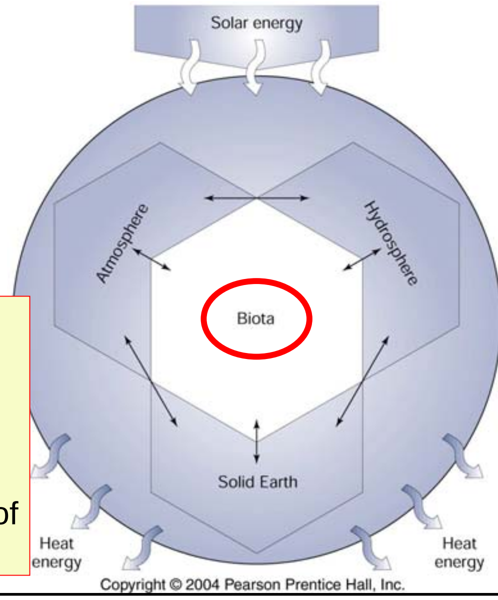
# Earth as a "system"

= group of components interacting with each other

= all living organisms

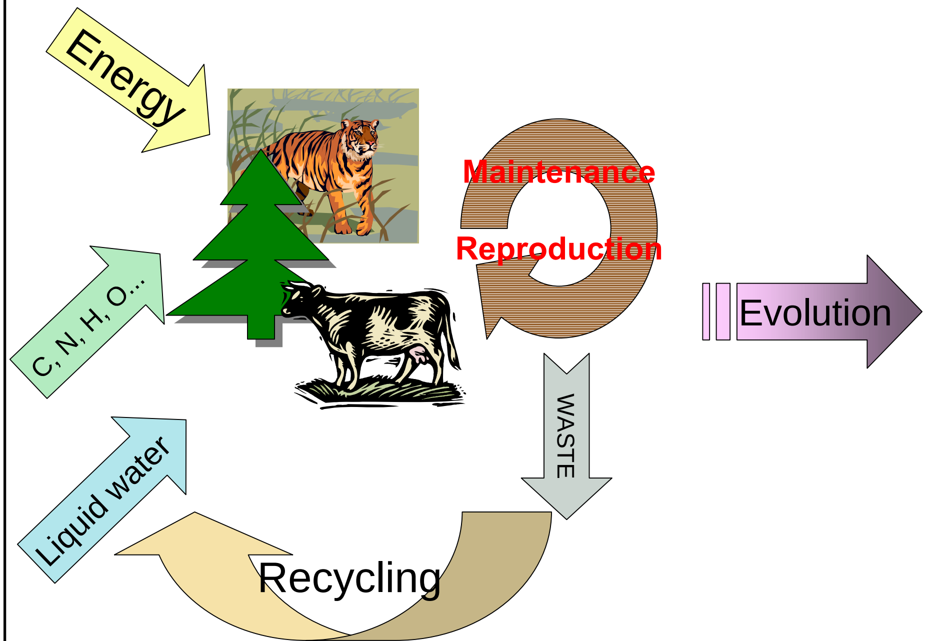
How does the biota interact with the different compartments of the earth system to regulate climate on different timescales and keep the conditions at the surface of this planet suitable for life?



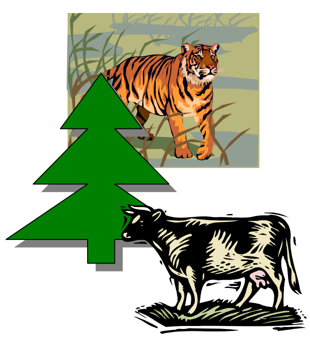

# Life on Earth

- Classification systems (lecture notes)
- Ecosystems (Kump et al.; Chap 9, 175-182

## Life on Earth – Broad characteristics



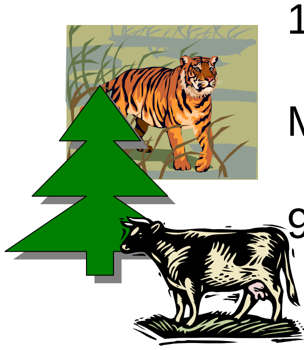

## Life on Earth



Versatile & Diverse

Species = group of related organisms potentially capable of reproducing

# Life on Earth



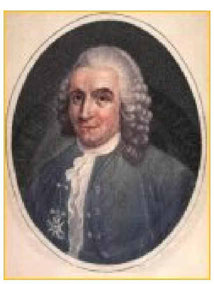
13 - 14 millions species

Mostly small organisms

99% have gone extinct

Species = group of related organisms potentially capable of reproducing

**KINGDOMS OF LIVING THINGS**
**IN THE LINNAEAN CLASSIFICATION SYSTEM**



Karl von Linné
1741 – 1783

| KINGDOM | STRUCTURAL ORGANIZATION | METHOD OF NUTRITION | TYPES OF ORGANISMS | NAMED SPECIES | TOTAL SPECIES (estimate) |
|---|---|---|---|---|---|
| Monera | small, simple single prokaryotic cell (nucleus is not enclosed by a | absorb food | bacteria, blue-green algae, and spirochetes | 4,000 | 1,000,000 |

(Metaphyta)

(Metazoa)

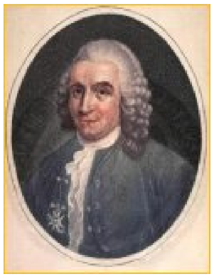
grouped in taxonomic categories according to the greater or lesser extent of their similarities

http://anthro.palomar.edu/animal/

NOTE: A growing number of researchers now divide the Monera into two distinct kingdoms: Eubacteria (the true bacteria) and Archaebacteria (bacteria-like organisms that live in extremely harsh anaerobic environments such as hot springs, deep ocean volcanic vents, sewage treatment plants, and swamp sediments). Viruses, prions, and other non-cellular entities are not included in the five kingdoms.

The numbers of named and estimated total species were derived from Gibbs, W. Wayt (2001) "On the Termination of Species", *Scientific American* Vol. 285, No. 5.

# KINGDOMS OF LIVING THINGS IN THE LINNAEAN CLASSIFICATION SYSTEM



Karl von Linné
1741 – 1783

| KINGDOM | STRUCTURAL ORGANIZATION | METHOD OF NUTRITION | TYPES OF ORGANISMS | NAMED SPECIES | TOTAL SPECIES (estimate) |
|---|---|---|---|---|---|
| Monera | small, simple single prokaryotic cell (nucleus is not enclosed by a membrane); some form chains or mats | absorb food | bacteria, blue-green algae, and spirochetes | 4,000 | 1,000,000 |
| Protista | large, single eukaryotic cell (nucleus is enclosed by a membrane); some form chains or colonies | absorb, ingest, and/or photosynthesize food | protozoans and algae of various types | 80,000 | 600,000 |
| Fungi | multicellular filamentous form with specialized eukaryotic cells | absorb food | funguses, molds, mushrooms, yeasts, mildews, and smuts | 72,000 | 1,500,000 |
| (Metaphyta) Plantae | multicellular form with specialized eukaryotic cells; do not have their own means of locomotion | photosynthesize food | mosses, ferns, woody and non-woody flowering plants | 270,000 | 320,000 |
| (Metazoa) Animalia | multicellular form with specialized eukaryotic cells; have their own means of locomotion | ingest food | sponges, worms, insects, fish, amphibians, reptiles, birds, and mammals | 1,326,239 | 9,812,298 |

NOTE: A growing number of researchers now divide the Monera into two distinct kingdoms: Eubacteria (the true bacteria) and Archaebacteria (bacteria-like organisms that live in extremely harsh anaerobic environments such as hot springs, deep ocean volcanic vents, sewage treatment plants, and swamp sediments). Viruses, prions, and other non-cellular entities are not included in the five kingdoms.

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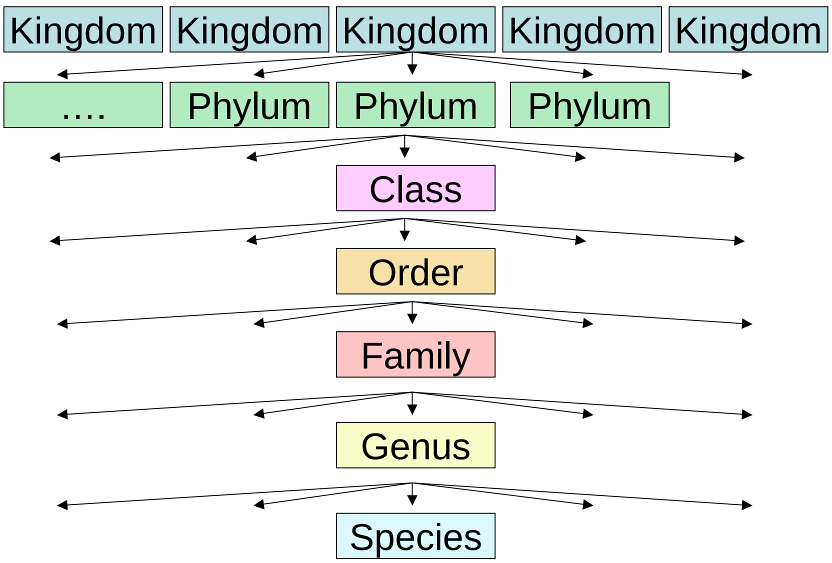


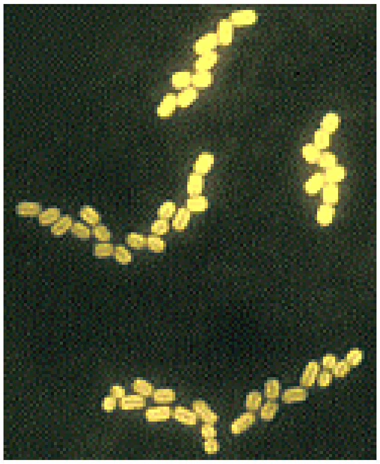
| | | |
|---|---|---|
| Eukaryote, multicellular, heterotrophic | Kingdom | Animalia |
| Supporting rod along body = Notochord (spinal cord) | Phylum | Chordata |
| Mammary glands, hair, warm-blooded, bear live young | Class | Mammalia |
| Collar bone, grasping hands, incisors/molars | Order | Primates |
| Upright posture, large brain, hand & feet, flat face… | Family | Hominidae |
| S-curved spine | Genus | Homo |
| | Species | **Homo sapiens** |

## Principal marine organisms

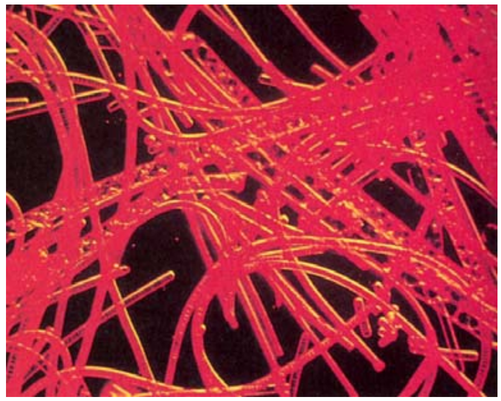
| Kingdom | Phylum | Class | Organism |
|---|---|---|---|
| **Monera** | **Cyanophyta** | | **blue-green algae** |
| | **Schizophyta** | | **bacteria** |
| Protista | Chrysophyta | | diatoms, coccolithophores |
| | Protozoa | | foraminifera, radiolaria, flagellates |
| | Pyrrophyta | | dinoflagellates, zooxanthellae |
| | Ciliophora | | ciliates |
| Fungi | Mycophyta | | fungi, lichens |
| Mataphytae | Rhodo-, Phaeo-, Chlorophyta | | red, brown, green algae |
| Metazoa | Ctenophora | | comb jellies |
| | Cnidaria | Hydrozoa | hydras |
| | | Scyphozoa | jellyfishes |
| | | Anthozoa | corals, sea anemones |
| | Porifera | | sponges |
| | Bryozoa | | moss animals |
| | Platyhelmintes | | flatworms |
| | Chaetognatha | | arrow worms |
| | Annelida | | polychaete worms |
| | Brachiopoda | | lamp shells |

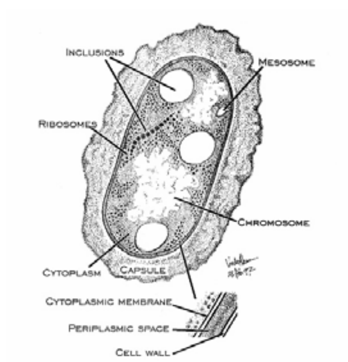
## Monera

**Bacteria**



**Blue-green algae**



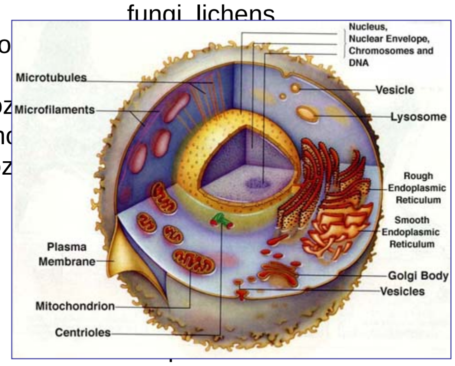



Procaryotes = unicellular organisms of relatively simple construction without a nuclear membrane.

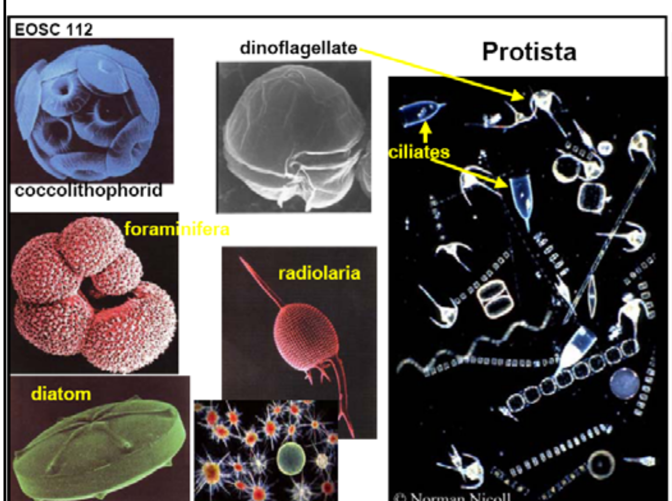
They have three architectural regions:
- **cytoplasmic region** that contains the cell **genome** (**DNA**)
- **cell envelope**
- **appendages** (e.g. **flagella)**

## Principal marine organisms

| Kingdom | Phylum | Class | Organism |
|---|---|---|---|
| Monera | Cyanophyta | | blue-green algae |
| | Schizophyta | | bacteria |
| **Protista** | **Chrysophyta** | | **diatoms, coccolithophores** |
| | **Protozoa** | | **foraminifera, radiolaria, flagellates** |
| | **Pyrrophyta** | | **dinoflagellates, zooxanthellae** |
| | **Ciliophora** | | **ciliates** |
| Fungi | Mycophyta | | fungi, lichens |
| Mataphytae | Rhodo-, Phaeo-, Chloro | | |
| Metazoa | Ctenophora | | |
| | Cnidaria | Hydroz | |
| | | Scyphc | |
| | | Anthoz | |
| | Porifera | | |
| | Bryozoa | | |
| | Platyhelmintes | | |
| | Chaetognatha | | |
| | Annelida | | |
| | Brachiopoda | | |




Many (but not all) species of **marine plankton** (small drifting organisms) belong to the kingdom Protista




**Phytoplankton** = Plants (coccolithophorids, diatoms, dinoflagellates, etc.)

**Zooplankton** = Animals (foraminifera, radiolaria, ciliates, etc.)

Giant kelp
(*Macrocystis pyrifera*)

## Principal marine organisms

Pacific Rockweed
(*Fucus distichus*)

| | Phylum | | |
|---|---|---|---|
| | Cyanophyta | | |
| | Schizophyta | | |
| | Chrysophyta | | |
| | Protozoa | | foraminifera, radiolaria, flagellates |
| | Pyrrophyta | | dinoflagellates, zooxanthellae |
| | Ciliophora | | ciliates |
| | Mycophyta | | fungi, lichens |
| Metaphytae | Rhodo-, Phaeo-, Chlorophyta | | red, brown, green algae |
| **Metazoa** | **Ctenophora** | | **comb jellies** |
| | **Cnidaria** | **Hydrozoa** | **hydras** |
| | | **Scyphozoa** | **jellyfishes** |
| | | **Anthozoa** | **corals, sea anemones** |
| | Porifera | | sponges |
| | Bryozoa | | moss animals |
| | Platyhelmintes | | flatworms |
| | Chaetognatha | | arrow worms |
| | Annelida | | polychaete worms |
| | Brachiopoda | | lamp shells |

## Principal marine organisms

| Kingdom | Phylum | Class | Organism |
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| | Ciliophora | | ciliates |
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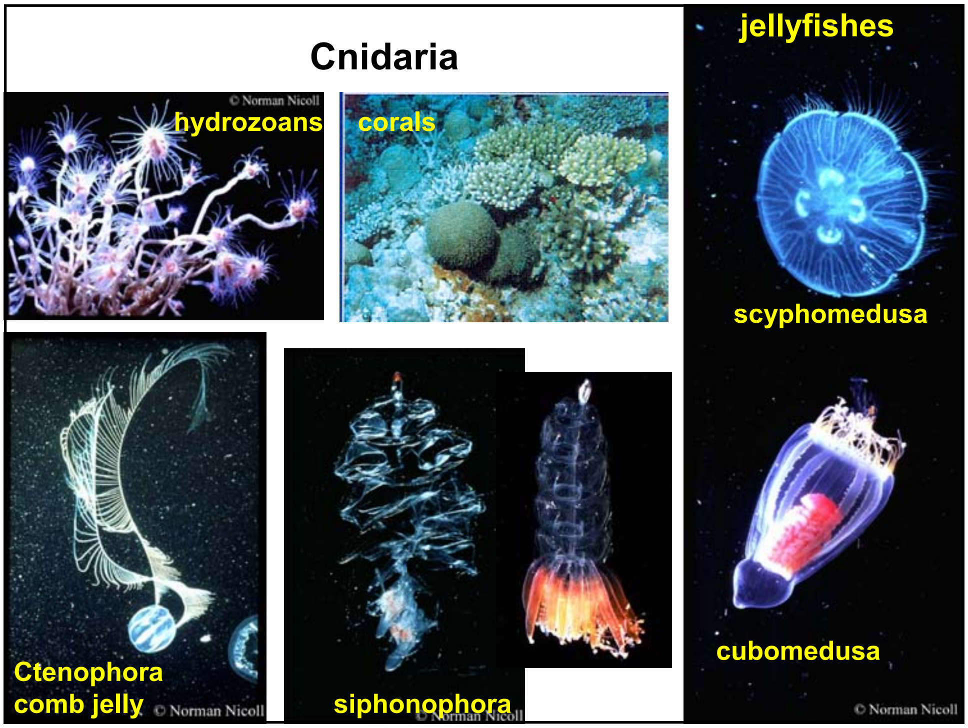


## Principal marine organisms

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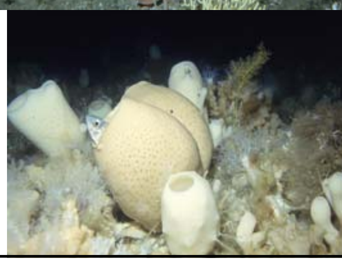
| **Metazoa** | Ctenophora | | comb jellies |
| | Cnidaria | Hydrozoa | hydras |
| | | Scyphozoa | jellyfishes |
| | | Anthozoa | corals, sea anemones |
| | **Porifera** | | **sponges** |
| | **Bryozoa** | | **moss animals** |
| | Platyhelmintes | | flatworms |
| | Chaetognatha | | arrow worms |
| | Annelida | | polychaete worms |
| | Brachiopoda | | lamp shells |

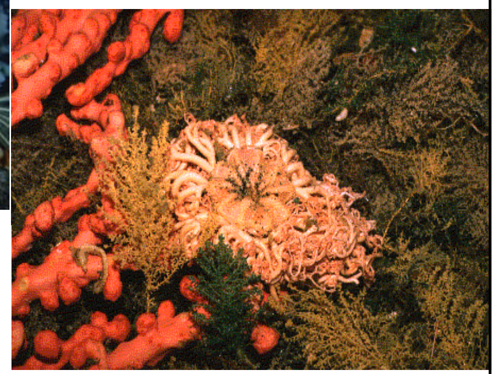
## Poriphera

**sponges**



## Bryozoa

**moss animals**



## Principal marine organisms

| Kingdom | Phylum | Class | Organism |
|---|---|---|---|
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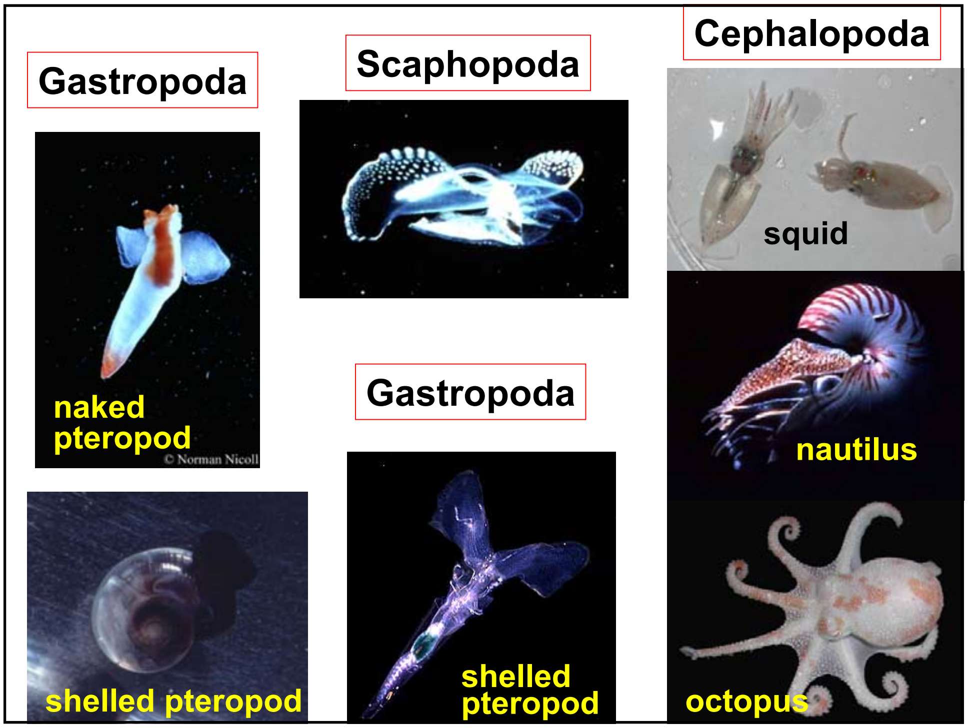
| | Porifera | | sponges |
| | Bryozoa | | moss animals |
| | Platyhelmintes | | flatworms |
| | **Chaetognatha** | | **arrow worms** |
| | **Annelida** | | **polychaete worms** |
| | Brachiopoda | | lamp shells |

**Annelida**

**polychaete**

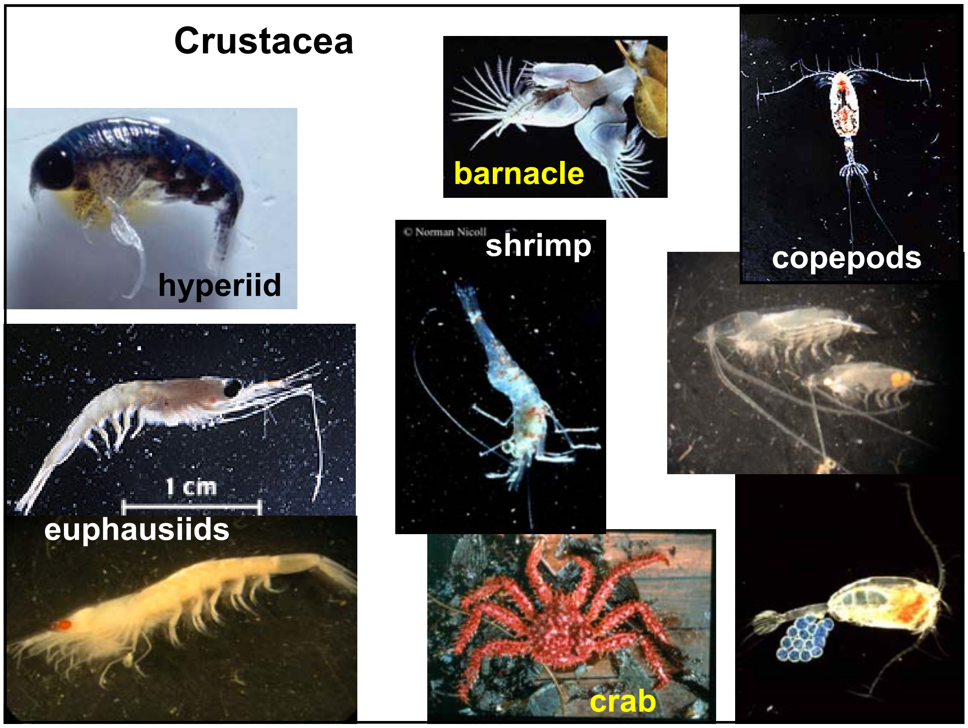

**Principal marine organisms** (cont.)

| Kingdom | Phylum | Class | Organism |
|---|---|---|---|
| **Metazoa** | **Mollusca** | Amphineura | chitons |
| | | **Gastropoda** | **snails, limpets** |
| | | **Bivalvia** | **clams, oysters, mussels** |
| | | **Scaphopoda** | **tooth shells** |
| | | **Cephalopoda** | **octopuses, squid** |
| | Arthropoda | Merostomata | horseshoe crabs |
| | | Pycnogonida | sea spiders |
| | | Crustacea | copepods, shrimps, crabs… |
| | Echinodermata | Asteroidea | starfish |
| | | Echinoidea | sea urchins |
| | | Holothuroidea | sea cucumbers |
| | | Ophiuroidea | brittle stars |
| | | Crinoidea | sea lilies |
| | Protochordata | Urochordata | appendicularians, salps |
| | Chordata | Cephalochordata | lancelets |
| | | Pisces | fishes |
| | | Reptilia | sea turtles, sea snakes |
| | | Aves | sea birds |
| | | Mammalia | seals, whales, sea otters… |




**Principal marine organisms** (cont.)

| Kingdom | Phylum | Class | Organism |
|---|---|---|---|
| **Metazoa** | Mollusca | Amphineura | chitons |
| | | Gastropoda | snails, limpets |
| | | Bivalvia | clams, oysters, mussels |
| | | Scaphopoda | tooth shells |
| | | Cephalopoda | octopuses, squid, nautiluses |
| | **Arthropoda** | Merostomata | horseshoe crabs |
| | | Pycnogonida | sea spiders |
| | | **Crustacea** | **copepods, shrimps, crabs** |
| | Echinodermata | Asteroidea | starfish |
| | | Echinoidea | sea urchins |
| | | Holothuroidea | sea cucumbers |
| | | Ophiuroidea | brittle stars |
| | | Crinoidea | sea lilies |
| | Protochordata | Urochordata | appendicularians, salps |
| | Chordata | Cephalochordata | lancelets |
| | | Pisces | fishes |
| | | Reptilia | sea turtles, sea snakes |
| | | Aves | sea birds |
| | | Mammalia | seals, whales, sea otters… |




## **Principal marine organisms** (cont.)

| Kingdom | Phylum | Class | Organism |
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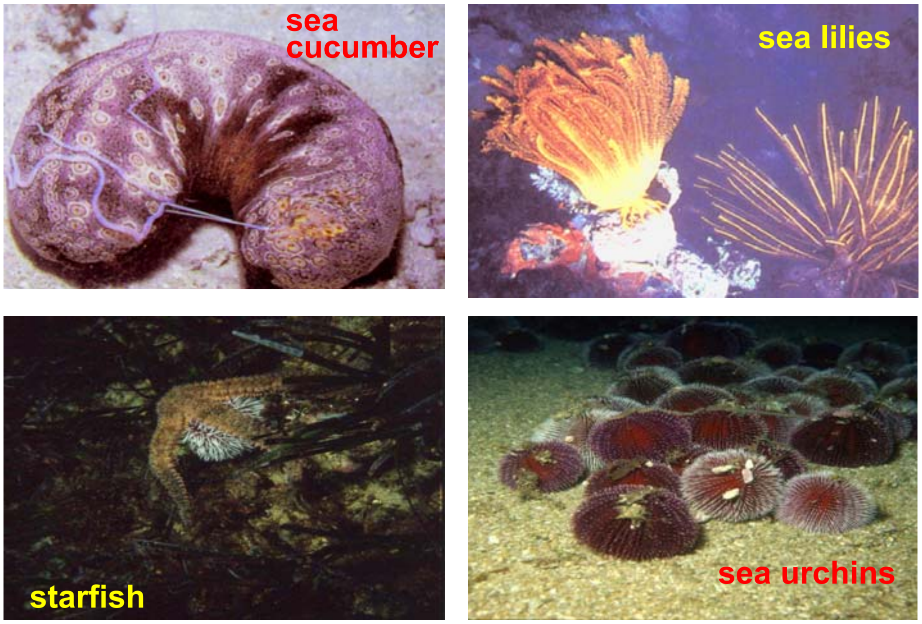
| | | Bivalvia | clams, oysters, mussels |
| | | Scaphopoda | tooth shells |
| | | Cephalopoda | octopuses, squid, nautiluses |
| | Arthropoda | Merostomata | horseshoe crabs |
| | | Pycnogonida | sea spiders |
| | | Crustacea | copepods, shrimps, crabs… |
| | **Echinodermata** | **Asteroidea** | **starfish** |
| | | **Echinoidea** | **sea urchins** |
| | | **Holothuroidea** | **sea cucumbers** |
| | | **Ophiuroidea** | **brittle stars** |
| | | **Crinoidea** | **sea lilies** |
| | Protochordata | Urochordata | appendicularians, salps |
| | Chordata | Cephalochordata | lancelets |
| | | Pisces | fishes |
| | | Reptilia | sea turtles, sea snakes |
| | | Aves | sea birds |
| | | Mammalia | seals, whales, sea otters… |

## Echinodermata




## **Principal marine organisms** (cont.)

| Kingdom | Phylum | Class | Organism |
|---|---|---|---|
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| | | Gastropoda | snails, limpets |
| | | Bivalvia | clams, oysters, mussels |
| | | Scaphopoda | tooth shells |
| | | Cephalopoda | octopuses, squid, nautiluses |
| | Arthropoda | Merostomata | horseshoe crabs |
| | | Pycnogonida | sea spiders |
| | | Crustacea | copepods, shrimps, crabs… |
| | Echinodermata | Asteroidea | starfish |
| | | Echinoidea | sea urchins |
| | | Holothuroidea | sea cucumbers |
| | | Ophiuroidea | brittle stars |
| | | Crinoidea | sea lilies |
| | **Protochordata** | **Urochordata** | **appendicularians, salps** |
| | Chordata | Cephalochordata | lancelets |
| | | Pisces | fishes |
| | | Reptilia | sea turtles, sea snakes |
| | | Aves | sea birds |
| | | Mammalia | seals, whales, sea otters… |

## Urochordata or Tunicates

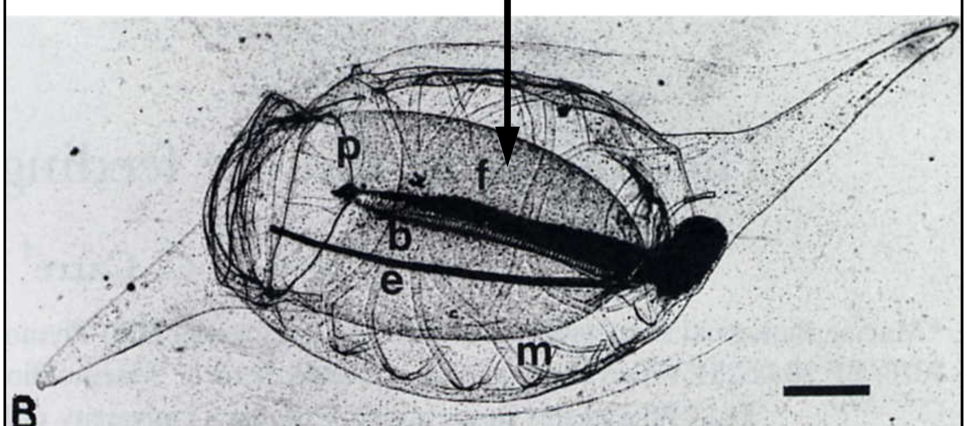
salp
colonies





## *Salpa fusiformis* (from Bone *et al.*, 2000)

filtering net



**Principal marine organisms** (cont.)

| Kingdom | Phylum | Class | Organism |
| --- | --- | --- | --- |
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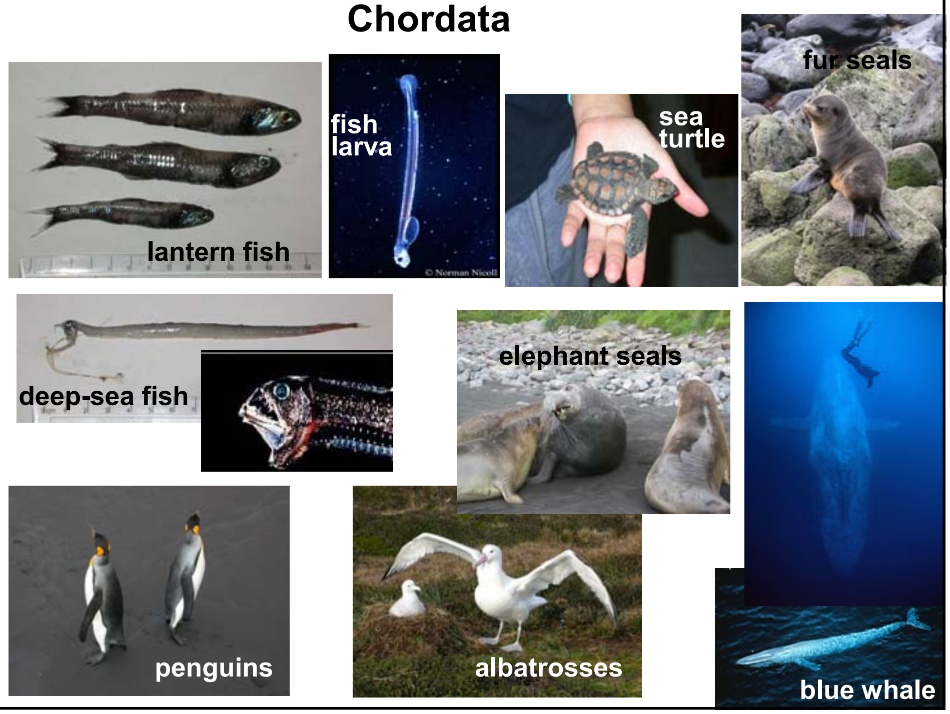
| | | Ophiuroidea | brittle stars |
| | | Crinoidea | sea lilies |
| | Protochordata | Urochordata | appendicularians, salps |
| | **Chordata** | Cephalochordata | lancelets |
| | | **Pisces** | **fishes** |
| | | **Reptilia** | **sea turtles, sea snakes** |
| | | **Aves** | **sea birds** |
| | | **Mammalia** | **seals, whales, sea otters**… |

## Chordata




## Classification by lifestyle

**Plankton**: organisms which float in the water and have no abilities to propel themselves against a current (or swim weakly)

- phytoplankton (plants)
- zooplankton (animals)
  - neuston

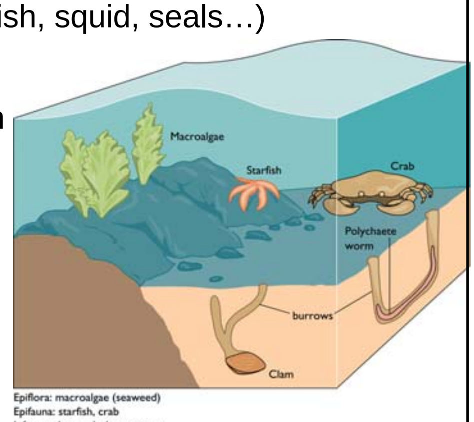
**Nekton**: the active swimmers (fish, squid, seals…)

**Benthos**: organisms which are attached or move on or beneath the sea bottom (98% of all species)

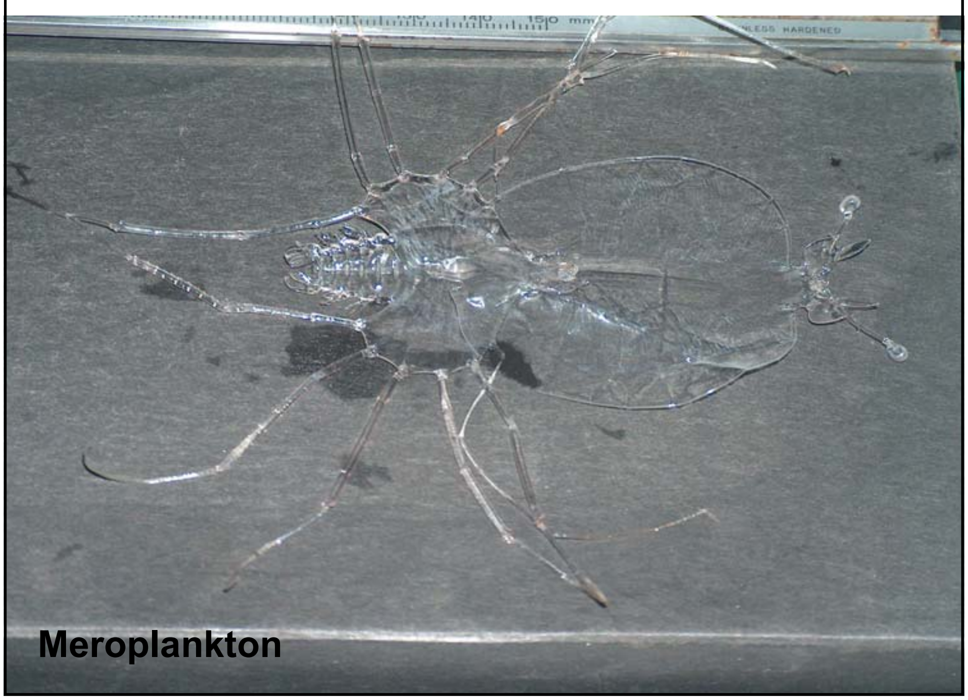
- epifauna & epiflora
- infauna

Nectobenthic, Benthopelagic

Holoplankton vs Meroplankton



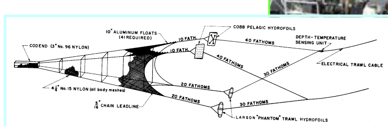
## Meroplankton



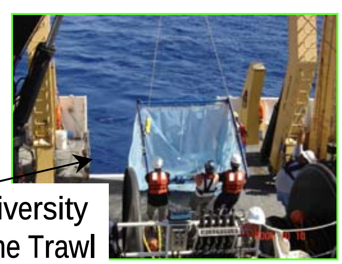
Meroplankton

## Sampling gears

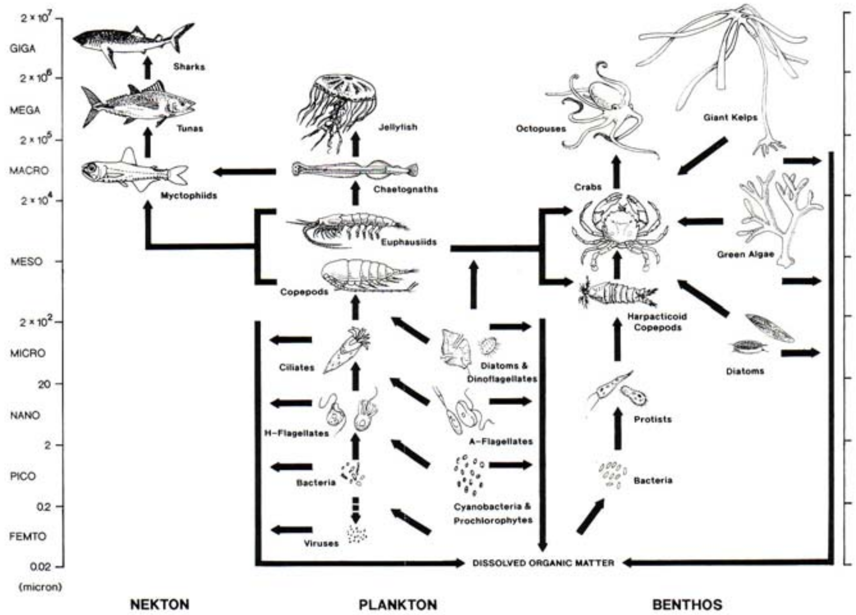
140 m² "Stauffer modified" pelagic Cobb trawl



1.8 m IKMT



2 m Hokkaido University Rectangular Frame Trawl

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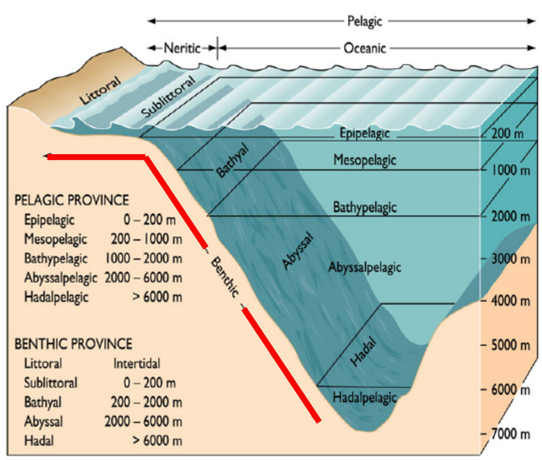
## Ocean habitats




(a) BIOZONES

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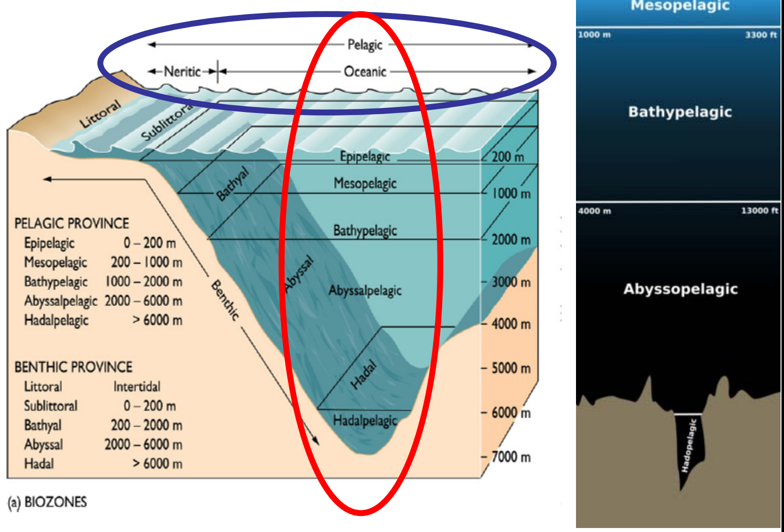
# Ocean habitats

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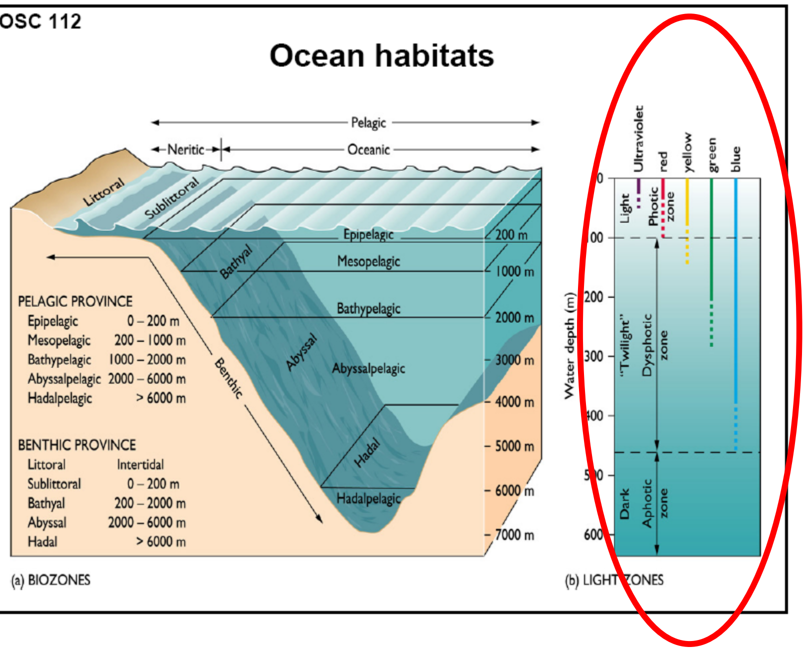
# Ocean habitats



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## Percentages of marine habitats

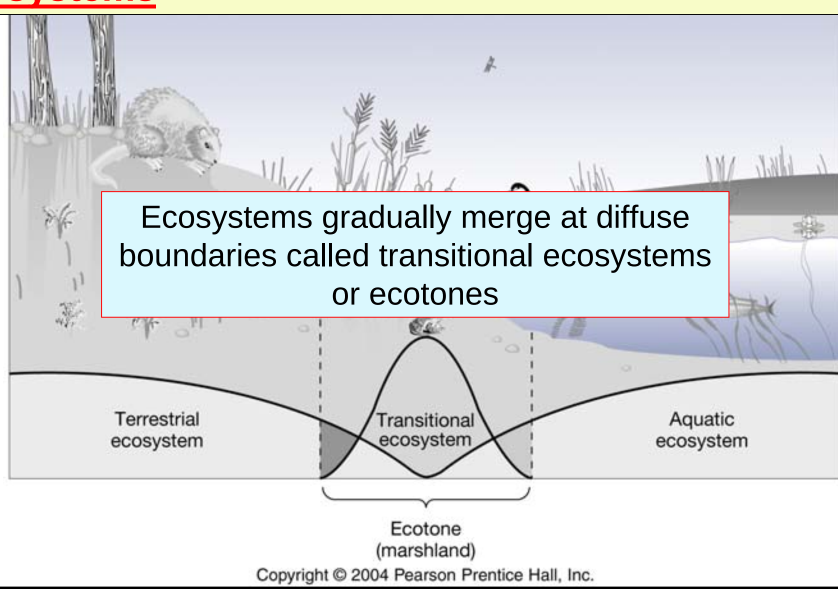
**Pelagic environments**

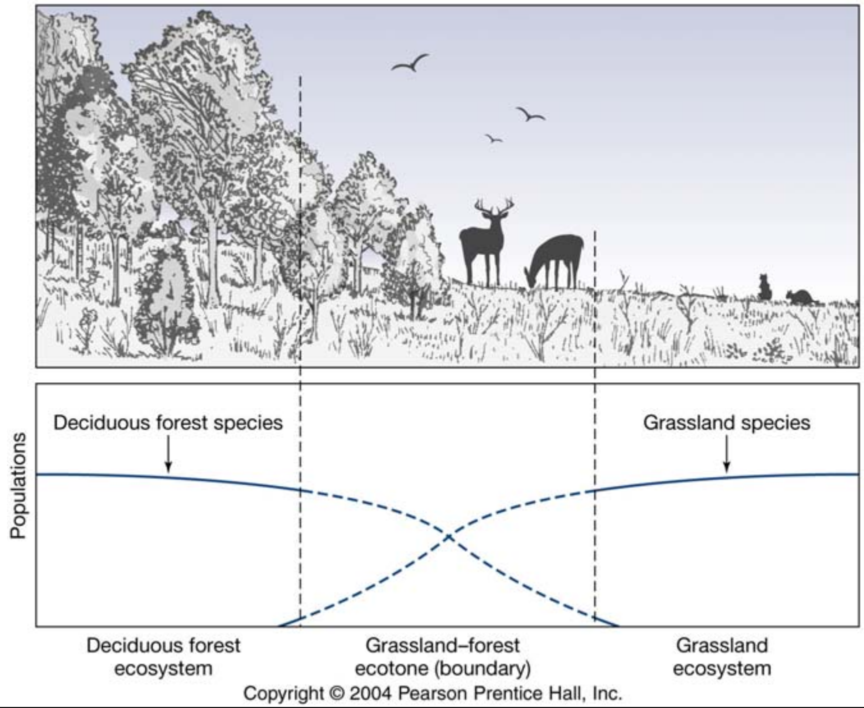
| Zone | Depth (m) | Volume (%) |
|---|---|---|
| Epipelagic | 0-200 | 3 |
| Mesopelagic | 200-1000 | 28 |
| Bathypelagic | 1000-2000 | 15 |
| Abyssalpelagic | 2000-6000 | 54 |
| Hadalpelagic | > 6000 | <1 |

**Benthic environments**

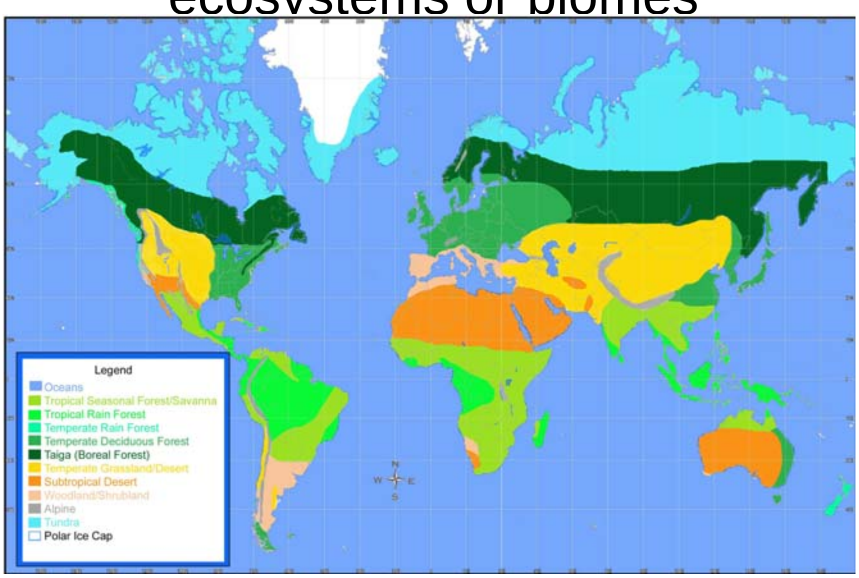
| Zone | Depth (m) | Area (%) |
|---|---|---|
| Sublittoral | 0-200 | 8 |
| Bathyal | 200-2000 | 16 |
| Abyssal | 2000-6000 | 75 |
| Hadal | > 6000 | 1 |

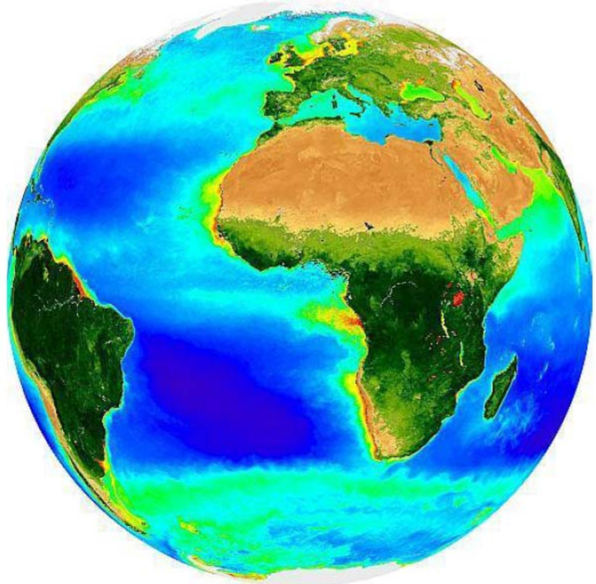
organisms are not living in isolation but interact with each other and their physical surroundings, forming **ecosystems**



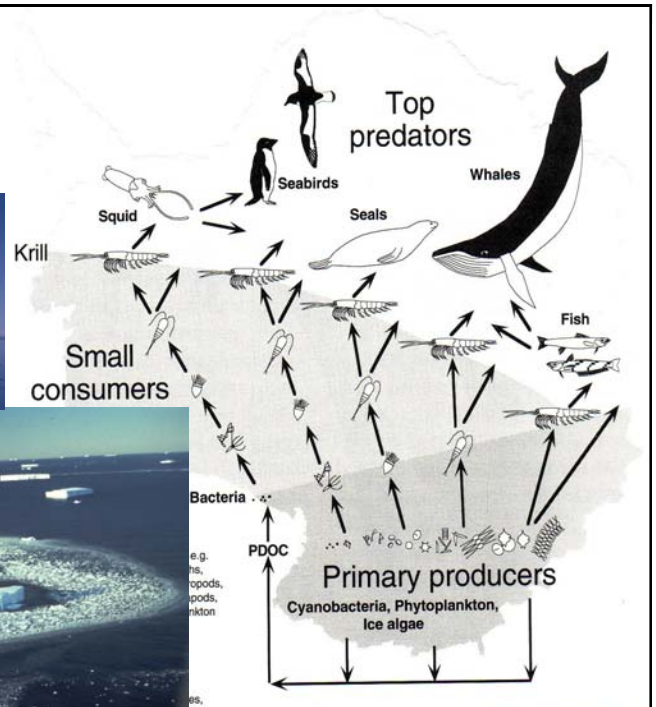



# Continents can be subdivided in ecosystems or biomes

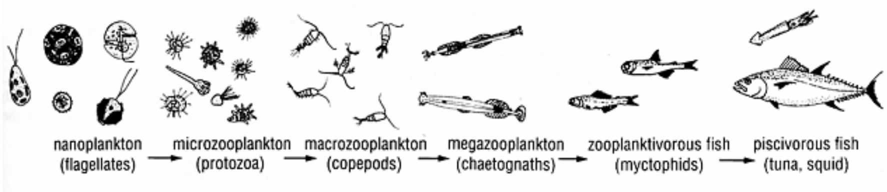




**Antarctic food web**

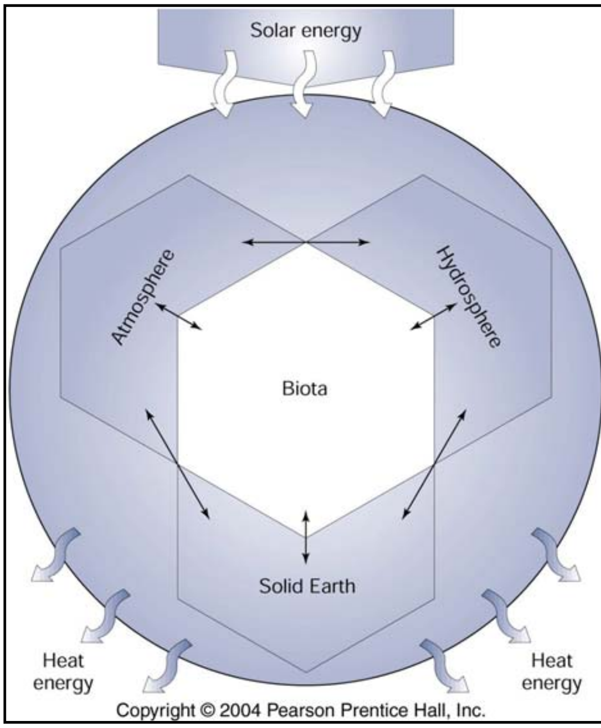



Oligotrophic low nutrient environments:
**Small** phytoplankton (e.g. cyanobacteria) and small grazers (e.g. nanoflagellates, ciliates)




# Life on Earth

- Classification systems (lecture notes)
- Ecosystems (Kump et al.; Chap 9, 175-182)
- Food chains (lecture notes; Kump et al.; Chap. 9, 173-175; Chap. 8, 153-158)




"Earth System"

Categorization of the biota using a broader classification system based on:

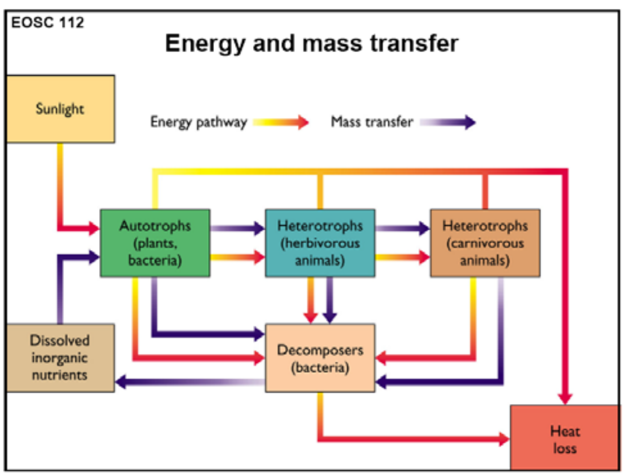
-how organisms obtain energy needed for metabolic activities

- how organisms obtain chemical elements needed to produce living tissues and deposit biominerals

Assemblages of species interact with each other and their environment to form ecosystems

Material → recycled

Energy → added & dissipated

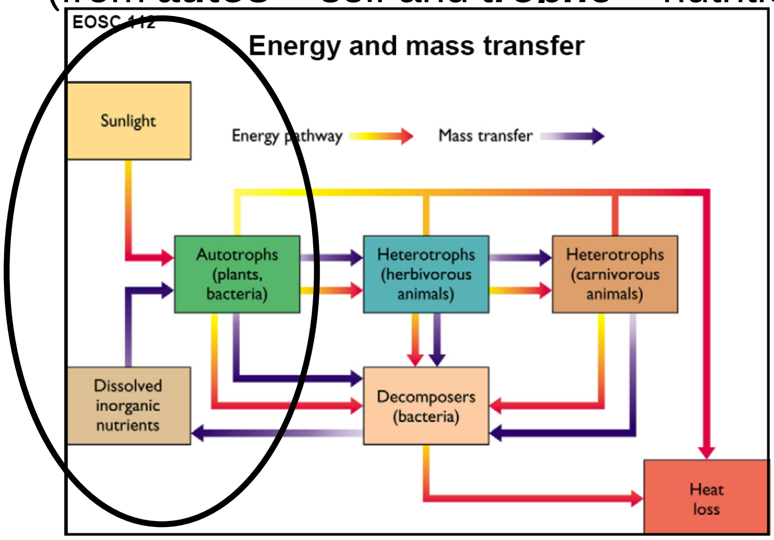



Food Chain

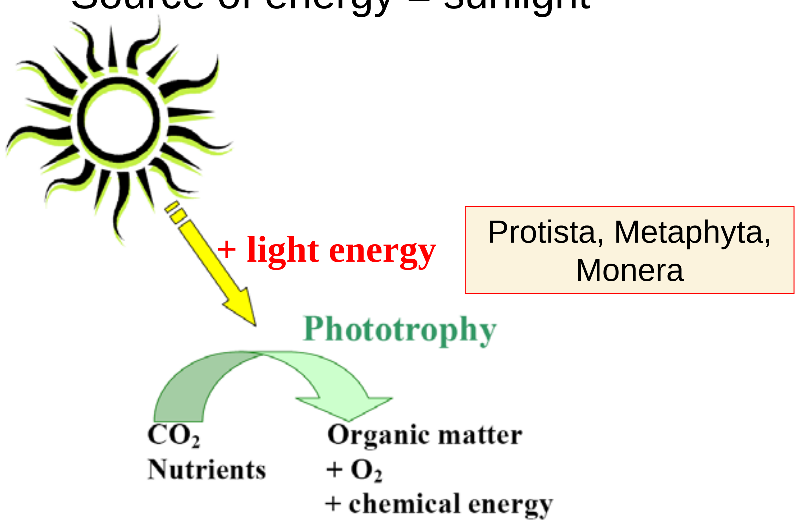
First step in the food chain:

autotrophs (primary producers)

(from ***autos*** = self and ***trophe*** = nutrition



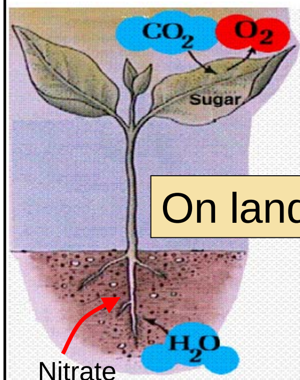

Source of energy = sunlight



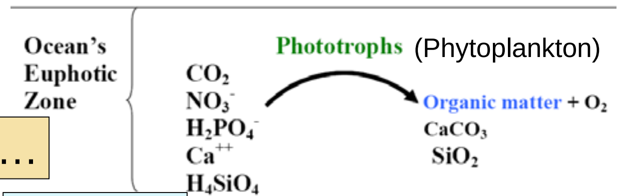

..use **chlorophyll** to capture energy from sunlight to convert $CO_2$ and inorganic nutrients into organic matter = **photosynthesis**

$$6\ CO_2 + 6\ H_2O + \textbf{light} \rightarrow C_6H_{12}O_6 + 6\ O_2$$

carbohydrate




On land…




At sea…

**Photosynthesis converts sunlight energy into chemical energy stored in the chemical bonds of organic matter**

Elemental analysis of marine phyptoplankton

**TABLE 8-1**

**Redfield Ratios**

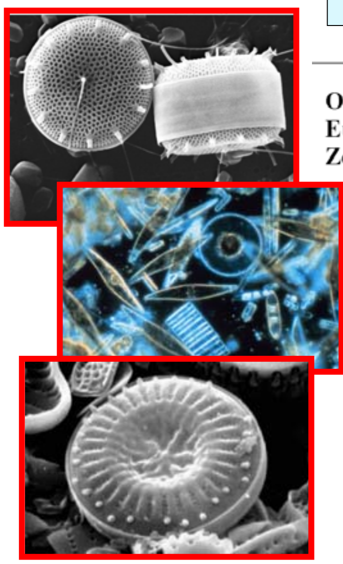
| *Element* | *Relative number of atoms in living phytoplankton* |
|---|---|
| Carbon | 106 |
| Nitrogen | 16 |
| Phosphorus | 1 |
| Iron | 0.01 |



$$106\ CO_2 + 16\ NO_3^{-} + 1\ PO_4^{3-} + 122\ H_2O + 19\ H^{+}$$

$$\rightarrow (CH_2O)_{106}(NH_3)_{16}(H_3PO_4)_1 + 138\ O_2$$

## Diatoms



Many phytoplankton species produce skeletons (calcium carbonate or glass)

Ocean's Euphotic Zone

$CO_2$, $NO_3^-$, $H_2PO_4^-$, $Ca^{++}$, $H_4SiO_4$ —**Phototrophs** (Phytoplankton)→ Organic matter + $O_2$, $CaCO_3$, $SiO_2$

## Coccolithophorid


### KINGDOMS OF LIVING THINGS IN THE LINNAEAN CLASSIFICATION SYSTEM

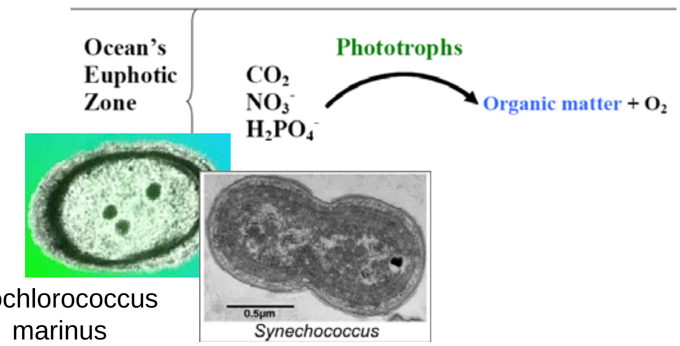
Primary producers are:
- Protista
- Metaphyta
- **Monera**

| | KINGDOM | STRUCTURAL ORGANIZATION | METHOD OF NUTRITION | TYPES OF ORGANISMS | NAMED SPECIES | TOTAL SPECIES (estimate) |
|---|---|---|---|---|---|---|
| | Monera | small, simple single prokaryotic cell (nucleus is not enclosed by a membrane); some form chains or mats | absorb food | bacteria, blue-green algae, and spirochetes (Cyanobacteria) | 4,000 | 1,000,000 |
| | Protista | large, single eukaryotic cell (nucleus is enclosed by a membrane); some form chains or colonies | absorb, ingest, and/or photosynthesize food | protozoans and algae of various types | 80,000 | 600,000 |
| | Fungi | multicellular filamentous form with specialized eukaryotic cells | absorb food | funguses, molds, mushrooms, yeasts, mildews, and smuts | 72,000 | 1,500,000 |
| (Metaphyta) | Plantae | multicellular form with specialized eukaryotic cells; do not have their own means of locomotion | photosynthesize food | mosses, ferns, woody and non-woody flowering plants | 270,000 | 320,000 |
| (Metazoa) | Animalia | multicellular form with specialized eukaryotic cells; have their own means of locomotion | ingest food | sponges, worms, insects, fish, amphibians, reptiles, birds, and mammals | 1,326,239 | 9,812,298 |

NOTE: A growing number of researchers now divide the Monera into two distinct kingdoms: Eubacteria (the true bacteria) and Archaebacteria (bacteria-like organisms that live in extremely harsh anaerobic environments such as hot springs, deep ocean volcanic vents, sewage treatment plants, and swamp sediments). Viruses, prions, and other non-cellular entities are not included in the five kingdoms.

The numbers of named and estimated total species were derived from Gibbs, W. Wayt (2001) "On the Termination of Species", *Scientific American* Vol. 285, No. 5.

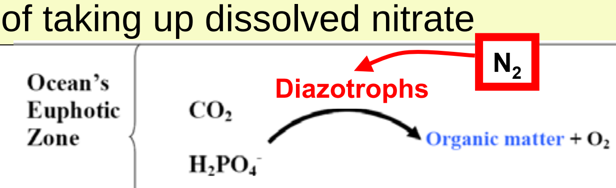
At sea…

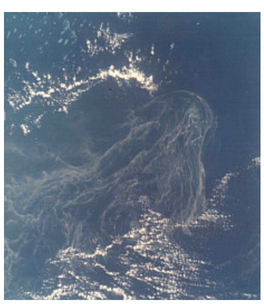



Prochlorococcus marinus

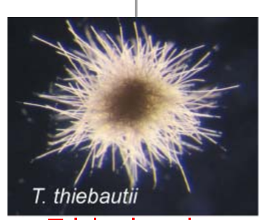
.. some species of cyanobacteria are the most numerous organisms on earth and account for half the total primary production in the marine environment

Some cyanobacteria (e.g. Trichodesmium) not only fix $CO_2$ to produce organic matter but also fix molecular $N_2$ instead of taking up dissolved nitrate



Trichodesmium seen from space




Trichodesmium

Natural Fertilizers

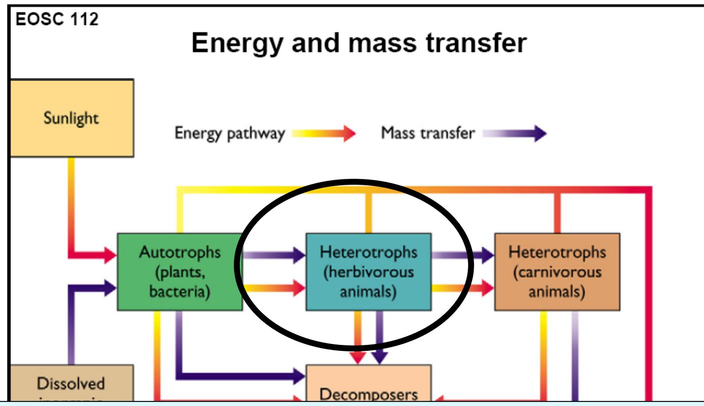
$$106\ CO_2 + \cancel{16\ NO_3^-} + 1\ PO_4^{3-} + 122\ H_2O + 19\ H^+$$

$$\rightarrow (CH_2O)_{106}(NH_3)_{16}(H_3PO_4)_1 + 138\ O_2$$

Second step in the food chain:

## Herbivores (Heterotrophs; Consumers)

(***heterone*** = (an)other and ***trophe*** = nutrition)




Heterotrophs require organic substrates to acquire the carbon, nitrogen, phosphorus and energy they need for growth and development

**Photosynthesis converts sunlight energy into chemical energy stored in the chemical bonds of organic matter..**

**..that energy is released during oxidation of organic matter by heterotrophs during respiration or heterotrophy**

**+ light**

**Phototrophy**

**Nutrients +** $CO_2$ → $C_{org} + O_2$ **+ chemical energy**

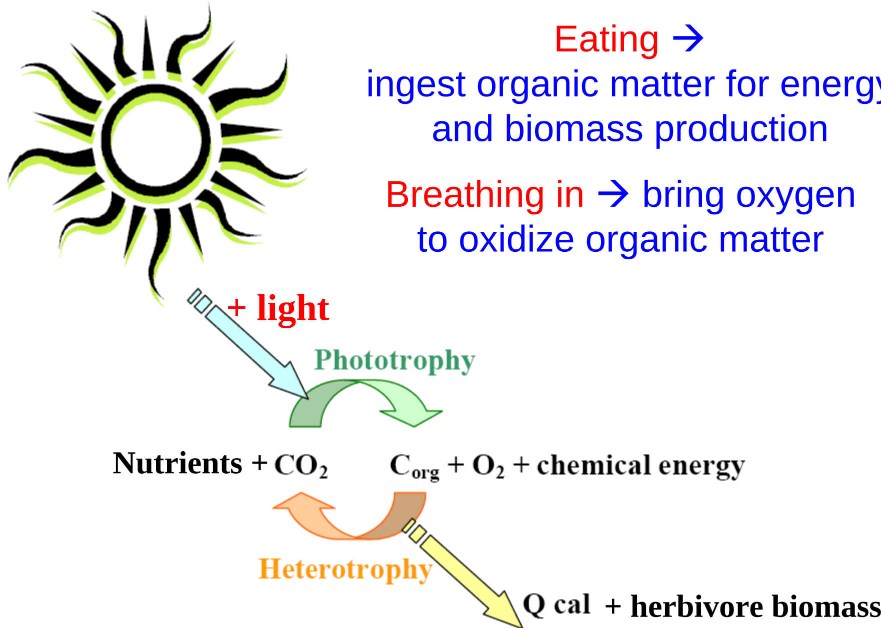
**Heterotrophy**

**Q cal + herbivore biomass**

Herbivores can use this energy to meet their needs for movement, reproduction, growth

Eating → ingest organic matter for energy and biomass production

Breathing in → bring oxygen to oxidize organic matter

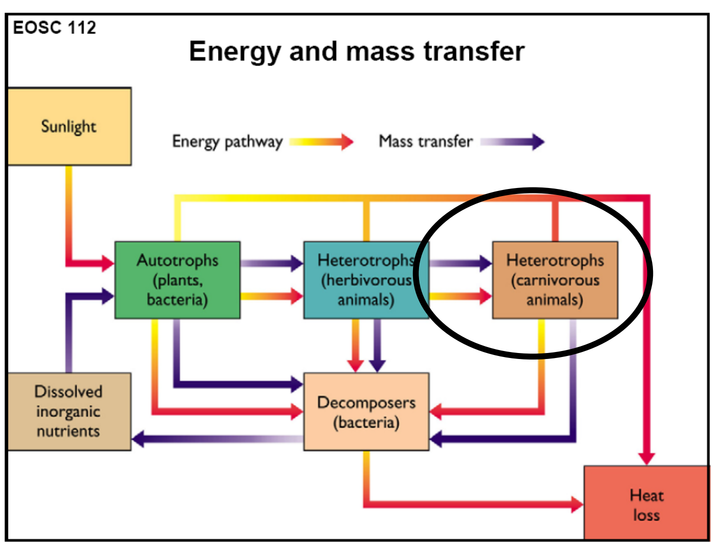


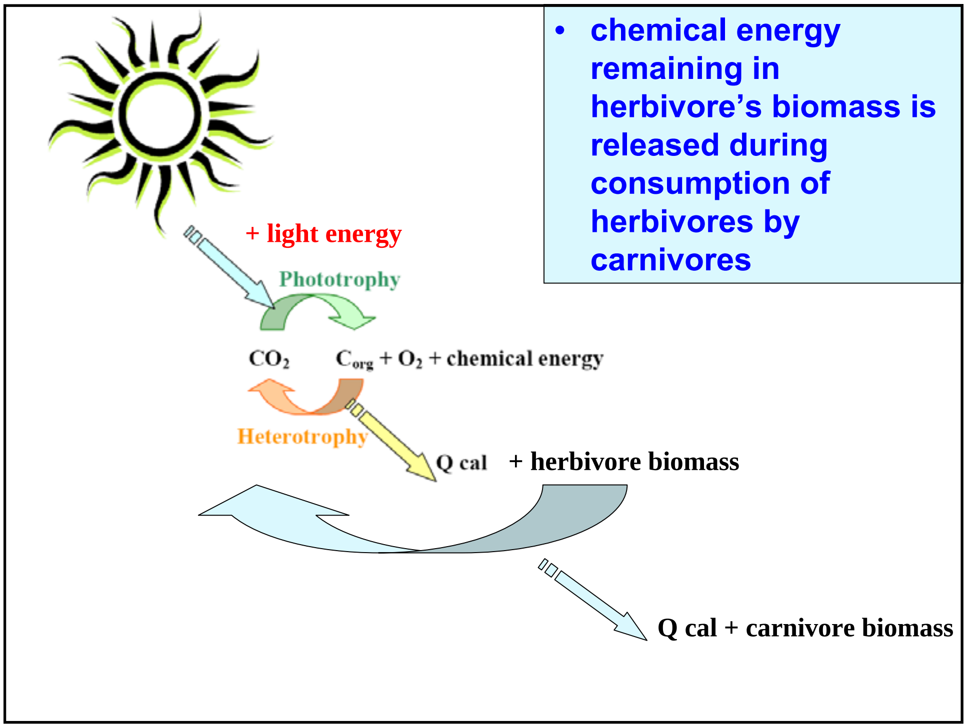

Breathing out → release $CO_2$

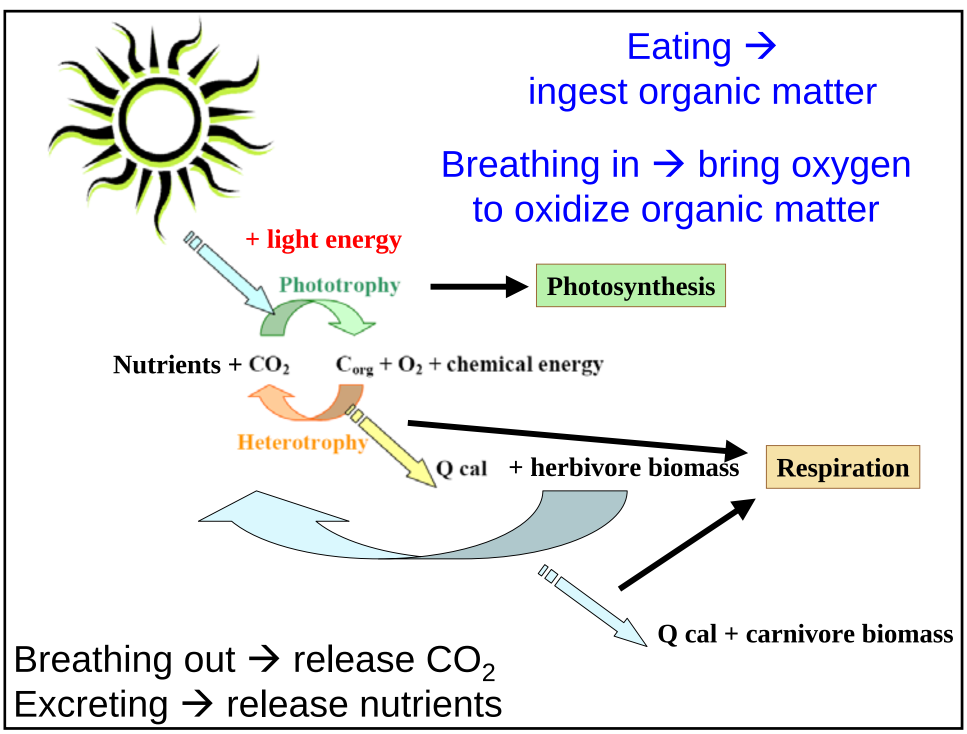
Excreting → release nutrients

Third and subsequent steps in the food chain:

## Carnivores (Heterotrophs; Consumers)

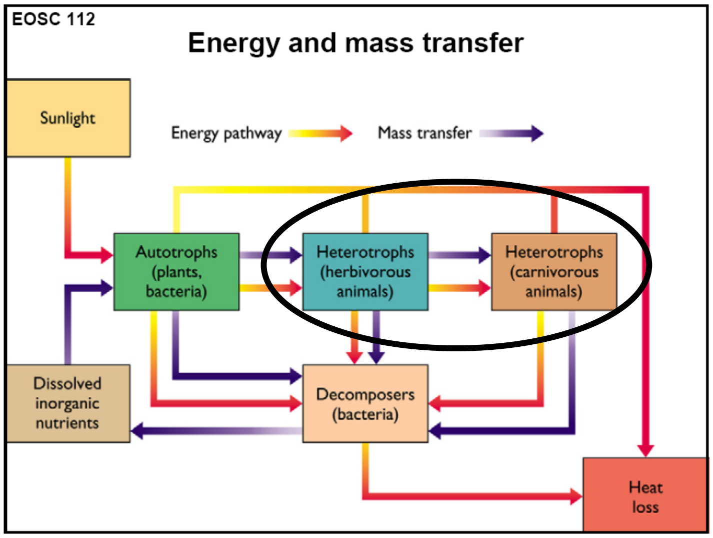



• chemical energy remaining in herbivore's biomass is released during consumption of herbivores by carnivores
+ light energy
Phototrophy
$CO_2$
$C_{org}$ + $O_2$ + chemical energy
Heterotrophy
Q cal + herbivore biomass
Q cal + carnivore biomass


Eating → ingest organic matter
Breathing in → bring oxygen to oxidize organic matter
+ light energy
Phototrophy
Photosynthesis
Nutrients + $CO_2$
$C_{org}$ + $O_2$ + chemical energy
Heterotrophy
Q cal + herbivore biomass
Respiration
Q cal + carnivore biomass
Breathing out → release $CO_2$
Excreting → release nutrients

Herbivores and carnivores = animals

(Heterotrophs; Consumers)

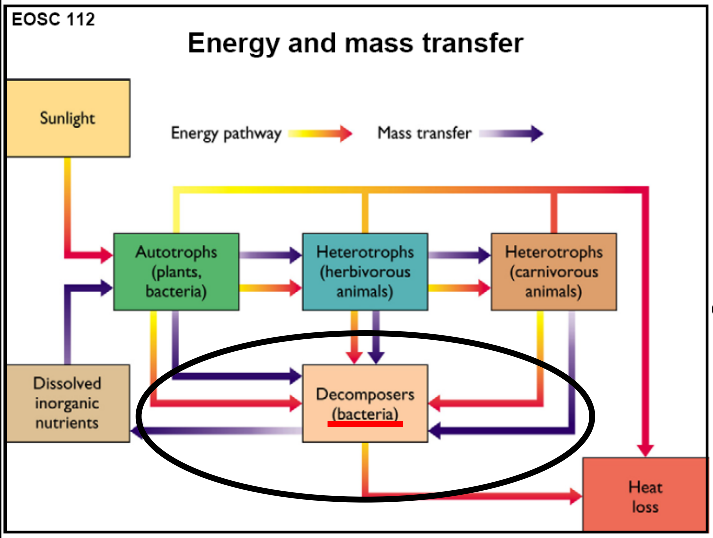



Example of feeding styles:

**Grazers** → consume plants
**Predators** → consume living animals
**Scavengers** → consume dead animals
**Filter feeders** → consume organic matter suspended in water
**Deposit feeders** → consume organic matter mixed with sediment

Terminal step in the food chain:

## Decomposers (Heterotrophs)




Decomposers consume biomass of dead autotrophs, herbivores and carnivores that did not get consumed in the food chain

→ insure complete recycling of nutrients and $CO_2$

## Primary Producers PHOTOSYNTHESIS

$$6\ CO_2 + 6\ H_2O + \textbf{light} \rightarrow C_6H_{12}O_6 + 6\ O_2$$

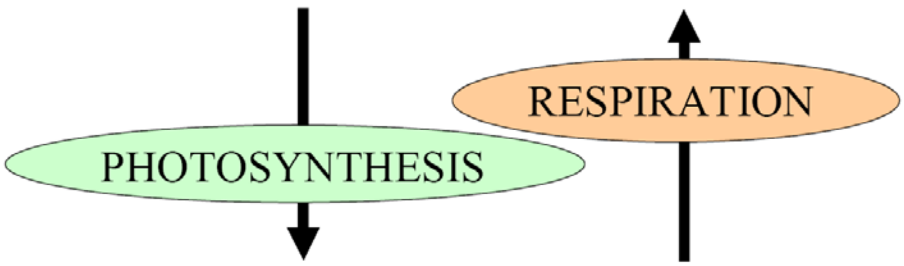
## Herbivores; Carnivores; Aerobic Decomposers **RESPIRATION**

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + \textbf{energy}$$

## In the ocean, photosynthesis and respiration follow the "Redfield Ratios"

**General Equation for Photosynthesis and Respiration**

$106\ CO_2 + 16\ NO_3^- + 1\ PO_4^{3-}$ $(+ 122\ H_2O + 19\ H^+)$




$(CH_2O)_{106}(NH_3)_{16}(H_3PO_4)_1 + 138\ O_2$

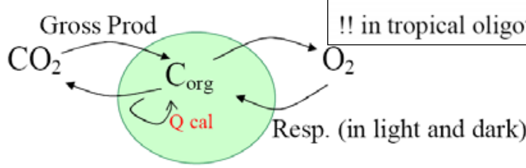
## Respiration by phototrophs

Phytoplankton cannot use light energy directly to fuel metabolic reactions

They oxidize aerobically a fraction of the organic matter they produce

Typically: Resp. Rate ≤ 0.1 Gross Prod. Rate

!! in tropical oligotrophic regions RR ≈ 0.4 GPR




Net Production = Gross Production - Respiration

Net Production → Fuels the food chain

Respiration → Mainly carbohydrates

$CH_2O + O_2 \rightarrow CO_2 + H_2O + 532\ kJ$

Herbivores; Carnivores; Aerobic Decomposers
**RESPIRATION**

$C_6H_{12}O_6$ + **6 $O_2$** → 6 $CO_2$ + 6 $H_2O$ + **energy**

Herbivores & Carnivores MUST use oxygen
..but some bacteria do not need oxygen and can live in anoxic environments

**Aerobic oxidation**:

$CH_2O + O_2 \rightarrow CO_2 + H_2O + 532$ kJ

**Anaerobic oxidation**:

- in poorly ventilated basins (e.g. Black Sea)
- in productive regions (e.g. Arabian Sea)
- in reducing sediments

*Denitrification:*

$CH_2O + 0.8\ NO_3^- + 0.8\ H^+ \rightarrow CO_2 + 0.4\ N_2 + 1.4\ H_2O + 505$ kJ

*Mn reduction:*

$CH_2O + 2\ MnO_2 + 4\ H^+ \rightarrow CO_2 + 2\ Mn^{2+} + 3\ H_2O + 349$ kJ

*Fe reduction:*

$CH_2O + 2\ Fe_2O_3 + 8\ H^+ \rightarrow CO_2 + 4\ Fe^{2+} + 5\ H_2O + 114$ kJ

*Sulfate reduction:*

$CH_2O + 0.5\ SO_4^{=} \rightarrow CO_2 + 0.5\ S^{=} + H_2O + 63$ kJ

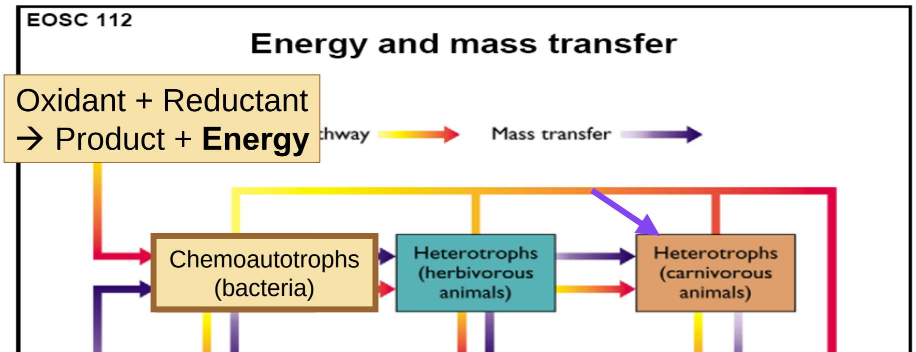
*Fermentation:*

$CH_2O \rightarrow 0.5\ CO_2 + 0.5\ CH_4 + 58$ kJ

Oxidants are used sequentially following order of energy yield

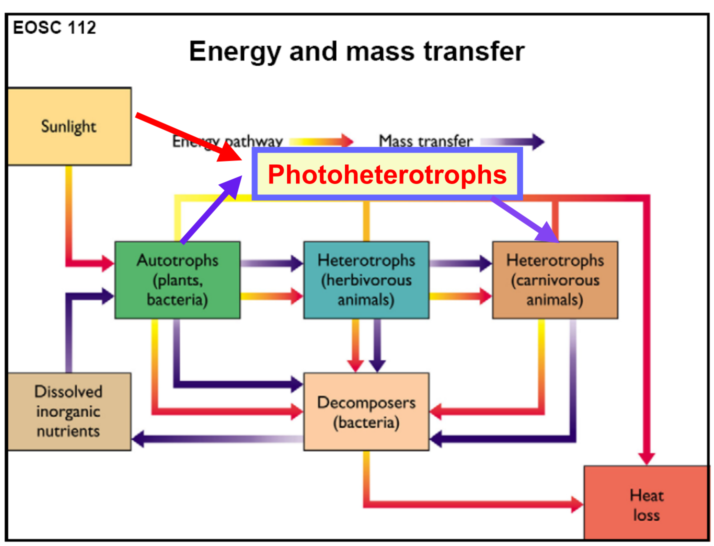
## Most autotrophs are phototrophs, but not all…

# Chemosynthesis




They live in areas where both oxidized and reduced molecules can come into contact to react spontaneously and produce energy.

Some organisms require organic compounds as a source of carbon and light as a source of energy



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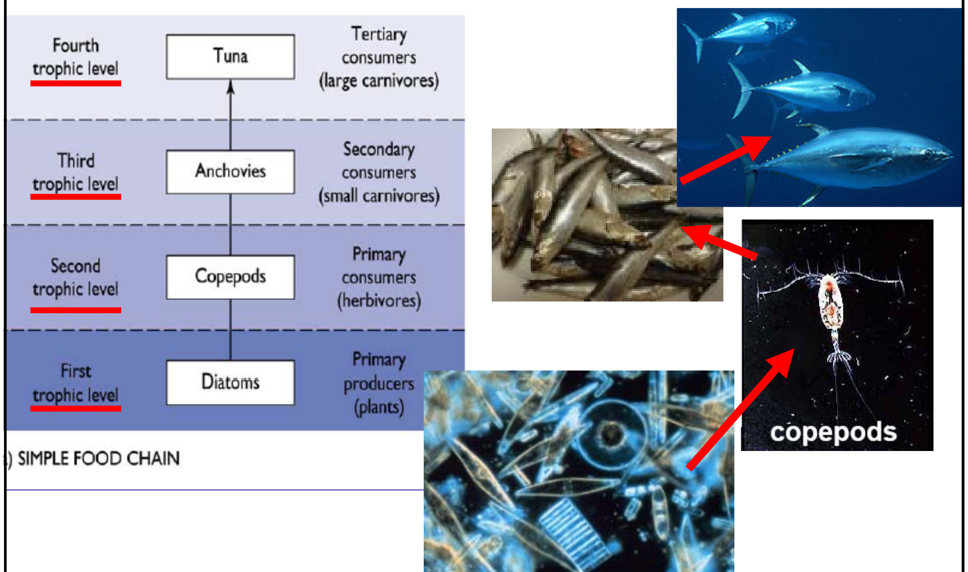
## Food chain and food web

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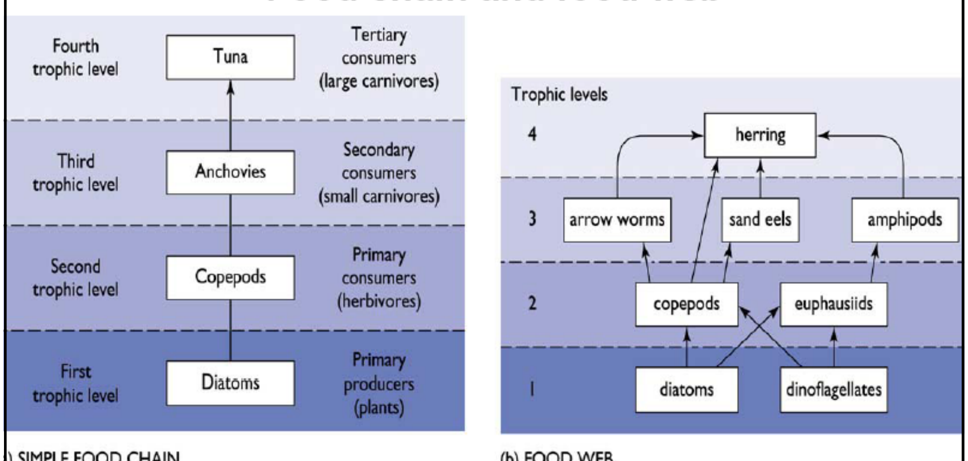
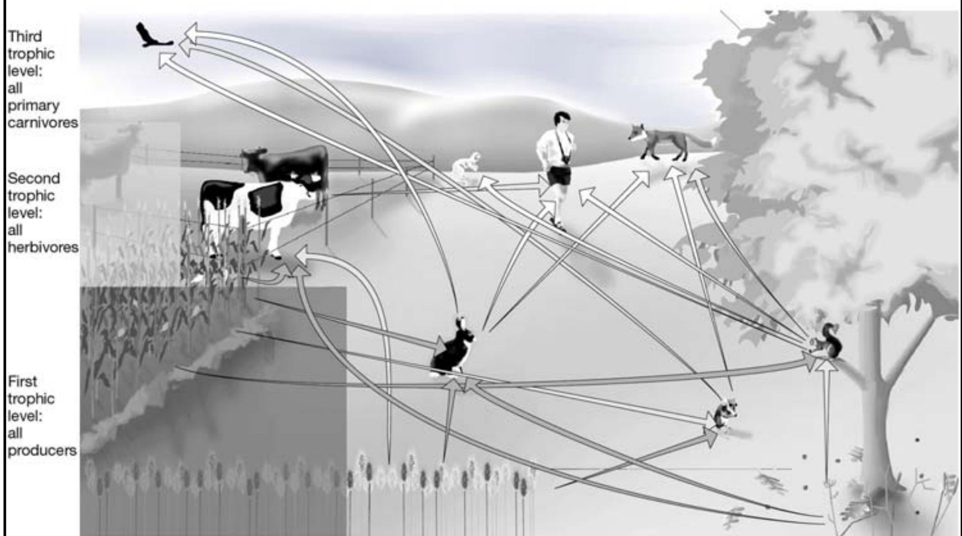
## Food chain and food web




Food Chains → linear simple relationship between trophic levels
Food Webs → interconnected food chains

## .. Same principles operate on land






## Only 10-20% of biomass is transferred to the next trophic level…

→ longer food chains require more autotroph biomass to sustain the top predators

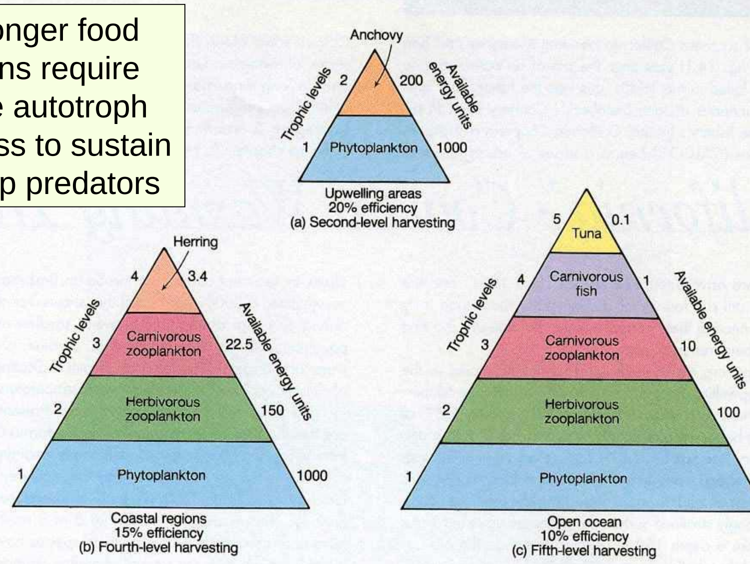
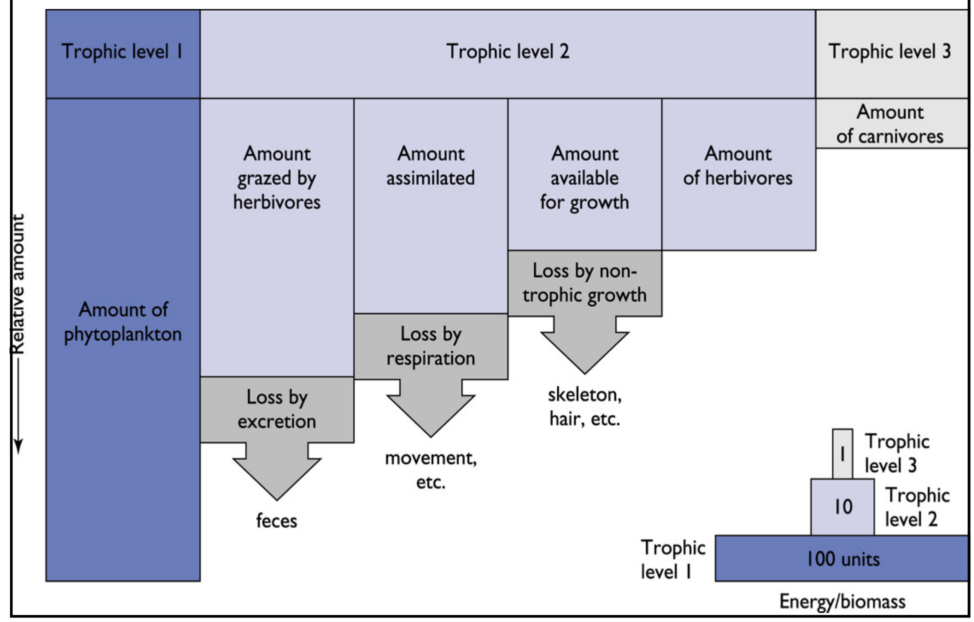
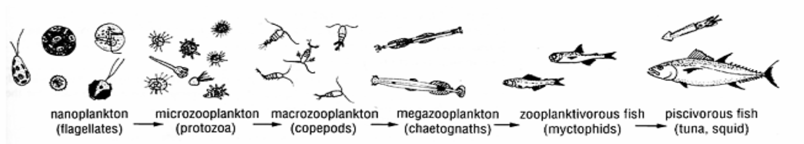


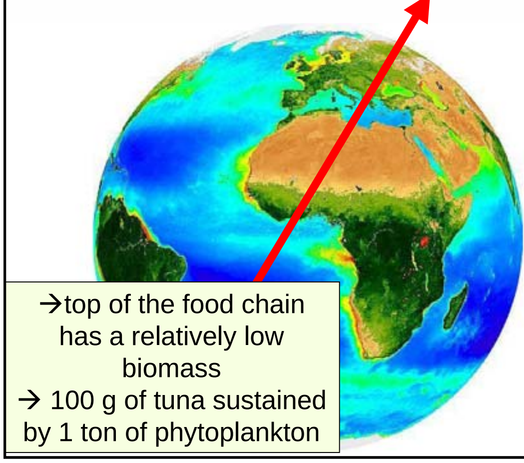

Figure 14.14

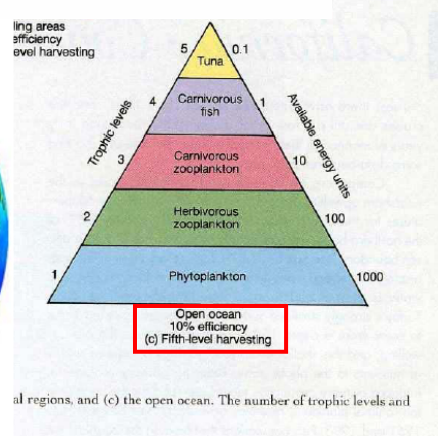
## Energy transfer efficiency concept




Oligotrophic low nutrient environments:
**Small** phytoplankton (e.g. cyanobacteria) and small grazers (e.g. nanoflagellates, ciliates)



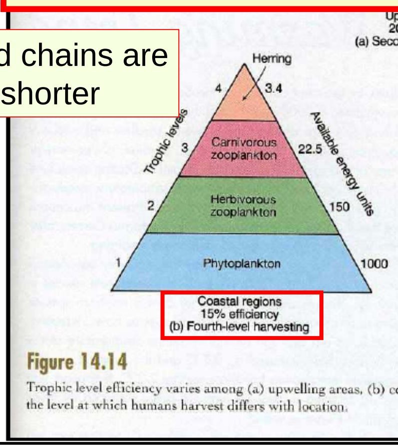



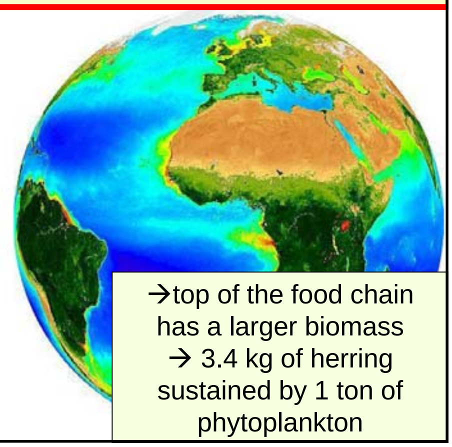



→top of the food chain has a relatively low biomass
→ 100 g of tuna sustained by 1 ton of phytoplankton

In coastal regions, supply of nutrients is higher, phytoplankton cells are larger…

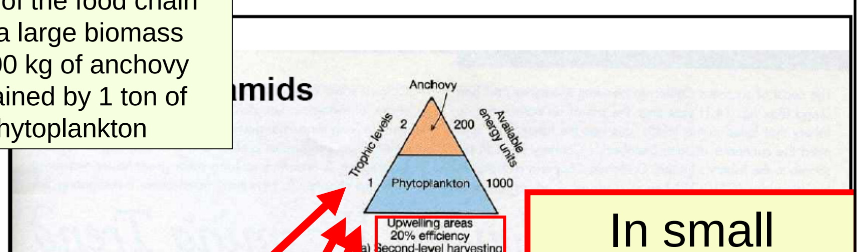
..food chains are shorter

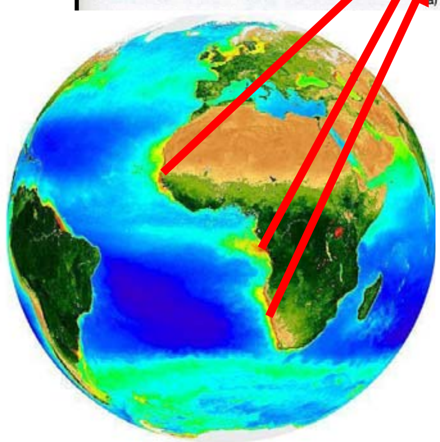


→top of the food chain has a larger biomass → 3.4 kg of herring sustained by 1 ton of phytoplankton

→top of the food chain has a large biomass → 200 kg of anchovy sustained by 1 ton of phytoplankton



In small "upwelling" areas, supply of nutrients is very high → food chains are very short..

## Productivity in various regions

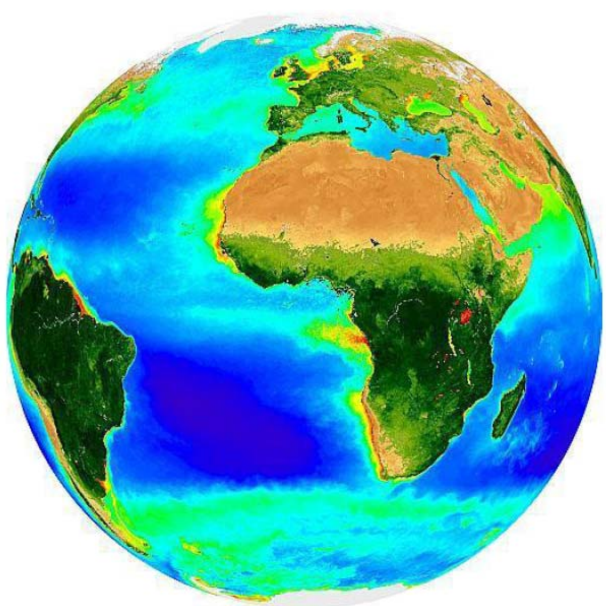
| Region | PP gC/m$^2$/yr | Area % | TPP Gt C/yr | Effic. % | # trophic levels | Fish prod. $10^6$ tons/yr |
|---|---|---|---|---|---|---|
| Upwelling | 640 | 0.1 | 0.23 | 20 | 2 | 46 |
| Coastal | 160 | 15 | 8.6 | 15 | 4 | 29 |
| Open ocean | 130 | 85 | 39.9 | 10 | 5 | 4 |

Upwelling regions cover a small area but:

- sustain high rates of primary production
- short food chains with high transfer efficiency between trophic levels

→ They sustain large biomass of commercial fish

## The ocean is not a uniform ecosystem…



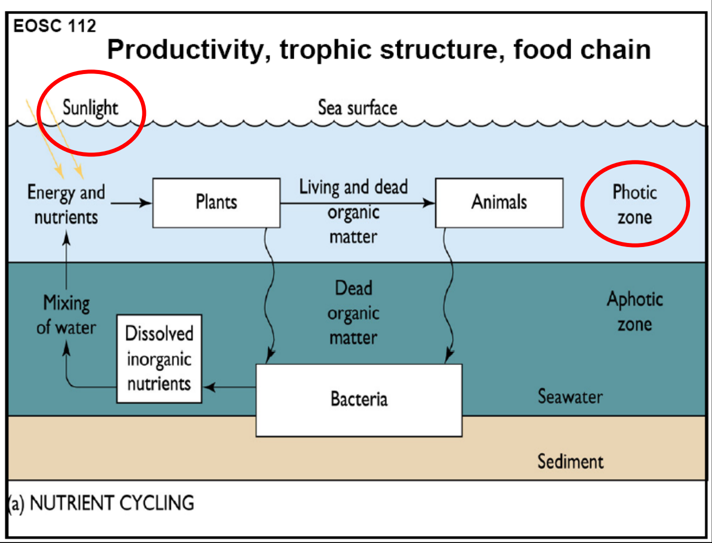
# Life on Earth

- Classification systems (lecture notes)
- Ecosystems (Kump et al.; Chap 9, 175-182)
- Food chains (lecture notes; Kump et al.; Chap. 9, 173-175; Chap. 8, 153-158)
- Factors controlling ocean productivity and the distribution of marine ecosystems (lecture notes)

# What produces such contrasts?

Producers, Consumers & Decomposers

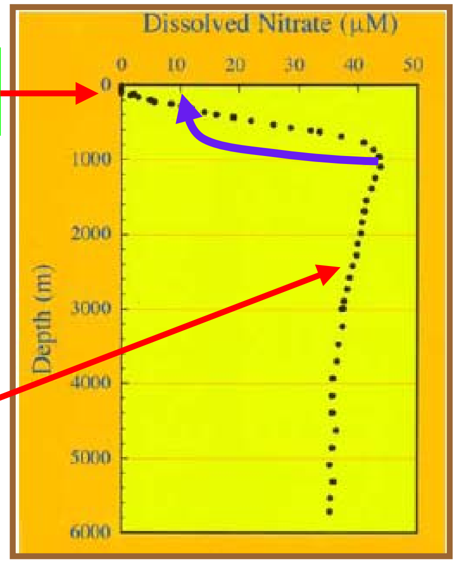
Consumers & Decomposers only, feeding on sinking organic matter



Low concentration due to uptake by phytoplankton

**Essential nutrients (nitrate,phosphate) and $CO_2$**

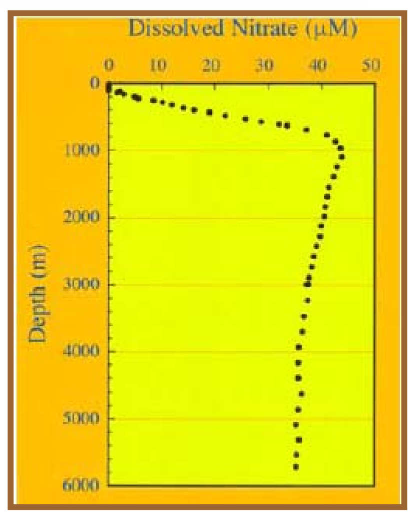
High concentration due to regeneration by bacteria




**Ocean productivity closely coupled to ocean physics**

$106\ CO_2$
$16\ NO_3^-$
$1\ PO_4^{3-}$ $\rightarrow (CH_2O)_{106}(NH_3)_{16}(H_3PO_4)_1$

PHOTOSYNTHESIS




Nutrients distribution and concentration..

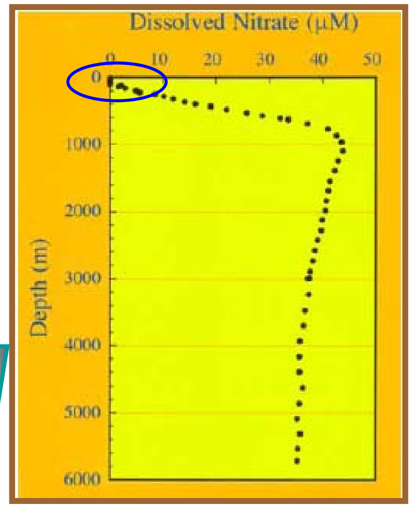
Redfield Ratios

$106\ CO_2$
$16\ NO_3^-$
$1\ PO_4^{3-}$

→ $(CH_2O)_{106}(NH_3)_{16}(H_3PO_4)_1$

Phosphate & nitrate surface concentration → 0
(limiting nutrients)

Redfield Ratios

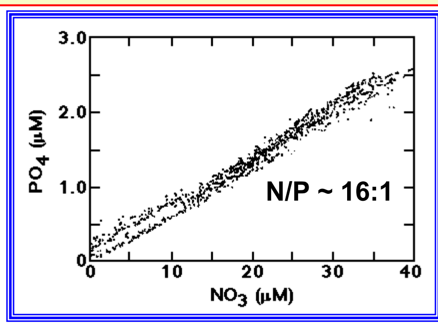


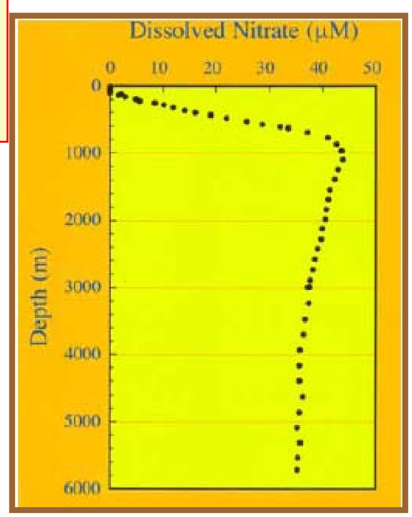

RESPIRATION

$106\ CO_2$
$16\ NO_3^-$
$1\ PO_4^{3-}$

← $(CH_2O)_{106}(NH_3)_{16}(H_3PO_4)_1$

Nitrate and phosphate seawater concentration gradually increases in proportion to the Redfield ratio



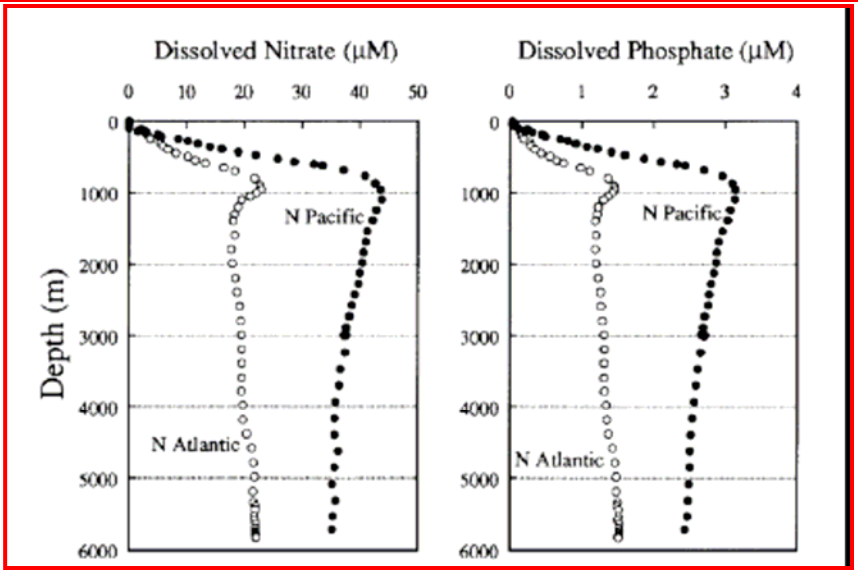




RESPIRATION

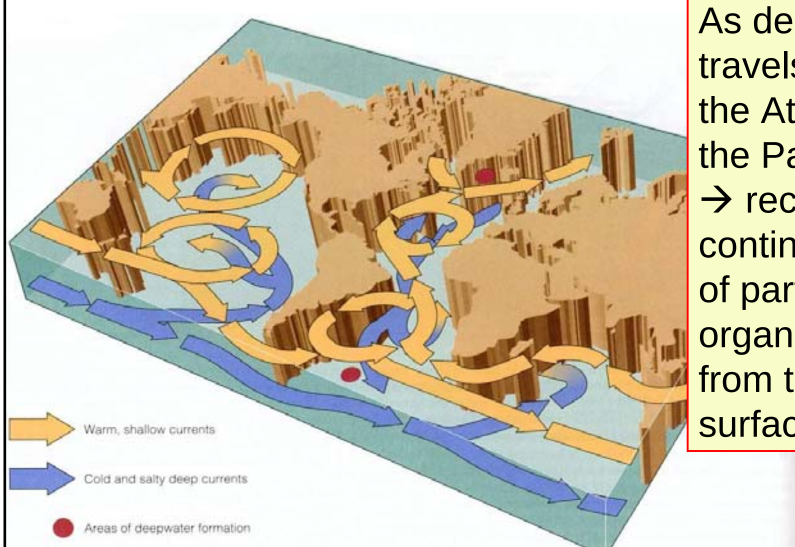
$106\ CO_2$
$16\ NO_3^-$
$1\ PO_4^{3-}$

← $(CH_2O)_{106}(NH_3)_{16}(H_3PO_4)_1$

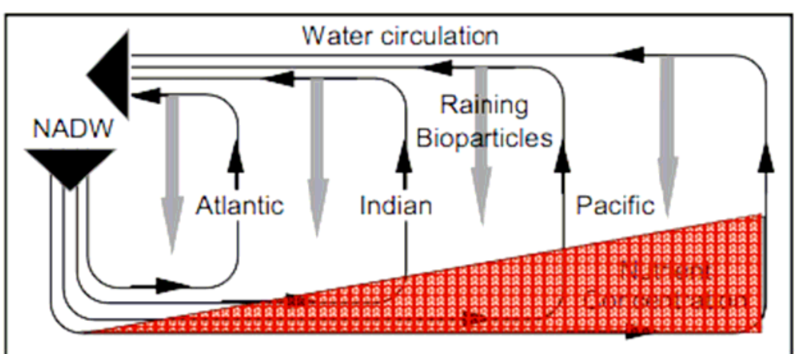
+ different nutrient concentrations in different ocean basins…




Interplay between biological cycling & Thermohaline circulation

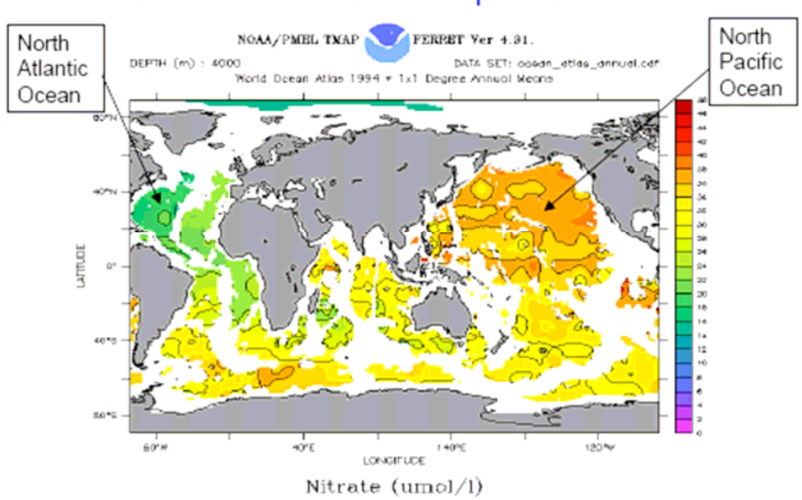



As deep water travels from the Atlantic to the Pacific → receives a continuous rain of particulate organic matter from the surface…




Idealized vertical section running from the Atlantic to Pacific
(from Broecker, 1997)

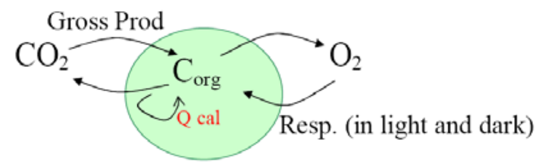
## World's Oceans at 4000m depth - another view



## Respiration by Phytoplankton
## (Gross vs Net Production)

Phytoplankton cannot use light energy directly to fuel metabolic reactions

They oxidize aerobically a fraction of the organic matter they produce



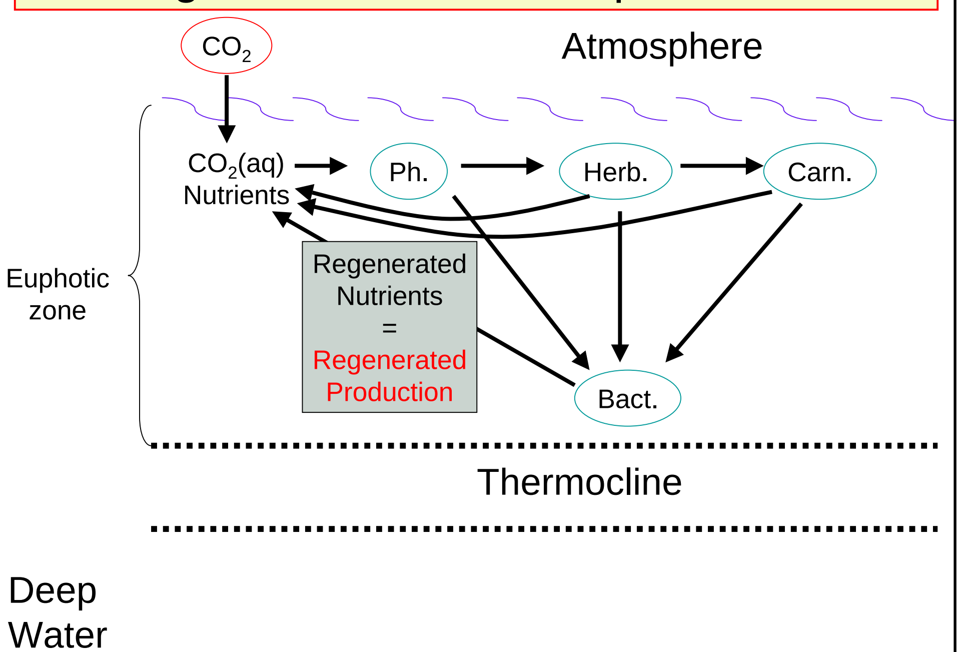

Net Production = Gross Production - Respiration

Fuels the food chain

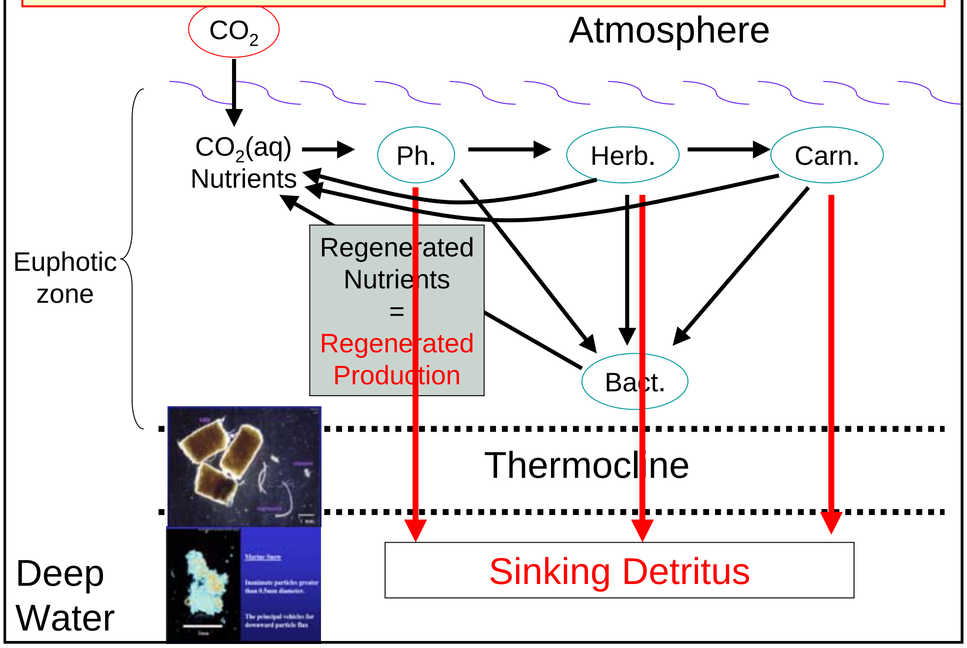
Mainly carbohydrates

$CH_2O + O_2 \rightarrow CO_2 + H_2O + 532\ kJ$

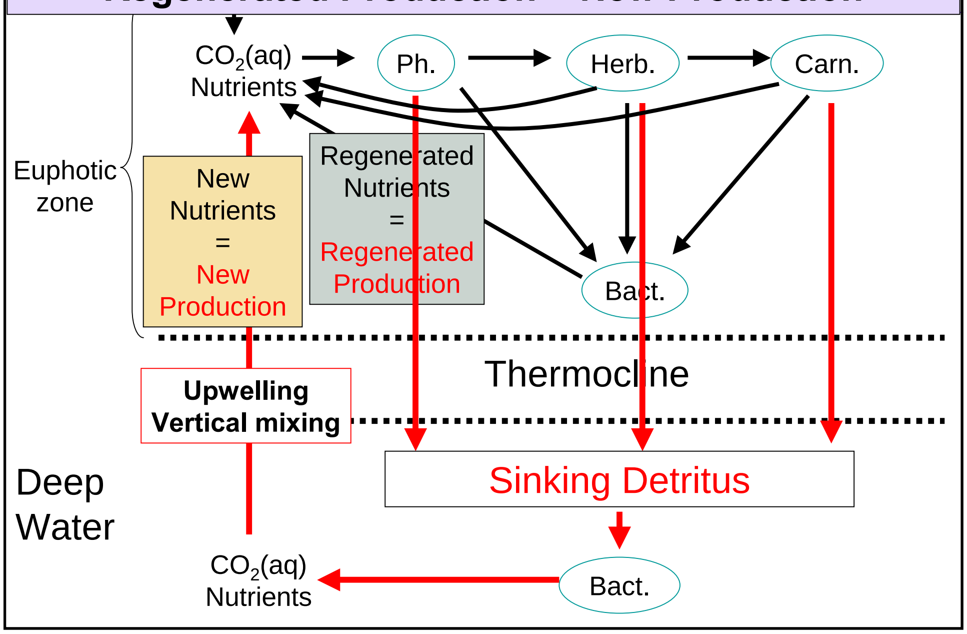
## "regenerated" vs "new" production

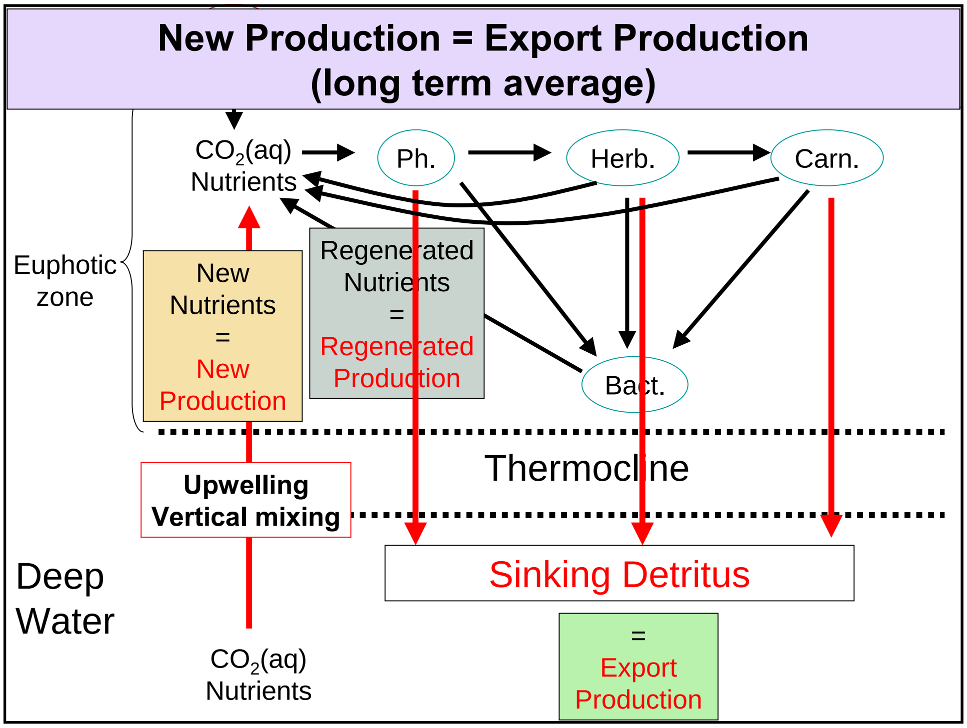


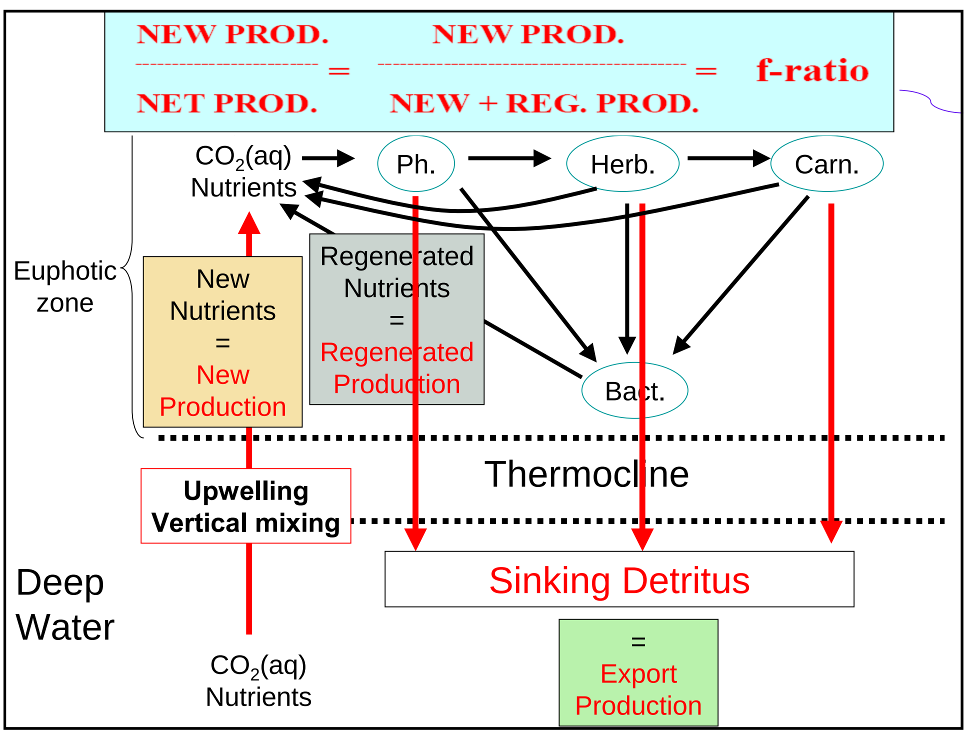
# “regenerated” vs “new” production

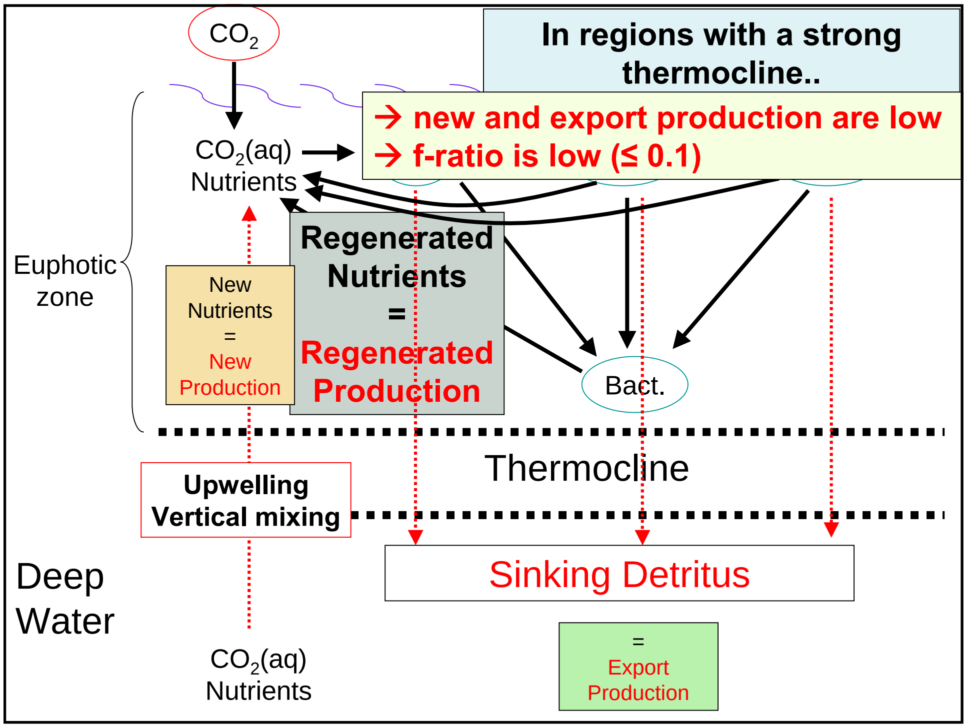


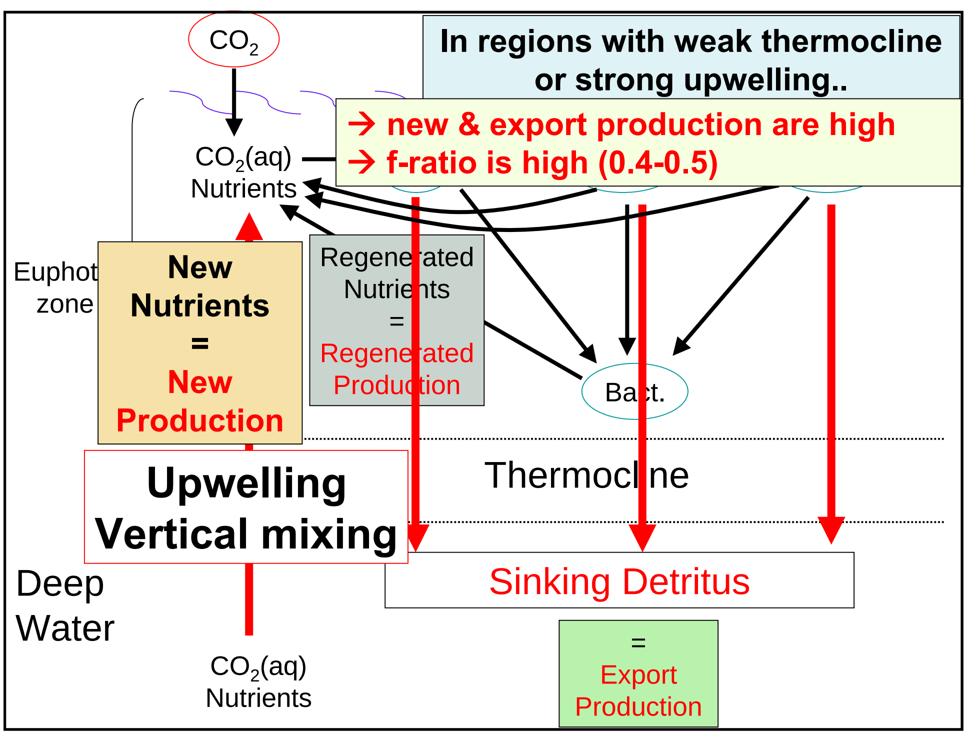

# Net Production = Regenerated Production + New Production




New Production = Export Production
(long term average)
CO2(aq)
Nutrients
Ph.
Herb.
Carn.
Euphotic
zone
New
Nutrients
=
New
Production
Regenerated
Nutrients
=
Regenerated
Production
Bact.
Thermocline
Upwelling
Vertical mixing
Deep
Water
Sinking Detritus
CO2(aq)
Nutrients
=
Export
Production


NEW PROD. / NET PROD. = NEW PROD. / NEW + REG. PROD. = f-ratio
CO2(aq)
Nutrients
Ph.
Herb.
Carn.
Euphotic
zone
New
Nutrients
=
New
Production
Regenerated
Nutrients
=
Regenerated
Production
Bact.
Thermocline
Upwelling
Vertical mixing
Deep
Water
Sinking Detritus
CO2(aq)
Nutrients
=
Export
Production


CO2
In regions with a strong thermocline..
→ new and export production are low
→ f-ratio is low (≤ 0.1)
CO2(aq)
Nutrients
Euphotic zone
New Nutrients = New Production
Regenerated Nutrients = Regenerated Production
Bact.
Thermocline
Upwelling Vertical mixing
Sinking Detritus
Deep Water
CO2(aq)
Nutrients
= Export Production


CO2
In regions with weak thermocline or strong upwelling..
→ new & export production are high
→ f-ratio is high (0.4-0.5)
CO2(aq)
Nutrients
Euphotic zone
New Nutrients = New Production
Regenerated Nutrients = Regenerated Production
Bact.
Thermocline
Upwelling Vertical mixing
Sinking Detritus
Deep Water
CO2(aq)
Nutrients
= Export Production

***Photosynthesis:***

$CO_2$ + Nitrate + Phosphate

→

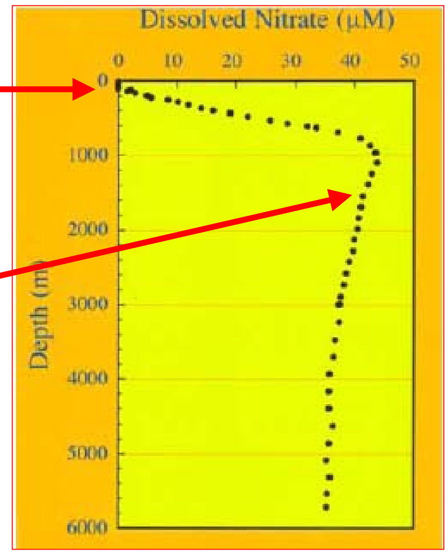
Organic matter

***Respiration:***

Organic matter +

→

CO2 + Nitrate + Phosphate




***Photosynthesis:***

$CO_2$ + Nitrate + Phosphate

→

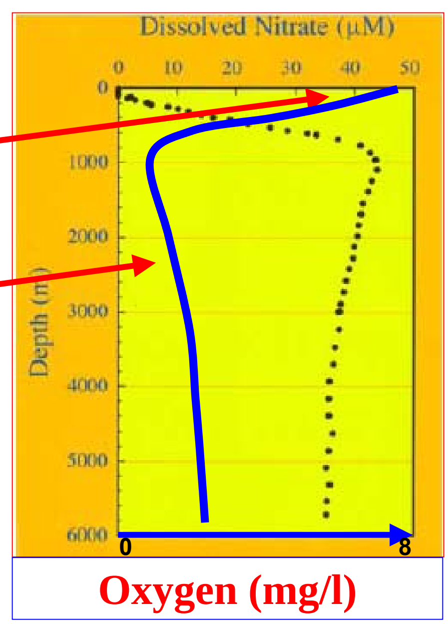
Organic matter + Oxygen ($O_2$)

***Respiration:***

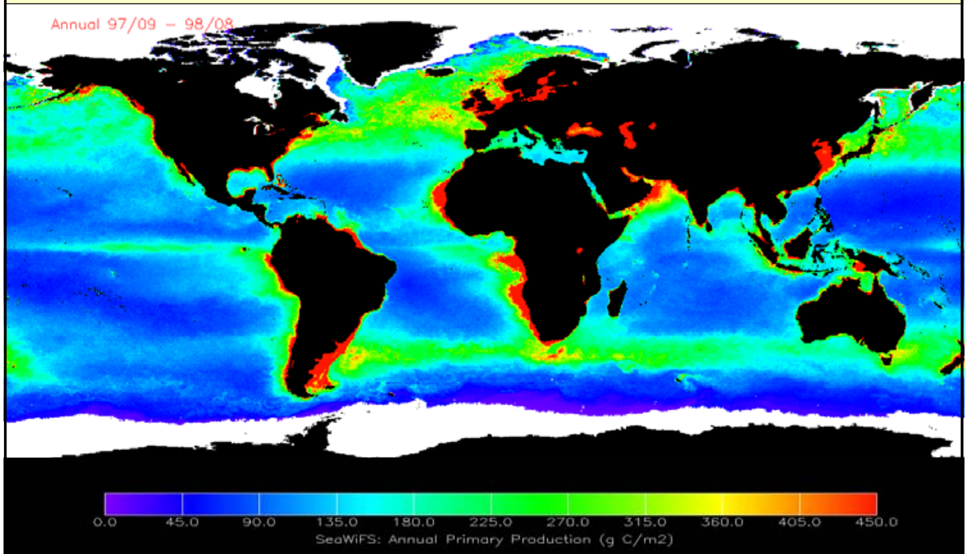
Organic matter + Oxygen ($O_2$)

→

CO2 + Nitrate + Phosphate

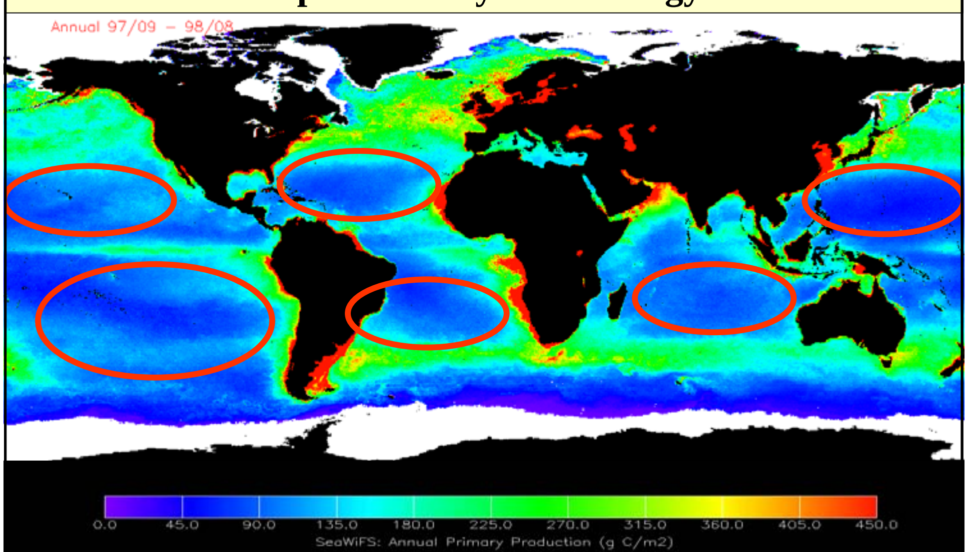


**Annual global primary production maps**



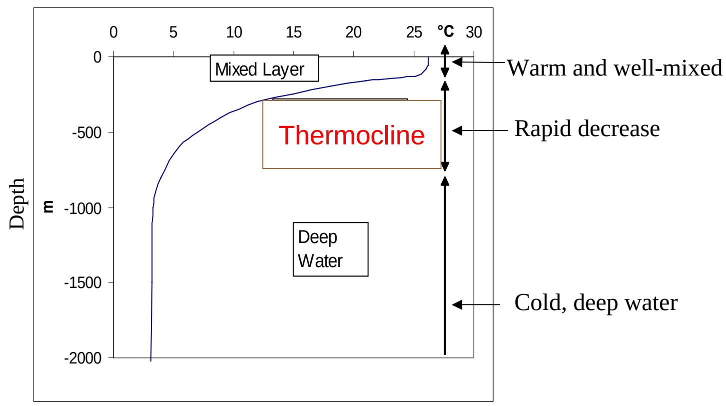

**Satellite data on ocean color provides global maps of ocean productivity (Algorithms must be used to convert spectral data to production rates)**

**Low productivity in central gyres**



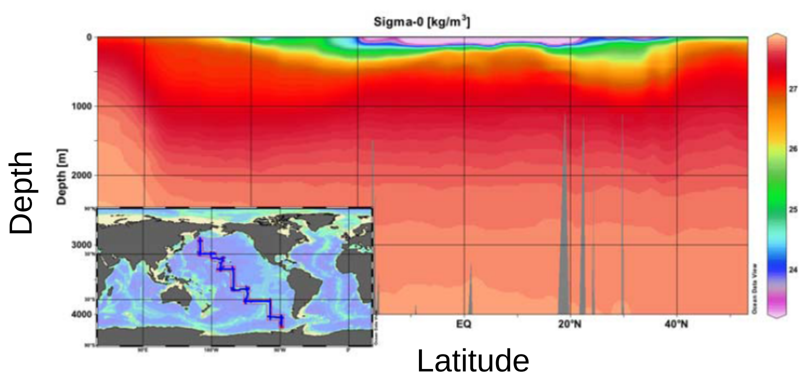

**➔ Due to thermal stratification limiting nutrient supply from below**

## Vertical distribution of temperature in the water column at low latitude:

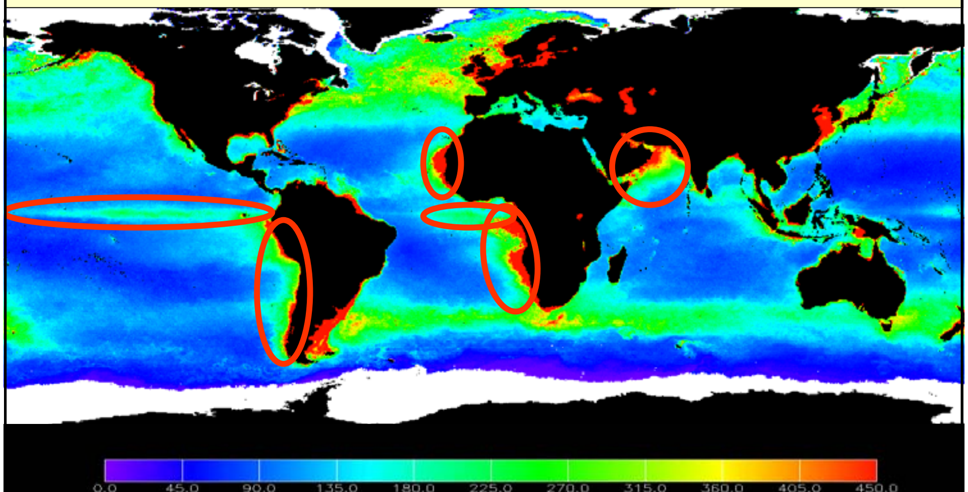



## Seawater density in the Pacific Ocean

**Thermal stratification limiting nutrient supply from below at low latitudes**



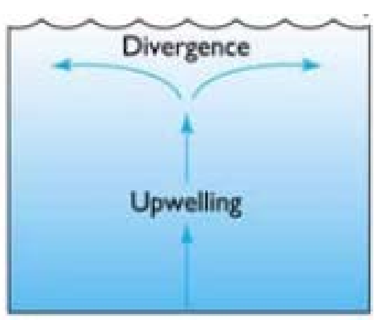
**higher productivity nearshore, at the equator, Arabian Sea, and eastern boundaries**



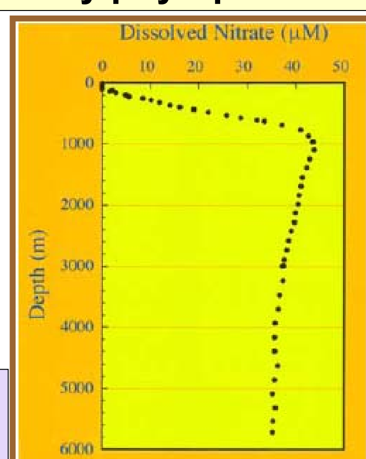

**Nearshore ➔ supply of nutrient from continental run-off and recycling from shallow sediments**
**Open ocean ➔supply of nutrients by upwelling**

**High productivity in upwelling regions**

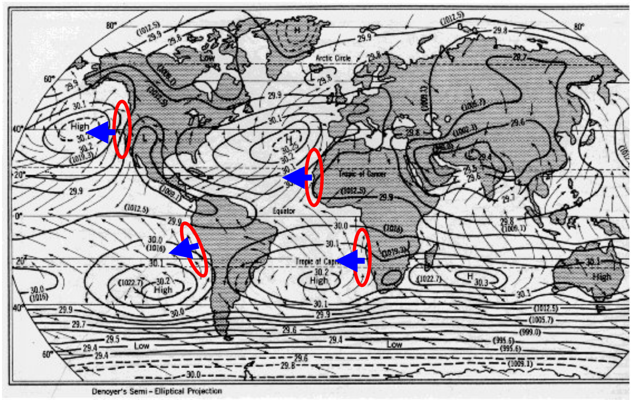
**Upwelling brings nutrient-rich deep water to the surface where they can be used by phytoplankton**




Upwelling occurs as a result of the interaction between winds and surface waters.



## *Coastal Upwelling*



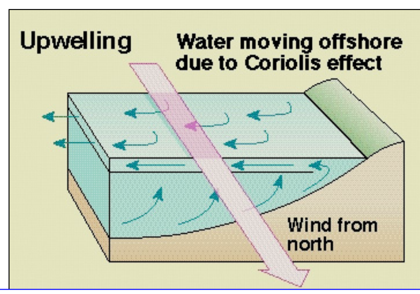
***…occur at the eastern margins of the oceans (off the west coasts of Africa and the Americas)***

***Subtropical high-pressure zone → prevailing winds blow towards the equator along the western coasts of the continents***

***→ Ekman transport carries surface waters offshore***

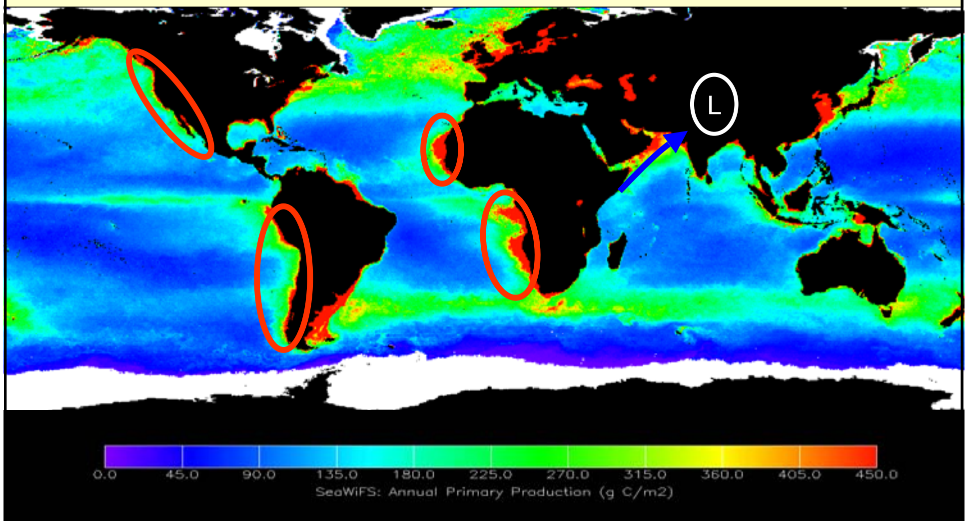
## *coastal upwelling*

(Northern Hemisphere)



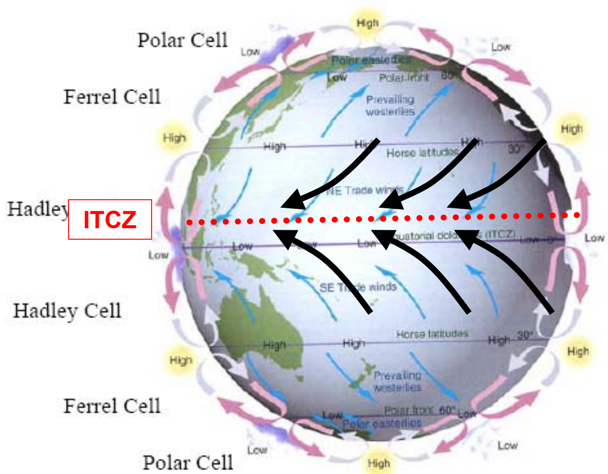

Surface waters carried offshore must be replaced by deeper water
→ upwelling

..accounts for high productivity off NW and SW Africa, Peru, chile and NW. America




seasonal upwelling in the Arabian Sea during summer monsoon

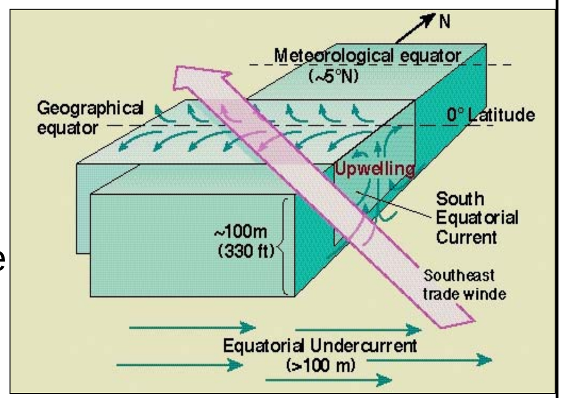
# Equatorial Upwelling

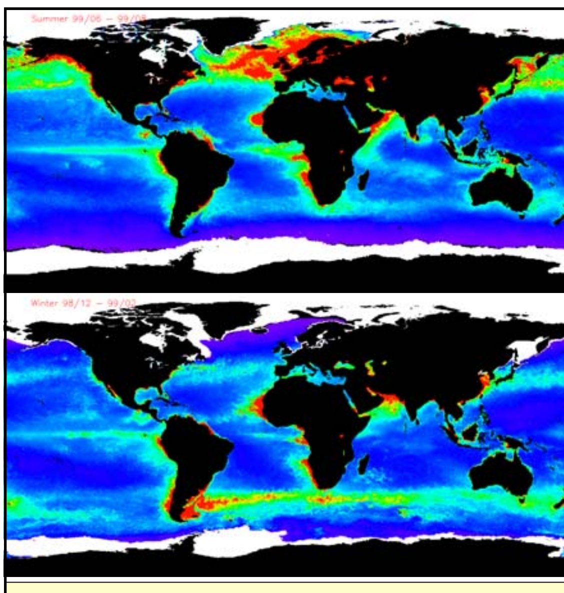


# Equatorial Upwelling

SE Trades flow across the Equator to ca. 5°N:
→ South Equatorial Current is diverted to the left south of the equator and to the right north of the equator
→ divergence at the equator

As surface waters are pushed away from the equator on both sides, they must be replaced by water rising from the thermocline.



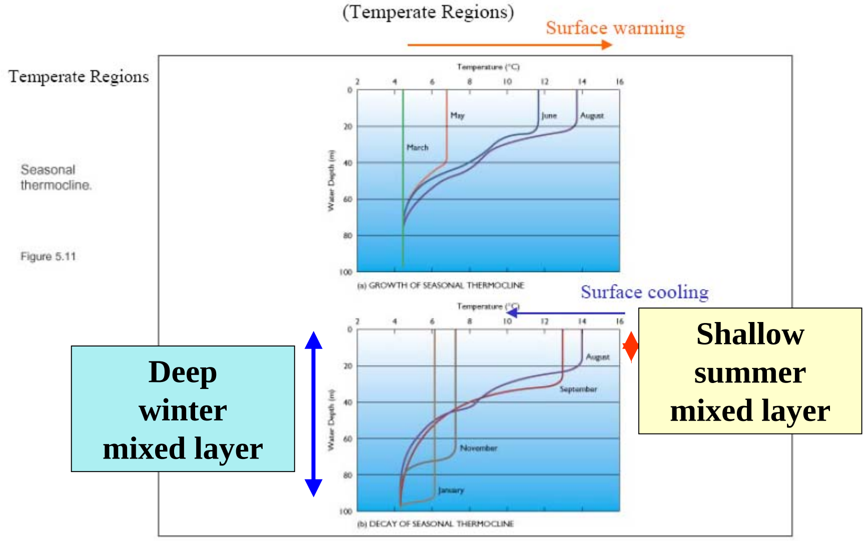
Boreal Summer

Austral Summer

**At mid latitude, higher productivity in spring or summer due to the seasonal breakdown of the thermocline and winter mixing bringing nutrients to the euphotic zone**

## Seasonal Changes in Thermocline Structure

(Temperate Regions)



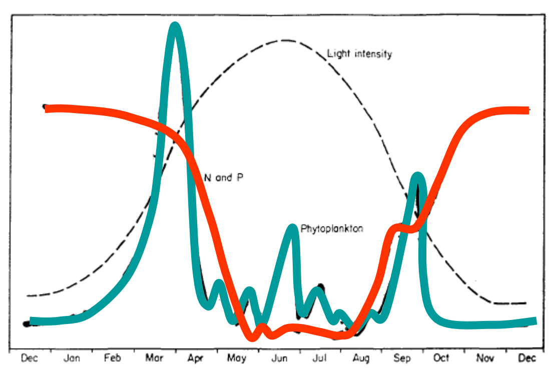
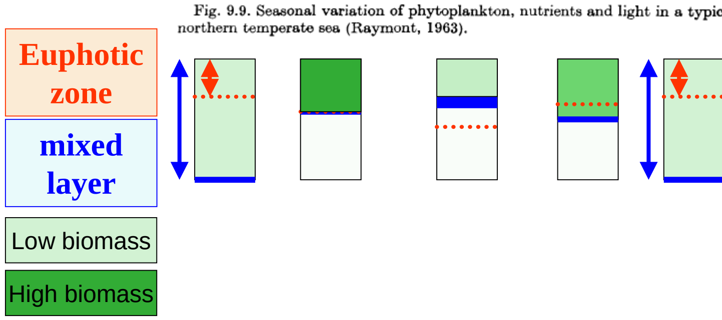
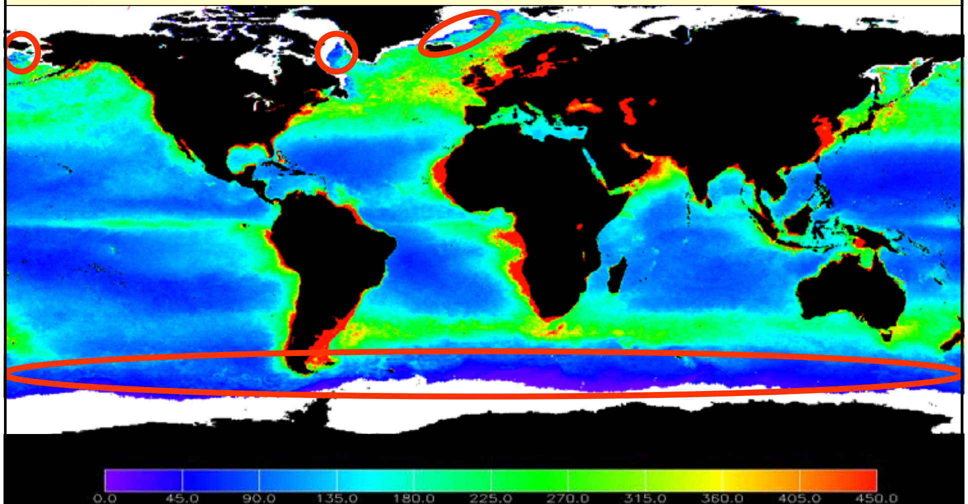



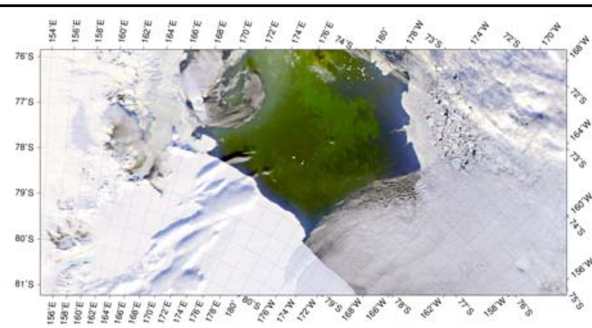

Fig. 9.9. Seasonal variation of phytoplankton, nutrients and light in a typical northern temperate sea (Raymont, 1963).



**At high latitude, productivity tends to be low because of low sun angle and lack of thermal stratification in the upper water column.**




**At mid latitude, higher productivity in spring or summer due to the seasonal breakdown of the thermocline and winter mixing bringing nutrients to the euphotic zone**



SeaWiFS 6 December 2004 14:12 UTC

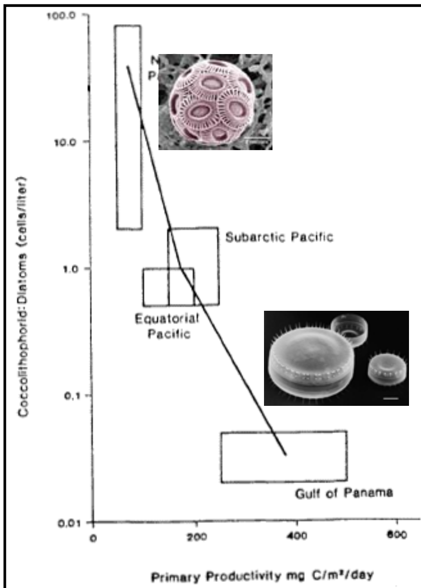
**Further towards the poles (seasonal ice)**

**→ brief but intense blooms after water column stratification resulting from melting ice in summer**

**→ productivity and the flux of organic matter to the deep ocean is highly seasonal**

**→ annually averaged productivity is low.**

**→Under permanent ice cover (e.g. in the high Arctic), productivity is very low.**




**As a general rule:**

**-<u>High productivity regions</u>**
**(low latitude upwelling regions , mid-latitude spring blooms, receding ice edges)**
**→dominated by silica-producing diatoms**
**→particles consist of organic matter and biogenic silica**

**-<u>Low productivity regions</u>**
**(central gyres)**
**→dominated by calcite-producing coccolithophorid**
**→particles consist of organic matter and biogenic carbonate**