Chapter 9:
Focus on the biota

With parts from
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Characteristics of Life

Life spreads exponentially: This continues unless inhibited by predation or until resources become limiting

Life needs energy: Life exists because it has found ways to catalyze natural chemical processes to gain an advantage in extracting energy relative to abiotic processes

Life needs material resources: … in a certain ratio

Life pollutes: Life produces wastes – these may become useful to other life forms, but life generally alters its own chemical environment

Life is versatile: Living things have found many different ways to survive

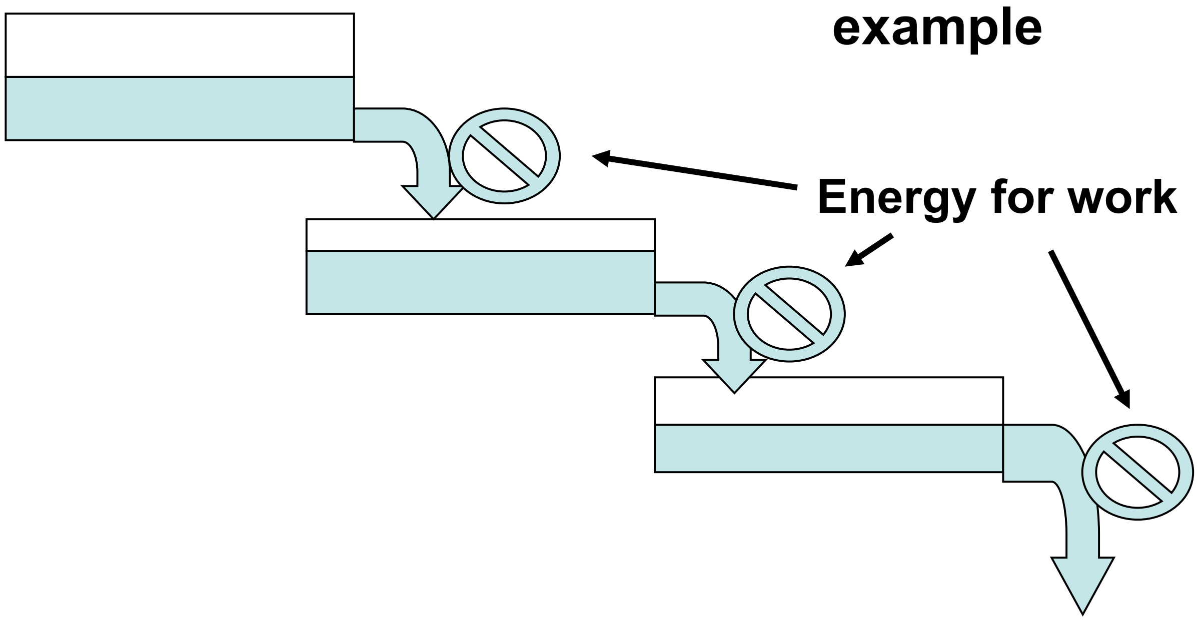
Life transmits information: Living things have a replicable, modifiable information system

Energetics: where does it come from?

General rule 1: energy flows from sources of high concentration to low concentration

General rule 2: with every energy conversion, some energy is lost as heat

Energy cascade: waterfall example



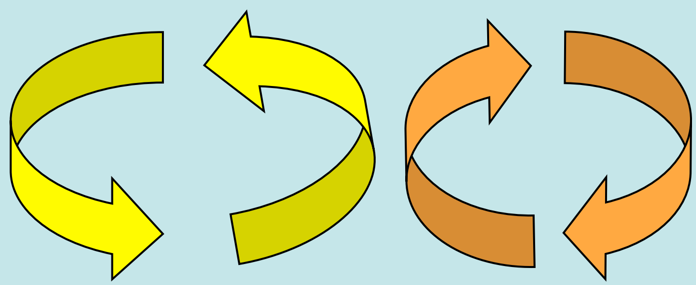
Electrons are the "currency" for energy in most chemical reactions

- **Most energy transferring reactions involve the transfer of electrons from one atom to another.**
- **This transfer may make available energy for doing work**
- **This work is harnessed through enzyme systems into forms that can be stored for doing biological work**

Coupled reduction-oxidation reactions

Oxidation reaction => e^-

=> e^- Reduction reaction



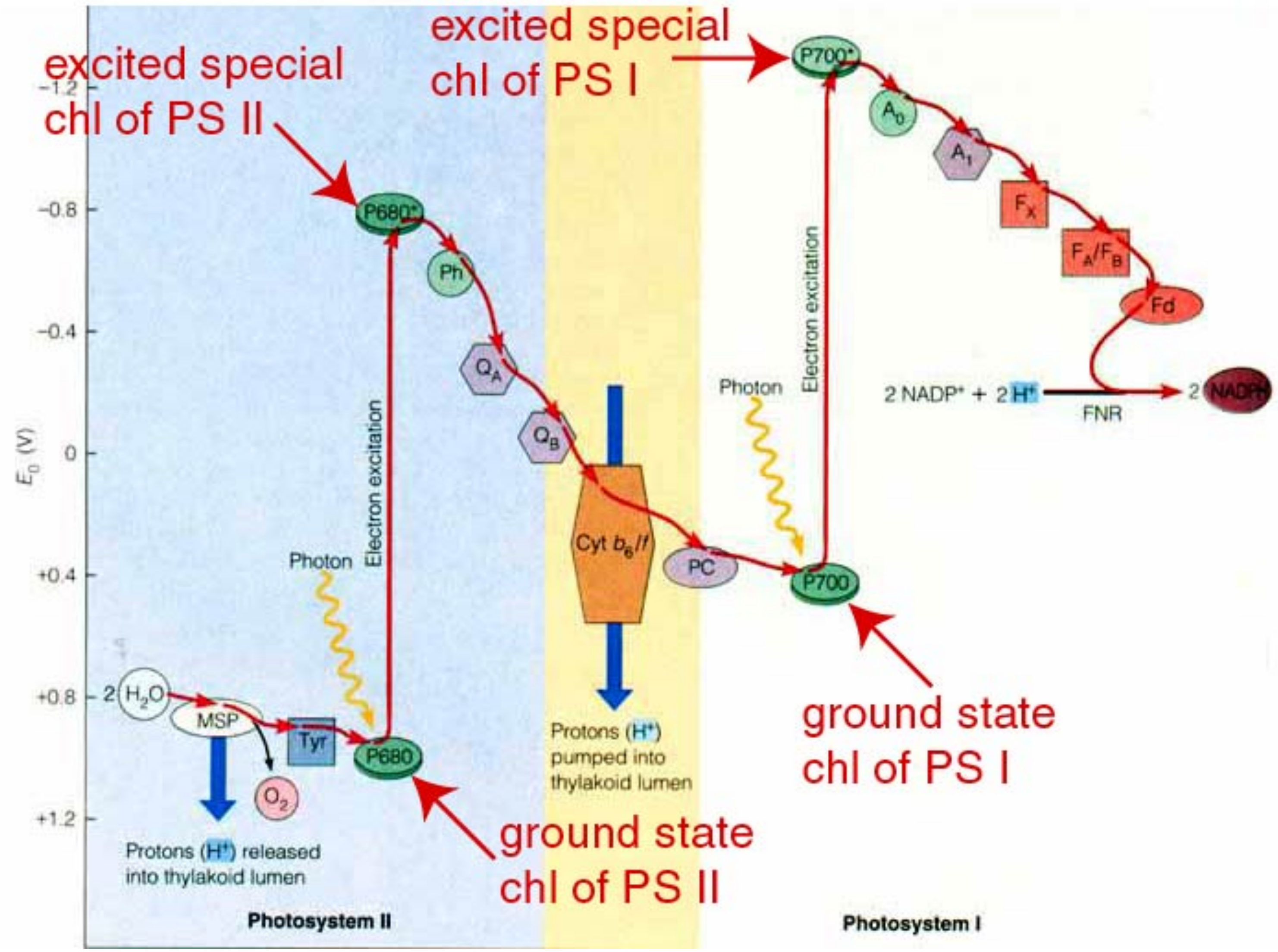
Coupled reactions for oxygenic photosynthesis

$12\ H_20$ + photon flux ==> $6\ O_2 + 24H^+ + 24e^-$

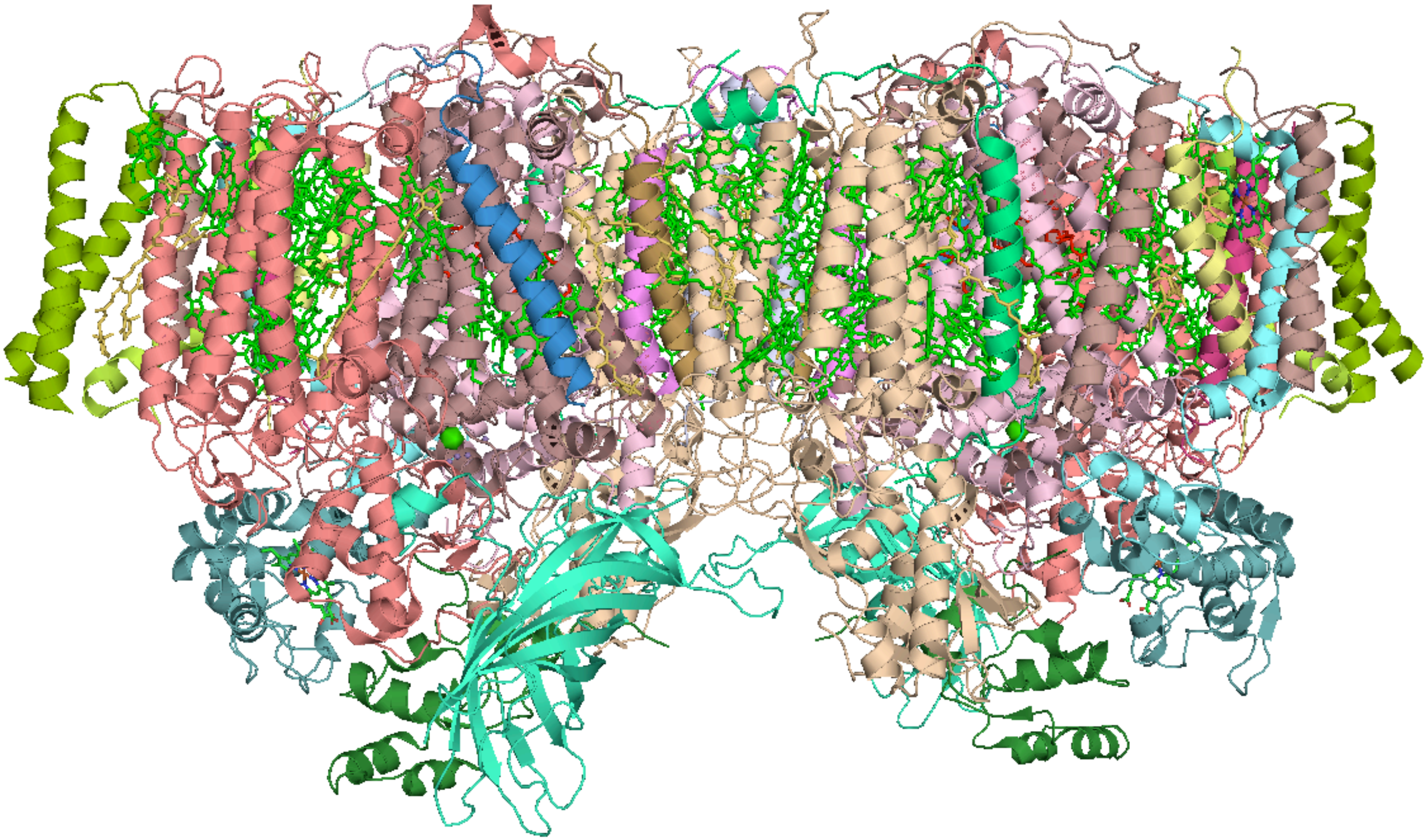
$\underline{6\ CO_2 + 24\ H^+ + 24\ e^- \quad ==> \quad C_6H_{12}O_6 + 6\ H_20}$

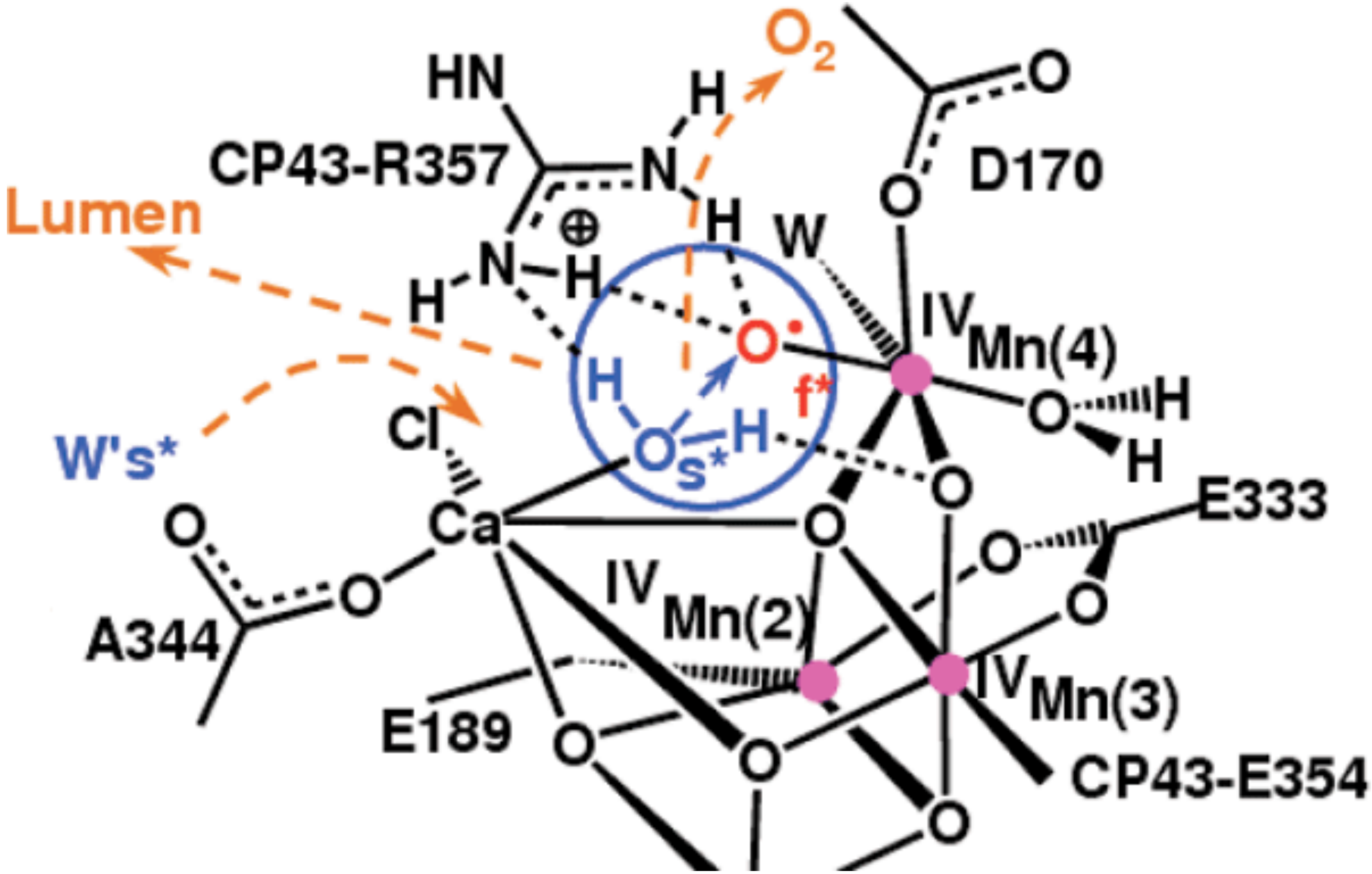
$6\ CO_2 + 6\ H_20$ ==> $C_6H_{12}O_6 + 6\ 0_2$

Plants also take a "tandem" approach:

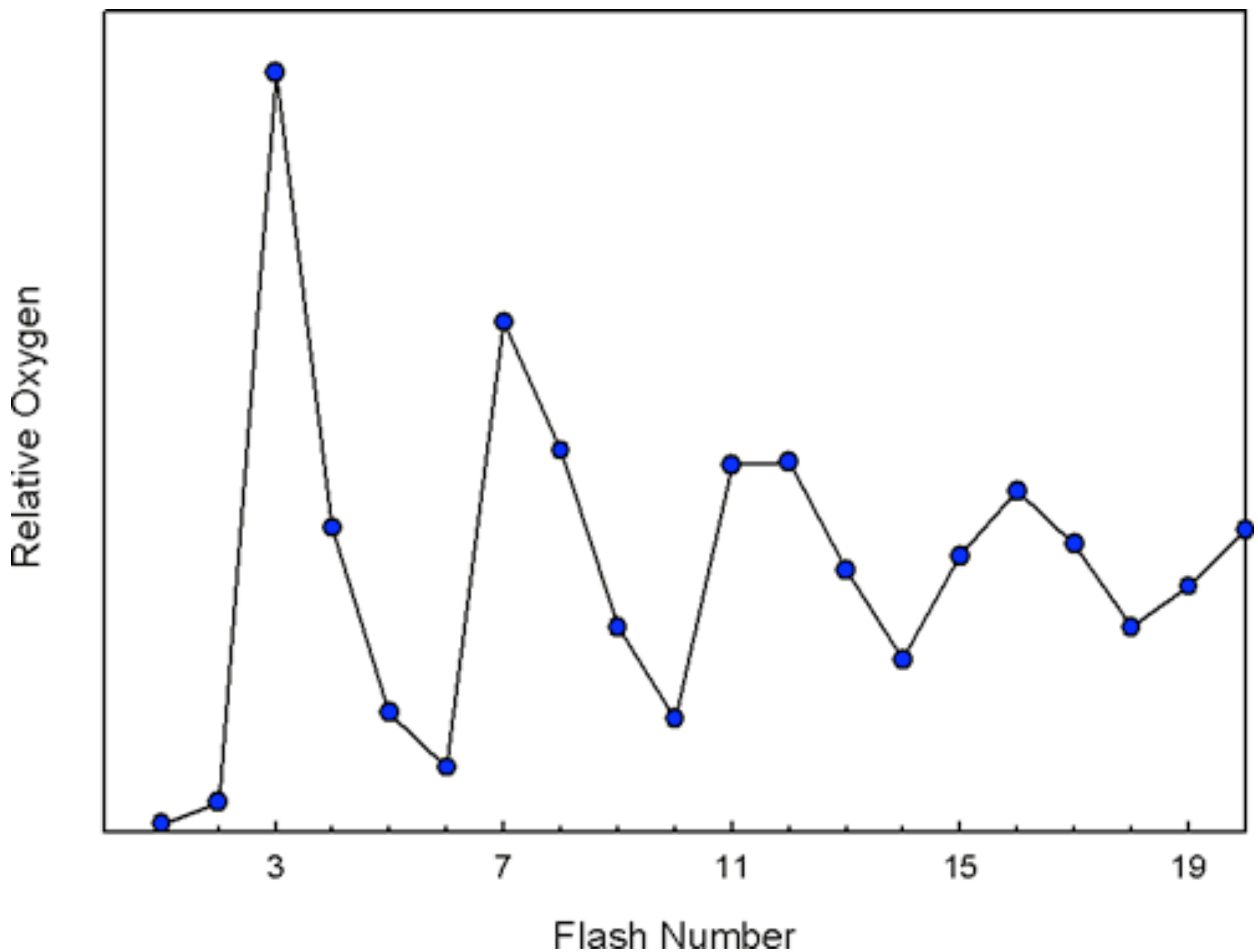


Photosystem II

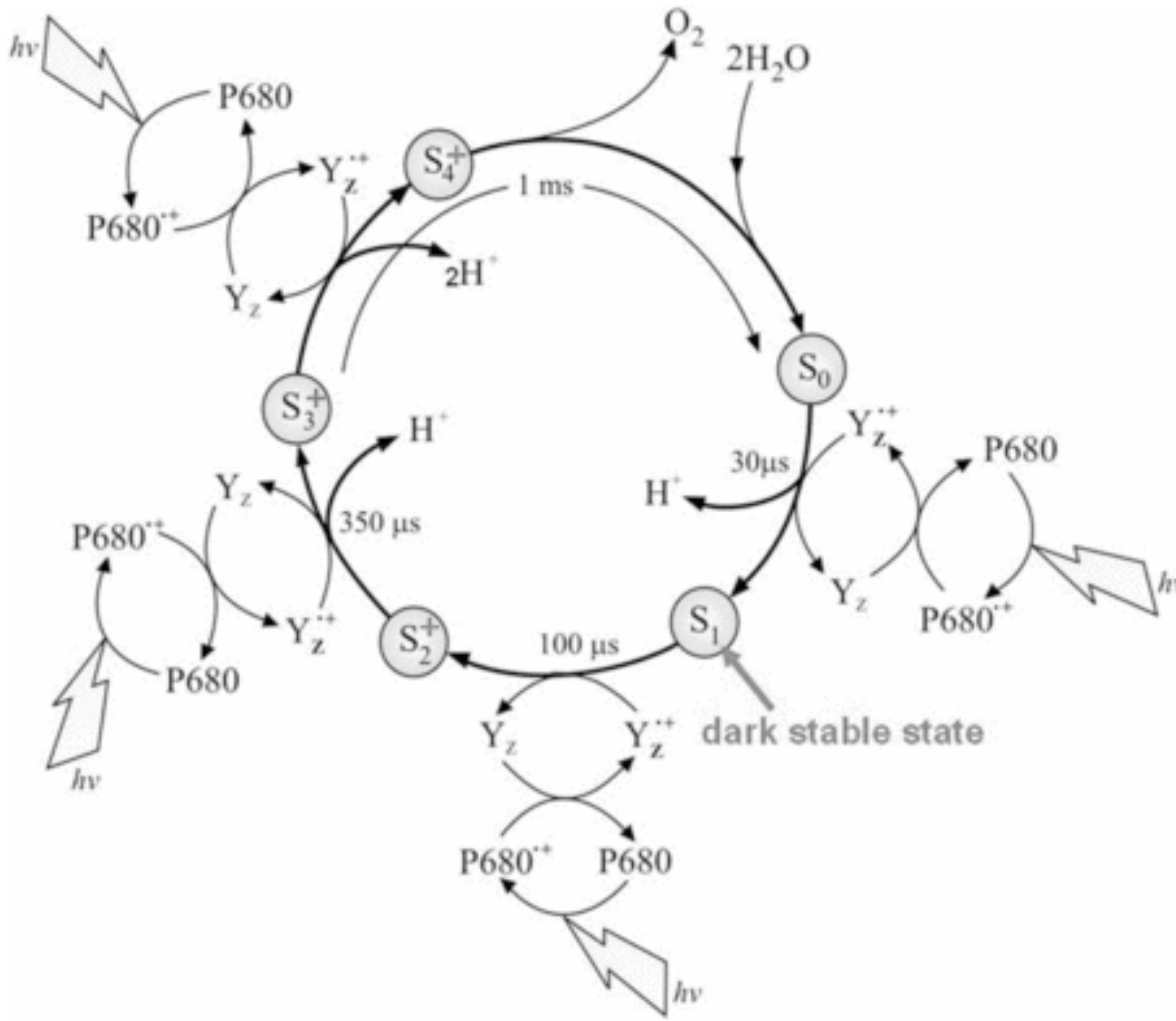



O2
HN
H
CP43-R357
N
D170
Lumen
H
W
N
H
H
IVMn(4)
O•
H
f*
H
W's*
Cl
Os*
H
E333
Ca
A344
IVMn(2)
IVMn(3)
E189
CP43-E354

Hitting PSII with short light flashes

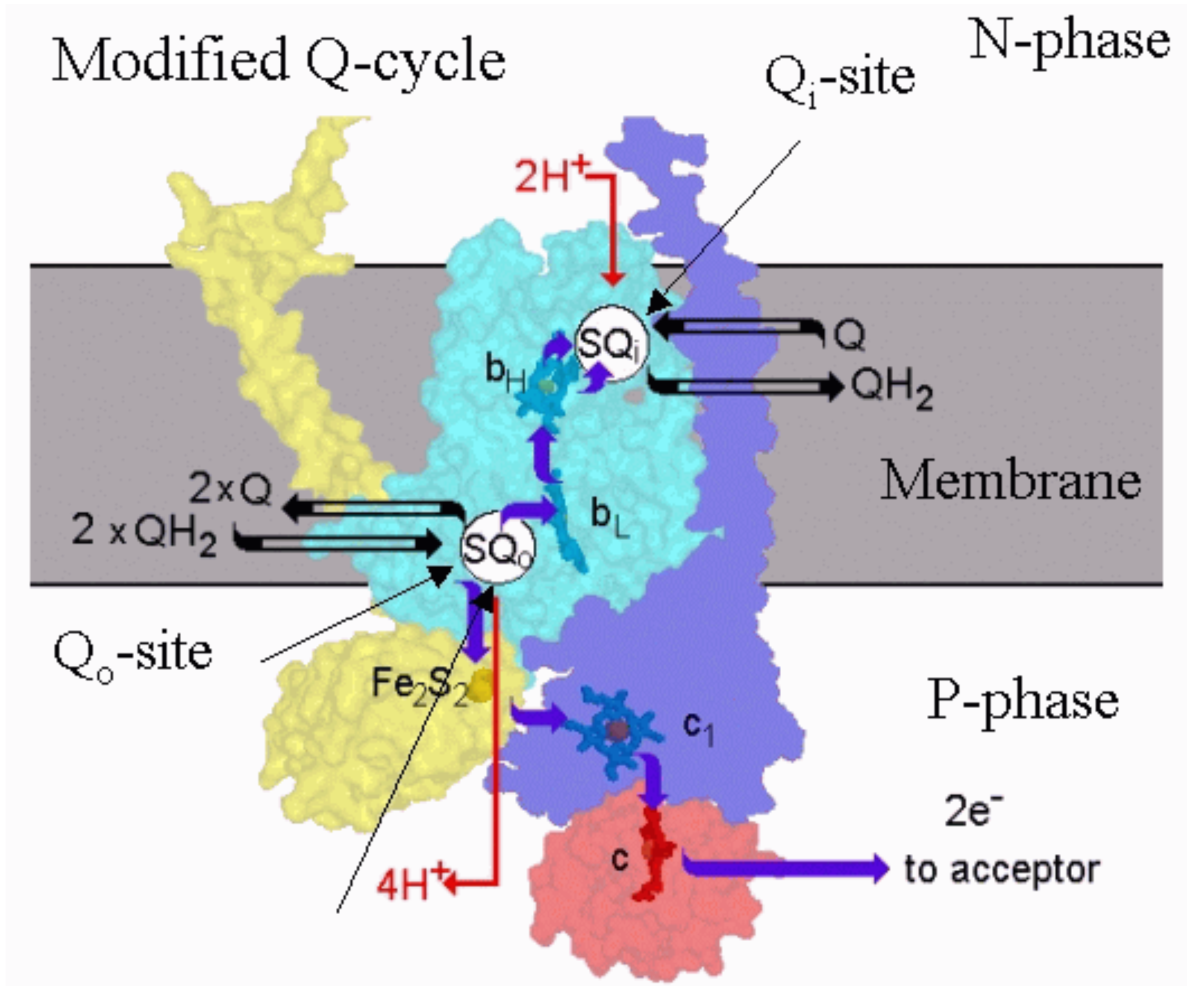


Kok cycle:



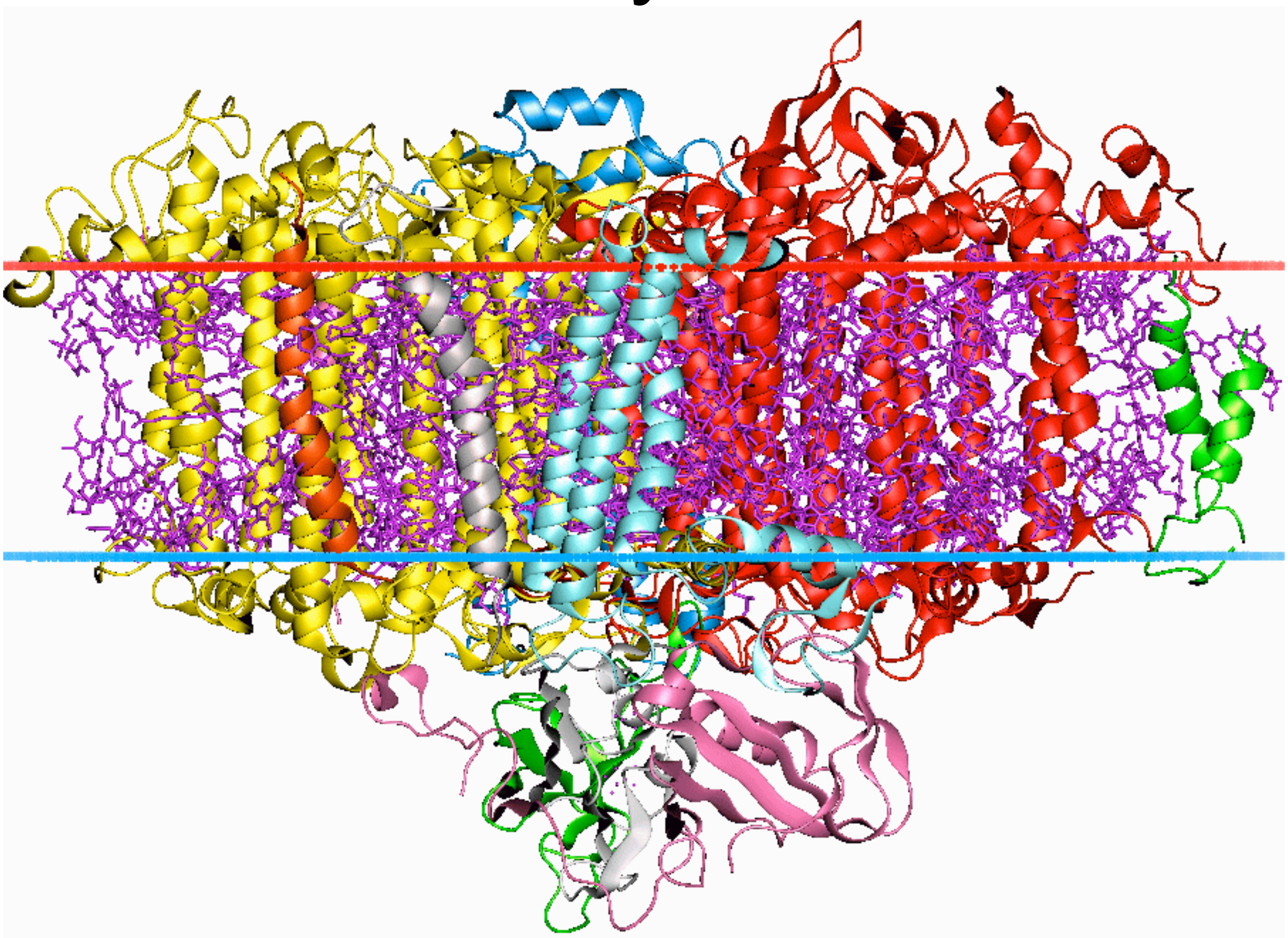
O2
2H2O
hv
P680
P680'+
Y'+z
Yz
S4+
1 ms
2H+
S0
S3+
H+
30μs
H+
Yz
P680'+
350 μs
P680
Y'+z
S2+
100 μs
S1
P680'+
hv
dark stable state
Yz
Y'+z
P680'+
P680
hv

Ubiquinol:cytochrome c oxidoreductase (bc1 complex)

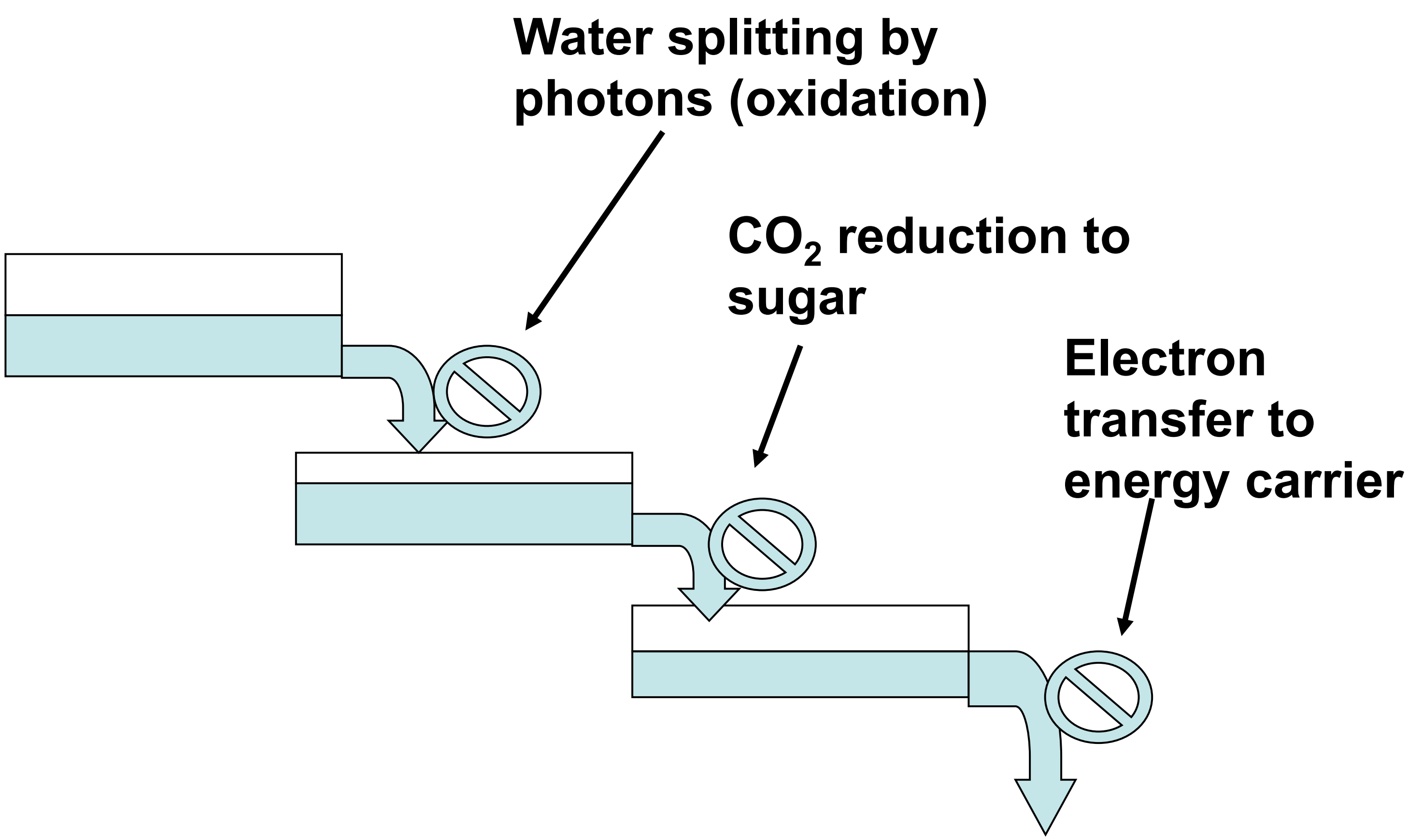


This group of electron transfer enzymes (known as bc1 complexes in mitochondria, bacterial respiratory chains and photosynthetic bacteria, or b6f complexes in the photosynthetic chains of photosynthesis) carries the main flux of energy through the biosphere. The annual synthesis (and consumption) of biomass in the biosphere represents a storage of energy 20-100 fold greater than all human energy usage, including fossil fuels and nuclear power. Because of inefficiencies in energy conversion, the flux in the biosphere is about 1000-fold greater than that through all anthropogenic processes.

Photosystem I



Life is supported by cascades of reduction-oxidation (“redox”) reactions



Ways of making a living

TABLE 9-1 Metabolic Pathways for Life

General Method for Acquiring Energy	Specific Pathway	Subcategory	Reactants	Byproducts
Autotrophy				
	Photosynthesis		Solar energy, CO_2	
		Oxygenic	H_2O	Molecular oxygen (O_2)
		Anoxygenic	Molecular hydrogen (H_2), reduced sulfur or reduced iron	Oxidized sulfur (native sulfur or sulfate), iron oxide (solid)
	Chemosynthesis		H_2, reduced forms of sulfur, nitrogen, iron or manganese	Oxidized sulfur, nitrate, iron and manganese oxides (solids)
Heterotrophy			Organic matter	
	Aerobic Respiration		O_2	CO_2, H_2O
	Anaerobic Respiration		Nitrate, sulfate, iron and manganese oxides	CO_2 and molecular nitrogen, ammonia, hydrogen sulfide, reduced and dissolved iron and manganese
	Fermentation		Complex organic molecules	Simple organic molecules

Source: K. H. Nealson and D. A. Stahl, *Geomicrobiology, Interactions between Microbes and Mineral* (Chapter 1). Reviews in *Mineralogy* 35, 1997, pp. 5–34.

Aerobic Respiration

$C_6H_{12}O_6 + 6\ H_20$ ➔ $6\ CO_2 + 24\ H\ + 24\ e^-$

$\underline{6\ O_2 + 24\ H^+ + 24\ e^-}$ ➔ $\underline{12\ H_2O}$

$C_6H_{12}O6 + 6\ O_2$ ➔ $6\ CO_2 + 6\ H_20$

Oxidation: C is the electron donor

Reduction: O is the electron receptor

Aerobic Chemoheterotrophy

Oxidation: Fe2+ is the electron donor

Reduction: O is the electron receptor

$4\ Fe^{2+}$ ➔ $4\ Fe^{3+}\ +\ 4\ e-$

$\underline{O_2 + 4\ H^+ + 4\ e^-}$ ➔ $\underline{2\ H_20}$

$O_2 + 4\ Fe^{2+} + 4\ H^+$ ➔ $4\ Fe^{+3}\ + 2\ H_20$

Fermentation:

Convert complex organic materials into simpler ones, gaining energy in the process (without oxidation)

Where do we get beer, wine, bread, etc.?

Methanogenesis

- Autotrophic methanogenesis:
  $CO_2 + 4H_2 \text{-->} CH_4 + 2H_2O$
- Heterotrophic methanogenesis:
  $CH_3COOH \text{-->} CH_4 + CO_2$
- Photosynthesis (oxygenic):
  $2CO_2 + 2H_2O \text{-->} 2CH_2O + O_2$
- Fermentation: $2CH_2O \text{-->} CH_3COOH$
- Heterotrophic methanogenesis
  $CH_3COOH \text{-->} CH_4 + CO_2$

- NET: $CO_2 + 2H_2O \text{-->} CH_4 + O_2$

Aggregated Units of Organization

- Tangible (touch, see, feel) units of study, e.g. mountain ranges, air and wind currents, individual animals, plants
- Interactions between these units of study.
- Conceptualization of aggregated entities emphasizing their interactions, feedbacks, etc.
  - El Nino-Southern Oscillation
  - Hydrologic units, e.g. atmosphere-watersheds

Conceptual Aggregative Entities

- **These are not “real” systems**
- **These are concepts, abstractions, mental conveniences, models, ontologies**
- **These cannot be seen in nature except to the extent that they are specified by humans.**
- **They exist as unspecified concepts in general discussion**
- **They can be specified in space and time through human assertion.**

Aggregated Units of the Biosphere (p. 175)

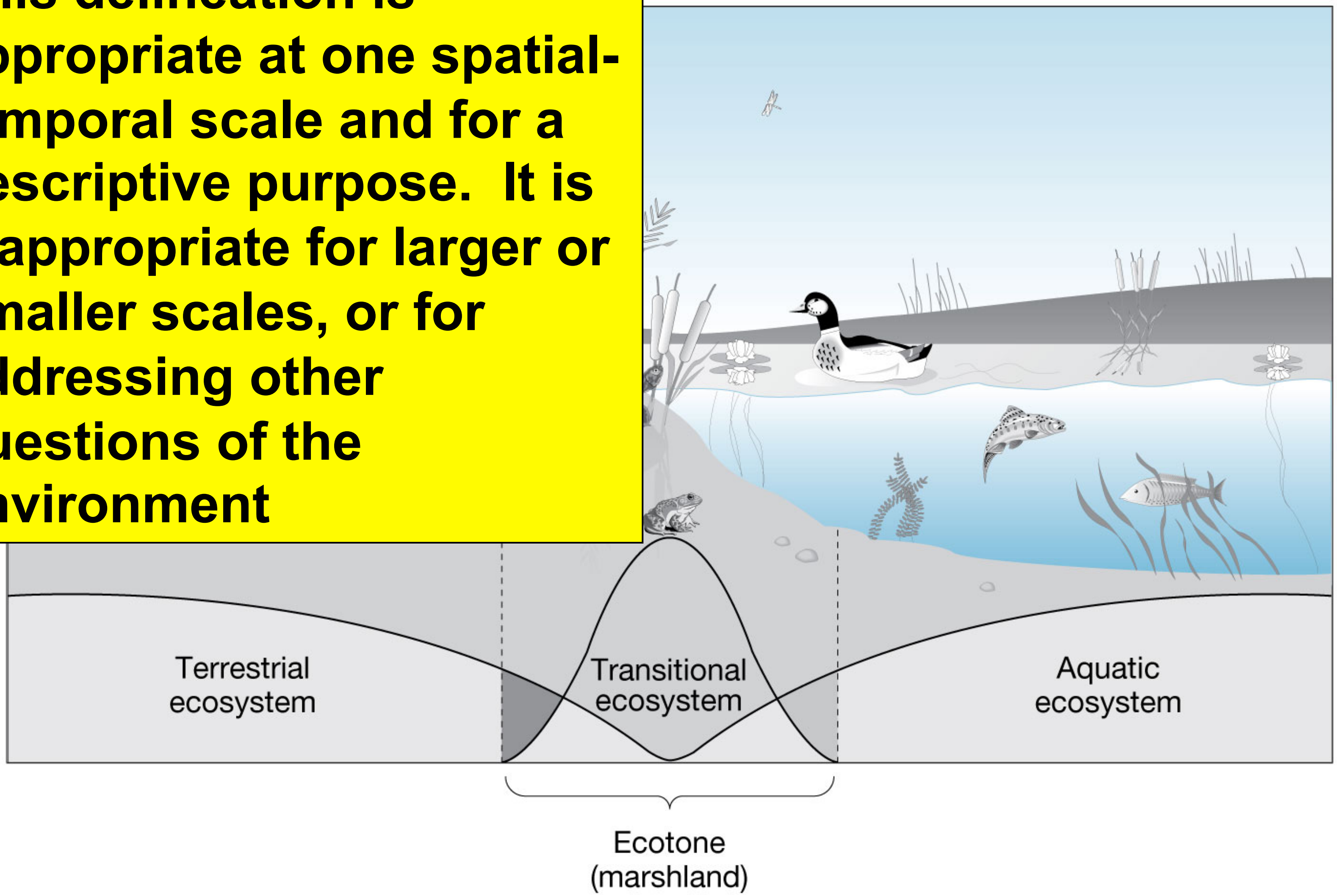
Tangibility (max = 5) ➔ Abstraction (max = 1

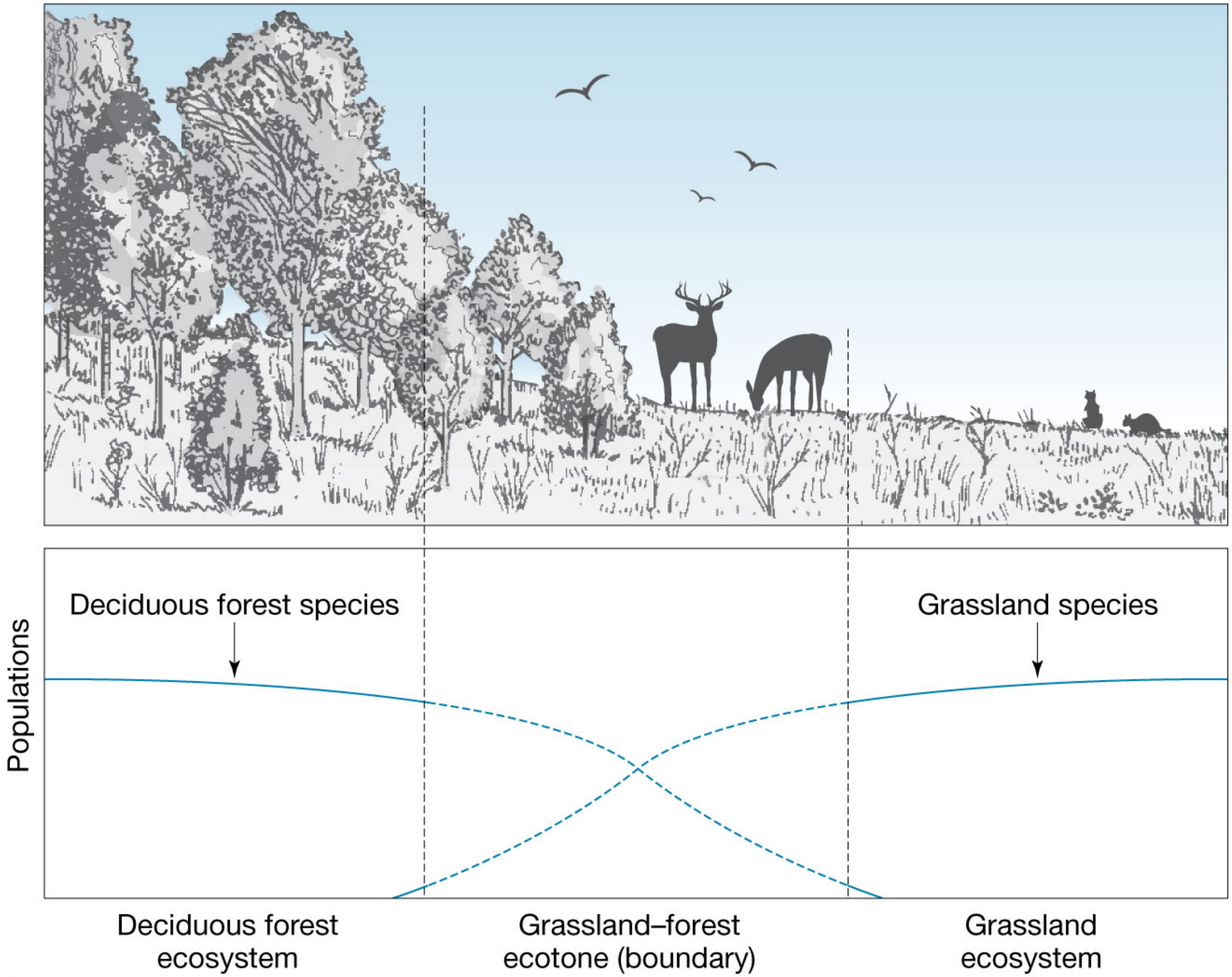
- **Organism** ___ ___ ___ ___ ___
- **Species** ___ ___ ___ ___ ___
- **Population** ___ ___ ___ ___ ___
- **Community** ___ ___ ___ ___ ___
- **Ecosystem** ___ ___ ___ ___ ___
- **Biome** ___ ___ ___ ___ ___
- **Biosphere** ___ ___ ___ ___ ___

Ecosystems are abstractions until someone specifies them based on some criterion.
Their delineations in nature are pragmatic, question-dependent

- **Spatial scale?**
- **Temporal scale?**
- **Species interactions?**
- **Energetics?**
- **Disturbance and recovery dynamics?**
- **Material storage and transfer?**

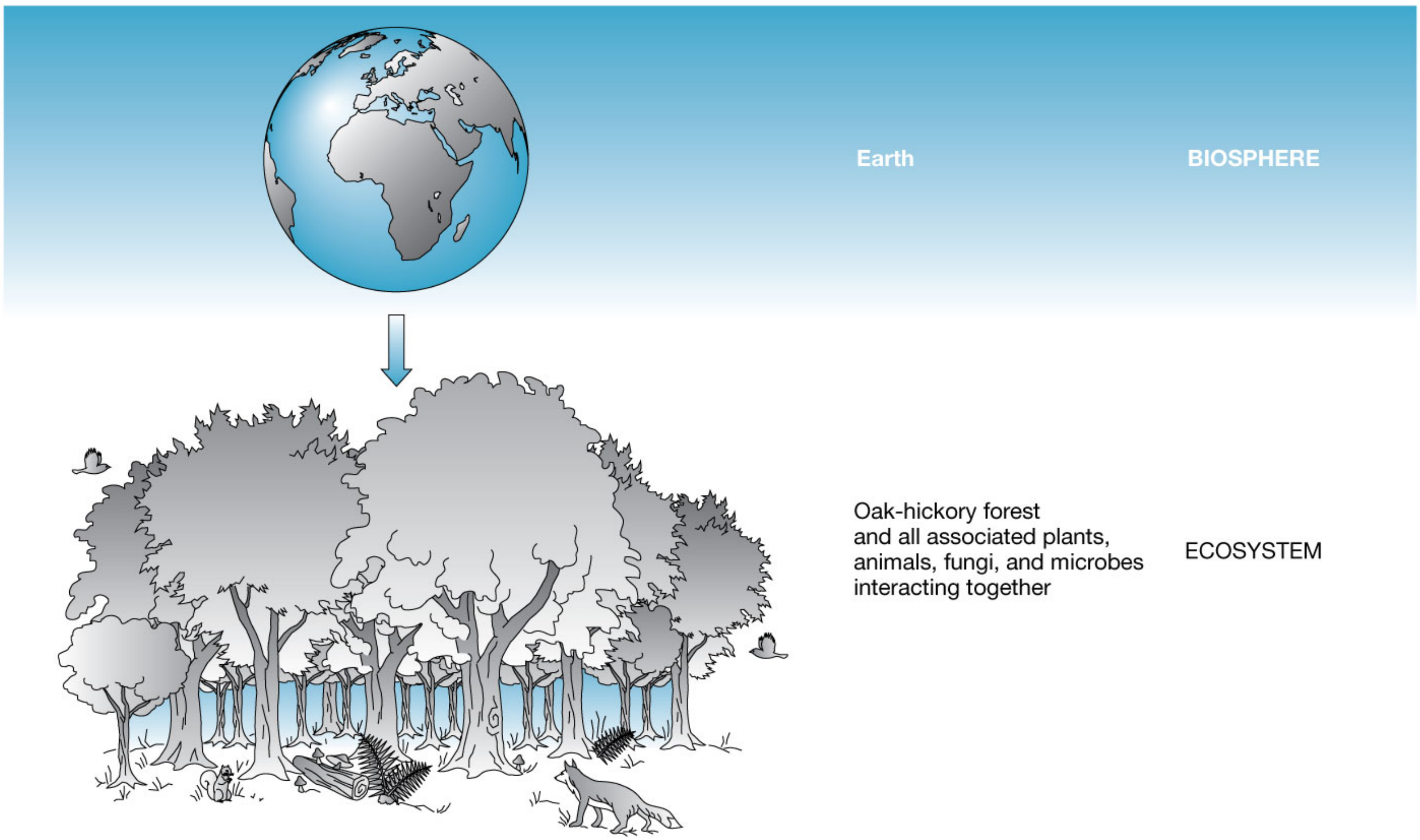
This delineation is appropriate at one spatial-temporal scale and for a descriptive purpose. It is inappropriate for larger or smaller scales, or for addressing other questions of the environment

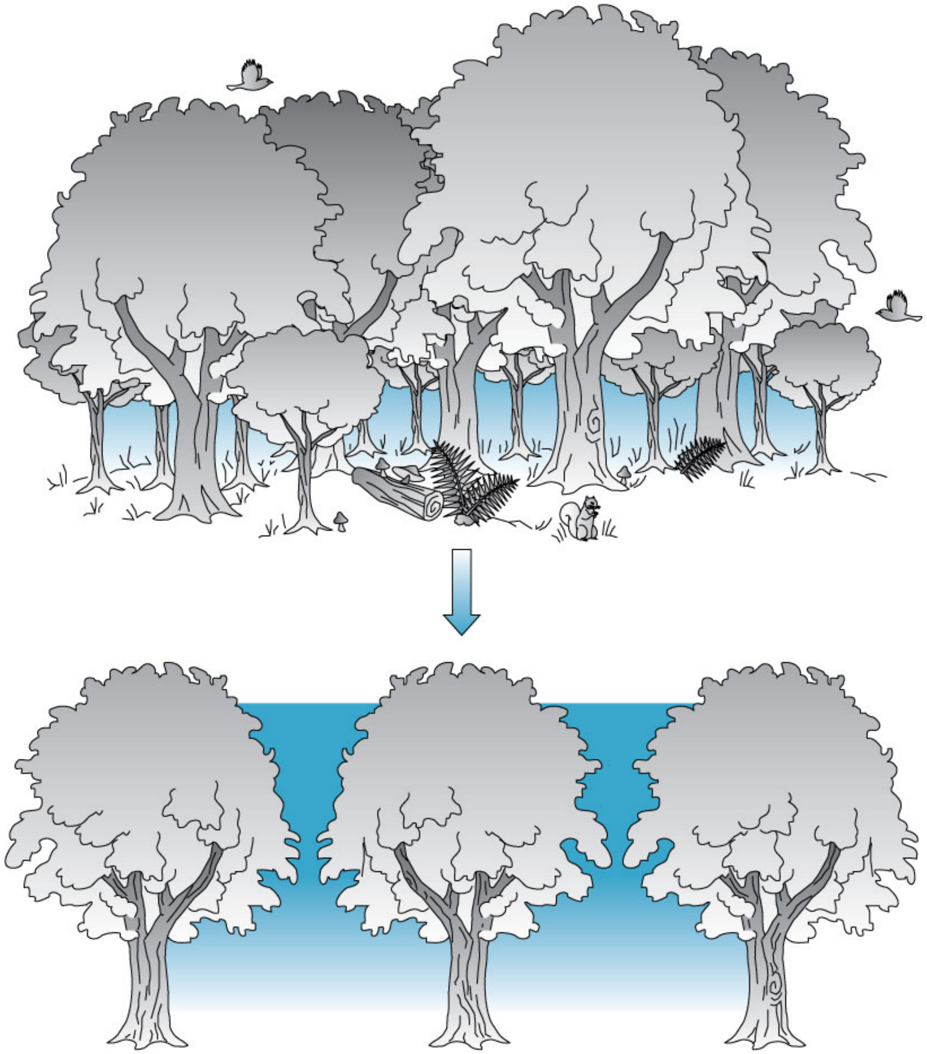



Deciduous forest species
Grassland species
Populations
Deciduous forest ecosystem
Grassland–forest ecotone (boundary)
Grassland ecosystem

Structure of Biosphere

- Organism, species: (different definitions for different organisms)
- Population: (all the individuals of a species taken together in a location)
- Community: (individual populations cannot exist in isolation - so you have more than one population)
- Biome: A region with a characteristic plant community
- Ecosystem: A community of plants, animals, fungi, microbes together with their supporting physical environment (including rocks!)
- Ecotone: The region at the border of two different ecosystems, with unique mixtures of characteristics


Earth
BIOSPHERE
Oak-hickory forest
and all associated plants,
animals, fungi, and microbes
interacting together
ECOSYSTEM



Oak canopy, dogwood understory, ferns, mosses, squirrels, and birds — COMMUNITY

Members of one species inhabiting the same area — POPULATION

One specific kind of plant, animal, fungus, or microbe — SPECIES

Does the physical environment control the kind of ecosystem that develops?

Or does the ecosystem have an effect on the physical environment?

National Center for Atmospheric Research (NCAR)

Explored, using the most sophisticated general circulation models, the effect of removing all forest north of 45° N latitude.

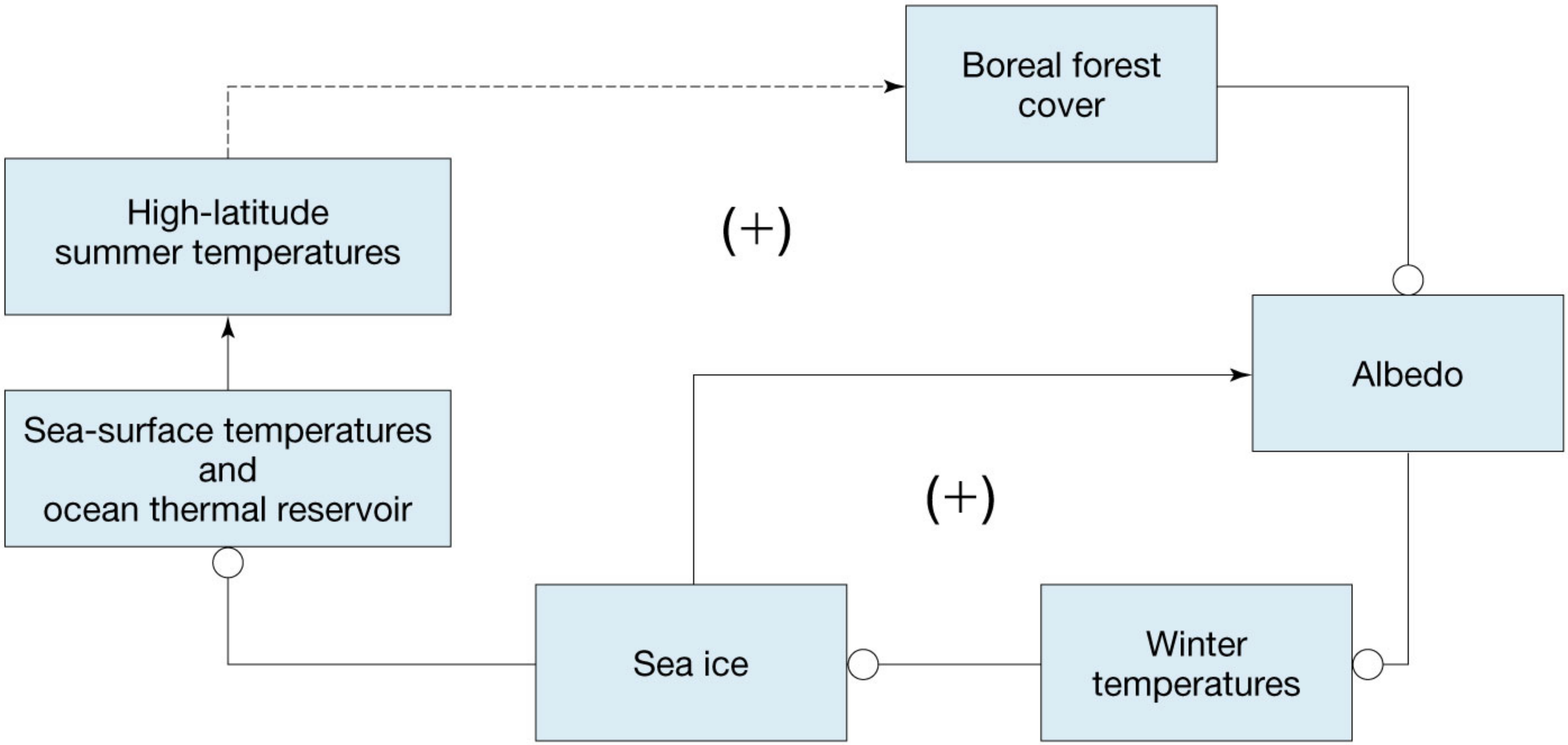
-Increased wintertime albedo substantially.

-Large drop in air temperatures generally - up to 12°C on land.

-This caused increased sea ice cover, even higher albedo, more cooling.

-Summer (July) temperatures we also 5°C cooler.

That is: There is a feedback system between the biosphere and physical conditions

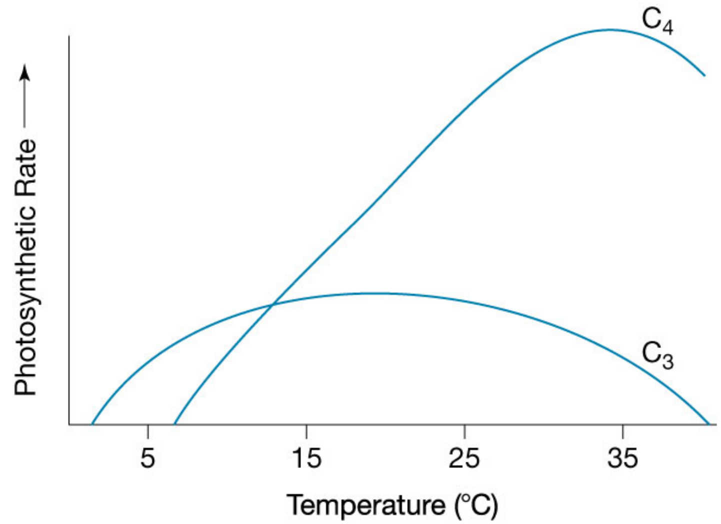


Complexities of C3 versus C4 response to rising temperatures

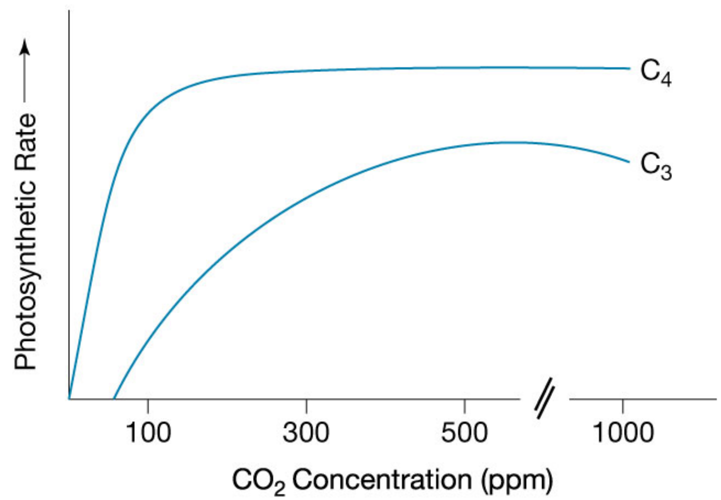
C3: Trees, most other plants, algae, cyano-bacteria

C4: Grasses, corn, pineapples (last 20 million years!)

C3 can grow at lower temperatures, but are less efficient



(a)



(b)

C4 may have evolved in response to lower atmospheric CO_2 levels during the Tertiary, and colder temperatures overall. The "break-even" point for C3 plants is ~70 ppm CO_2, and in the depths of ice ages we were getting down to 180 ppm or even less!

Species Interactions in ecosystems (p. 180)

Feeding relationships

- Food chain – Primary pathways of energy flow
- Food web – More complete specification of pathways of energy flow
- Trophic levels -- sequential position from original energy source

Measures of population, trophic level size

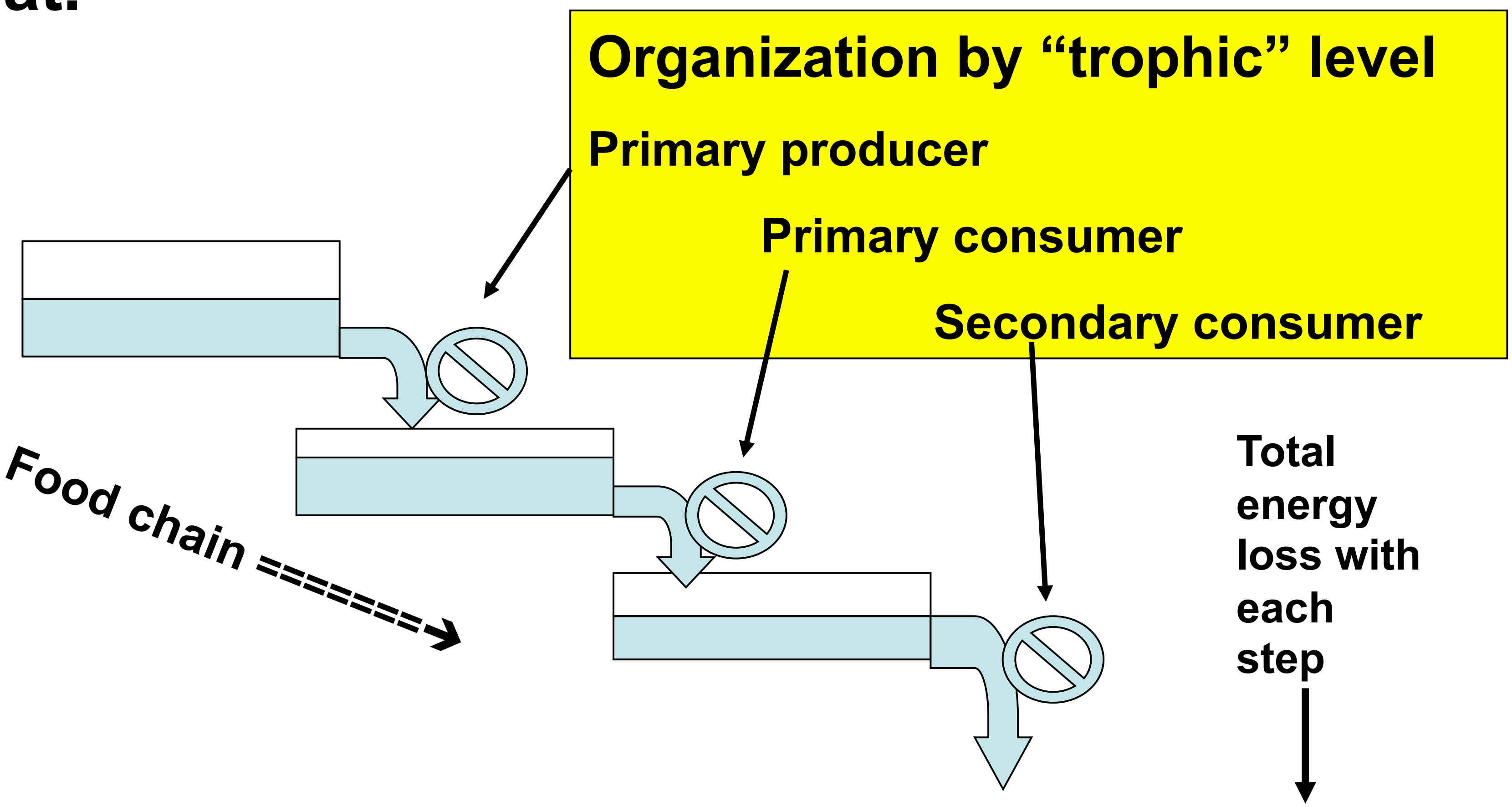
Numbers (density)

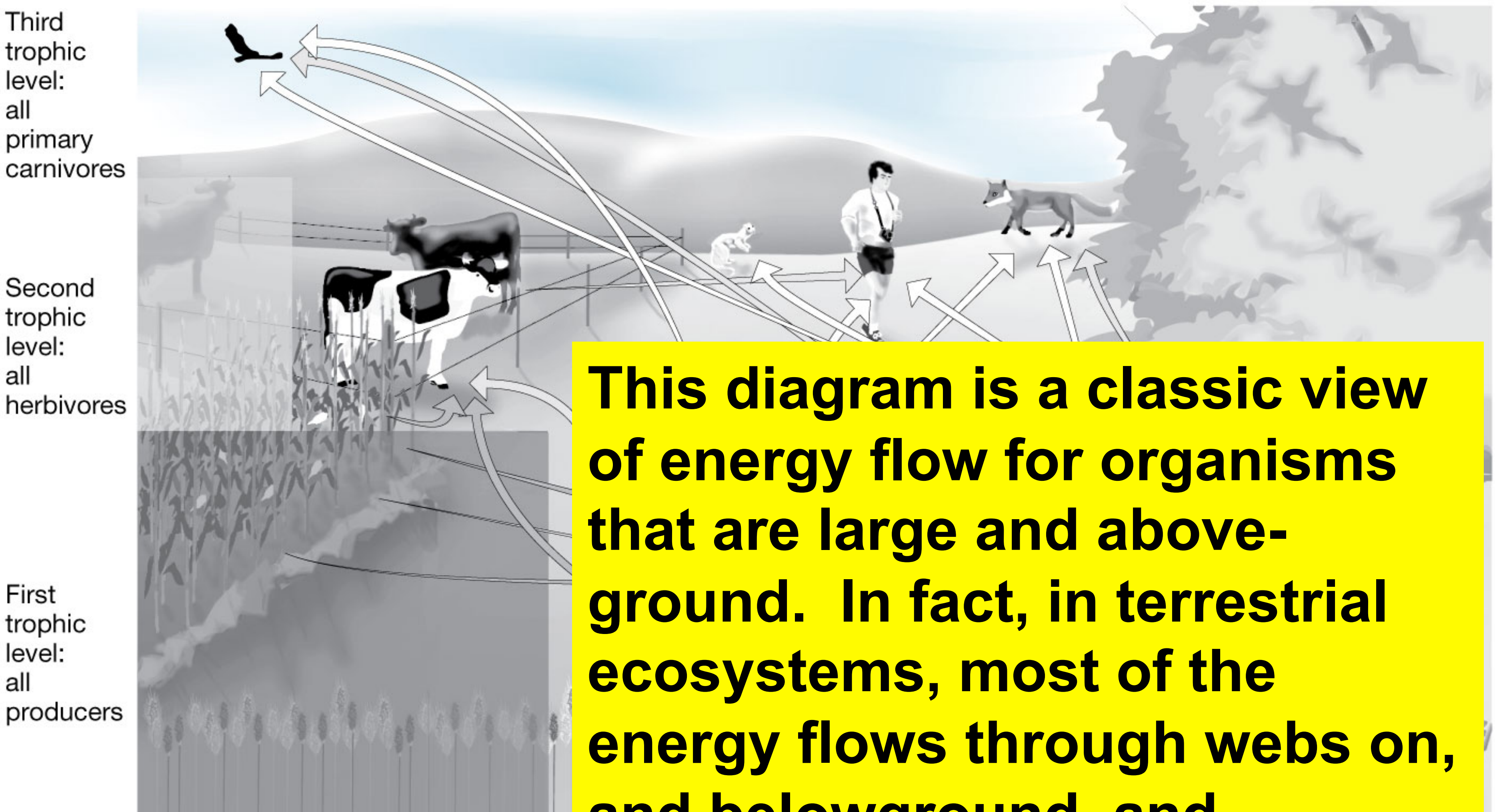
Biomass (mass of living matter)

Energy flow rates

Energetics at the ecosystem level

Ecosystems are thermodynamic systems as are cells and organisms. Energy cascades through steps from the original source to the final loss as heat.





This diagram is a classic view of energy flow for organisms that are large and above-ground. In fact, in terrestrial ecosystems, most of the energy flows through webs on, and belowground, and involves bacteria, fungi and tiny animals.

Species Interactions in ecosystems (p. 180)

- Competition
- Symbioses

The niche concept

Source of nutrition, habitat, reproduction requirements, etc. Applies primarily to animals.

Ecosystem disturbance and succession

- Ecosystems are nearly always undergoing disturbance or recovery in response to disturbance that is termed “succession.”
- “Steady state” is rarely achieved but is a useful “model” condition.
- Understanding the disturbance-recovery dynamics of particular ecosystems is fundamental to understanding nature, and for management purposes.

Biological Diversity (p. 183)

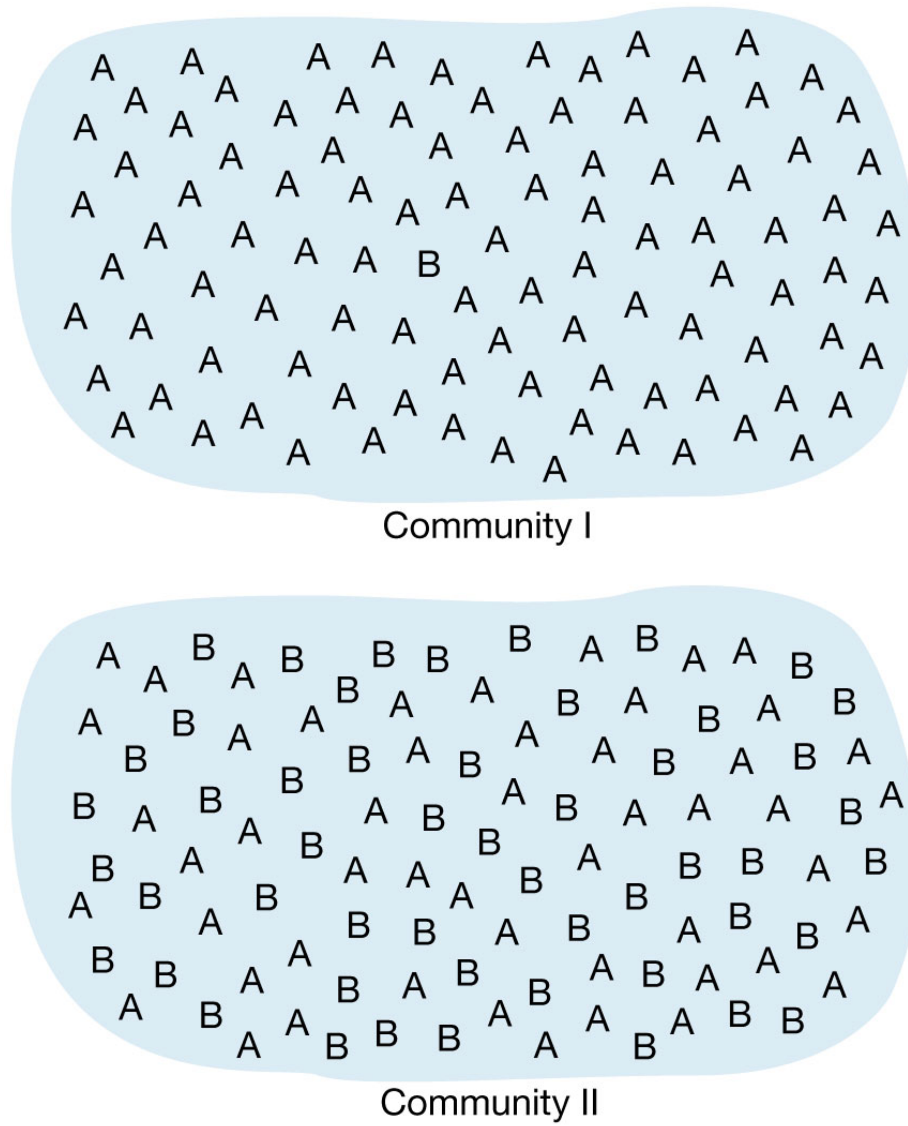
- A marvelous natural phenomenon of esthetic character.
- Highly dynamic over time but at the macroevolutionary scale (speciation and above), probably changes episodically
- The importance of diversity to stability is currently debated and seems to be highly situational (e.g. kind and intensity of disturbance).
- Genetic diversity has to be balanced against functional redundancy.

Biodiversity

- One simple measure is just the number of species in a community
- By this measure, Comm. I at right is just as diverse as Comm. 2 (problem!)
- Simpson's Diversity Index: 1-[(prop. A)^2 + (prop. B)^2 + …]

TABLE 9-2 Diversity of Two Simple Communities

	Number of Individuals, Species A	Number of Individuals, Species B	Simpson's Diversity Index
Community I	99	1	0.02
Community II	50	50	0.50



This (and chapter 9) are very Quick Overviews

- The biota is qualitatively and quantitatively fundamental to the behavior of the earth system
- Reference to the biota (especially including man) is incorporated in all remaining chapters of this excellent text.

Molecular Phylogeny

- **Based on ribosomal RNA**
- Look at the genetic code (*based on a particular fragment of ribosomal RNA*) of present-day organisms and measure how similar or different various organisms are from each other.
- Organisms that are genetically similar represent relatively recent evolutionary divergence
- Organisms that are very different from each other genetically represent evolutionary branching that occurred a long time ago.
- When you assemble the information from a large number of organisms, you come up with the phylogenetic tree.

- Hyperthermophilic chemoautotrophs
- Evidence from C isotope fractionation - but how?
- Anoxygenic photosynthesis, perhaps iron reducers very early
- Methanogens occur fairly close to the root of the molecular "tree of life"
- Is there a modern analog?