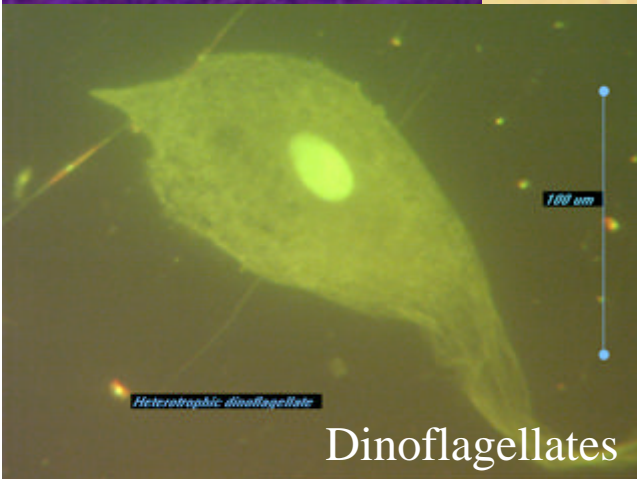
Flagellates



Ciliates



Dinoflagellates



## Protist grazers

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

*Note:* Protists can be autotrophs OR heterotrophs OR mixotrophs (*e.g., diatoms, coccolithophorids, dinoflagellates, "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*

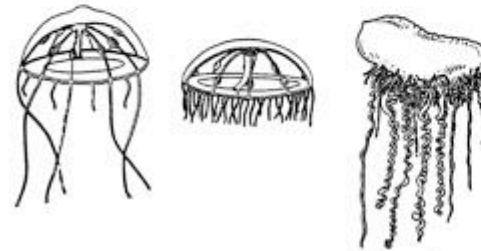


# Gelatinous Zooplankton

- 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

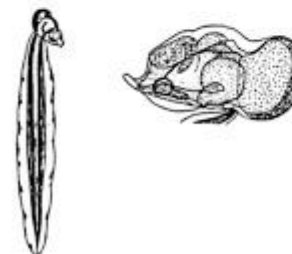
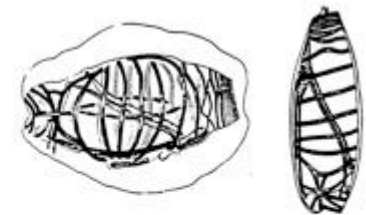
**GELATINOUS ZOOPLANKTON (Jelly Plankton)** - taxonomically diverse grouping sharing a common strategy - high water-content bodies and/or secreted mucus nets increase effective size of animal and its food gathering capability relative to other zooplankton of comparable organic biomass. Many of the oceanic 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 Portuguese man-of-war (*Physalia*), is particularly significant in oceanic waters. In these pelagic hydroids, several types of "individuals" perform different "jobs" within the colony.

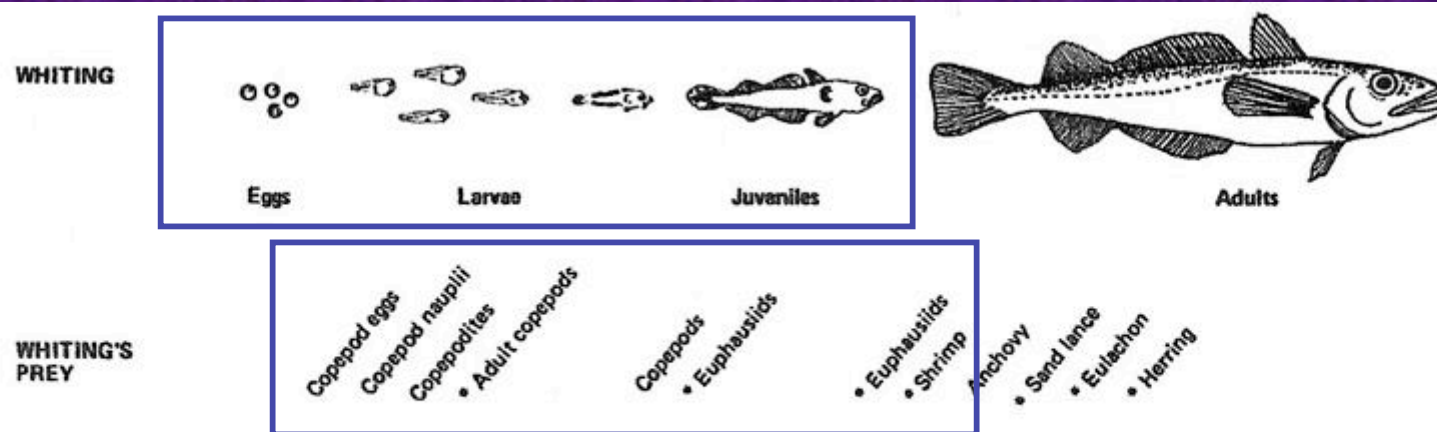
**SALPS** - barrel-shaped animal with muscle bands that contract to force water into a buccal opening and out of an atrial opening (jet-propulsion). Ciliary-mucus, filter-feeders - particles in the water current entering the buccal opening are captured on a net of mucus strands which is continuously 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\***

Biomes	Oceans	Taxonomic groups									Trophic groups					
		<i>Medusae</i>	<i>Siphophora</i>	<i>Chaetognatha</i>	<i>Ostracoda</i>	<i>Copepoda</i>	<i>Euphausiidae</i>	<i>Pteropoda</i>	<i>Appendicularia</i>	<i>Thaliacea</i>	<i>Coelenterate predators</i>	<i>Raptorial predators</i>	<i>Micro-herbivores</i>	<i>Macro-herbivores</i>	<i>Omnivores</i>	<i>Detritivores</i>
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

\*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.

# Why should we care that ecosystems differ?

- *Oceans: an important global sink for CO<sub>2</sub>*
  - Surface ocean gases are in equilibrium with atmosphere
  - **Photosynthesis** reduces dissolved CO<sub>2</sub> in ocean water to organic carbon (thus more CO<sub>2</sub> is drawn into the ocean from the atmosphere)
  - High phytoplankton growth rates means lots of CO<sub>2</sub> is reduced to organic carbon daily
  - But, most phytoplankton biomass turned over on a daily basis -- so most organic carbon converted back to CO<sub>2</sub> 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*



A fluorescence micrograph showing various marine microorganisms. The background is dark, with numerous small, bright green and orange-red spots and streaks scattered throughout. These spots represent individual organisms or cells that have been stained with fluorescent dyes. Some spots are larger and more intense, while others are smaller and fainter. The overall distribution is somewhat random, with a higher density of spots in certain areas.

## POC Transformations: Organisms and their wastes

- Consumer waste products
  - $\text{CO}_2$  (respiration)
  - Excretion of low MW material (e.g., amino acids, etc.)
  - Egestion of “dissolved” organic matter
- Heterotrophic Protist Waste
  - POC to DOC or  $\text{CO}_2$  - major remineralization role
- Metazoan Wastes
  - POC to DOC or  $\text{CO}_2$  - lesser role than protists
  - POC to packaged POC/DOC - vertical flux
  - Vertical Migrants - transport of wastes to deep waters

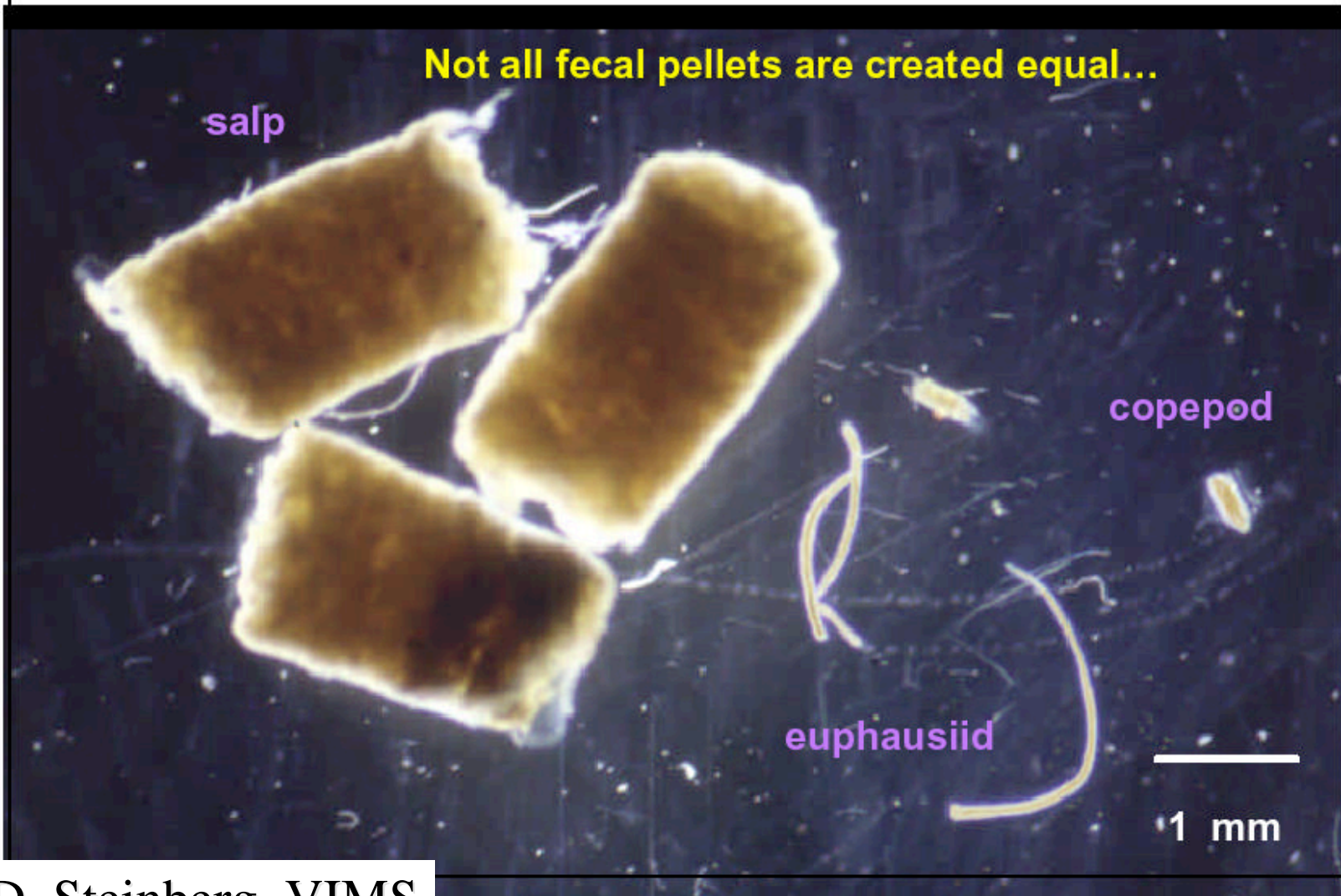
100  $\mu\text{m}$

*Rhizosolenia, Nitzschia, Pseudonitzschia*



# Fecal Pellets

Not all fecal pellets are created equal...

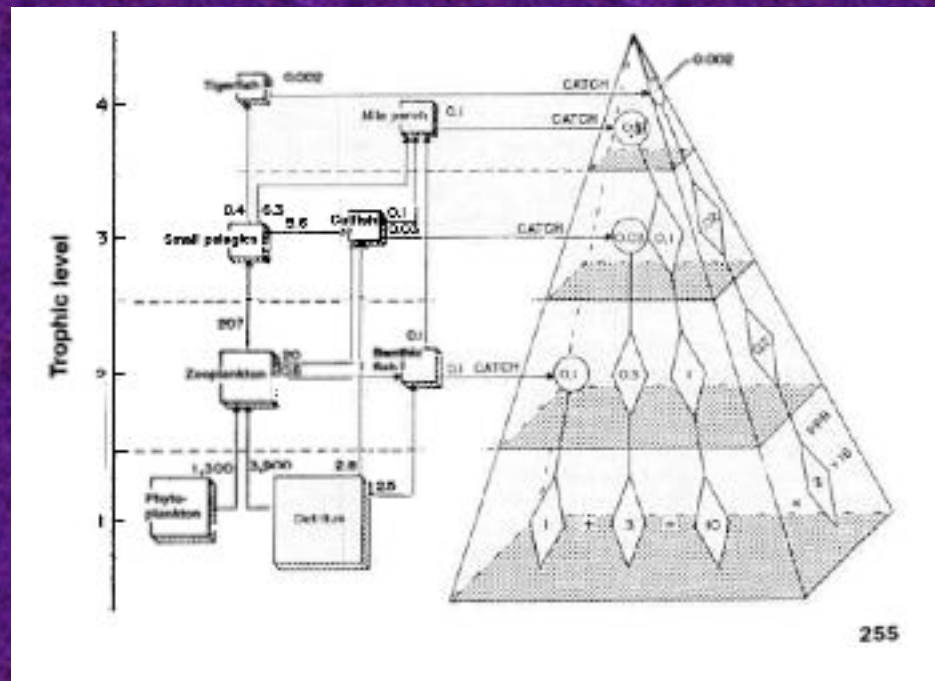


D. Steinberg, VIMS



# 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

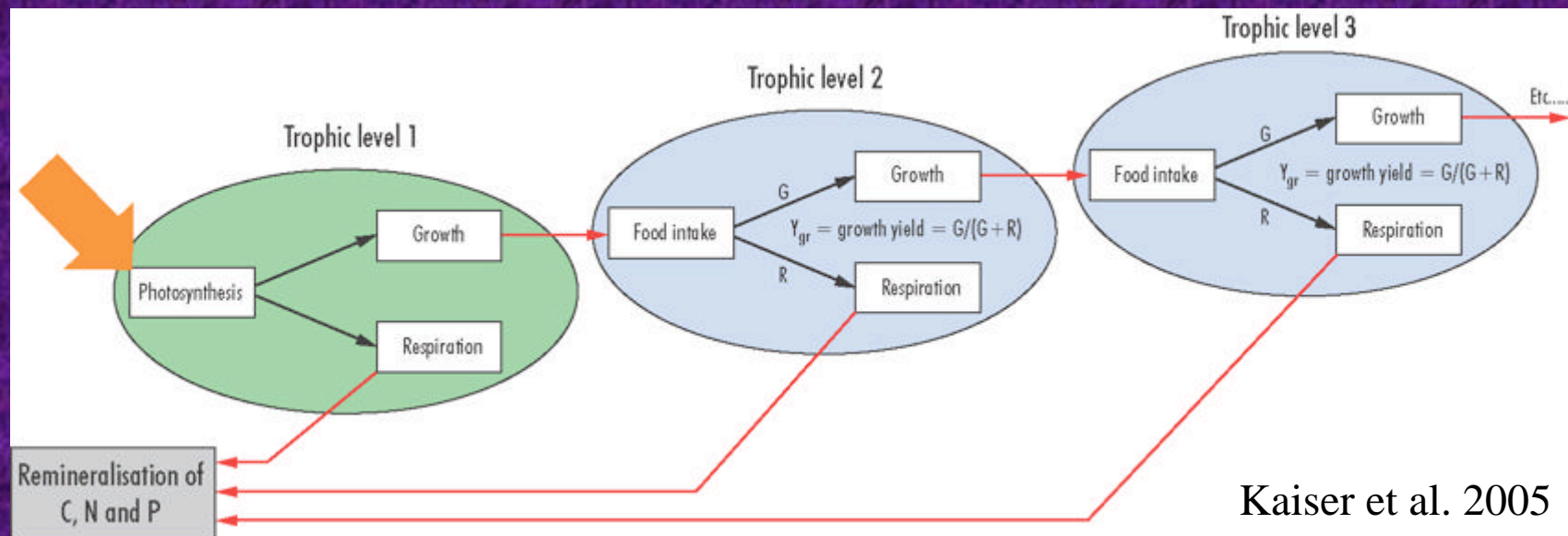
# Trophic Transfer Efficiency

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 =  $TTE(2) * TTE(3) * TTE(4) * TTE(n)$





# Low Energy Stable Systems

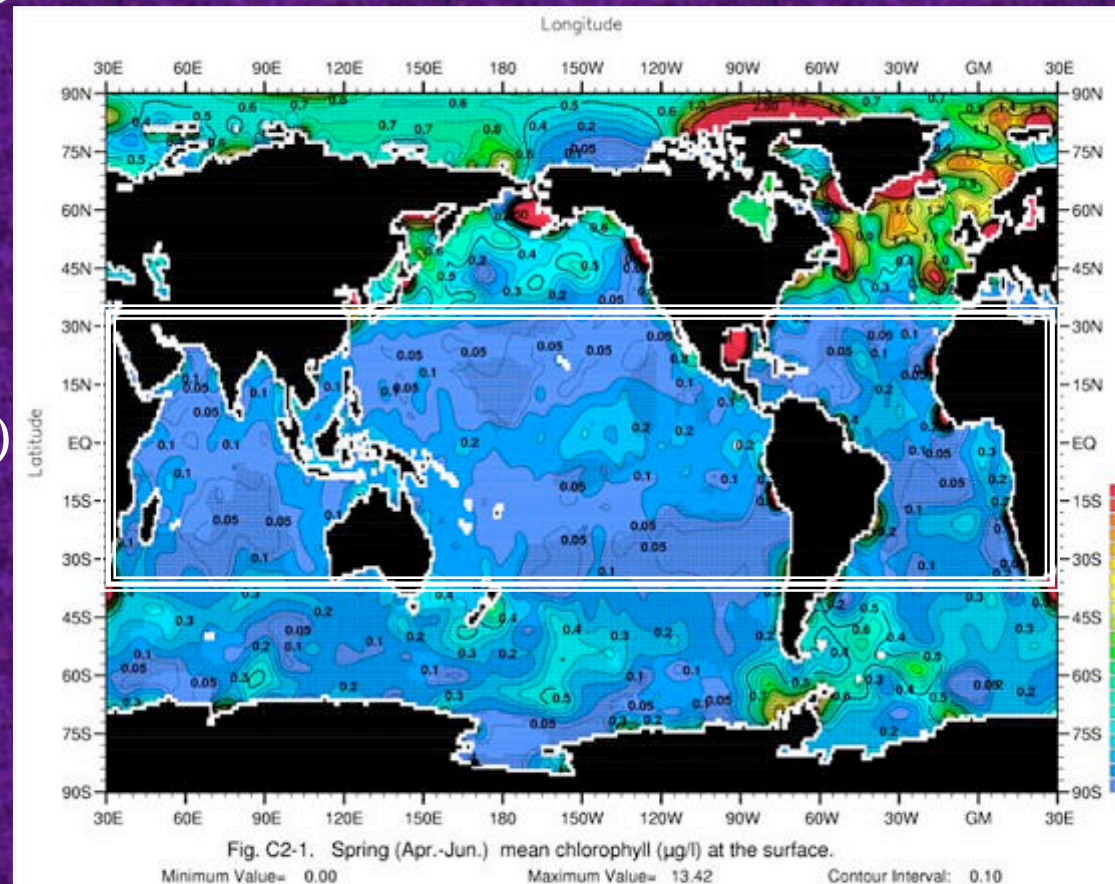
Low energy → Lack of nutrient re-supply

Low nutrients  
(oligotrophic)

Small Phytoplankton  
(high surface:volume ratio)

Long food chains  
(small consumers at base)

Relatively stable  
system



World Ocean Atlas 2001  
Ocean Climate Laboratory/NODC



# High Energy Unstable Systems

High energy  
(storm activity, eddy  
action, upwelling, etc.)



High nutrients  
(eutrophic)



Large Phytoplankton  
(small, too)



Short food chain (dynamic)  
(superimposed on stable long food chain)



Unstable (dynamic)  
system  
(High “new” production)

