Environmental Science

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1. Ecology

Scope, Biosphere, Ecosystem

Structural and Functional Attributes of Ecosystem, Natural Cycles

Energy Flow, Food Chain and Food Web

Biodiversity

Sustainable development, Man and Environment

I. What is ecology?

origin of word:

oikos = the family household
logy = the study of

interesting parallel to *economy* = management of the household

many principles in common – resources allocation, cost-benefit ratios

definitions:

Haeckel (German zoologist) 1870: “By ecology we mean the body of knowledge concerning the economy of Nature - the investigation of the total relations of the animal to its inorganic and organic environment.”

Burdon-Sanderson (1890s): Elevated Ecology to one of the three natural divisions of Biology: Physiology - Morphology – Ecology

Andrewartha (1961): “The scientific study of the distribution and abundance of organisms.”

Odum (1963): “The structure and function of Nature.”

Definition we will use (Krebs 1972):

“Ecology is the scientific study of the processes regulating the distribution and abundance of organisms and the interactions among them, and the study of how these organisms in turn mediate the transport and transformation of energy and matter in the biosphere (i.e., the study of the design of ecosystem structure and function).”

The goal of ecology is to understand the principles of operation of natural systems and to predict their responses to change.

II. Why study ecology?

Curiosity – How does the world around us work? How are we shaped by our surroundings?

Responsibility – How do our actions change our environment? How do we minimize the detrimental effects of our actions? Overfishing, habitat destruction, loss of biodiversity, climate change.

Nature as a guide – The living world has been around much longer than we have and has solved many problems with creative solutions. Ecological systems are models for sustainability. How can we feed our growing population? Where will we live?

Sustainability – a property of human society in which ecosystems (including humans) are managed such that the conditions supporting present day life on earth can continue.

Ecology helps us understand complex problems.

Examples:

Birds – Aero planes
Whale – Submarines
Tree structure –Database organization

IV. Where to study ecology?

Organism ← **(Tissues)** ← **Organelle** ← **Molecule** ← **Atom**

↓

Population: Group of interacting and interbreeding organisms.

↓

Community: Different populations living together and interacting.
Populations can interact as competitors, predator and prey, or symbiotically.

↓

Ecosystem: Organisms and their physical and chemical environments together in a particular area.
"The smallest units that can sustain life in isolation from all but atmospheric surroundings."

↓

Biome: Large scale areas of similar vegetation and climatic characteristics.

↓

Biosphere: Thin film on the surface of the Earth in which all life exists, the union of all of the ecosystems. This is a highly ordered system, held together by the energy of the sun.

When is an organism not an organism?

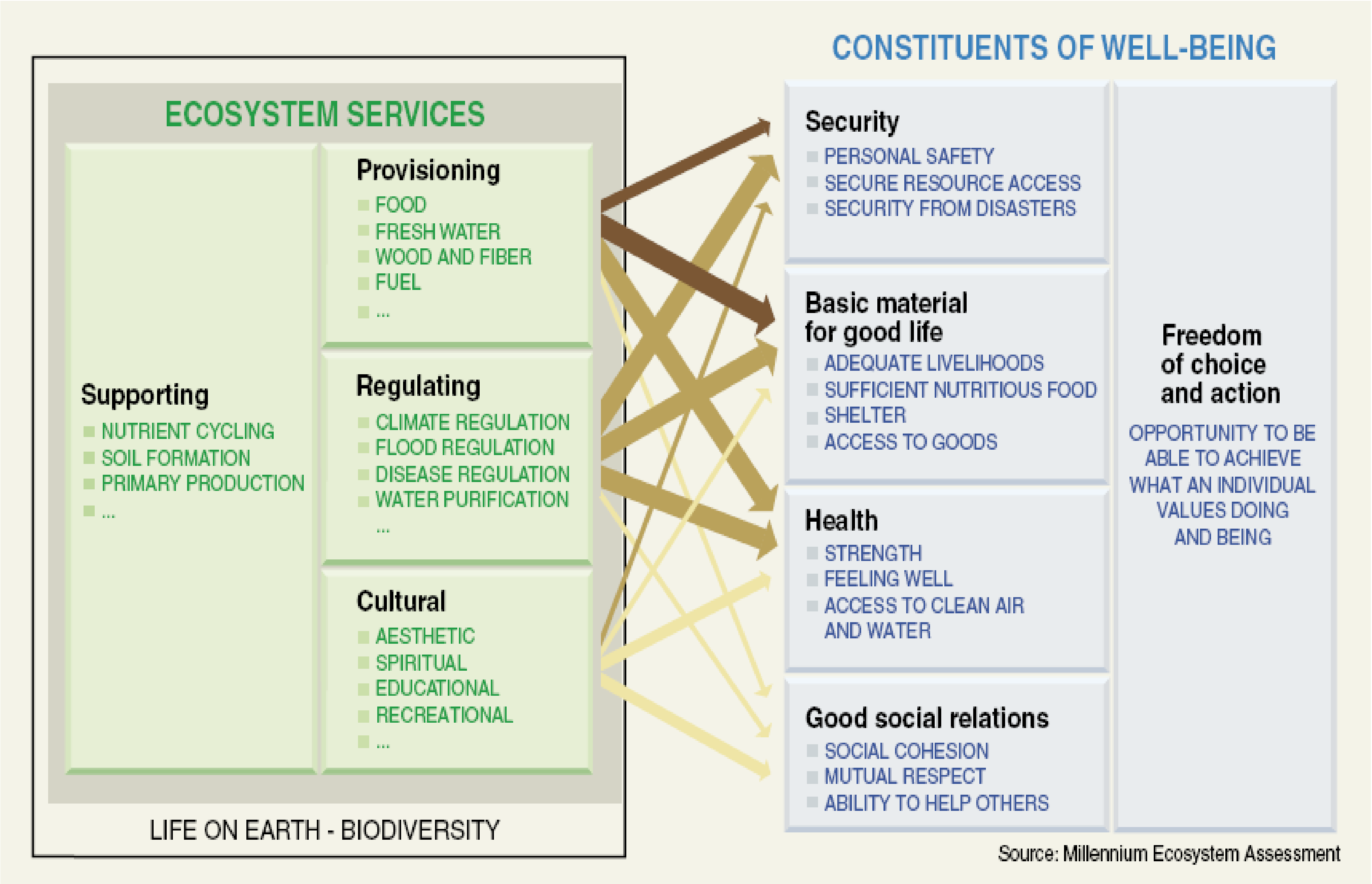
Populations are shaped by their abiotic surroundings, and, in turn, change their abiotic surroundings.
For example, O_2 in atmosphere from photosynthesis. Others?

These levels of organization do not exist in isolation. There are feedbacks between the largest and smallest scales.

Interactions among different levels lead to emergent properties.

Principle of hierarchical control (Odum): "As components combine to produce larger functional wholes in hierarchical series, new properties emerge. That is, one cannot explain all the properties at one level from an understanding of the components at the one below."

Ecosystem Services



MEA 2005

What is an ecosystem?

- Bounded ecological system consisting of all the organisms in an area and the physical environment with which they interact
  - Biotic and abiotic processes
  - Pools and fluxes

Ecosystem Ecology

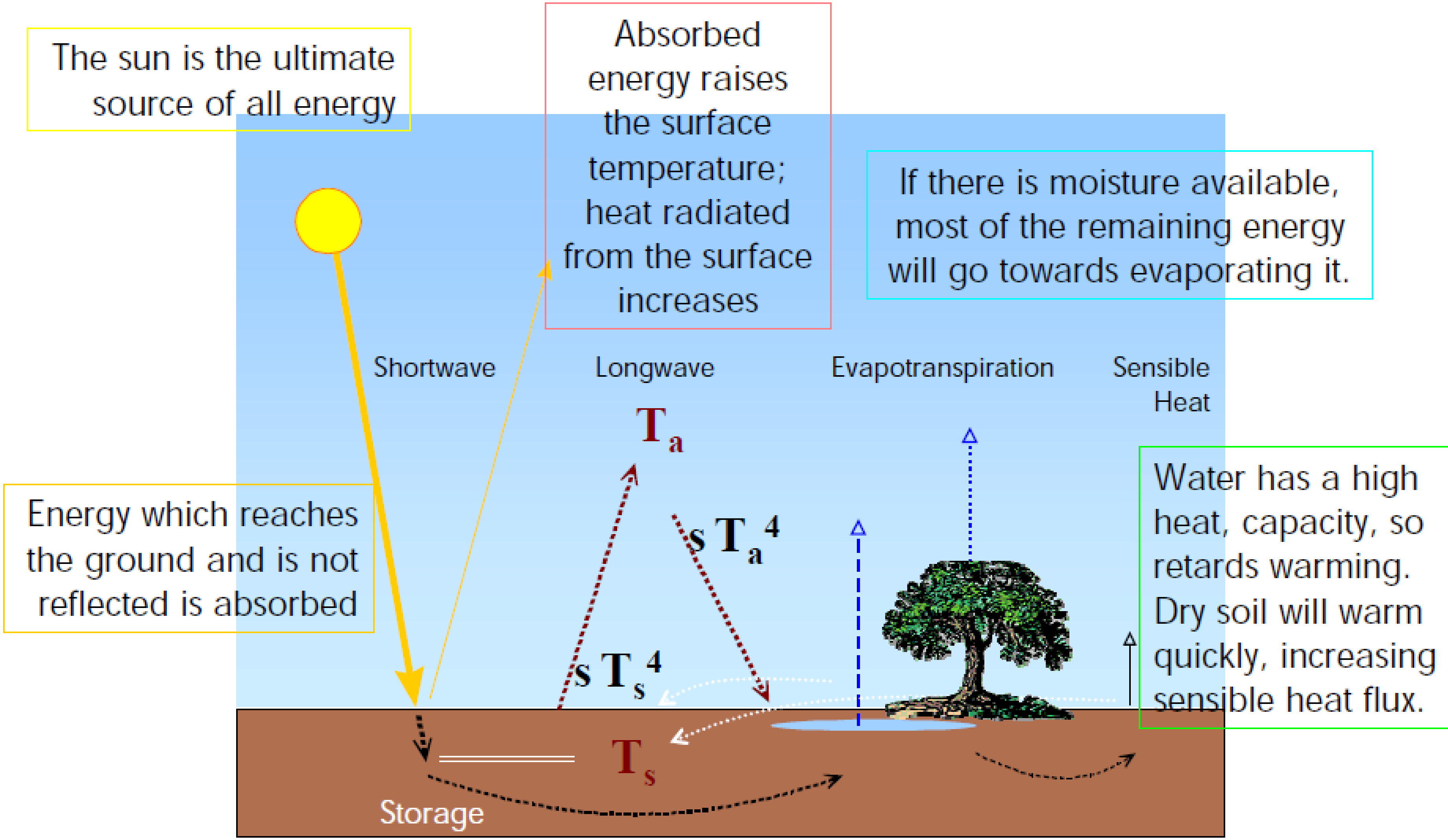
- It's a topic involving the study of Rates, Pools and Processes
- Involves Critical Thinking and Synthesis of Complex, Inter-related Systems

Ecosystem Ecology,

- Physics wins
  - Ecosystems function by capturing solar energy
    - Only so much Solar Energy can be capture per unit are of ground
  - Plants convert solar energy into high energy carbon compounds for work
    - growth and maintenance respiration
  - Plants transfer nutrients and water between air, soil and plant pools to sustain their structure and function
  - Ecosystems must maintain a Mass Balance
    - Plants can't Use More Water or Carbon than has been acquired
- Biology is how it's done
  - Species differentiation (via evolution and competition) produces the structure and function of plants, invertebrates and vertebrates
  - In turn, structure and function provides the mechanisms for competing for and capturing light energy and transferring matter,
  - Bacteria, fungi and other micro-organisms re-cycle material by exploiting differences in redox, passing electrons and extracting energy
  - Reproductive success that passes genes through the gene pool.

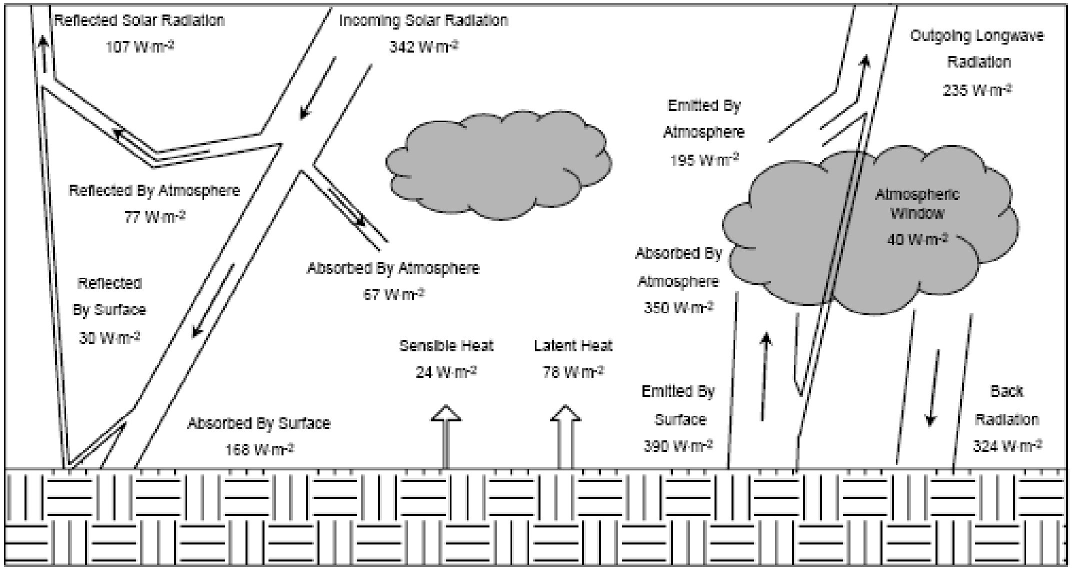
- Ecosystem Ecology involves
  - Capture and conversion of solar energy by autotrophs (plants)
  - Utilization of that energy by heterotrophs, herbivores, and higher trophic levels
  - Cycling of material between the atmosphere, biosphere and pedosphere

Energy Balance Over Land



The atmosphere absorbs 67 W m-2 of solar radiation and 350 W m-2 of long wave radiation from the surface; it emits 195 W m-2 of long wave radiation to space and 324 W m-2 onto the surface.
The excess loss of radiation compared with absorption is -102 W m-2.

Earth's Annual Global Energy Budget



- The surface gains 168 W m-2 of solar radiation and 324 W m-2 of long wave radiation from the atmosphere while emitting 390 W m-2 of long wave radiation.
- This gives the surface a net surplus of 102 W m-2. This surplus energy is returned to the atmosphere as sensible heat (24 W m-2) and latent heat (78 W m-2).

These heat fluxes arise as winds carry heat (sensible heat) and moisture (latent heat) away from the surface.

Over land, sensible and latent heat are important determinants of microclimates.

Microclimates are the climate near the ground and represent local climates due to topography, vegetation, soils, landforms, and structures.

It's all in the fluxes

Basic notions of the land's effects on climate (mean, diurnal cycle, seasonal cycle)

- Momentum
  - Orographic drag, surface roughness, turbulence
- Radiation
  - Solar radiation absorbed, reflected (albedo); longwave radiation
- Heat
  - Sensible heat (conduction), Latent heat (evaporation), Heat storage
- Moisture
  - Precipitation, evaporation, transpiration
- Aerosols
- Trace Gases

These fluxes are the means of communication between land and atmosphere

Ocean versus Land

Water

- Flows (x,y: 1y; z: 10^2y)
- High heat capacity (4.2×10^6 J m^{-3} K^{-1})
- Moderate heat conductivity (0.6 J m^{-1}K^{-1}s^{-1})
- Dark (a=0.05)
- Evaporation at potential rate

Dry Soil

- Stationary (essentially)
- Low heat capacity ($0.6\text{-}1.3\times10^6$ J m^{-3} K^{-1})
- Low heat conductivity (0.08-0.2 J m^{-1}K^{-1}s^{-1})
- Light (a=0.13-0.50)
- No evaporation

Vegetation

- Varies with time (species, density, color, coverage)
- Canopy creates microenvironment for radiation, heat exchange, interception of rain and snow
- Generally Dark (a=0.08-0.25)
- Transpiration controlled by photosynthesis, moisture stress

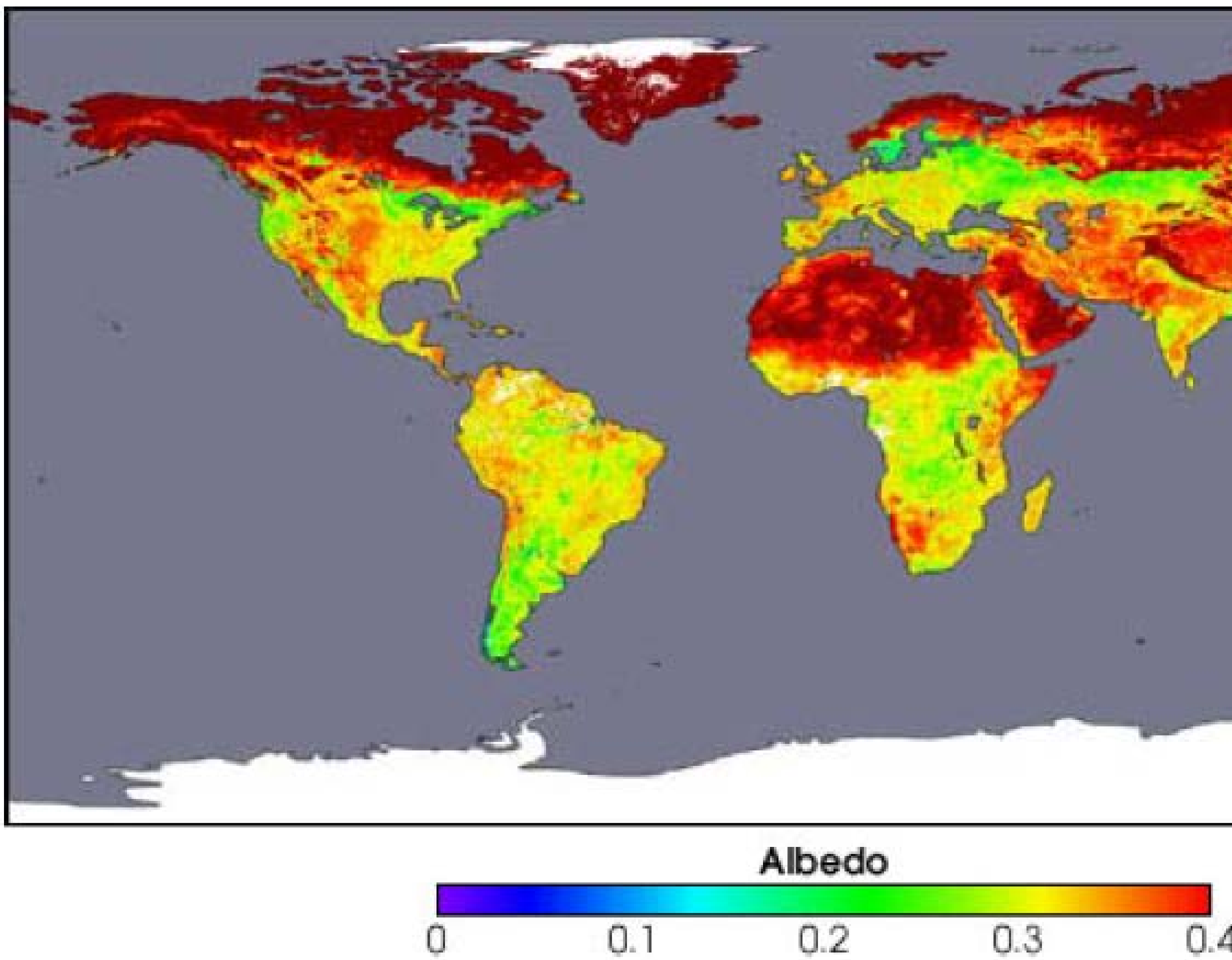
Wet Soil

- Water flows (x,y: 0-30d; z: 0-10^4y)
- Moderate heat capacity ($2.2\text{-}2.9\times10^6$ J m^{-3}K^{-1})
- High heat conductivity (0.8-1.7 J m^{-1}K^{-1}s^{-1})
- Not as light (a=0.1-0.4)
- Evaporation is a function of soil moisture

ECOLOGICAL ENERGETICS – ENERGY FLOW

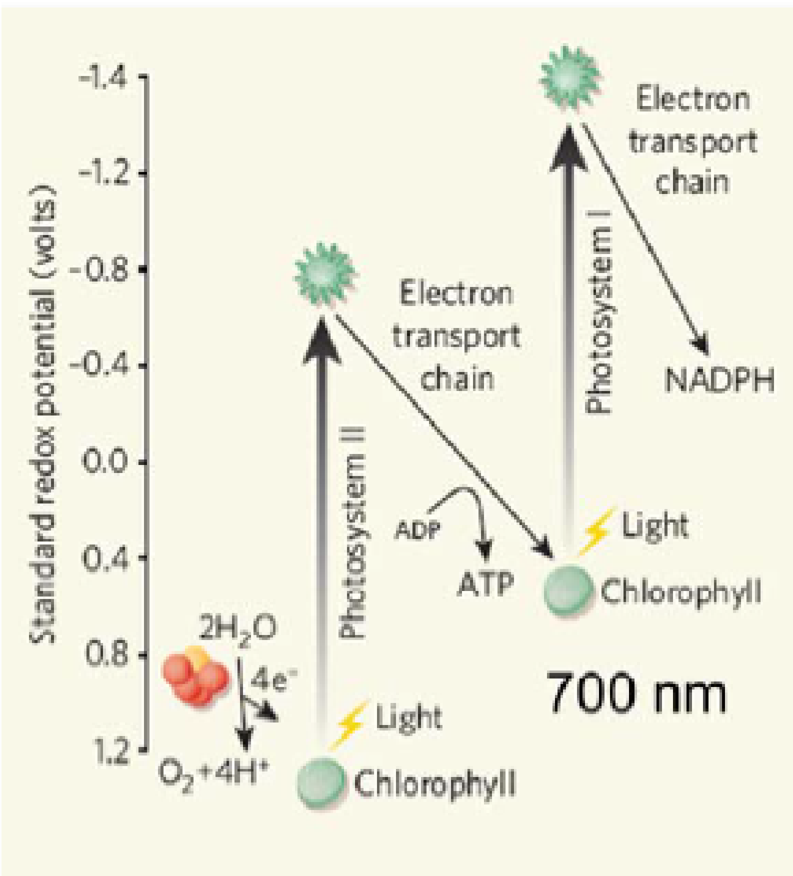
Light: Solar Energy

GLOBAL ALBEDO



Solar Energy Produces Chemical Energy Used by Life

Light ('Hill') Z Reactions: PS II and Ps I



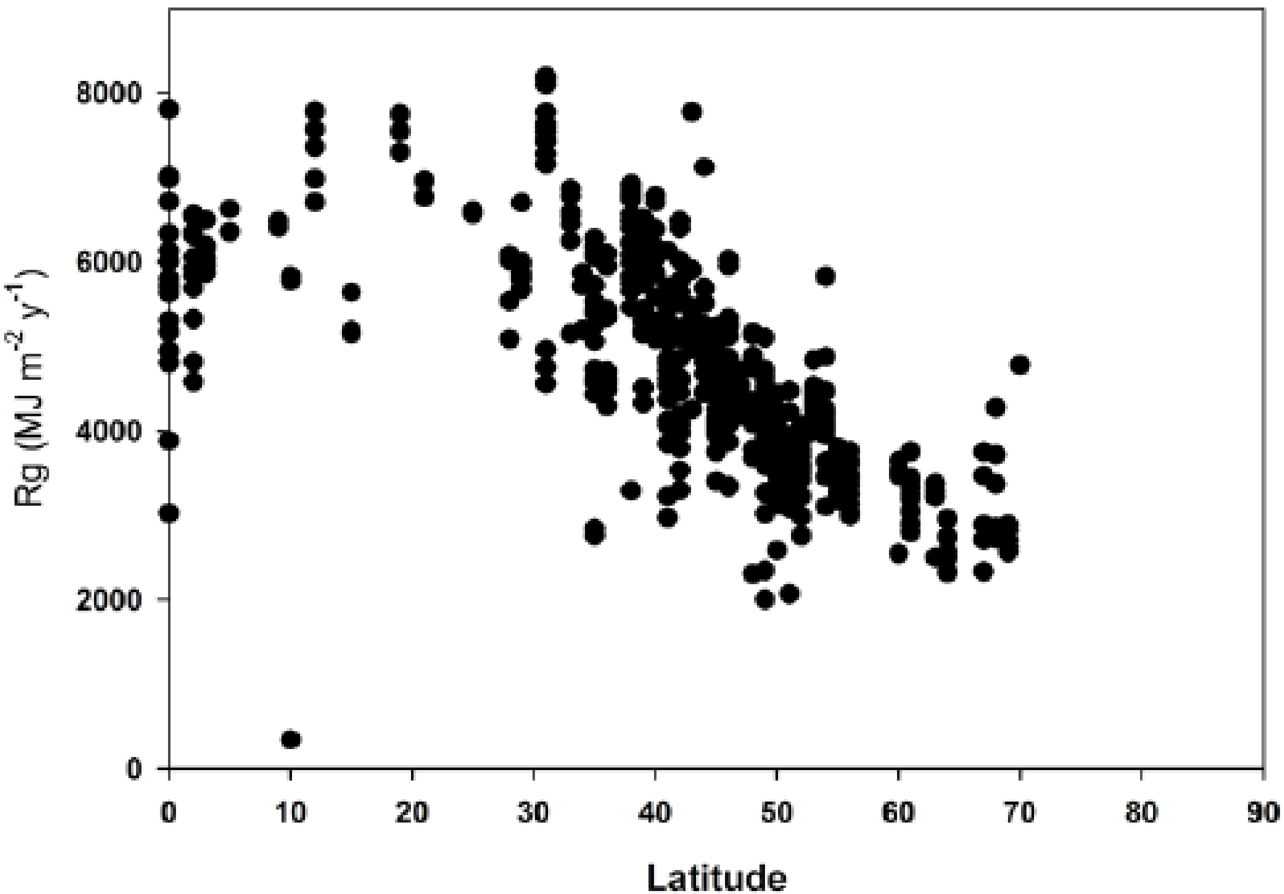
700 nm

680 nm

- Light Energy (400 to 700 nm) is absorbed by pigments
- This energy splits water and releases 4 electrons, e-
- These Electrons produce biochemical energy compounds, ATP and NADPH
  - Photosystem II uses 680 nm energy to generate ATP (non-cyclic electron transport)
  - PS I uses 700 nm solar energy to generate NADPH (cyclic electron transport).
- 8 Photons per CO_2 molecule are fixed
- Excess energy is lost as heat or fluorescence.

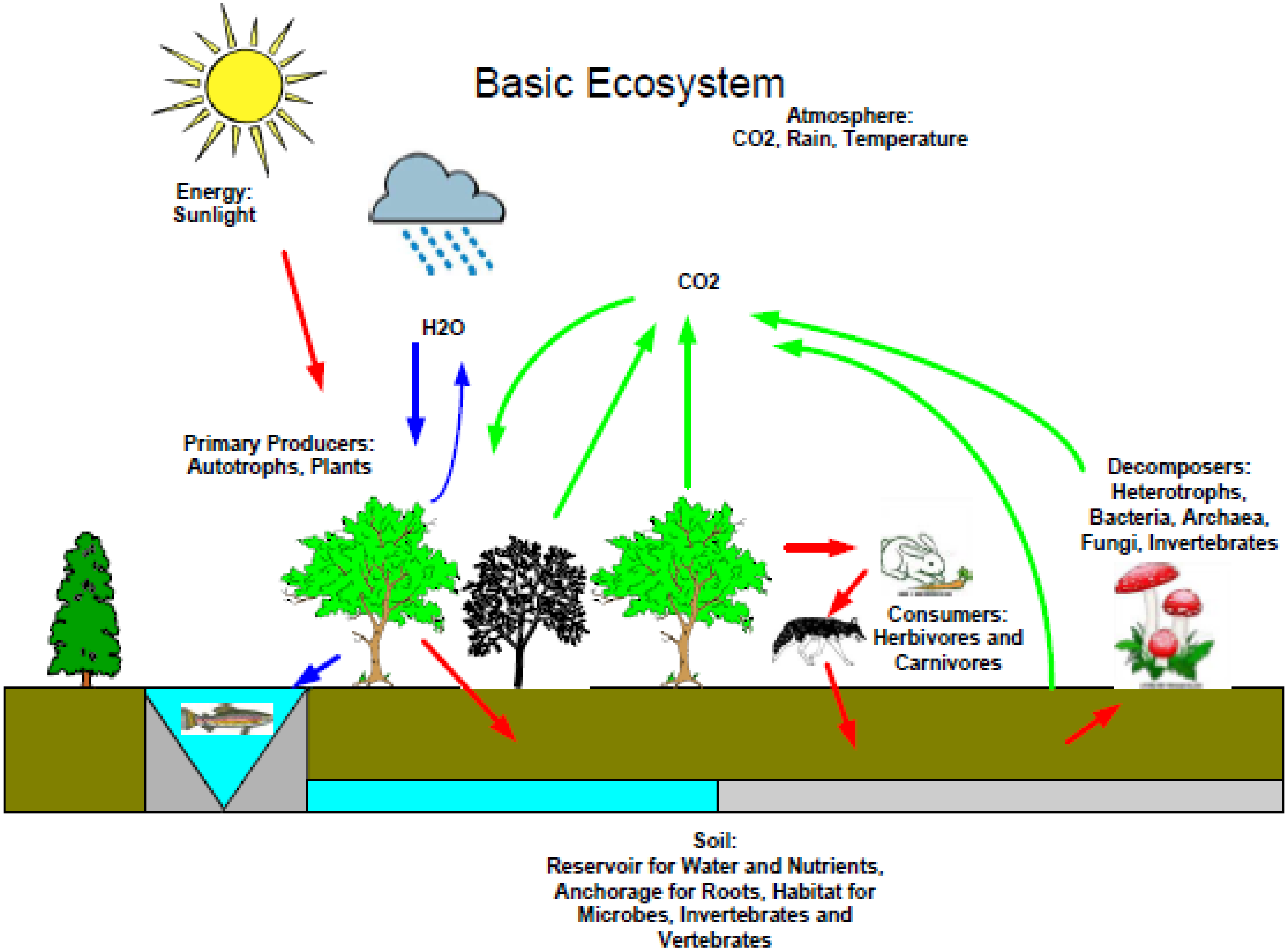
Energy Drives Metabolism:
How Much Energy is Available and Where

FLUXNET database



Solar Radiation Decreases with increaseing Latitude, except near the Tropics due to Clouds

Basic Ecosystem

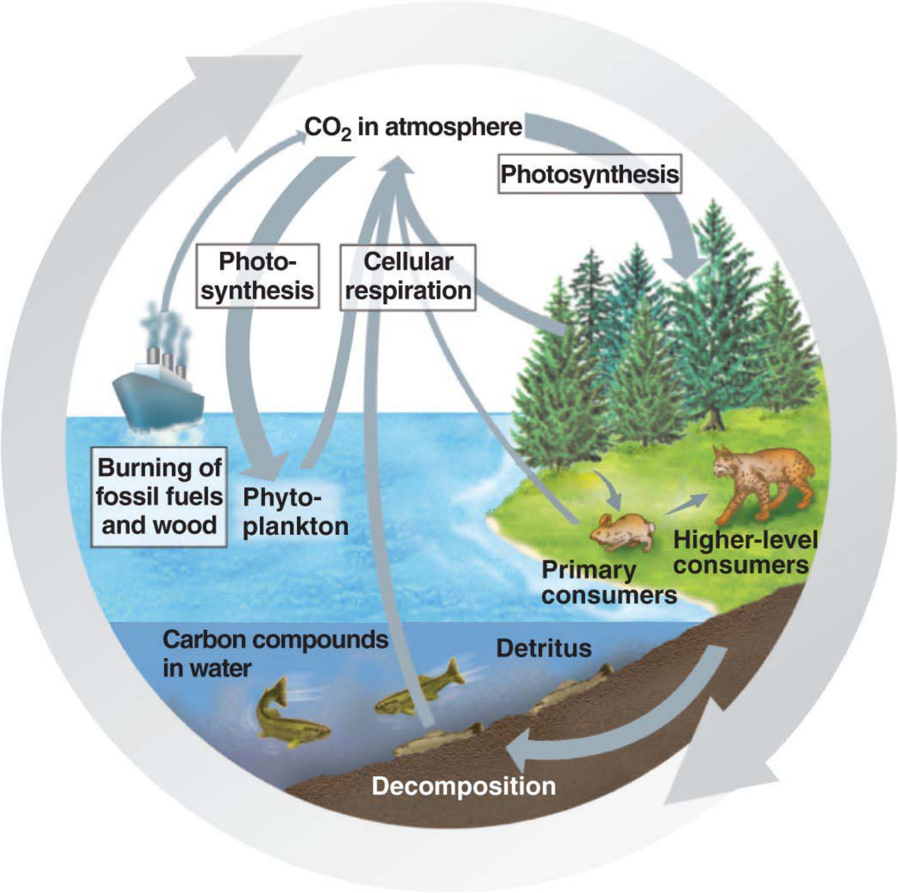


Challenge to Ecosystem Ecology is to Define the Rates/Velocities associated with the Arrows and the Size of the Pools

The Carbon Cycle

- Carbon-based organic molecules are essential to all organisms

- Carbon reservoirs include fossil fuels, soils and sediments, solutes in oceans, plant and animal biomass, and the atmosphere



- CO_2 is taken up via photosynthesis and released via respiration

- Volcanoes and the burning of fossil fuels contribute CO_2 to the atmosphere

Carbon dioxide is the most widely discussed greenhouse gas.

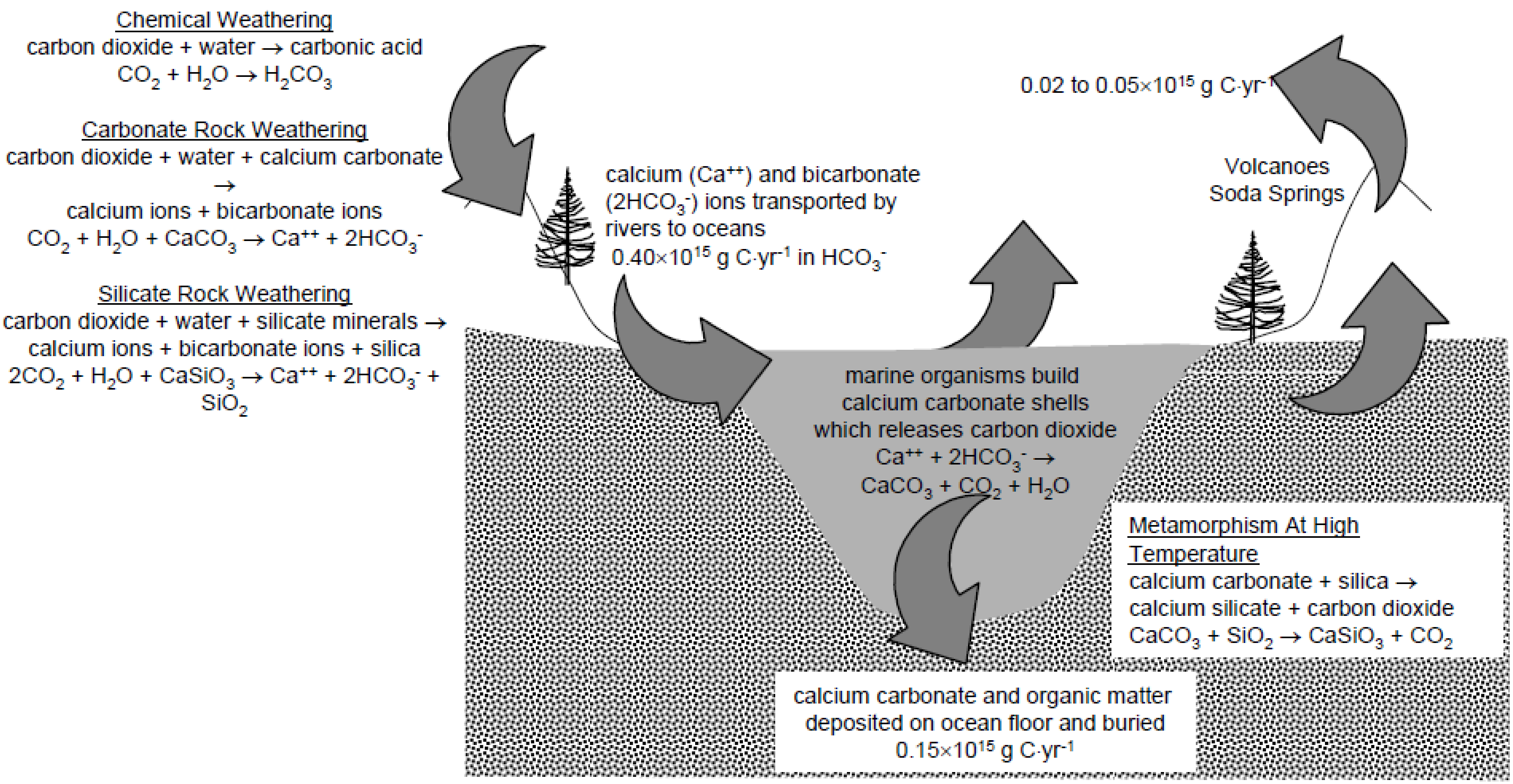
Its current concentration in the atmosphere is about 365 parts per million by volume (ppm), which is the result of geological processes, biological processes, and human activities.

Of the some 10^{23} g of carbon on Earth, all but a small portion is buried in sedimentary rocks.

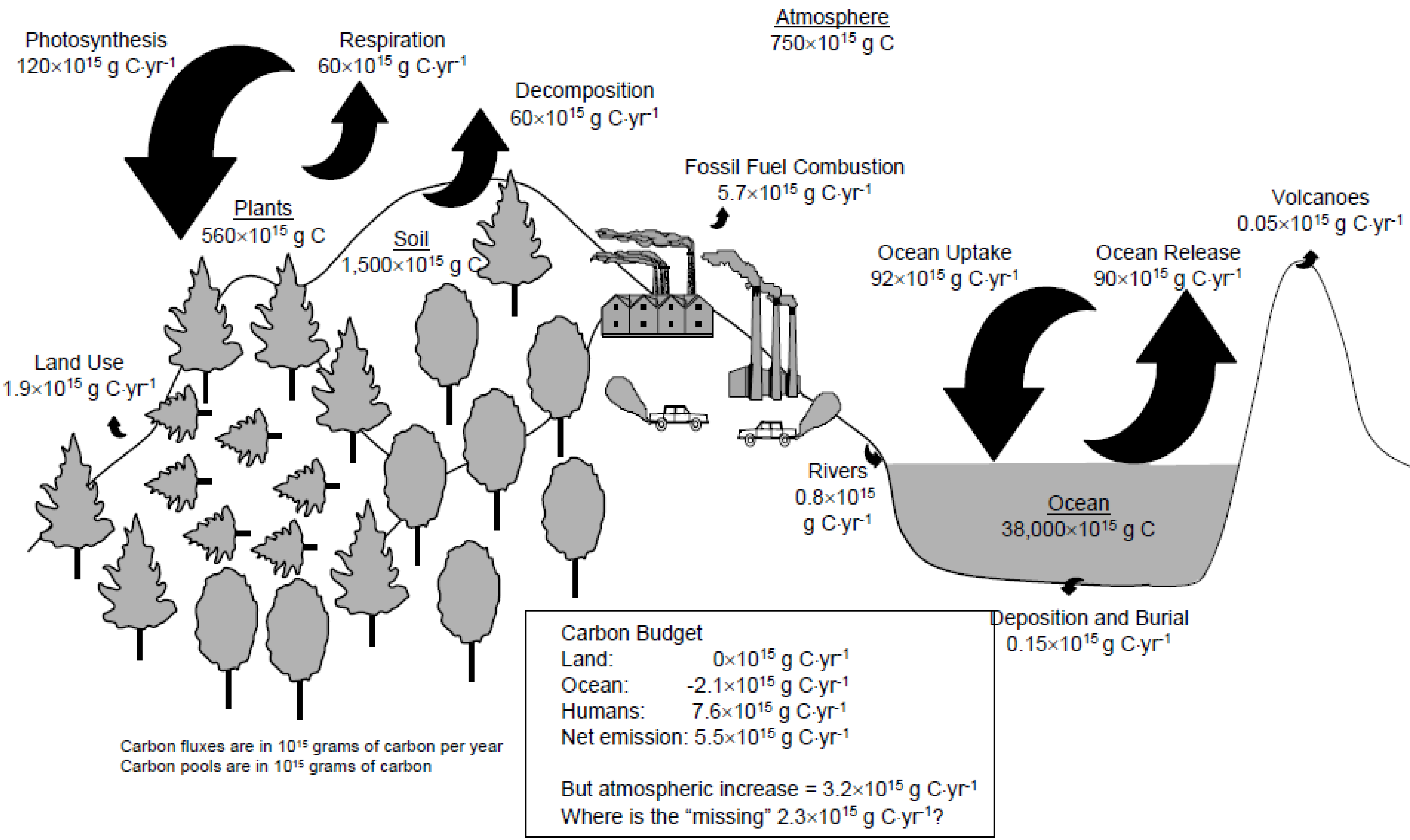
Only about 0.04% of this carbon (40 000 × 10^{15} g) is in biologically active pools near Earth's surface, and of this the vast majority (38 000 × 10^{15} g) is contained in oceans.

Plants and soil contain 2060 × 10^{15} g C. The atmosphere has the least carbon: 750 × 10^{15} g C.

Geochemical Carbon Cycle

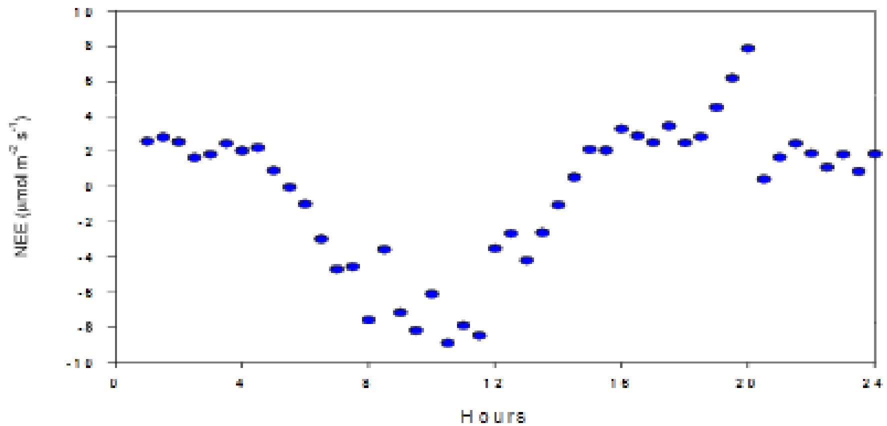


Global Carbon Cycle

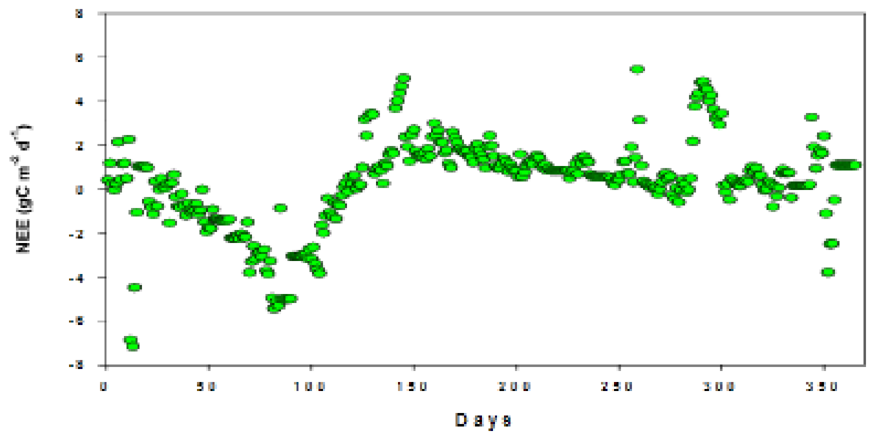


Time Scales of CO_2 Fluxes

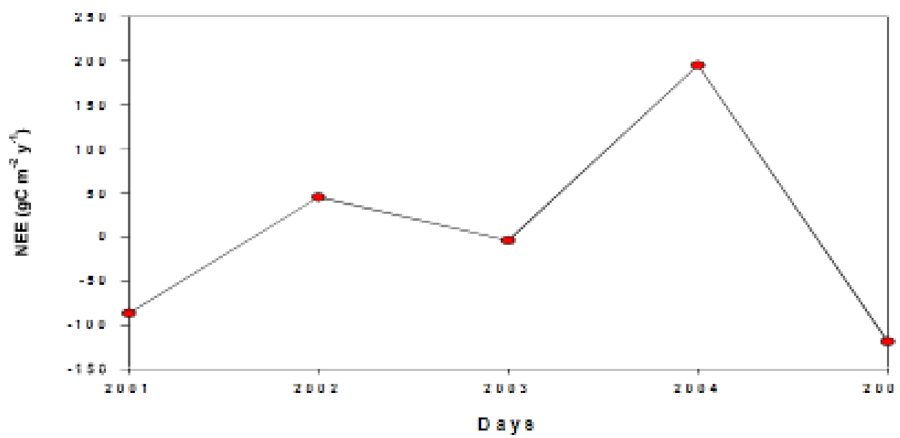
Diurnal Pattern



Seasonal Pattern



Interannual



How much is C in the Air?

- Mass of Atmosphere
  - F=Pressure x Area=g x Mass
  - Surface Area of the Globe = $4\pi R^2$
  - M_{atmos} = 101325 Pa 4π $(6378\ 10^3\ m)^2/9.8\ m^2\ s^{-1}$=
  - 5.3 10^{21} g air
- Compute C in Atmosphere @ 380 ppm

$$M_{atmos} = \frac{P \cdot 4\pi R^2}{g}$$

$$M_c = M_{atmos} \frac{p_c}{P} \frac{m_{co2}}{m_a} \frac{m_c}{m_{co2}} = 833 \cdot 10^{15}\, gC$$

- Each 2.19 GtC emitted causes a 1 ppm increase in Atmospheric CO_2

CO_2 in 50/100 years Business as Usual?

- Current Anthropogenic C Emissions
  - 7 GtC/yr, (1 GtC = 10^{15} g=1Pg)
  - 45% retention in Atmosphere
- Net Atmospheric Efflux over 50 years
  - 7 * 50 * 0.45 = 157 GtC
- Atmospheric Burden over 50 years
  - 833 (@380 ppm) + 157 = 990 GtC,
- Conversion back to mixing ratio
  - 451 ppm (2.19 Pg/ppm) or 1.6 x pre-industrial level of 280 ppm
- To keep atmospheric CO2 below 450 ppm the world must add less than157 GtC into the atmosphere over the next 100 to 200 years.

CO_2 in 50 years, at Steady-State

- 8 GtC/yr, Anthropogenic Emissions
  - 45% retention
- 8 * 50 * 0.45 = 180 GtC, integrated Flux
- Each 2.19 GtC emitted causes a 1 ppm increase in Atmospheric CO_2
- 833 (@380 ppm) + 180 = 1013 GtC, atmospheric burden
- 462 ppm with BAU in 50 years
  - 1.65 times pre-industrial level of 280 ppm
- BAU C emissions will be ~ 16 to 20 GtC/yr in 2050
- To stay under 462 ppm the world can only emit 400 GtC of carbon, gross, into the atmosphere!

Carbon Emission and Ecosystem Services

- US accounts for about 25% of Global C emissions
  - $0.25*7.0\ 10^{15}$ gC = $1.75\ 10^{15}$ gC
- Per Capita Emissions, US
  - $1.75\ 10^{15}$ gC/300 10^{6} = $5.833\ 10^{6}$ gC/person= 5.833 mtC
- Ecosystem Service, net C uptake
  - ~100 gC m^{-2}
- Land Area per Person
  - $3.03\ 10^{4}\ m^{2}$/person = 3.03 ha/person
- US Land Area
  - $9.1\ 10^{8}$ ha
  - $1.75\ 10^{9}$ ha needed by US population to offset its C emissions Naturally!

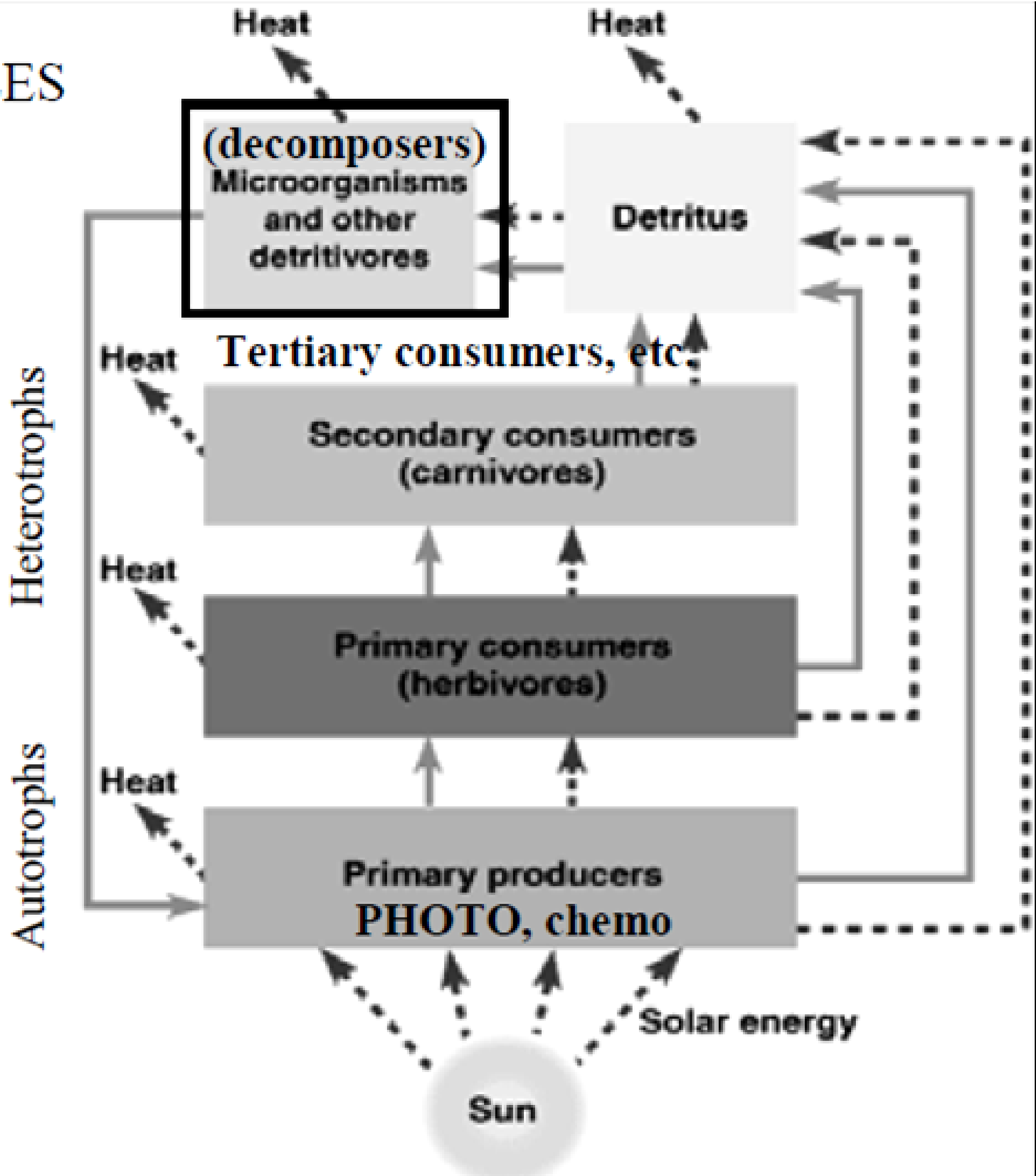
ECOSYSTEM PRINCIPLES

1- Energy flow
2- Chemical cycling

ENERGY- Cannot be recycled, flows through ecosystems, from an external source, enters as light exits as heat.

MATTER- Cycles within ecosystems.

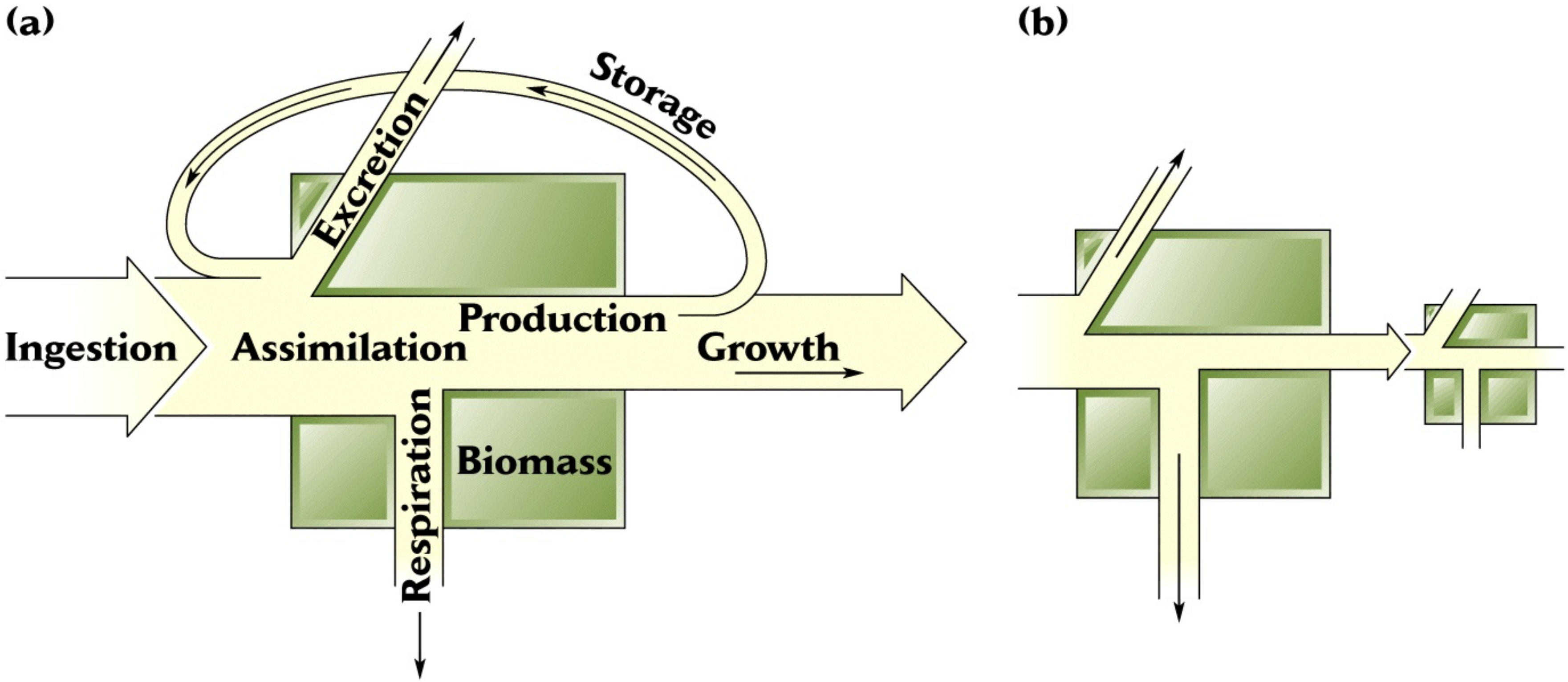
Energy flow and chemical cycling described by grouping species in a community into trophic levels according to main source of nutrition and energy



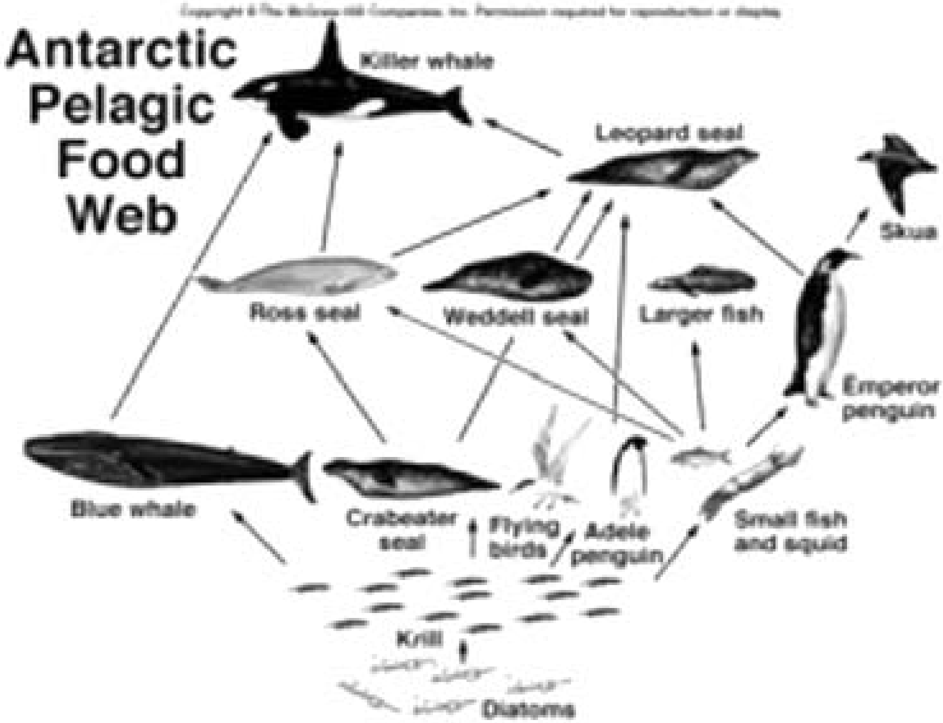
1953 Eugene Odum – model Energy flow, later adapted for nutrients as well

(1) Energy flows in one direction, absorbed light is lost as heat or transferred into chemical energy through photosynthesis (**Annual Gross Primary Production**) by **autotrophic** organisms.

(2) Autotrophs spend some energy to respire, other goes into growth, which becomes available to **heterotrophs** at the next higher level (**Annual Net Primary Production**)



A. Food chains are simplifications of food webs



Simplified food web

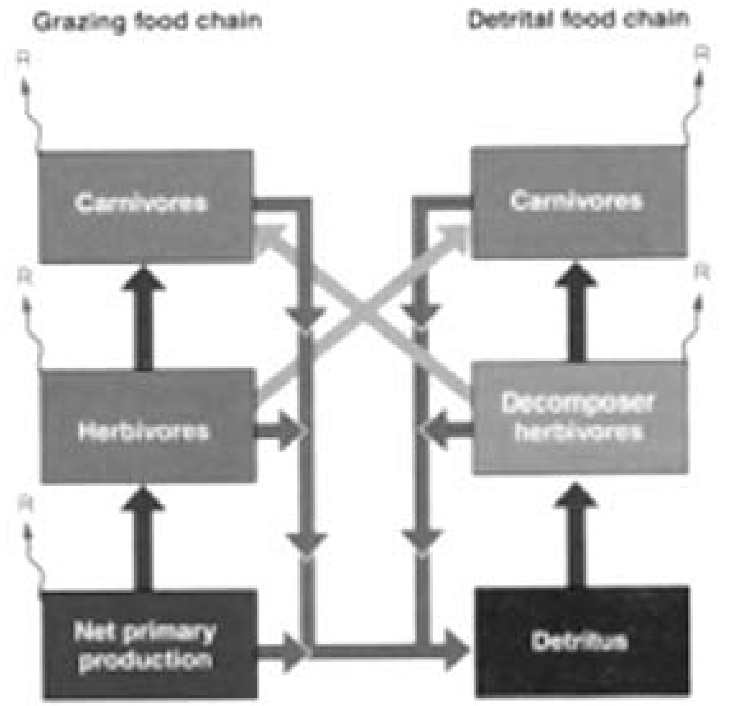
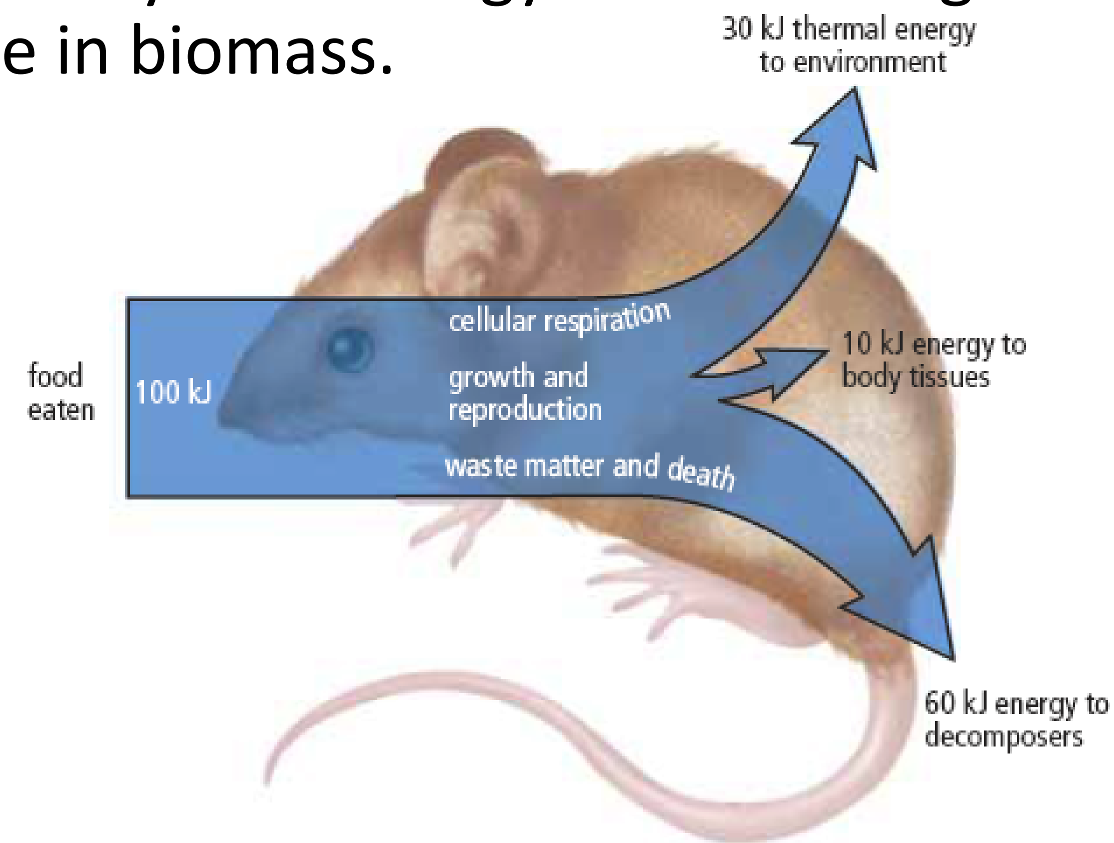


FIGURE 24.24 Grazing and detrital food chains from Figure 24.21 combined, showing their connections. R = respiration

- Each level loses large amounts of the energy it gathers through basic processes of living.
- 80 – 90 percent of energy taken in by consumers is used in chemical reactions in the body and is lost as thermal energy.
- There is very little energy left over for growth or increase in biomass.

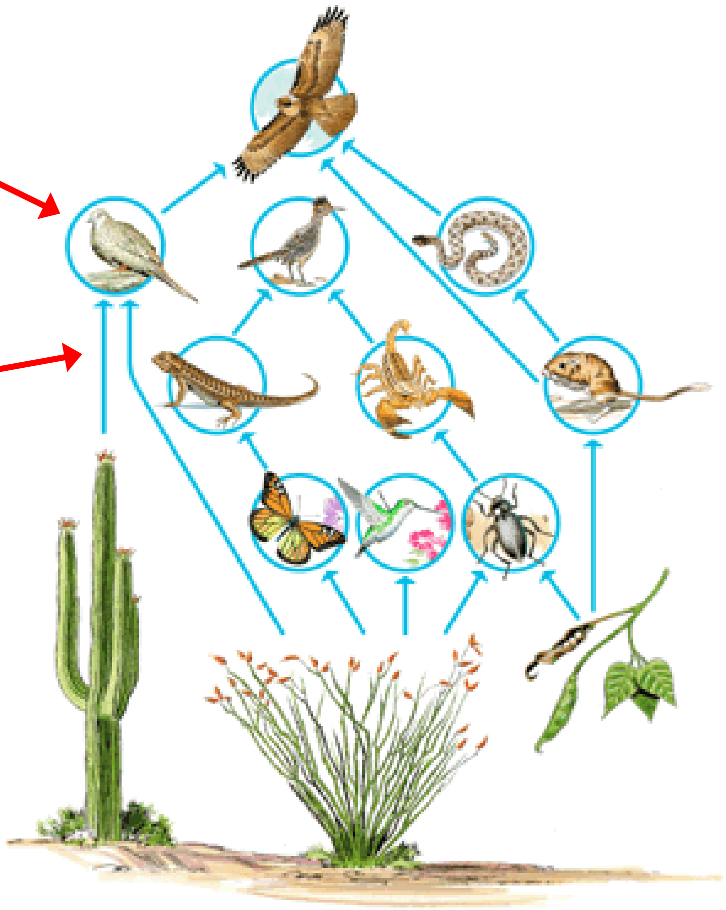


Food Webs

Trophic (energy & nutrition) relationships among organisms

Nodes
Taxonomic or functional categories

Links
Flow of material (including energy-rich molecules)



Paine, R. T. (1966) – Food webs are the "*ecologically flexible scaffolding around which communities are assembled and structured*"

Provenance of image unknown

Food Webs

Elton (1927) observed that predators tend to be larger & less numerous than their prey – **"pyramid of numbers" (a.k.a. "Eltonian pyramid")**

Elton's hypothesis: Predators must be larger than prey to subdue them

Pyramid could represent numbers, biomass, energy consumed per year, *etc*.

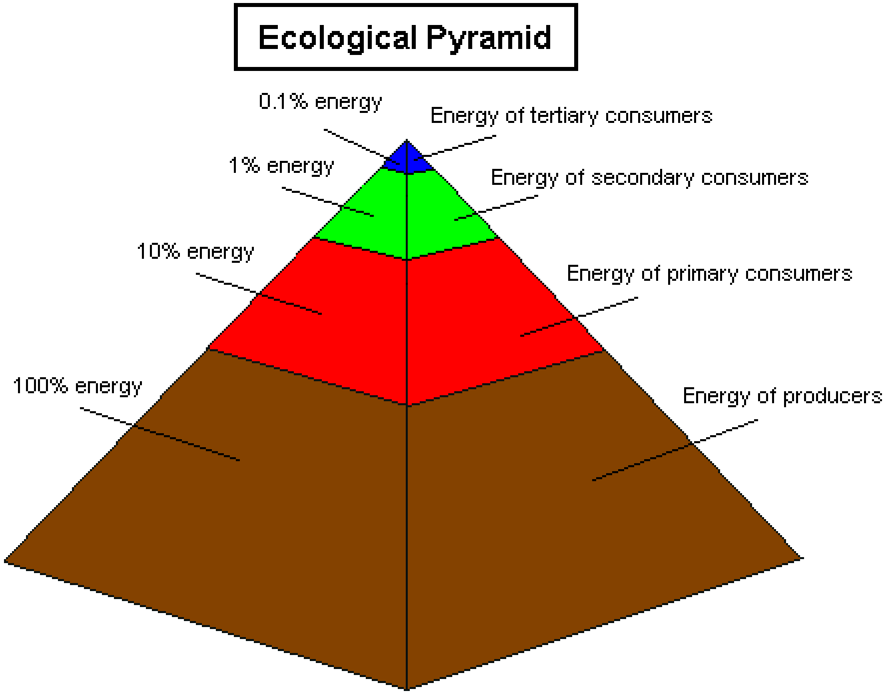
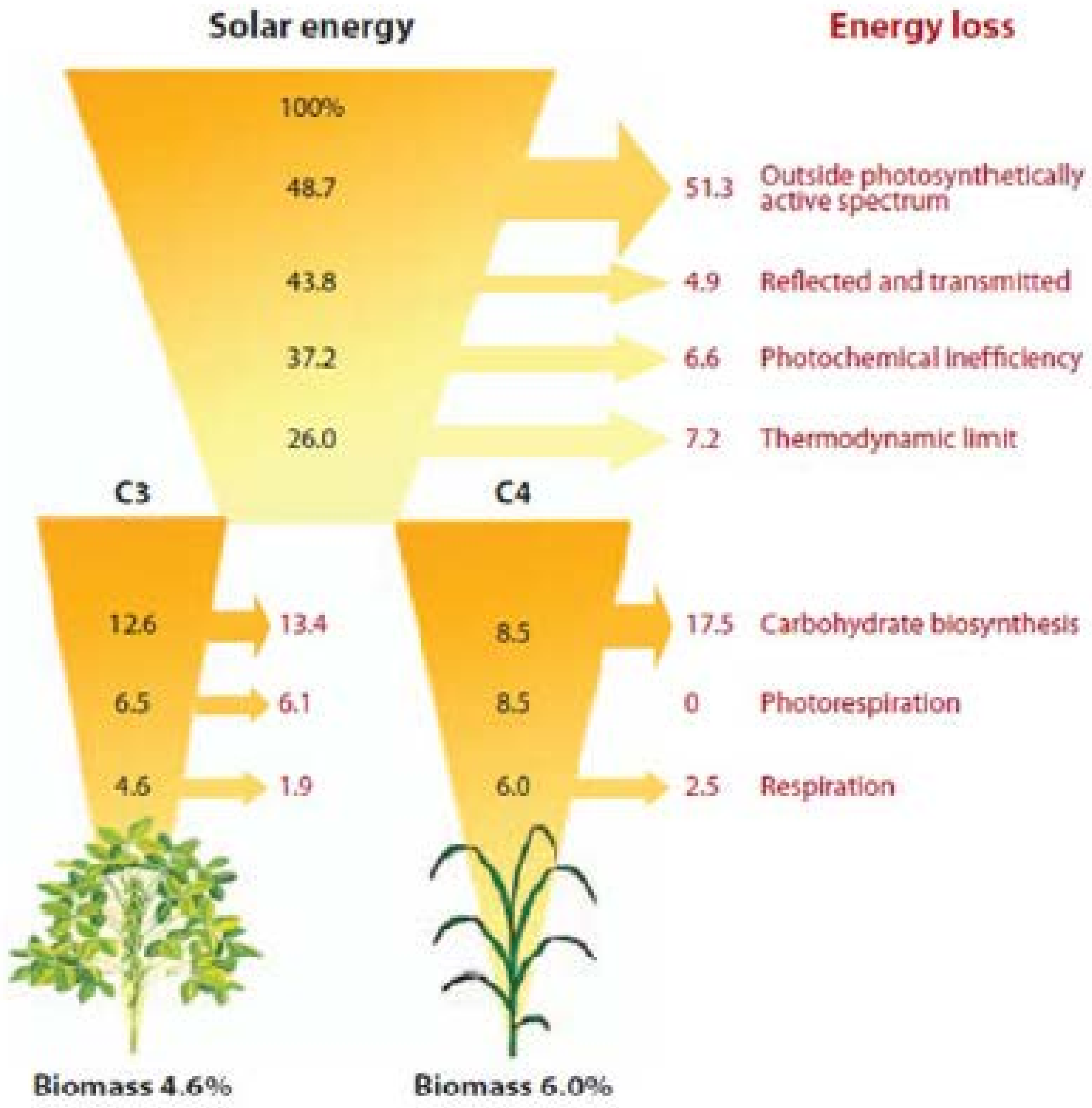


Image from http://mrskingsbioweb.com/ecology.html

Eating the Sun: Converting Solar Energy to Biomass on an Ideal Summer Day Not the Annual Efficiency



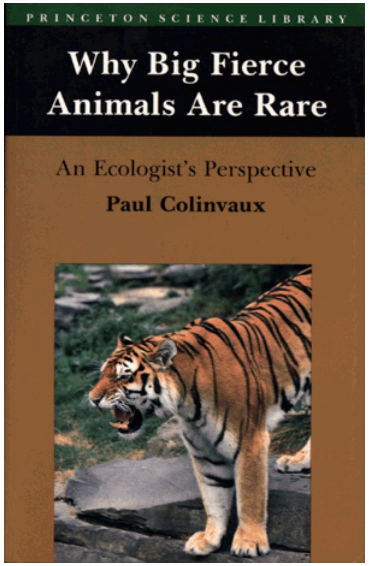
Food Webs

Lindeman (1942) introduced the "**energy-efficiency hypothesis**" – the fraction of energy entering one trophic level that passes to the next higher level is low (~ 5 - 15%)

The **first** and **second laws of thermodynamics** predict inefficiency:

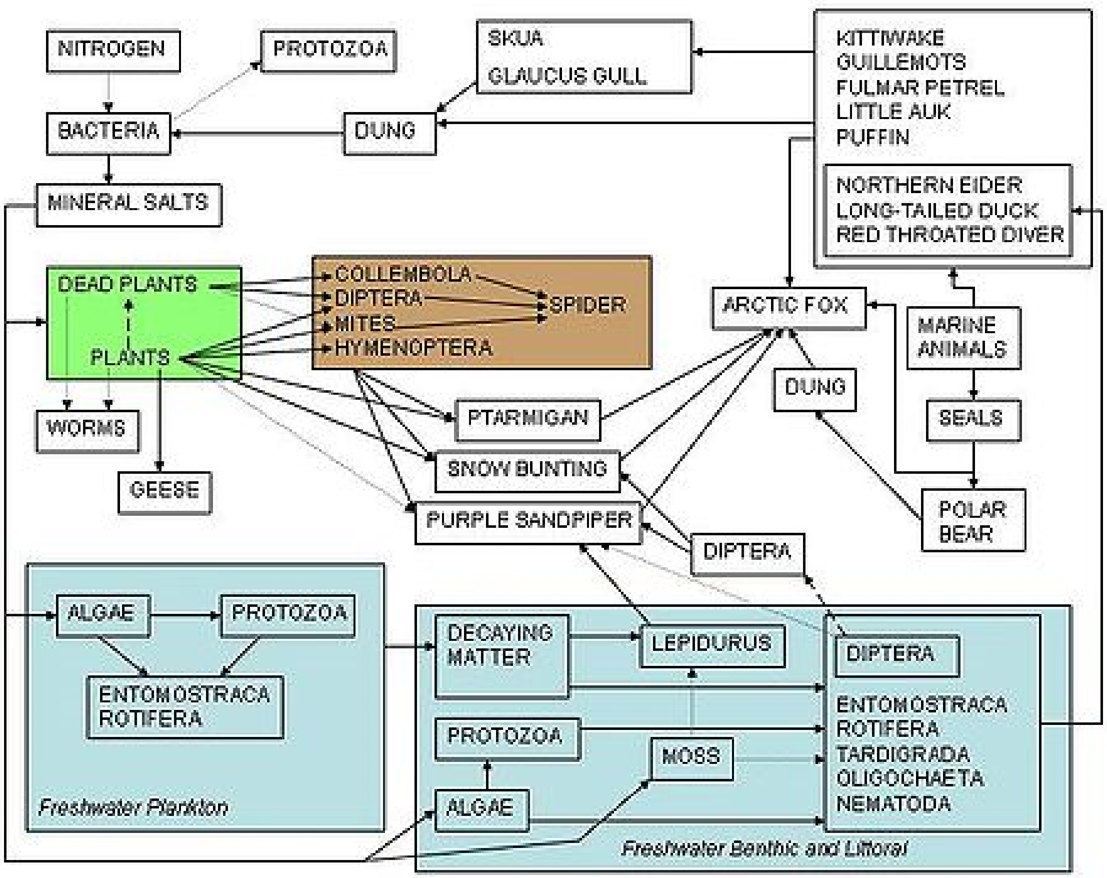
1st Law = Conservation of Energy

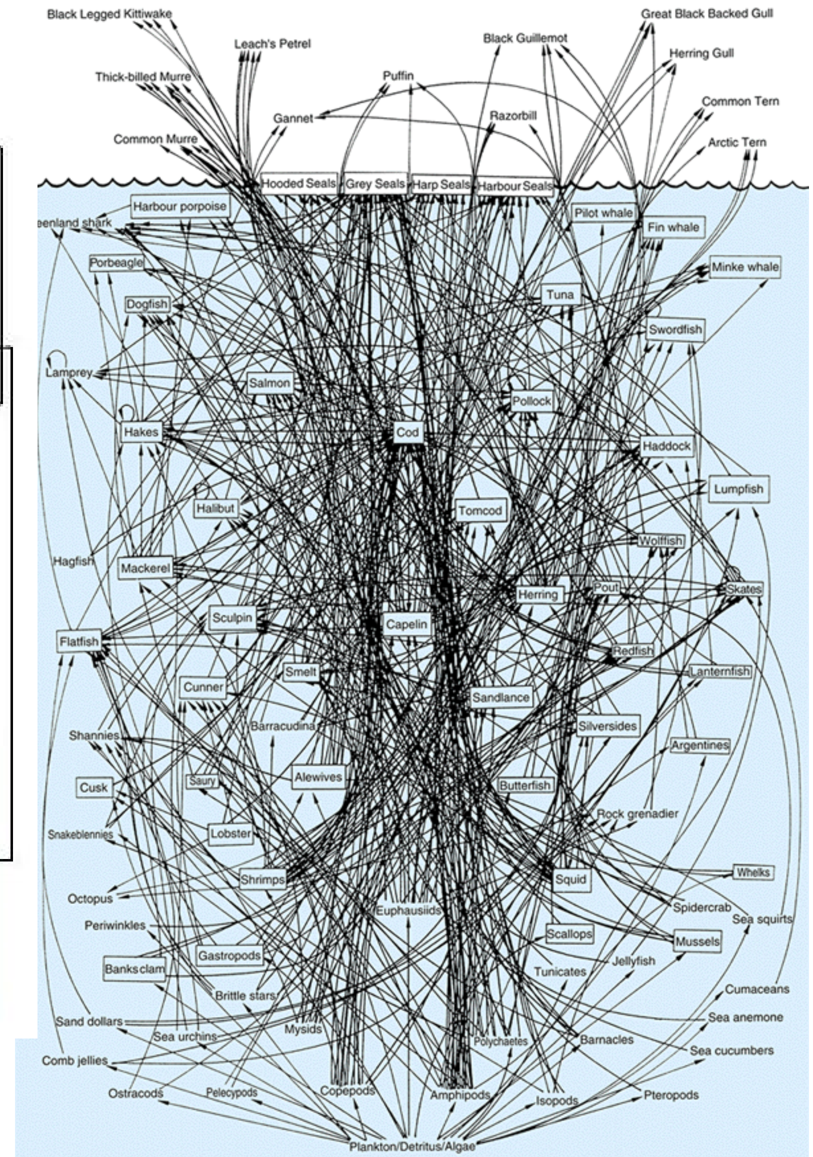
2nd Law = Energy transformations result in an increase in entropy, *i.e.*, only a fraction of the energy captured by one trophic level is available to do work in the next



Inverted pyramids of biomass can occur (*e.g*., whales, krill, phytoplankton in southern oceans), but only when productivity and turnover of producers is extremely high

Food Webs
Multiple-species interactions





A simplified food web for the Northwest Atlantic

Food Webs - *stability*

Connectance (*c*): Number of *links* (*L*) or connections between species (*S*) or nodes – expressed as a proportion of maximum connectance:

$$c = t_L / [S(S\text{-}1)/2]$$

Treatment	N	t_L	max t_L	C
Original MS† food web, with 3 *Littorina* species aggregated	8	10	28	.36
Original MS† food web, but with 3 *Littorina* species disaggregated	10	14	45	.31
Edwards et al.‡ reconstruction of original MS web	11	24	55	.44
Edwards et al.‡ reconstruction with birds-mammals-fish and 3 *Littorina* species all disaggregated	15	48	105	.46
As above, but with heterogeneous groups (plankton, algae, and decomposers) removed	12	40	66	.61

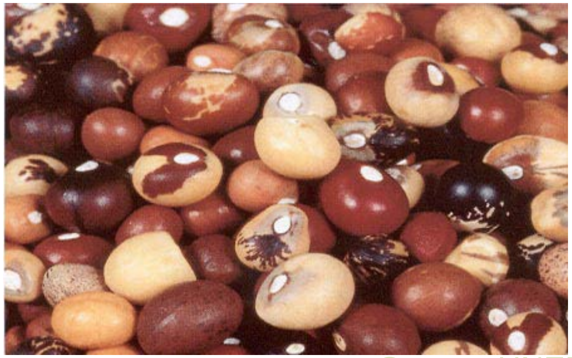
Biodiversity

Genetic diversity refers to the variation of genes within species. This covers distinct populations of the same species (such as the thousands of traditional rice varieties in India)

Species diversity refers to the variety of species within a region. The number of species in a region -- its species "richness" -- is one often- used measure, but a more precise measurement, "taxonomic diversity", also considers the relationship of species to each other

Ecosystem diversity is harder to measure than species or genetic diversity because the "boundaries" of communities -- associations of species -- and ecosystems are elusive. Nevertheless, as long as a consistent set of criteria is used to define communities and ecosystems, their numbers and distribution can be measured..."

"Global Biodiversity Strategy," 1992:



Source: UNEP

Source: biosphere-vosges-pfaelzerwald.org

Functional Aspects of Biodiversity

BIODIVERSITY
Species richness, composition, interaction...

ECOSYSTEM FUNCTIONING
Productivity, biomass, nutrient cycling…….

ABIOTIC ENVIRONMENT
temperature, rainfall, soil fertility……

Loreau (2010). *Phil. Tran. R. Soc. (B)*, 365, 49-60

- Ecology has traditionally regarded biodiversity as an epiphenomenon driven by the abiotic environment and ecosystem functioning
- Recent biodiversity and ecosystem functioning research has focused on the reverse effect of biodiversity on ecosystem functioning

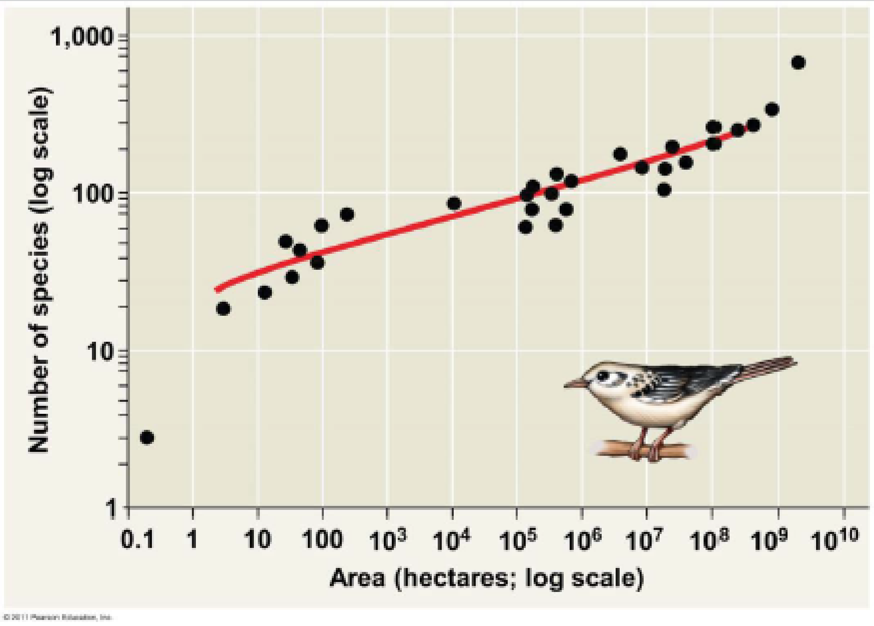
Functional Aspects of Biodiversity include:

1. Materials and energy stocks & flows
2. Ecological stability
3. Behaviors
4. Economic Activities
5. Ecosystem services

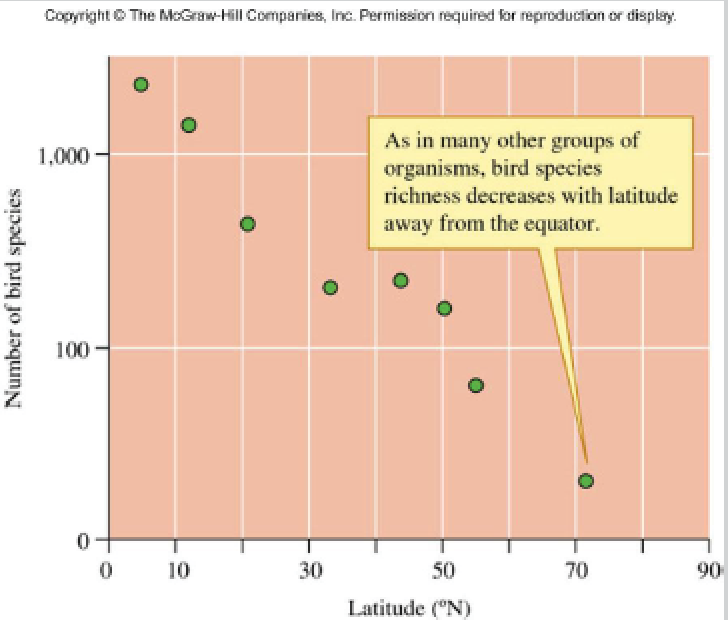
Two general «laws»

1. Species-area relationships
2. Species richenss decreases towards the poles

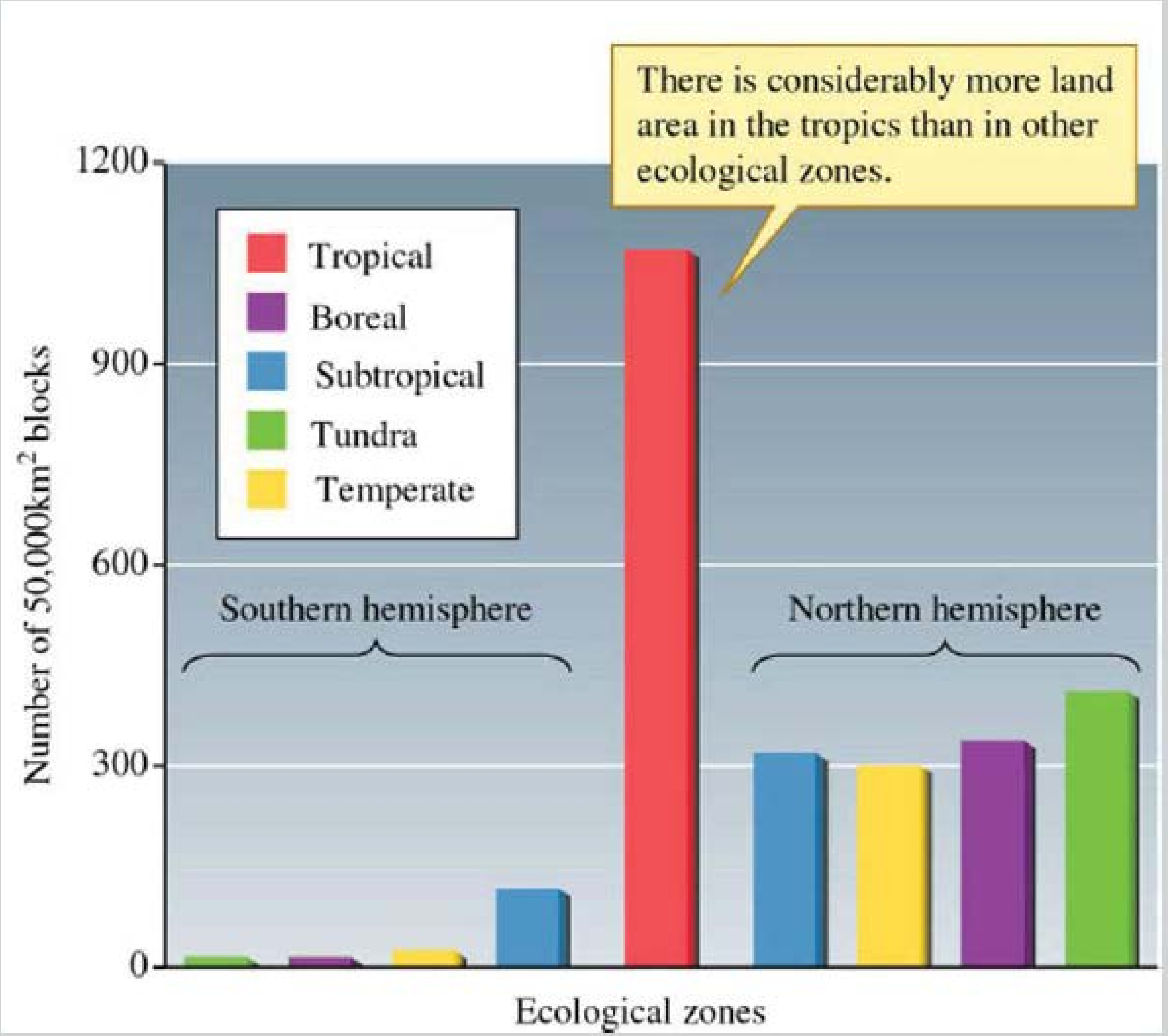
Birds and area



Birds and latitude



Area and latitude



Explanations for the latitudinal gradient in diversity

- History
  - Time since last major change
- Productivity
  - Larger populations, lower probability for extinction
- Heterogenity
- Favourableness
- Interactions, niche width
- Area

Altitude for latitude

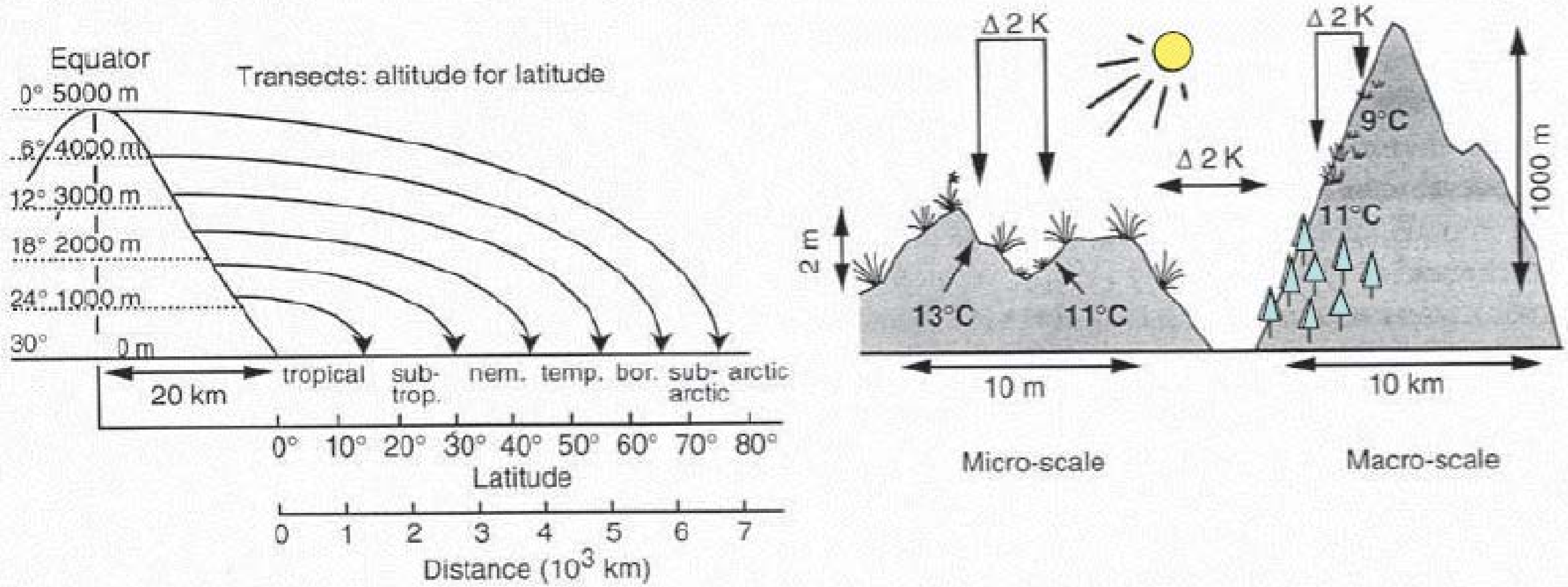


Fig. 1.4. Altitude for latitude: over short elevational distances thermal gradients represent the climate across vast latitudinal distances. Space for time: thermal contrasts across the relief "simulate" differences in temperature along elevational gradients. These are "natural" experiments, ideally suited for comparative functional ecology

Körner (2003)

100 m upward corresponds to ca 600 km north-south

Diversity Index

A) A diversity index is a mathematical measure of species diversity in a given community.
B) Based on the species richness (the number of species present) and species abundance (the number of individuals per species).
C) The more species you have, the more diverse the area, right?
D) However, there are two types of indices, dominance indices and information statistic indices.
E) The equations for the two indices we will study are:

$$\text{Shannon Index (H)} = -\sum_{i=1}^{s} p_i \ln p_i$$

$$\text{Simpson Index (D)} = \frac{1}{\sum_{i=1}^{s} p_i^{2}}$$

The Shannon index is an information statistic index, which means it assumes all species are represented in a sample and that they are randomly sampled. Can you point out any problems in these assumptions?

In the Shannon index, **p** is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), **ln** is the natural log, **Σ** is the sum of the calculations, and **s** is the number of species.

The Simpson index is a dominance index because it gives more weight to common or dominant species. In this case, a few rare species with only a few representatives will not affect the diversity. Can you point out any problems in these assumptions?

In the Simpson index, **p** is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), **Σ** is still the sum of the calculations, and **s** is the number of species.

Let's look at an example. Area 1 was sampled and the following specimens were collected.

order	description	number of individuals (n)	n/N	p_i	p_i^2	ln p_i	p_i ln p_i
Orthoptera (grasshopper)	green with red legs	6	6/27	0.222	0.049	-1.505	-0.334
Orthoptera (grasshopper)	brown with a yellow stripe	5	5/27	0.185	0.034	-1.687	-0.312
Lepidoptera (butterfly)	large, blue	1	1/27	0.037	0.001	-3.297	-0.122
Lepidoptera (butterfly)	small, blue	3	3/27	0.111	0.012	-2.198	-0.244
Coleoptera (beetle)	red & blue	12	12/27	0.444	0.198	-0.812	-0.360

s (number of species) = 5
N (total number of individuals) = 27
Σ (sum) of p_i^2 $(n/N)^2$ = 0.294
Σ (sum) of $p_i \ln p_i$ = -1.372
H = -(-0.334 + -0.312 + -0.122 + -0.244 + -0.360) = **1.372**
D = 1/ (0.049 + 0.034 + 0.001 + 0.012 + 0.198) = 1/0.294 = **3.4**

These are the specimens collected from Area 2.

order	description	number of individuals (n)	n/N	p_i	p_i^2	ln p_i	p_i ln p_i
Hymenoptera (wasp)	black	12	12/91	0.132	0.017	-2.025	-0.267
Hymenoptera (wasp)	purple	21	21/91	0.231	0.053	-1.465	-0.338
Hymenoptera (bee)	striped	5	5/91	0.055	0.003	-2.900	-0.160
Orthoptera (grasshopper)	green with red legs	25	25/91	0.245	0.060	-1.406	-0.345
Orthoptera (grasshopper)	brown with a yellow stripe	2	2/91	0.022	0.0004	-3.817	-0.084
Lepidoptera (butterfly)	large, blue	17	17/91	0.187	0.035	-1.677	-0.314
Lepidoptera (butterfly)	small, blue	9	9/91	0.099	0.010	-2.313	-0.229

s (number of species) = 7
N (total number of individuals) = 91
Σ (sum) of p_i^2 $(n/N)^2 = 0.179$
Σ (sum) of **p_i ln p_i** = -1.736

H = -(-0.267 + -0.338 + -0.160 + -0.345 + -0.084 + -0.314 + -0.229) = **1.736**
D = 1/(0.017 + 0.053 + 0.003 + 0.060 + 0.00004 + 0.035 + 0.010) = **5.59**

Community Similarity

A) Calculating community similarities (what the communities have in common in terms of species) helps us determine if we are comparing apples to apples and oranges to oranges.
B) There are many indices that do this, we will use Sorenson's coefficient.
C) Sorenson's coefficient gives a value between 0 and 1, the closer the value is to 1, the more the communities have in common.
   a. Complete community overlap is equal to 1; complete community dissimilarity is equal to 0.
D) The equation is:

$$\text{Sorenson's Coefficient (CC)} = \frac{2C}{S1 + S2}$$

Where C is the number of species the two communities have in common, S1 is the total number of species found in community 1, and S2 is the total number of species found in community 2.

Example 1:

There are 20 species found in community 1 and 25 in community 2. Between them, they have 5 species in common. The calculation would be:

$$\text{Sorenson's Coefficient (CC)} = \frac{2*5}{20+25} = 10/45 = 0.222$$

According to Sorenson's coefficient, these communities do not have much overlap or similarity.

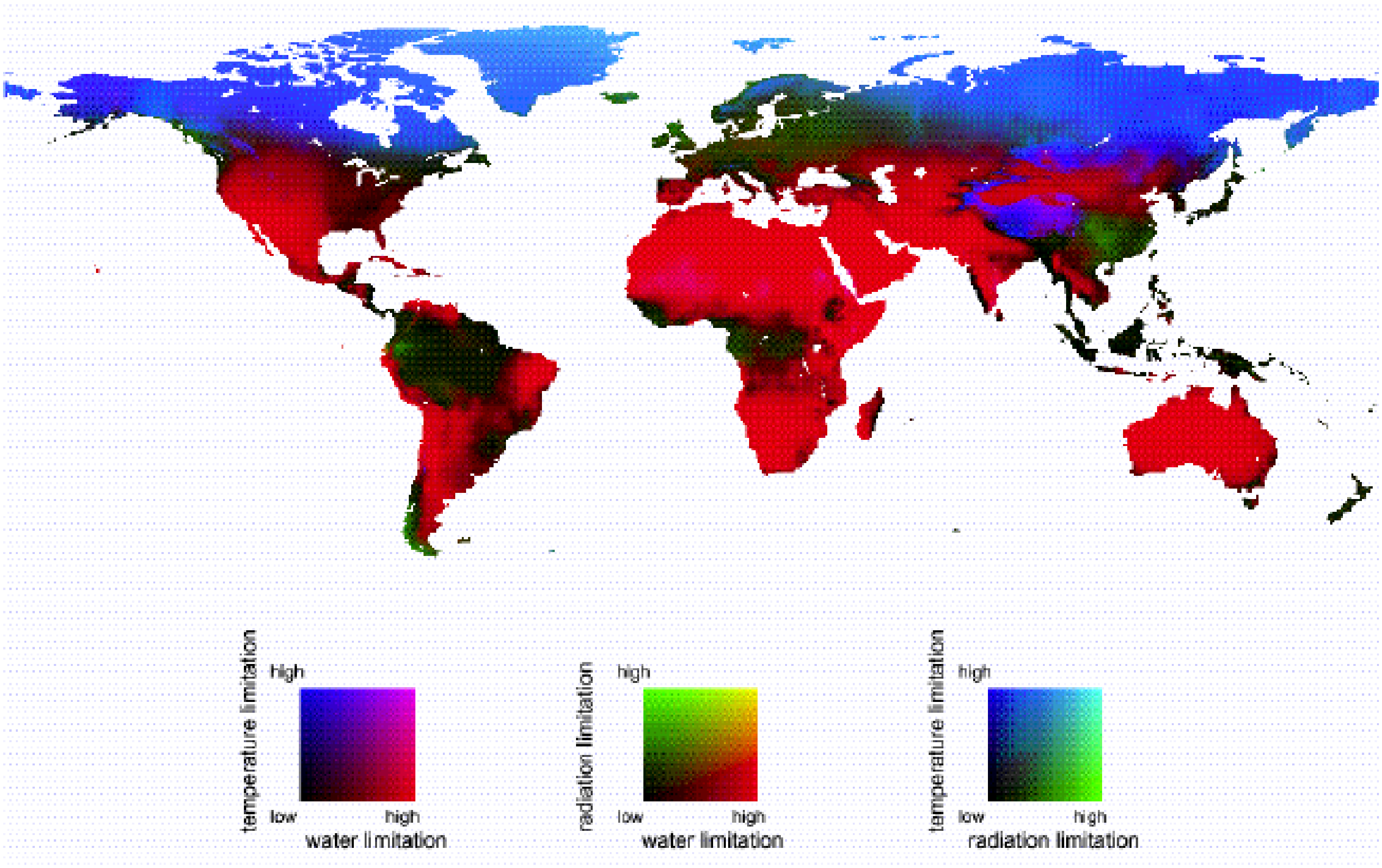
Example 2:

There are 15 species found in community 1 and 25 in community 2. Between them, they have 12 species in common. The calculation would be:

$$\text{Sorenson's Coefficient (CC)} = \frac{2*12}{15+25} = 24/40 = 0.6$$

According to Sorenson's coefficient, these communities have quite a bit of overlap or similarity.

Dominant Environmental Controls on Net Primary Productivity



Tropical Evergreen Broadleaved Rainforests

- Rain > 1500 mm
- ET: ~ 1000-1300 mm
- T_{min} > 15 C
- LAI ~5-7 m^2 m^{-2}
- Ht: ~30 to 40 m
- Biomass: ~ 400 g m^{-2}

Temperate Deciduous Broadleaved Forests

- Rain: 700-1500 mm
- ET: 300 to 600 mm
- T_{min} > -15 to -40 C
- LAI: ~5 to 6 m^2 m^{-2}
- Ht: 20 to 30 m
- Biomass: ~200 g m^{-2}

Boreal Conifer Forests

- Rain: ~400-900 mm
- ET: ~200- 400 mm
- T_{min} < = -40 C
- LAI: ~2-4
- Ht: 10 to 20 m
- Biomass: 120 g m^{-2}

Grasslands

- Rain: 200-500 mm/year
- ET: < 400 mm
- T_{min}: -1 to 15 C
- LAI: ~1-3
- Biomass: 3 g m^{-2}
- Height
  - Perennial, < 1 m
  - Annual, < 1 m

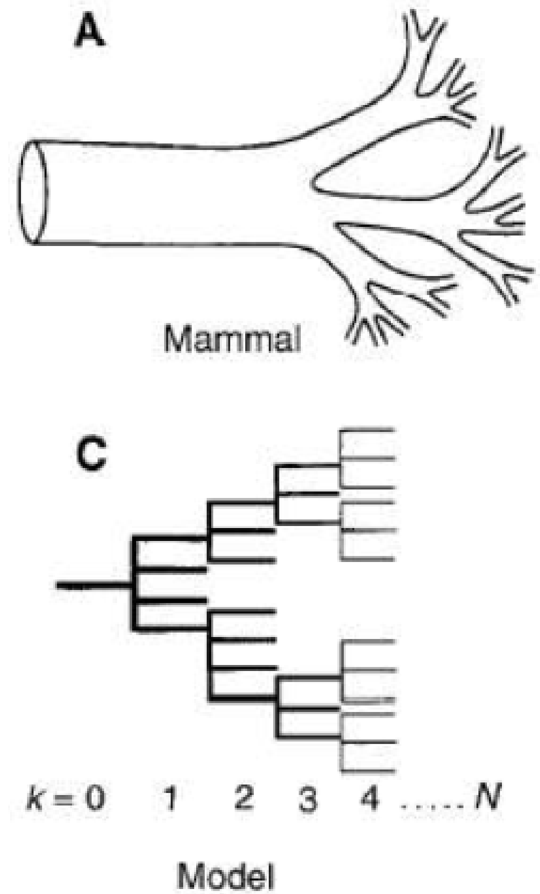
Ecosystem as a Complex Adaptive System

- Self-Organized Criticality
  - Strange attractor in a dynamic system
  - Delicate balance between stability and collapse
  - Power-Law Behavior
- Individuality of components
  - *'Individual agents drive evolutionary change from the bottom up, so that system evolution emerges from the interplay of processes at diverse scales'*
- Localized interaction among components
  - Competition, predation and sexual reproduction exert Positive and Negative Feedbacks
- Diversity of components
  - Mutation refreshes diversity
- Autonomous Processes
- Components
  - Aggregation
  - Non-linearity
  - Hierarchal Structure
  - Scale Emergent Processes
  - Heterogeneity of components
  - Flows of material and Energy

Example of Successive Branching and Area Preservation

Fundamentals of ¼ scaling

- Living things are sustained by transport of materials (water, nutrients) through networks of paths.
- For the network to function, it must be space filling throughout the volume
- the final branch is scale invariant
- the energy required to transport material must be minimized.
  - The hydrodynamic resistance must be minimized.

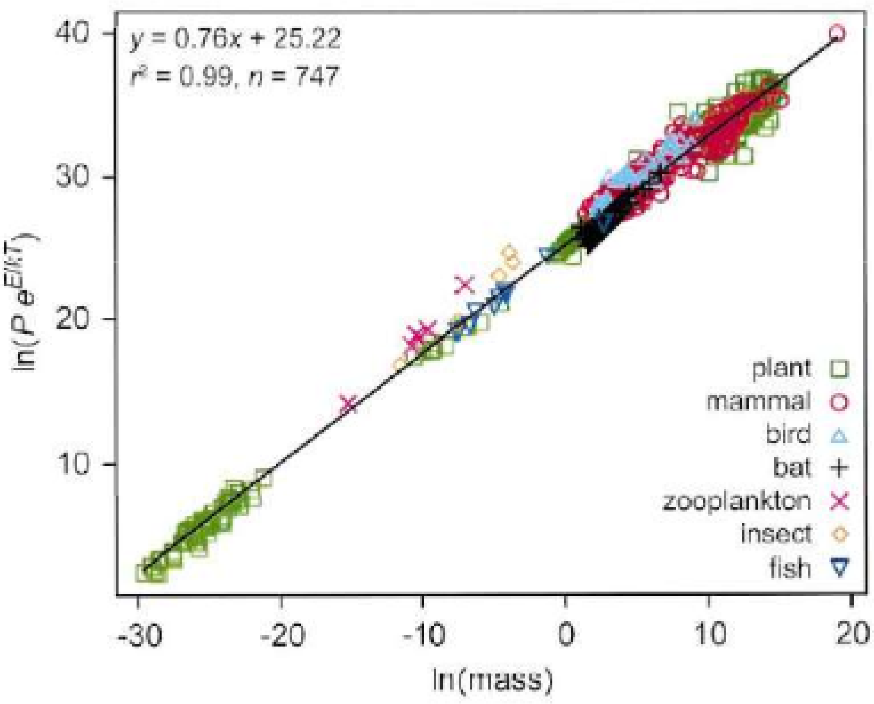


West et al 1997 Science

Life spans +20 Orders of Magnitude in Mass

- Blue Whale 10^{18}g
- phytoplanckton, 10^{-13}g

MacARTHUR AWARD LECTURE



10^{-14} kg

10^{8} kg

Emergent Processes

- Whole > Sum of Parts
  - Photosynthesis and Light
    - Leaf Photosynthesis is non-linear and saturating function of light and is independent of diffuse light
    - Canopy Photosynthesis is a quasi-linear function of light and a strong function of diffuse/direct light
  - Photosynthesis and CO_2
    - Leaf Photosynthesis increases non-linearly with CO_2
    - Canopy photosynthesis experiences a down-regulation due to feedbacks with decomposition of plant matter and release of nutrients and decreases in stomatal conductance
  - Albedo
    - Optical Properties of many green leaves are similar
    - Forests are darker than grasslands and absorb more energy
    - At regional scale, forests evaporate water vapor, which forms clouds and increases the planetary albedo

Conventional Biomes

ecosystem processes are a function of macroclimate (latitude, altitude, circulation)

Ecosystem processes = $f(C)$

C = Climate (precipitation & temperature)

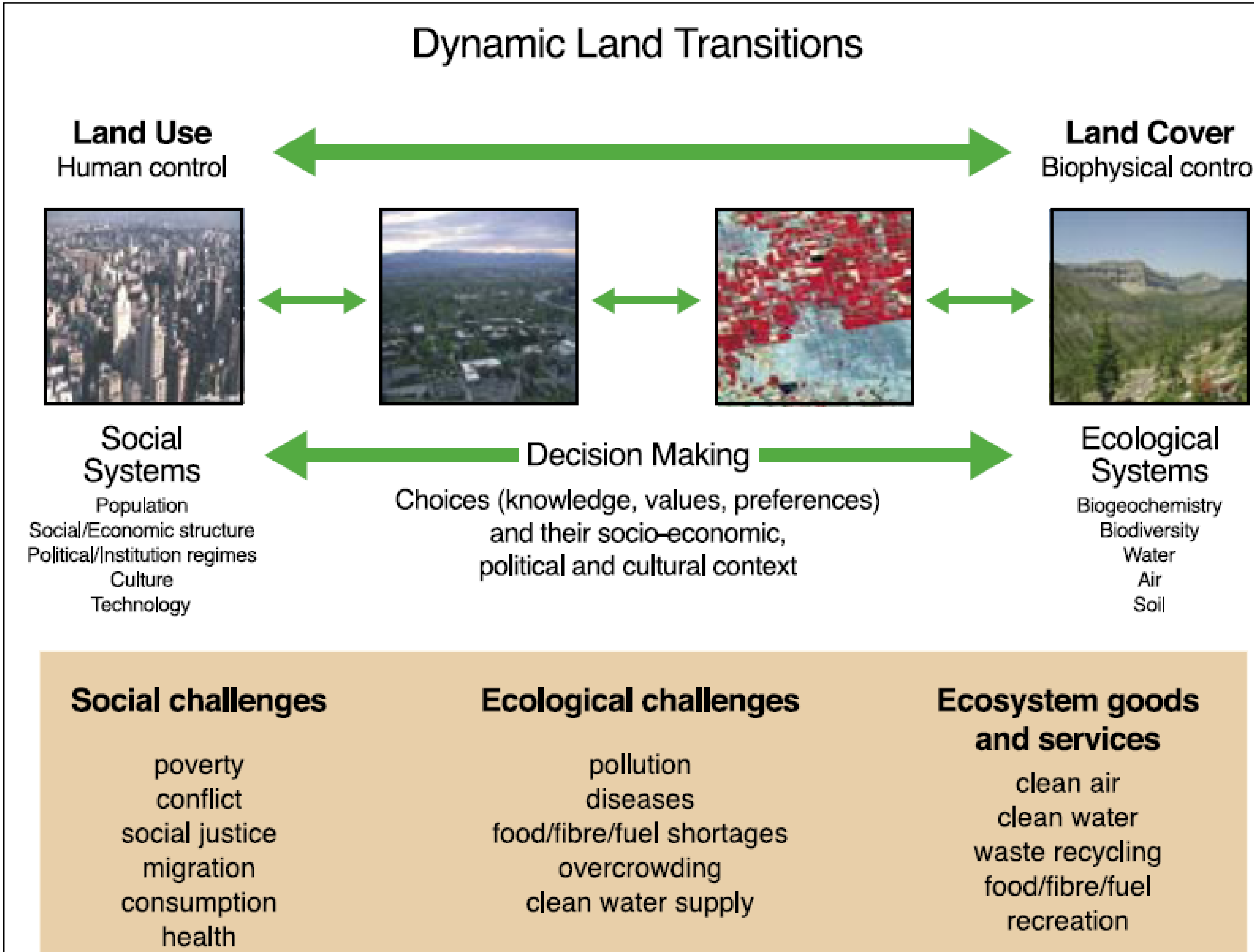
Anthropogenic Biomes

ecosystem processes are *mostly* a function of human populations and their ecosystem interactions (land use)

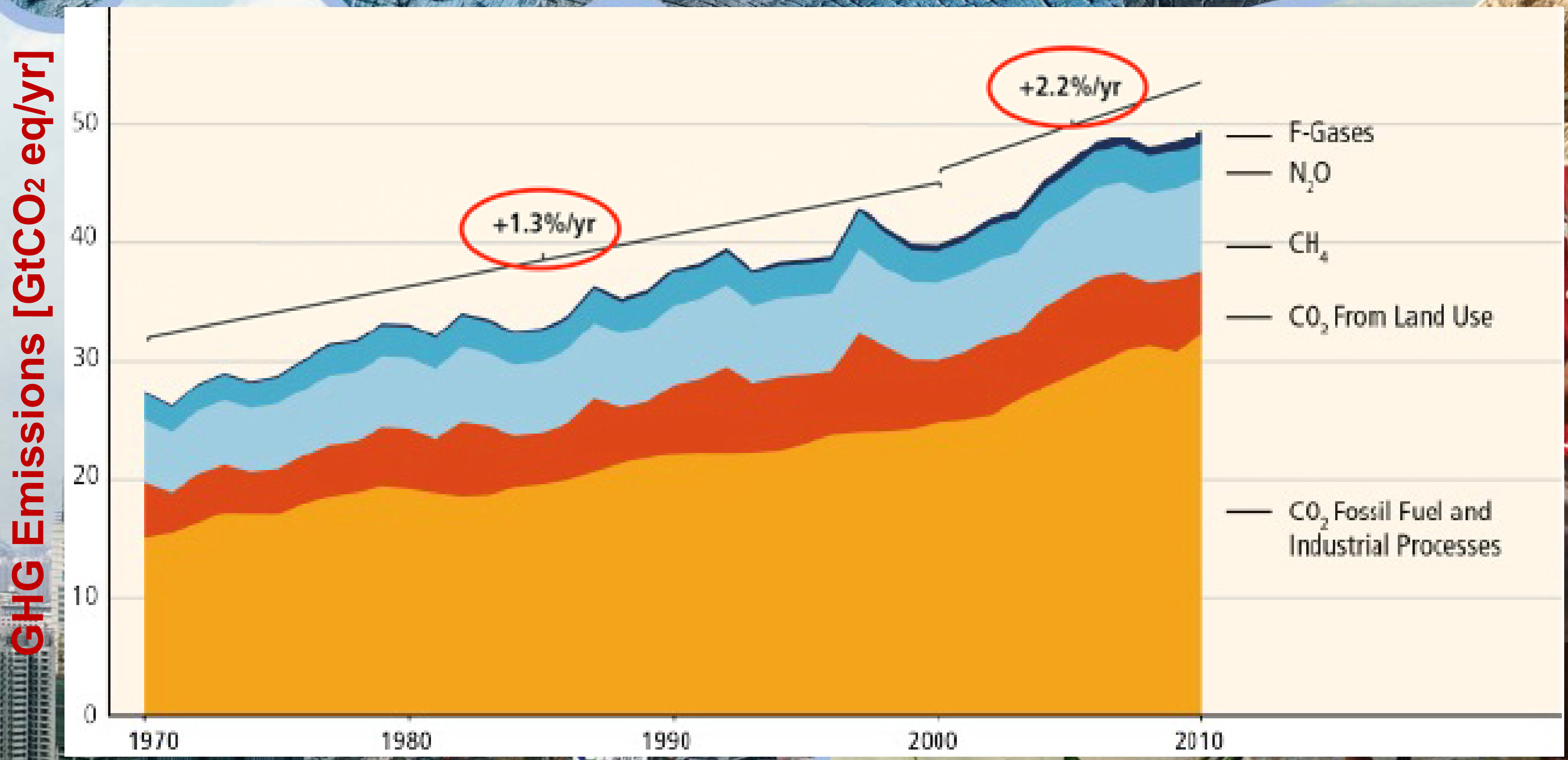
$$\text{Ecosystem processes} = f(P, T)$$

P = Population density

T = Land use (how land & resources are used)

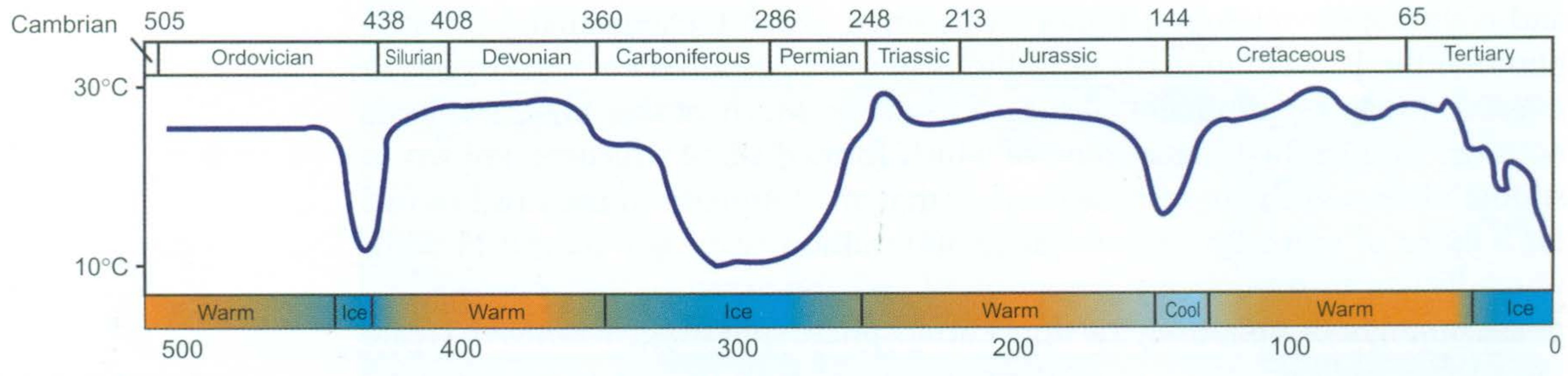

Dynamic Land Transitions
Land Use
Human control
Land Cover
Biophysical control
Social
Systems
Population
Social/Economic structure
Political/Institution regimes
Culture
Technology
Decision Making
Choices (knowledge, values, preferences)
and their socio-economic,
political and cultural context
Ecological
Systems
Biogeochemistry
Biodiversity
Water
Air
Soil
Social challenges
poverty
conflict
social justice
migration
consumption
health
Ecological challenges
pollution
diseases
food/fibre/fuel shortages
overcrowding
clean water supply
Ecosystem goods
and services
clean air
clean water
waste recycling
food/fibre/fuel
recreation

GHG emissions growth between 2000 and 2010 has been larger than in the previous three decades



AR5 WGIII SPM

Global Temperature during the past 500 million years



Earth temperature change during the past 70 million years

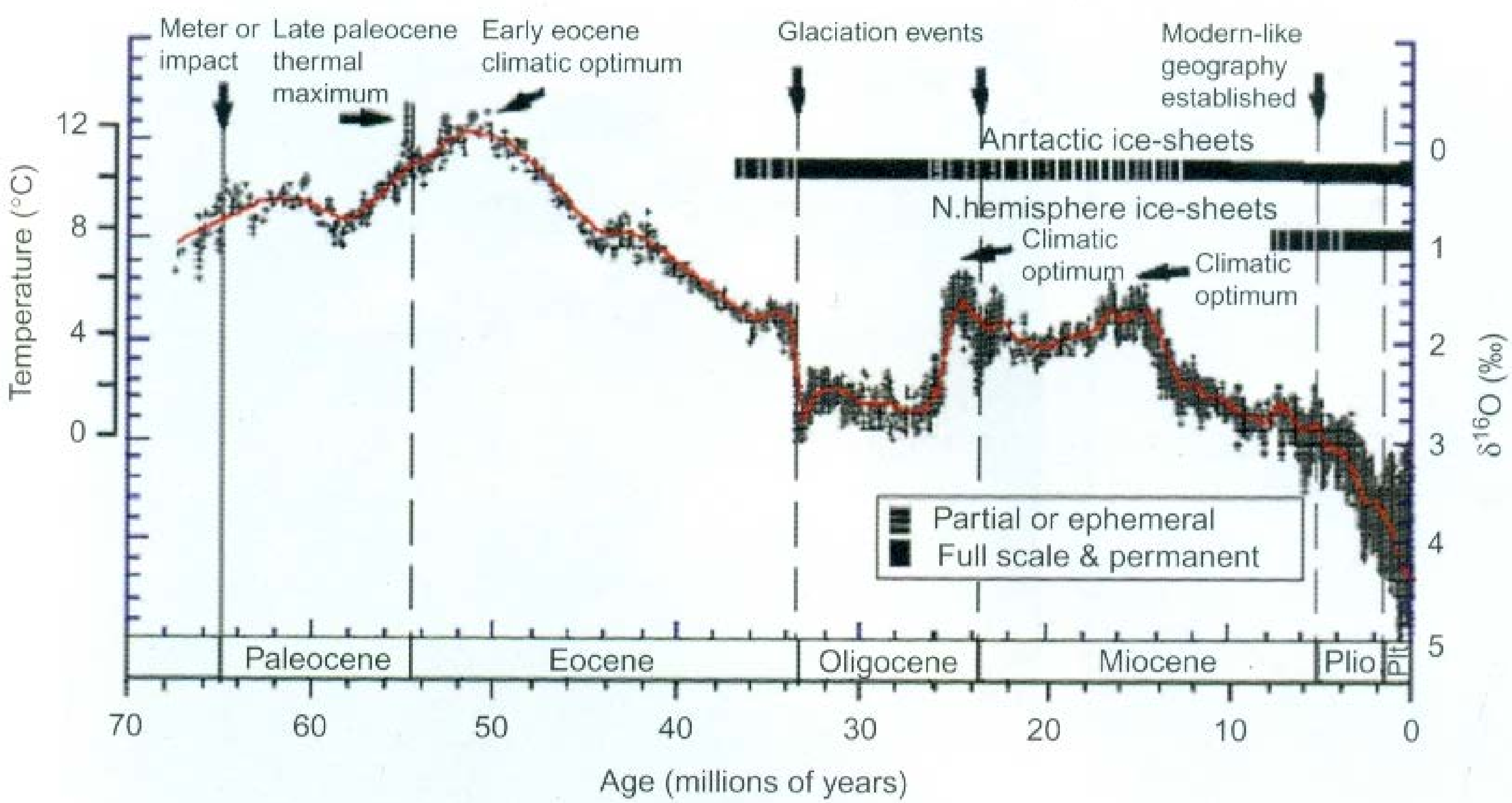


Table 9.1 The Five Largest Mass Extinction Events

Time Frame (Millions of Years Ago)	Geologic Marker	Biological Impact	Possible Cause
440	Ordovician–Silurian	100 families of marine life extinct, including half of all genera	Rapid cooling
365	End-Devonian	20% of all families lost, mostly marine organisms—perhaps in several episodes	Removal of CO_2 from the atmosphere after the emergence of land plants
250	Permian–Triassic	Extinction of 90% of all species—land and marine	Massive volcanism (Siberian Traps), methane release
200	End-Triassic	Loss of large amphibians	Unclear
65	Cretaceous–Tertiary (K-T)	Extinction of dinosaurs and many marine species	Extraterrestrial impact(s)