Ocean life, bioenergetics and plankton metabolism

Biological Oceanography (OCN 621)

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Life is…

- Cellular
- Self replicating
- Responsive to external stimuli
- Carbon-based
- Built from DNA, RNA, protein, lipid, and carbohydrate

Classification of life

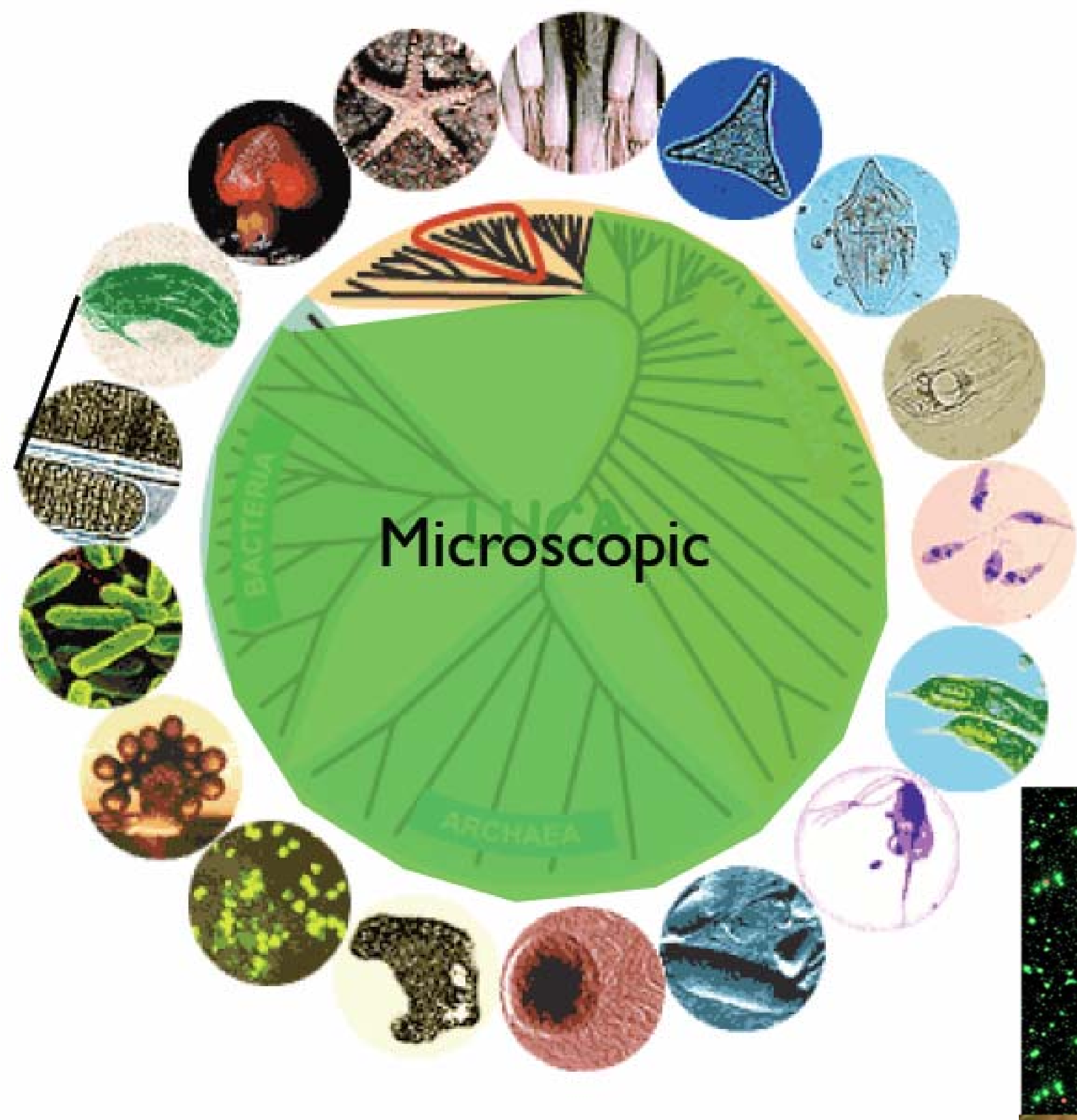
No Nucleus

Unicellular

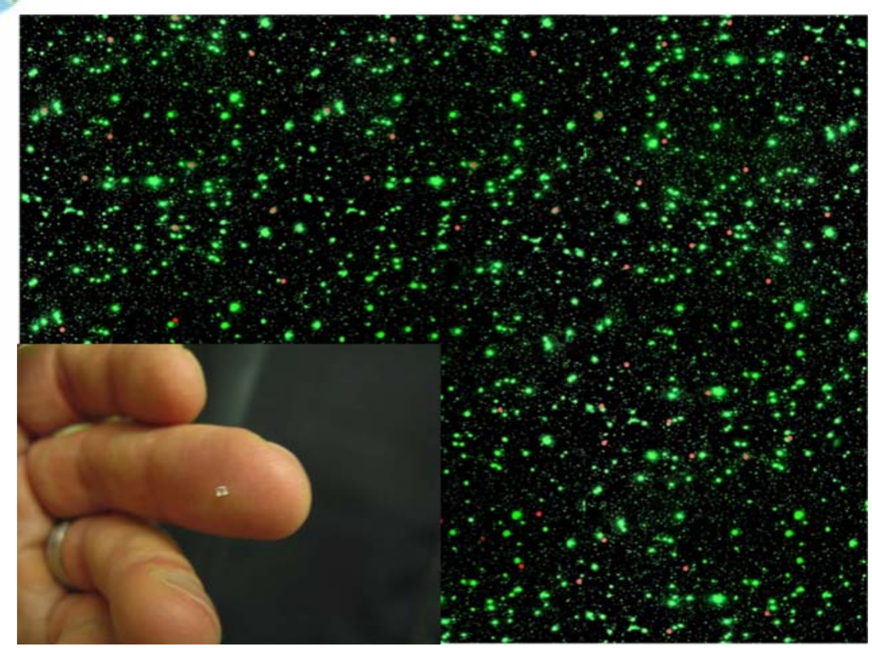
With Nucleus

Uni- or Multi-Cellular

Most life is microscopic

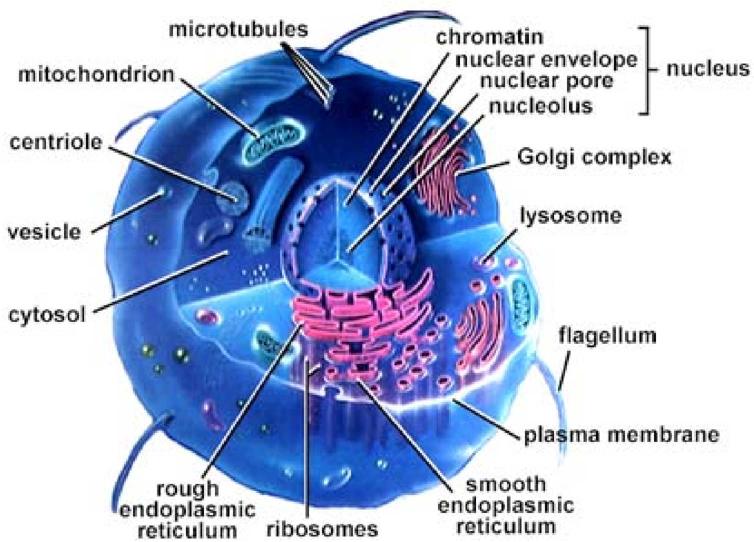


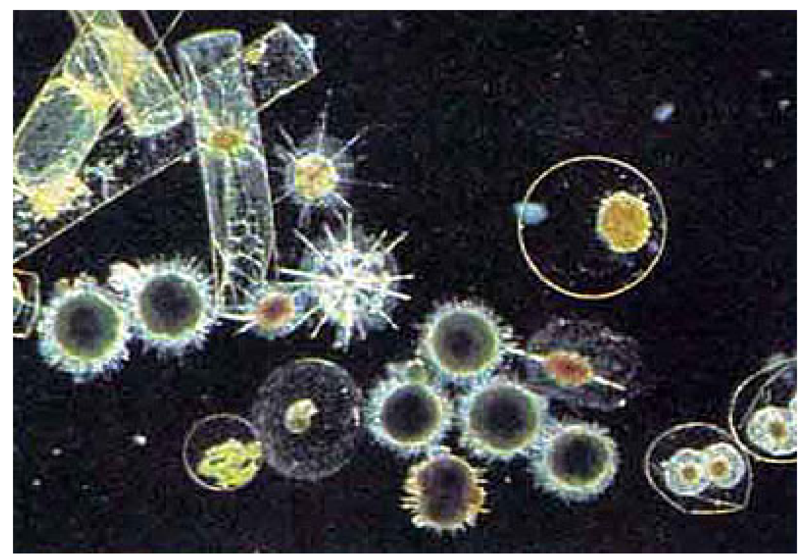
In the ocean, microscopic organisms account for >60% of the total living biomass.



Ecosystems are hierarchically organized

- **Cells → Organisms→ Populations→ Assemblages → Communities**
- **This organizational system dictates the pathways that energy and material travel through a system.**
- **Cells are the lowest level of structure capable of performing ALL the functions of life.**

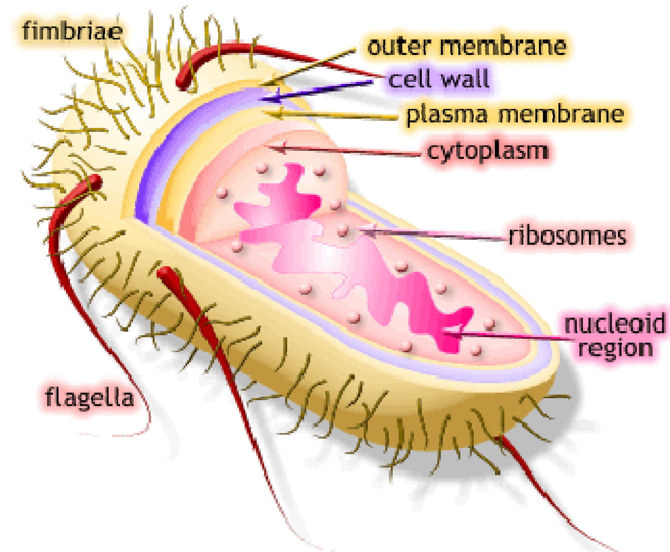


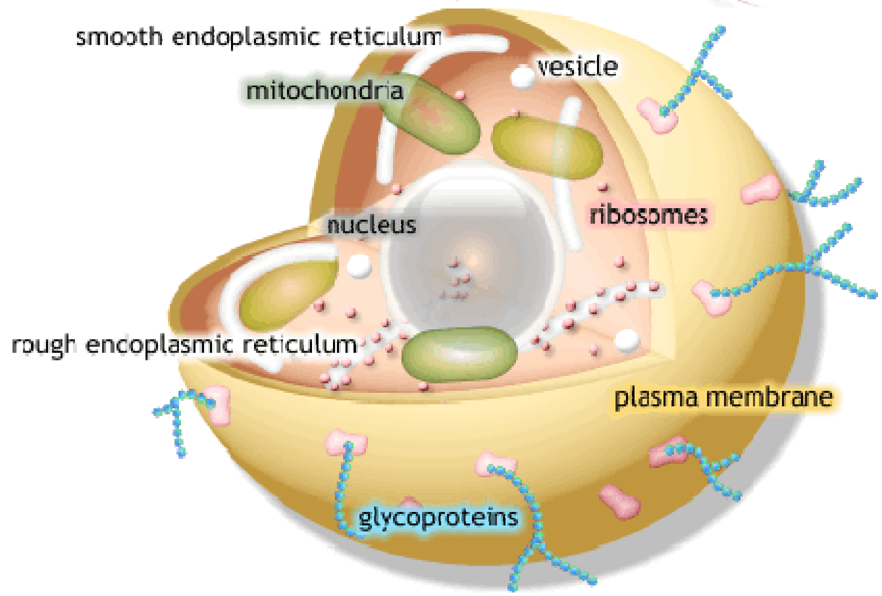


Two primary cellular forms

- **Prokaryotes:** lack internal membrane-bound organelles. No nucleus - genetic information is not separated from other cell functions. Bacteria and Archaea are prokaryotes.

- **Eukaryotes:** membrane-bound organelles (nucleus, mitochrondrion, etc .). Compartmentalization (organization) of different cellular functions allows sequential intracellular activities. All other organisms besides Bacteria and Archaea.



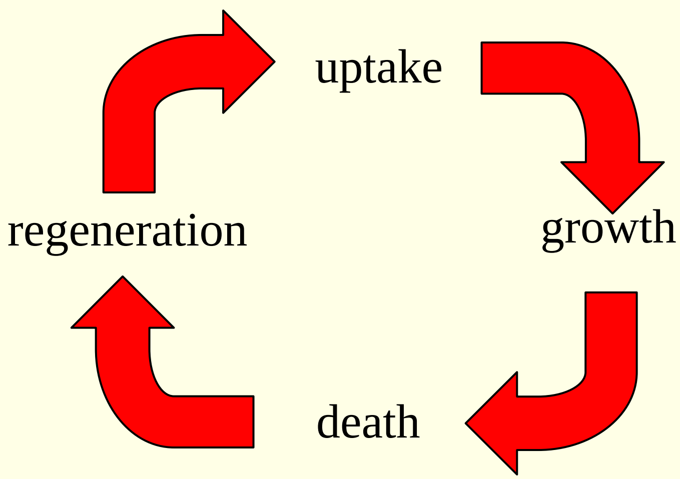


What does life require?

- Energy
- Electron acceptors and donors
- Nutrients (C, N, P, S, Fe, etc.)

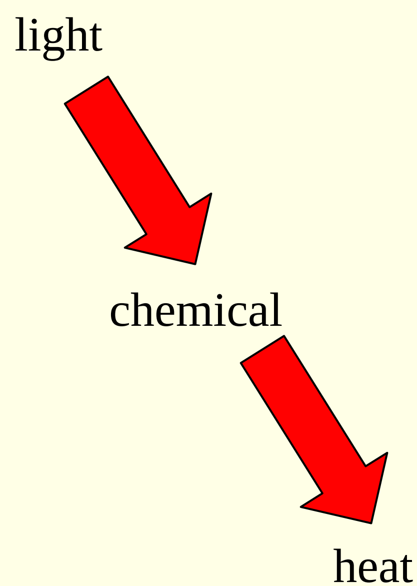
Energy flows, matter cycles

Matter (C, N, P)



Cycles

Energy

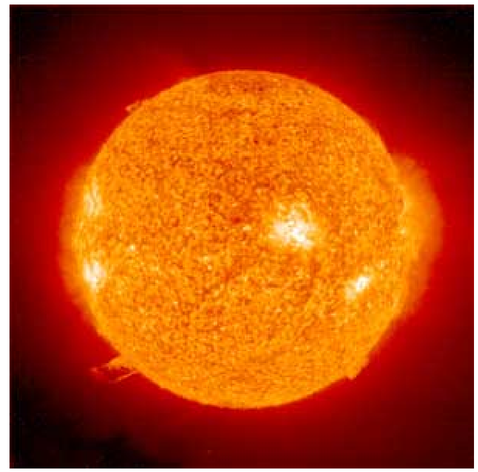


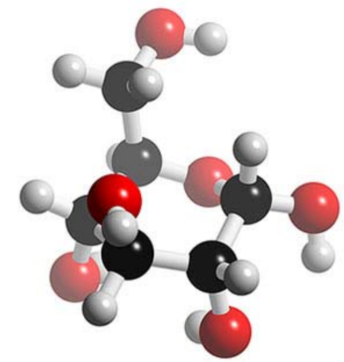
Unidirectional

Cells harvest energy from the environment for controlled transformations of material

Classification of life by types of cellular metabolism

- **<u>Energy</u> source**
  - –Sun: <u>Photo</u>
  - –Chemical: <u>Chemo</u>
- **<u>Reduction</u> source**
  - –Organic : <u>organo</u>
  - –Inorganic: <u>litho</u>
- **<u>Carbon</u> source**
  - –Inorganic molecules: <u>auto</u>
  - –Organic molecules: <u>hetero</u>

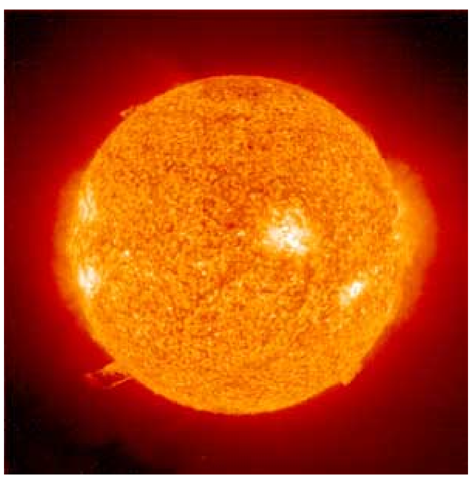
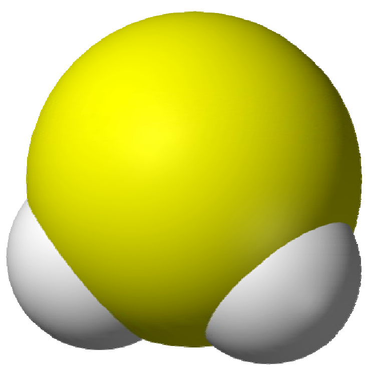
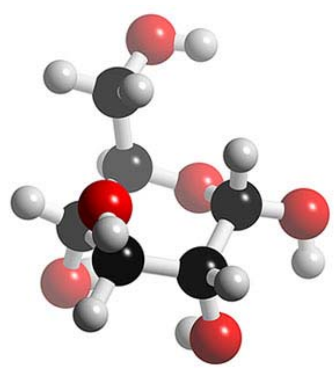
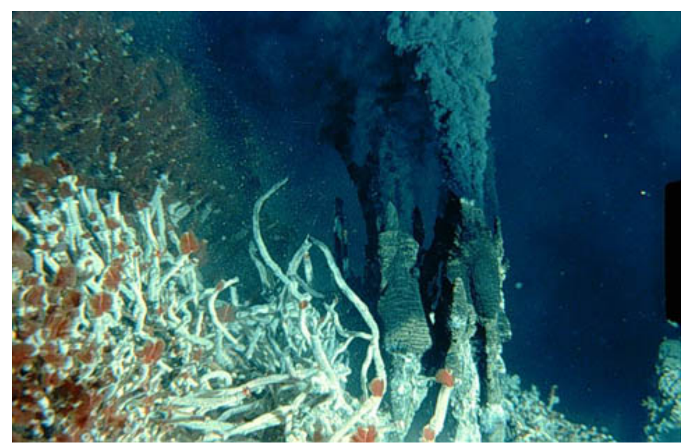




Thus, an organism that utilizes light for energy, water for reducing power, and CO_2 for carbon is a <u>photolithoautotroph</u>. An organism that utilizes organic matter for energy, reducing power, and carbon is a <u>chemoorganoheterotroph</u>.

Where do cells acquire energy?

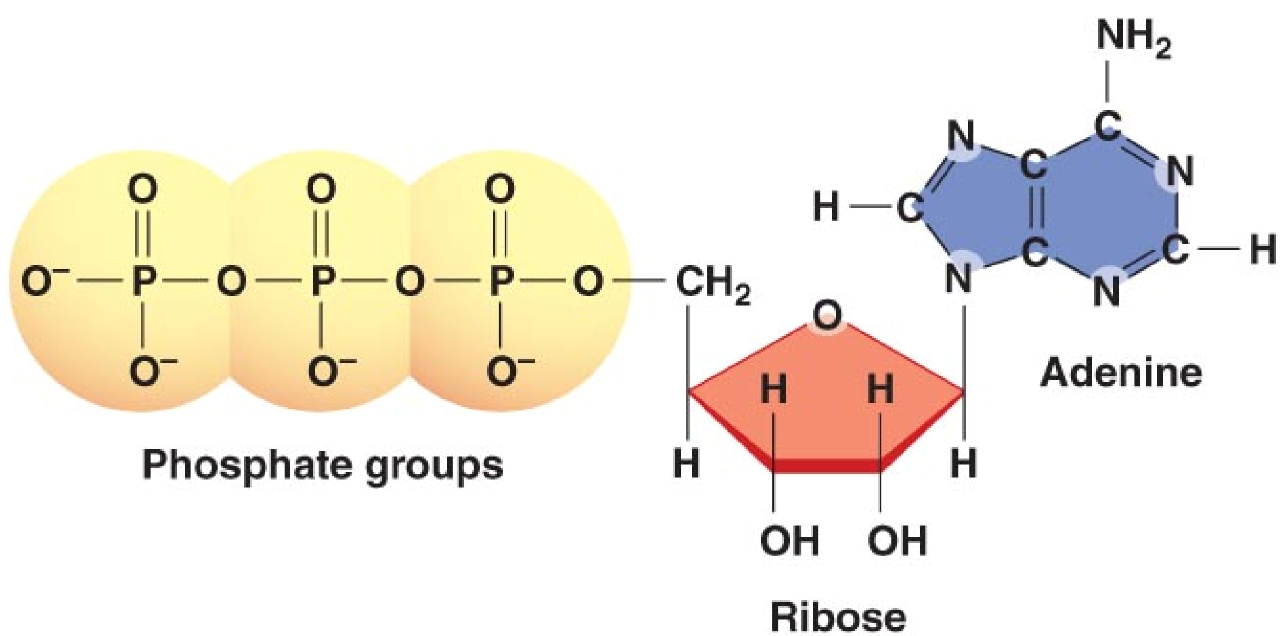
- **Sources of Energy in the sea:**
  - **Light-aside from hydrothermal vents, sunlight is the ultimate energy source for life in the sea (phototrophy).**
  - **Chemical-both organic and inorganic molecules (chemotrophy).**

ATP: universal cellular energy currency

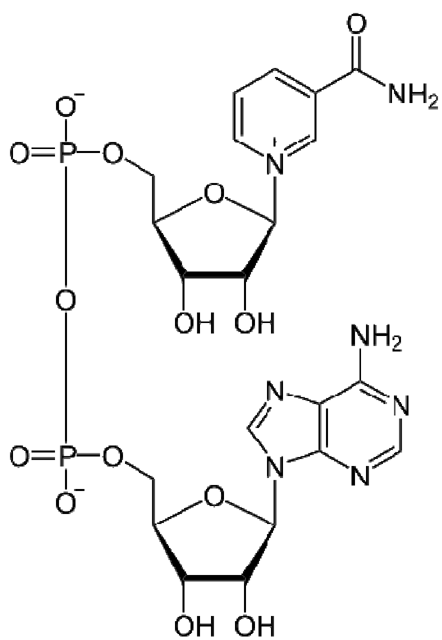
Cells store chemical energy by adding phosphate to ADP; breaking these phosphate groups off of ATP yields energy. The phosphate groups can be transferred to other molecules (e.g. amino acids) and these receptor molecules are more reactive than ATP. This provides a means for the cell to fuel cellular biosynthesis or transport solutes into or out of the cell.

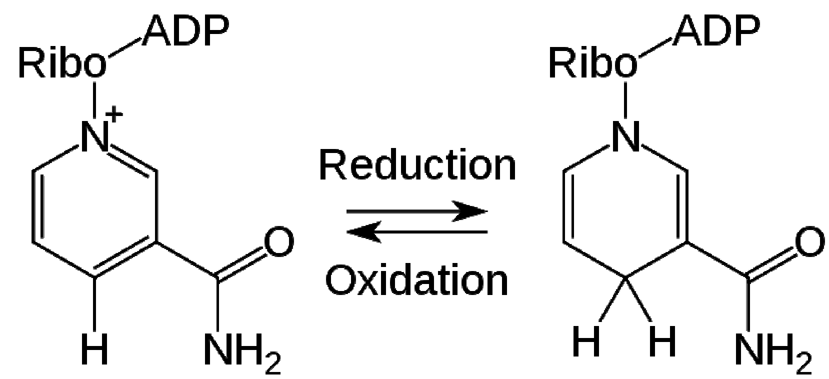
(a) ATP consists of three phosphate groups, ribose, and adenine.



NADH : electron carriers

- The harvesting and storage of energy by cells is mediated by a series of redox reactions.
- Synthesis of reduced material (organic molecules) requires energy (in the form of electrons). Biochemical consumption of reduced material releases energy.
- NAD+ serves as the primary intermediate electron acceptor, forming NADH. When NADH transfers its electrons to an acceptor, energy is released.



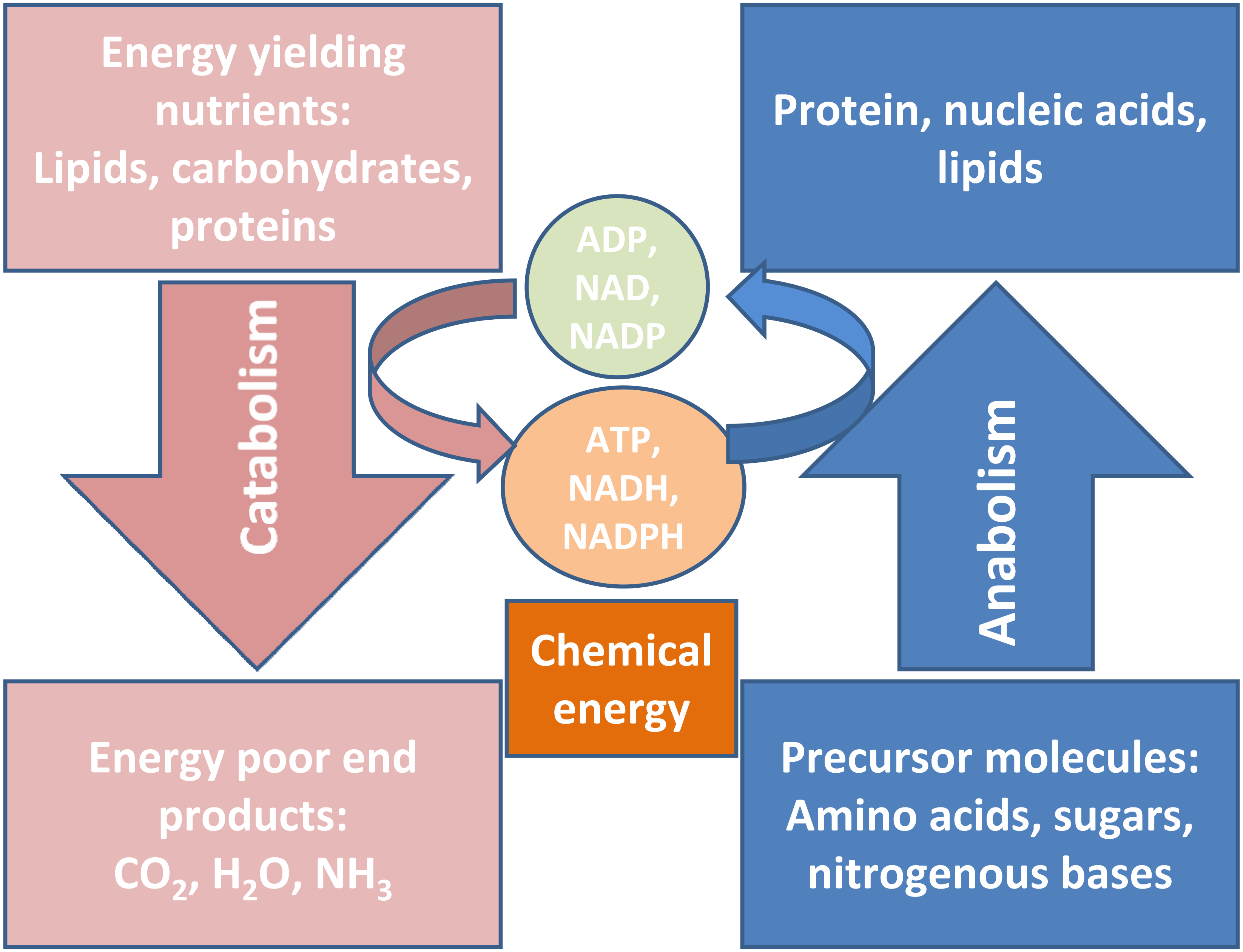


$$NAD^{+} + H^{+} + 2e^{-} \longrightarrow NADH$$

What are cells doing with energy harvested from the environment?

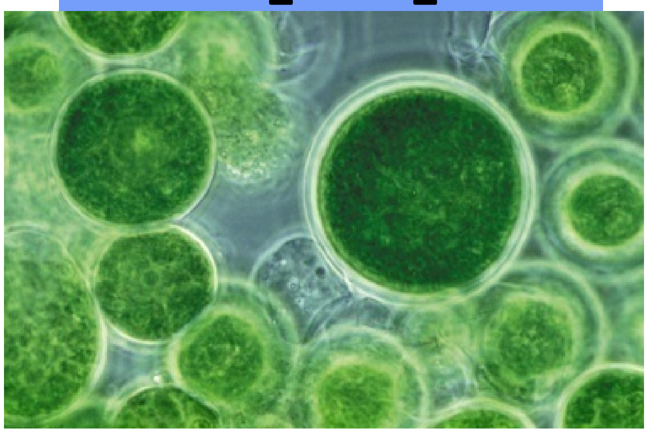
- Growing and producing: creation of new cells/cell constituents (requires synthesis of specific biomolecules)
- Transporting material against concentration gradients (active transport)
- Moving (motility)
- Homeostasis (keep intracellular conditions stable)

Catabolism and Anabolism



Oxygenic Photosynthesis:

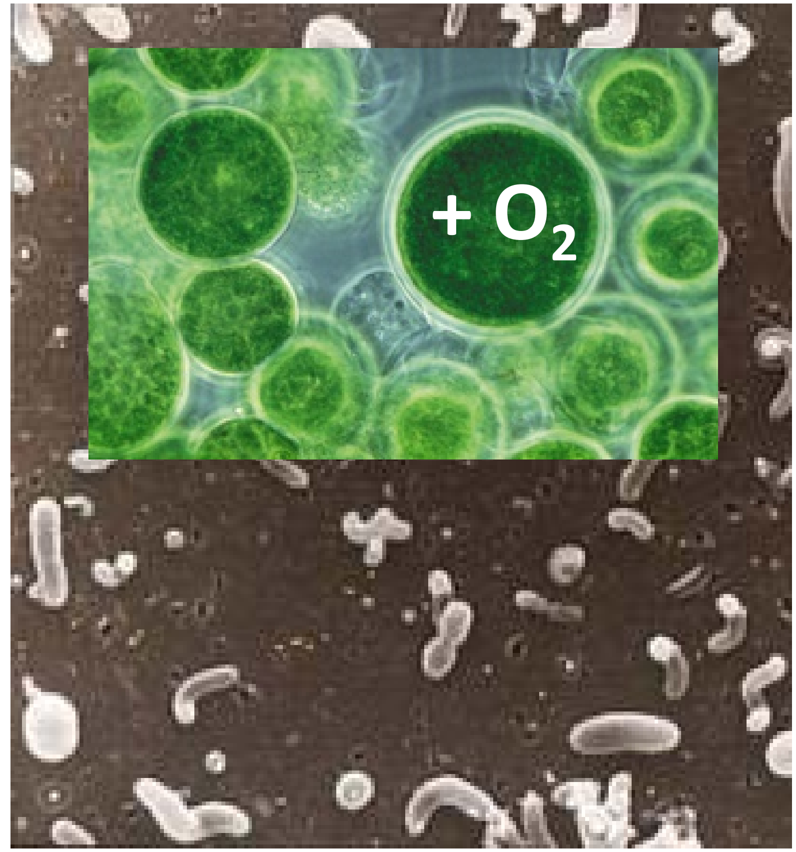
$+ CO_2 + H_2O =$



$+ O_2$

ATP and NADH are created via series of redox reactions. Both ATP and NADH are required for creation of new cellular material – primary production.

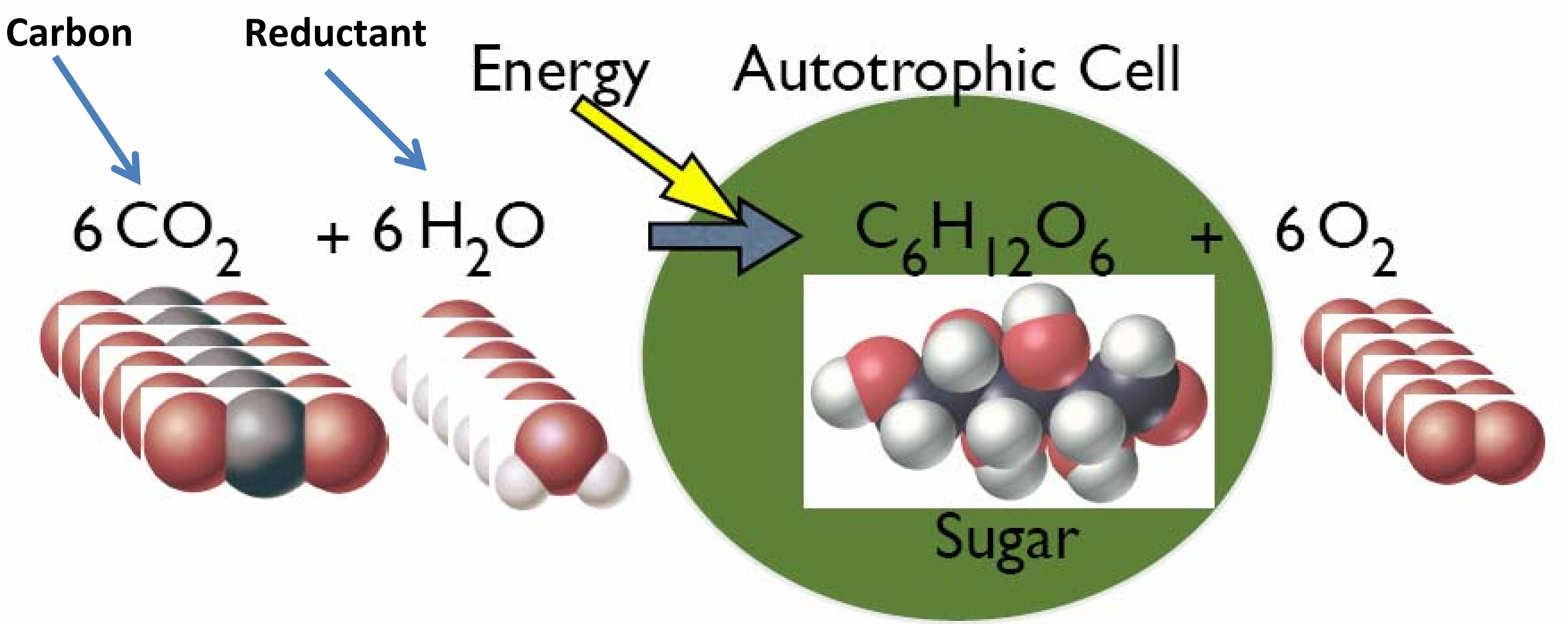
Aerobic Respiration:



$= CO_2 + H_2O$

ATP and NADH are formed during oxidation of cellular material; some energy lost as heat.

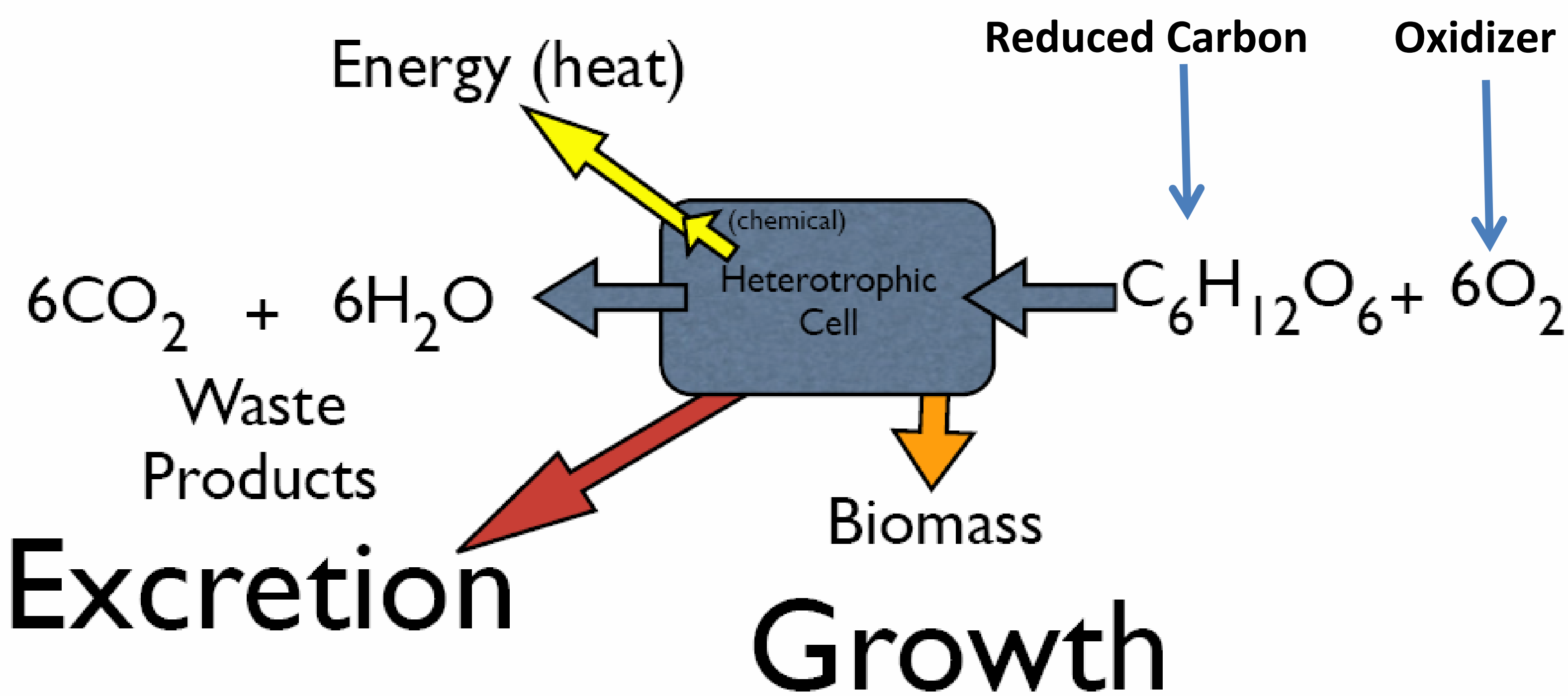
Photosynthetic organisms capture energy from sunlight and convert this to chemical energy (ATP) and reducing power (NADH). Energy and reductant are required for fixing CO_2 into sugar.



Cells are more than sugar. Other compounds are built from simple sugars plus nutrients (Nitrogen, Phosphorous & trace metals)

Respiration

All living things respire..including plants!



Energy generation by aerobic respiration of organic matter includes several linked biochemical pathways:

Glycolysis

Krebs cycle or Citric acid cycle

Electron transport phosphorylation

Overall chemical equation describing oxygenic photosynthesis:

Electron donor (reductant) — Sunlight — Reduced carbon, energy

$$6CO_2 + 12H_2O \xrightarrow{\text{Sunlight}} C_6H_{12}O_6 + 6O_2 + 6H_2O + \text{heat}$$

energy

Overall chemical equation describing aerobic respiration:

Electron acceptor

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + 686\ \text{kcal}\ (\text{ATP} + \text{heat})$$

Reduced carbon, energy

energy

Other reduced compounds that contain bioavailable energy

- Sources of chemical energy:
  - CH_4, H_2, NH_4^+, NO_2^-, H_2S, …
  - These substrates fuel energy demands of mostly chemolithautotrophic organisms (bacteria and archaea).

When oxidizing these compounds, organisms can obtain reductant and ATP.

Some Important Energy Generating Metabolisms

•Oxygenic Photosynthesis
ATP and NADPH are made in large amounts
Produces oxygen as a bi-product during splitting of water for reducing power

•Anoxygenic Photosynthesis
ATP made in large amounts
Reduction of NADP does not involve water; hence no oxygen produced

•Aerobic Respiration
ATP and NADH are made in abundance
Requires oxygen

•Anaerobic Respiration
Lower ATP yield than aerobic respiration; NAD easily reduced
Requires electron acceptor other than oxygen

Fermentation
Little ATP, no net NAD reduction, MOST SIMPLE SYSTEM

Alternate electron Acceptors for Respiration

REACTION	DG°' (kcal/mole)	deltaG°'
CH_20 + $\mathbf{O_2}$ → $CO_2 + H_2O$		-686
5 CH_2O + 4 $\mathbf{NO_3^-}$ → 4 HCO_3^- + CO_2 + 3 H_2O + 2 N_2		-570
CH_2O + 3 CO_2 + H_2O + 2 $\mathbf{MnO_2}$ → 4 HCO_{3-} + 2 Mn^{2+}		-349
CH_2O + 7 CO_2 + 4 $\mathbf{Fe(OH)_3}$ → 8 $HC0_{3-}$ + 3 H_2O + 4 Fe^{2+}		-114
2CH_20 + $\mathbf{SO_4}$ → 2 HCO_3^- + H_2S		-77
CH_20 → CO_2 + CH_4		-58

deltaG°' (kcal/mole) = free energy released per mole of glucose oxidized

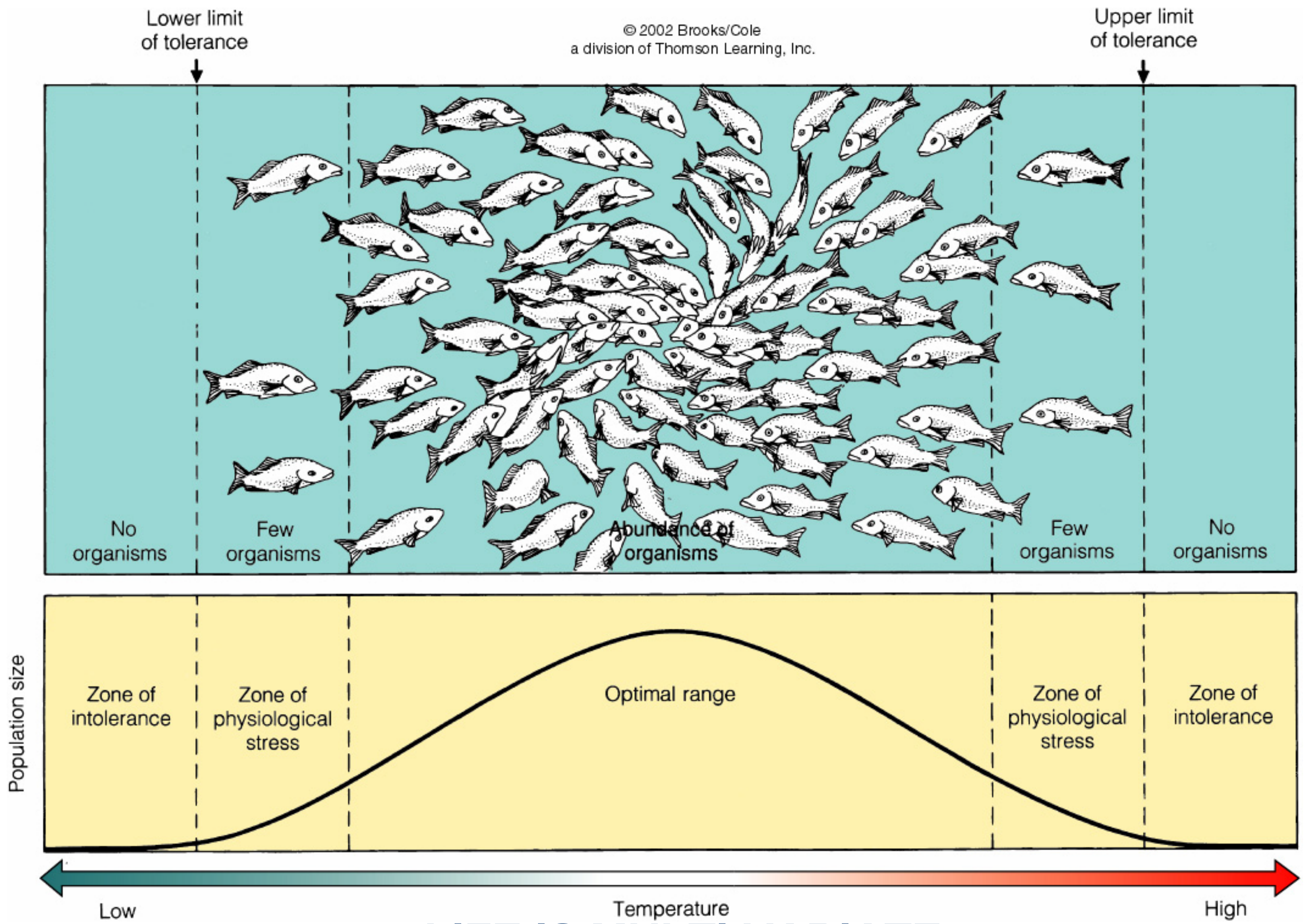
CONCEPT: Some energetic transformations are more energetically favorable than others. These will usually occur first under natural conditions - i.e., the most energetically favorable terminal electron acceptor (O_2) will be used until it is no longer available, then the environment will favor organisms (bacteria) capable of utilizing alternative electron acceptor to oxidize organic matter.

Coincidentally….

- Ocean plankton produce ~50% of all organic matter (and hence oxygen) on the planet.
- The amount of organic matter (and hence oxygen) in the biosphere is determined by the balance between primary production (oxygen producing) and respiration (oxygen consuming).
- In the ocean, this balance is almost always close to even; production of organic matter is closely linked (in time and space) to its consumption.
- We will revisit this is later lectures….

Controls on types of organisms, abundances, distributions

- **Habitat:** The physical/chemical setting or characteristics of a particular environment, e.g., light vs. dark, cold vs. warm, high vs. low pressure
- Each marine habitat supports a somewhat predictable assemblage of organisms that collectively make up the **community**, e.g., rocky intertidal community, coral reef community, abyssobenthic community
- The structure and function of the individuals/populations in these communities arise from evolution and selective adaptations in response to the habitat characteristics
- **Niche:** The role of a particular organism in an integrated community



LIFE IS MULTI-VARIATE

Numerous environmental factors control where organisms live:

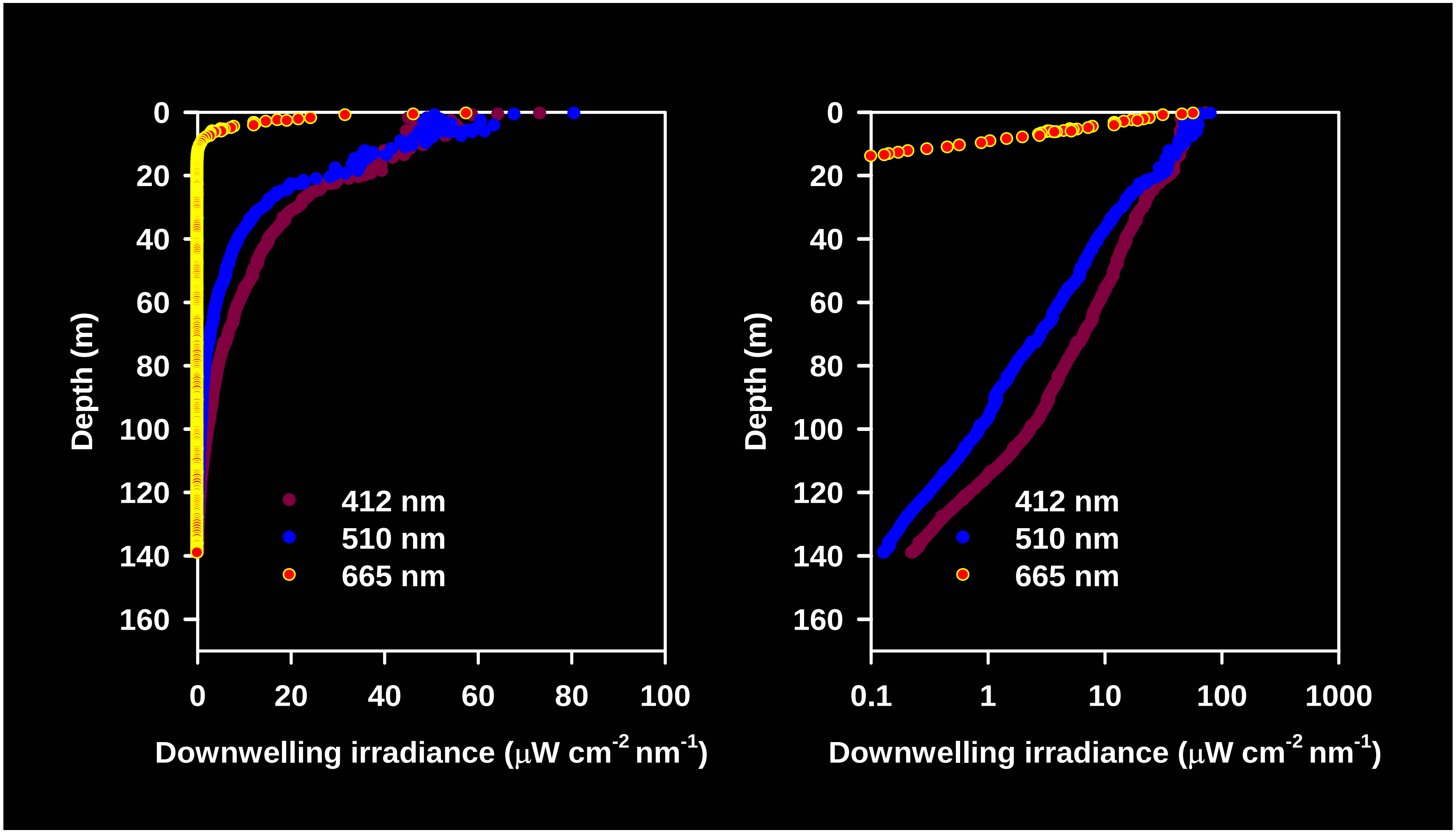
Temperature
nutrients
salt
pressure
oxygen
biology (predation, disease)

Some important ocean habitat controls

- Sources of energy (light, reduced substrates)
- Temperature/stratification
- Nutrient supply and concentrations
- Oxygen
- pH

Profile of irradiance with depth

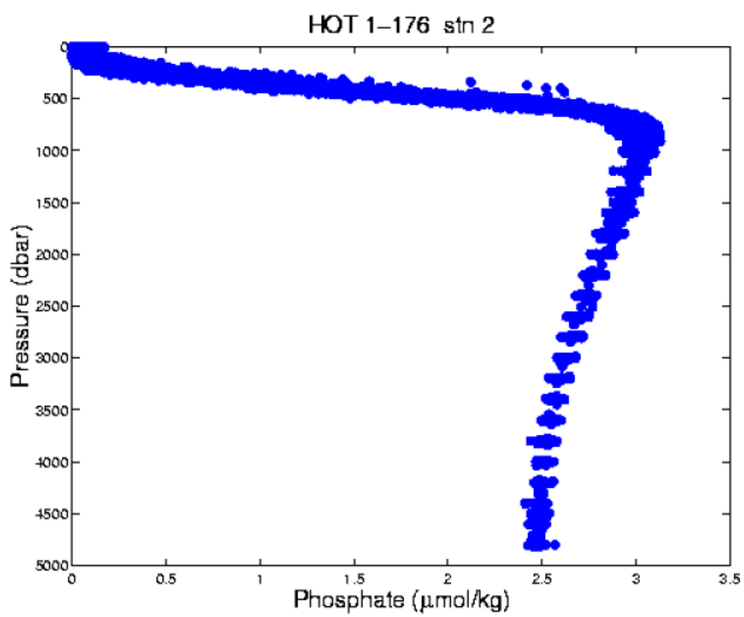
In the blue-green regions of the visible spectrum, sunlight penetrates deep into the ocean

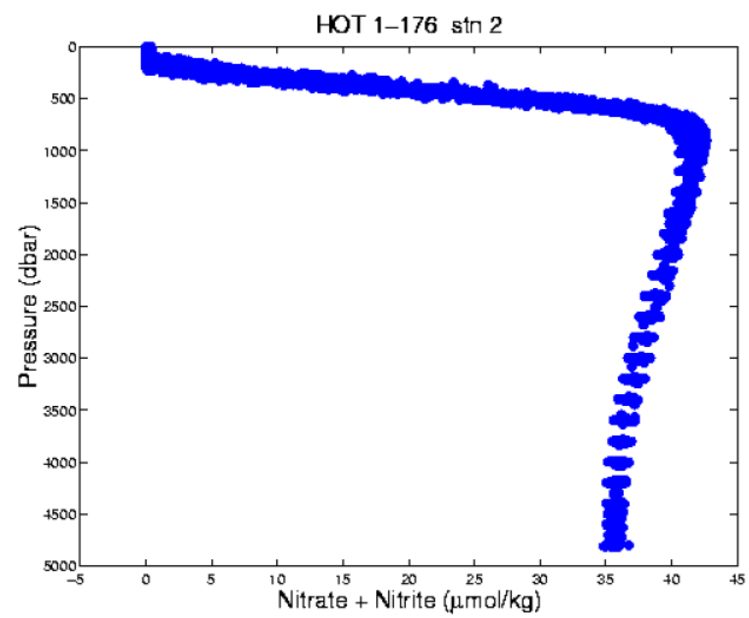


Nutrient sources

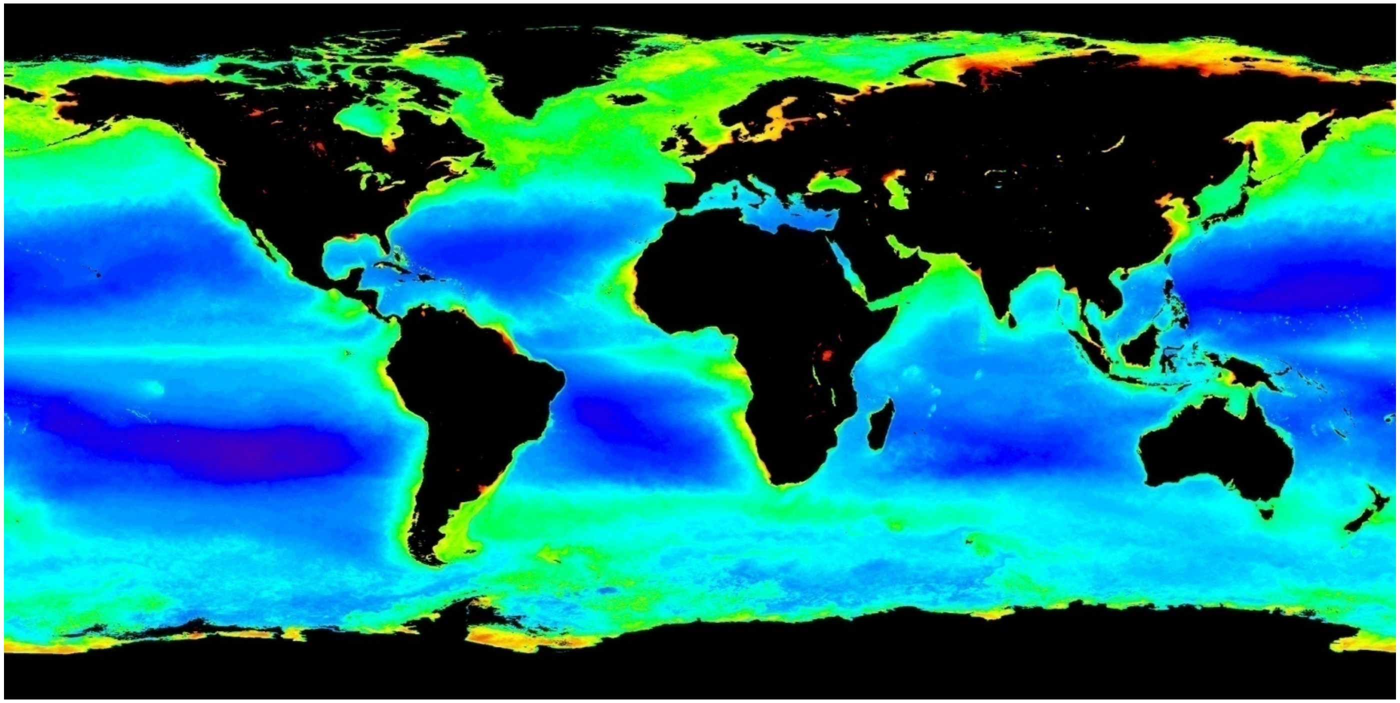
- **Nitrogen: protein, nucleic acids**
  - NO_3^-, NO_2^-, N_2, NH_3, organic N
- **Phosphorus: nucleic acids, lipids**
  - PO_4^{3-}, organic P
- **Carbon: nucleic acids, protein, lipids, carbohydrates, etc.**
  - CO_2, organic C
- **Sulfur: amino acids, protein, lipids**
  - SO_4^{2-}, S, H_2S, organic S

Vertical Profiles of inorganic nutrients (phosphate and nitrate)

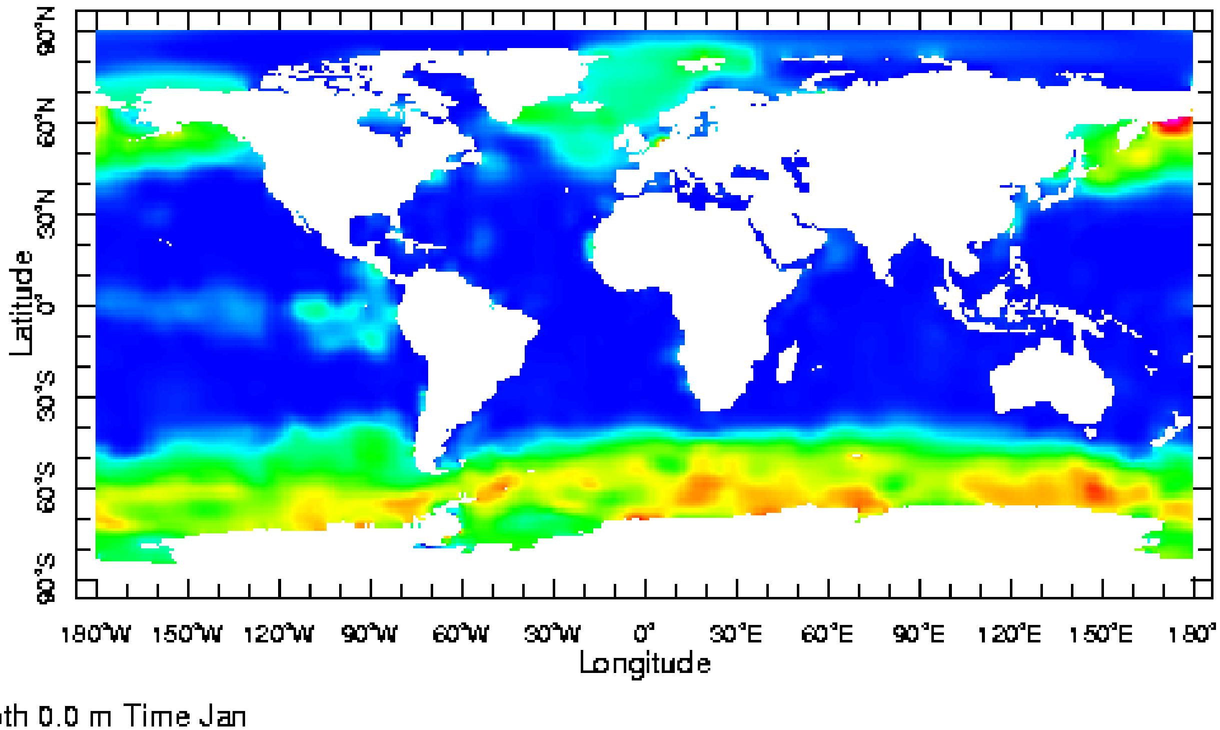




Nutrient distributions with depth (pressure) at Station ALOHA

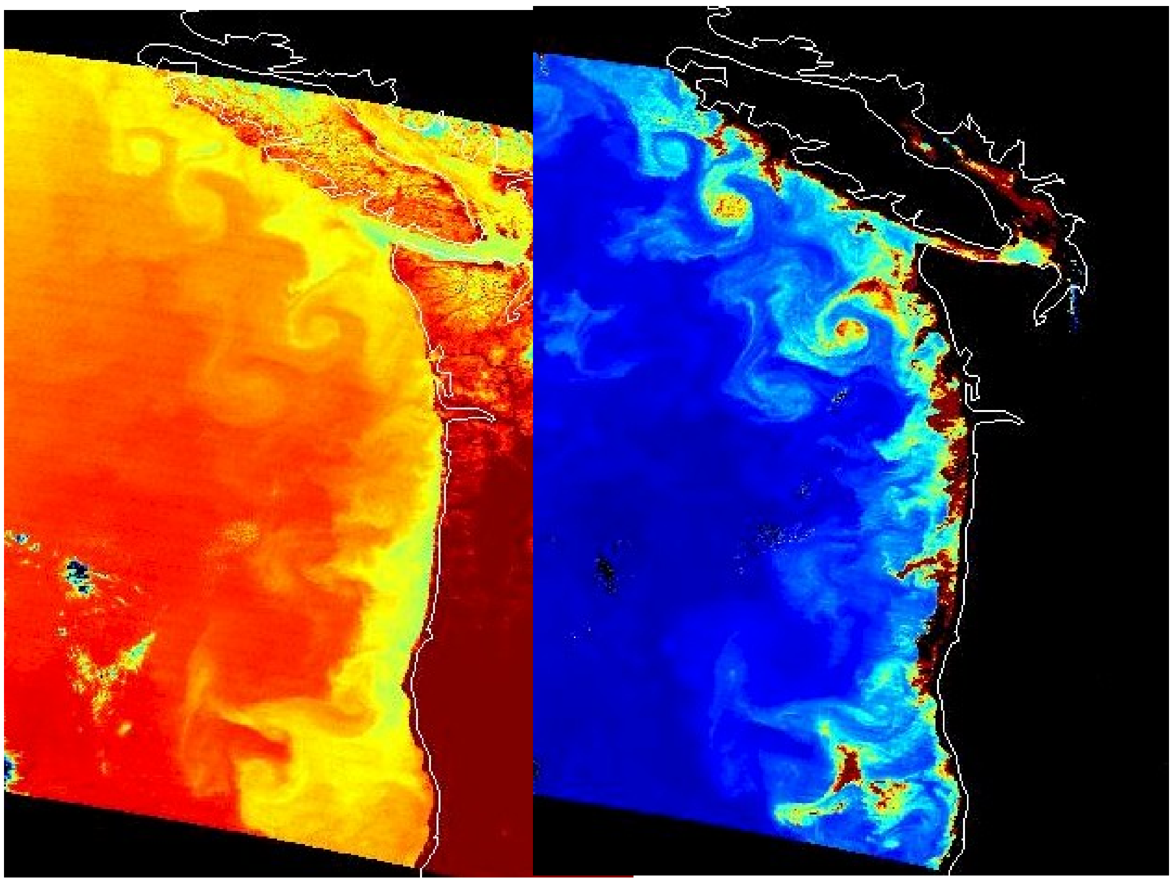


Clearly distinguishable ocean habitats with elevated “plant” biomass in regions where nutrients are elevated



Spatial discontinuities at various scales (basin, mesoscale, microscale) in ocean habitats play important roles in controlling plankton growth and distributions.

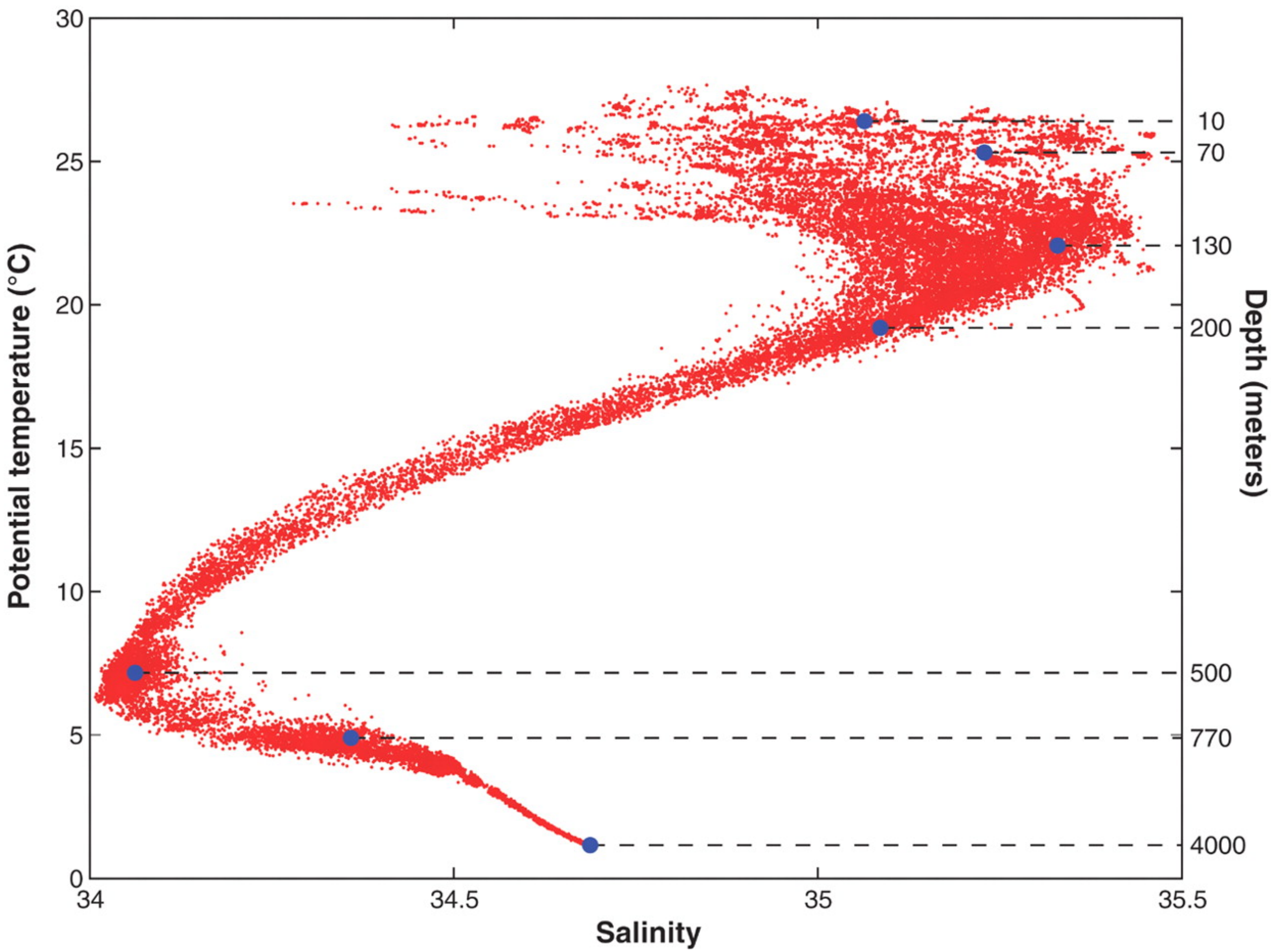
The ocean is stirred more than mixed



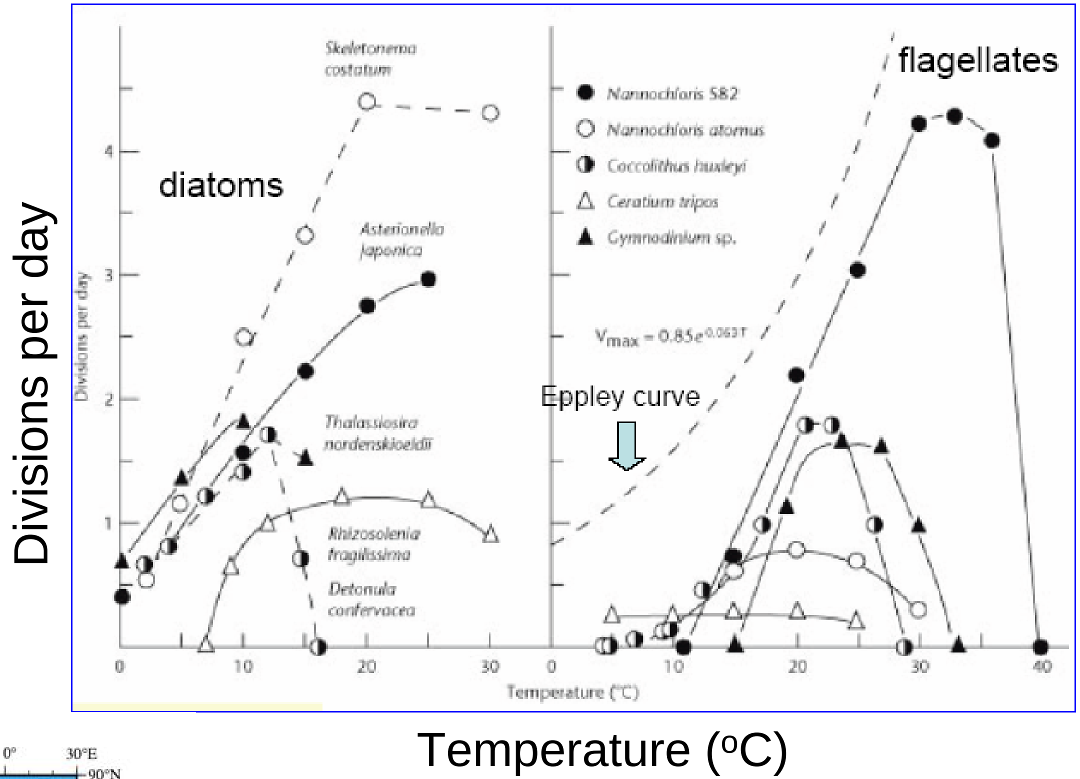
Sea Surface Temperature (°C)

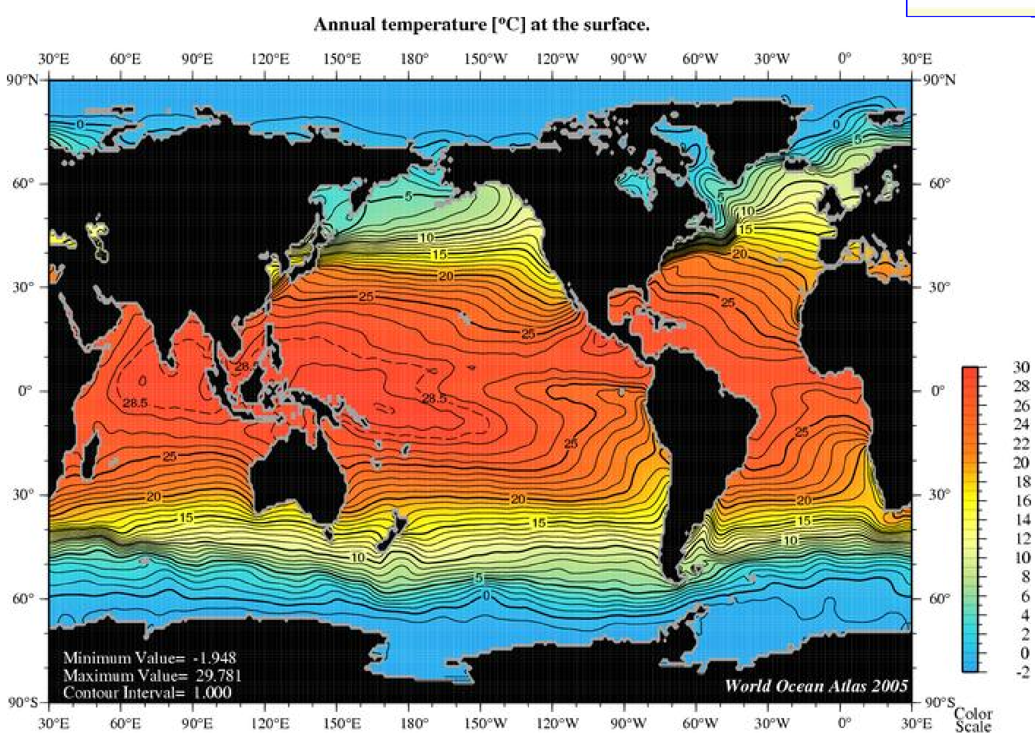
Chl a ($mg\ m^{-3}$)

Temperature-salinity plot from Station ALOHA showing the time-dependent changes in physical ocean properties. Note greater variability in physical environment in upper 200 m; deep sea (>1000 m) largely invariant with time.



Temperature plays an important role in controlling plankton growth and distributions. In this example, diatoms have a wider range of optimal temperatures than flagellated phytoplankton.





Which group of plankton would be predicted to have a more cosmopolitan distribution?