Mary River turtle
(*Elusor macrurus*)

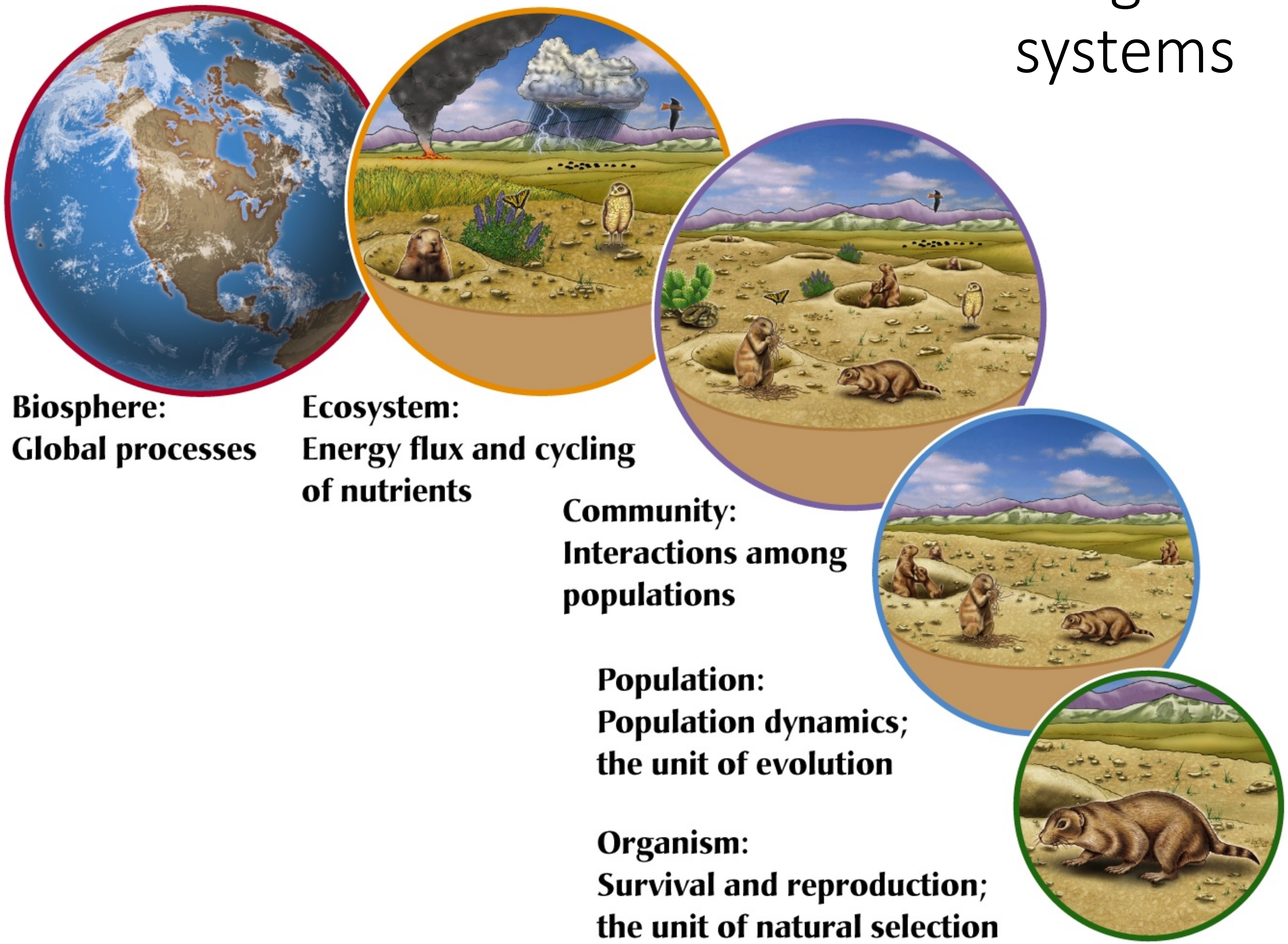
Continuing with Chapter 3 from the book

(Reminder: homework due Tuesday

and

Reminder: Wednesday, extra session)

ecological systems



Major components of an ecosystem…

- **Individual Organism** (“No smaller unit in biology ... has a separate life in the environment...”)
- **Population** (many organisms of the same species living together)
- **Guild** (a group of populations that utilizes resources in essentially the same way)
- **Community** (many populations of different kinds living in the same place)
- **Ecosystem** (assemblages of organisms together with their physical environment; community + physical environment)
- **Biosphere** (the global ecosystem, all organisms and environments on earth)

Major components of an ecosystem

- <u>Individual Organism</u> ("No smaller unit in biology ... has a separate life in the environment...")
- **<u>Cell</u>** (fundamental structural and functional unit of life)
- <u>Molecule</u> (chemical combination of two or more atoms of the same or different elements)
- <u>Atom</u> (smallest unit of a chemical element that exhibits its chemical properties)

What is ecology?

- Ecology is the **science** by which we study how **organisms** (animals, plants, and microbes) **interact in** and **with** the **natural world**.
- in that case - ecology is the oldest science!
- early ecologists were applied ecologists. how so?
- ecology is also a ‘pure’ science - understanding for the sake of understanding
- ecologists strive to develop an understanding of very basic and apparent problems in a way that recognizes the uniqueness and complexity of all aspects of nature but seeks patterns and predictions within the complexity

Perspectives of Ecologists: Organism Approach

- How do form, physiology, and behavior lead to survival?
- Focus is on adaptations, modifications of structure and function, that suit the organism for life in its environment:
  - adaptations result from evolutionary change by natural selection, a natural link to population approach…

? - Why are trees the dominant plants in warm, moist environments – and shrubs the dominant plants in regions with cool, wet winters and hot, dry summers?

Perspectives of Ecologists: Population Approach

- What determines the numbers of individuals and their variations in time and space?
- Focus is on processes of birth and death, immigration and emigration, influenced by:
  - the physical environment
  - evolutionary processes
  - interactions with other populations, a natural link to community approach…

? – Why have mosquitoes increased in number and in extent?

Perspectives of Ecologists: Community Approach

- How are communities structured from their component populations?
- Focus is on the diversity and relative abundance of different kinds of organisms living together, affected by:
  - population interactions, promoting and limiting coexistence
  - feeding relationships, responsible for fluxes of energy and materials, a natural link to ecosystem approach...

? – what is the relationship between birds, crops, and insects?

Perspectives of Ecologists: Ecosystem Approach

- How can we account for the activities of populations in the common "currencies" of energy and materials?
- Focus is on movements of energy and materials and influences of:
  - organisms large and small
  - climate and other physical factors, including those acting on a global scale, a natural link to biosphere approach...

? – movement of Nitrogen… ?

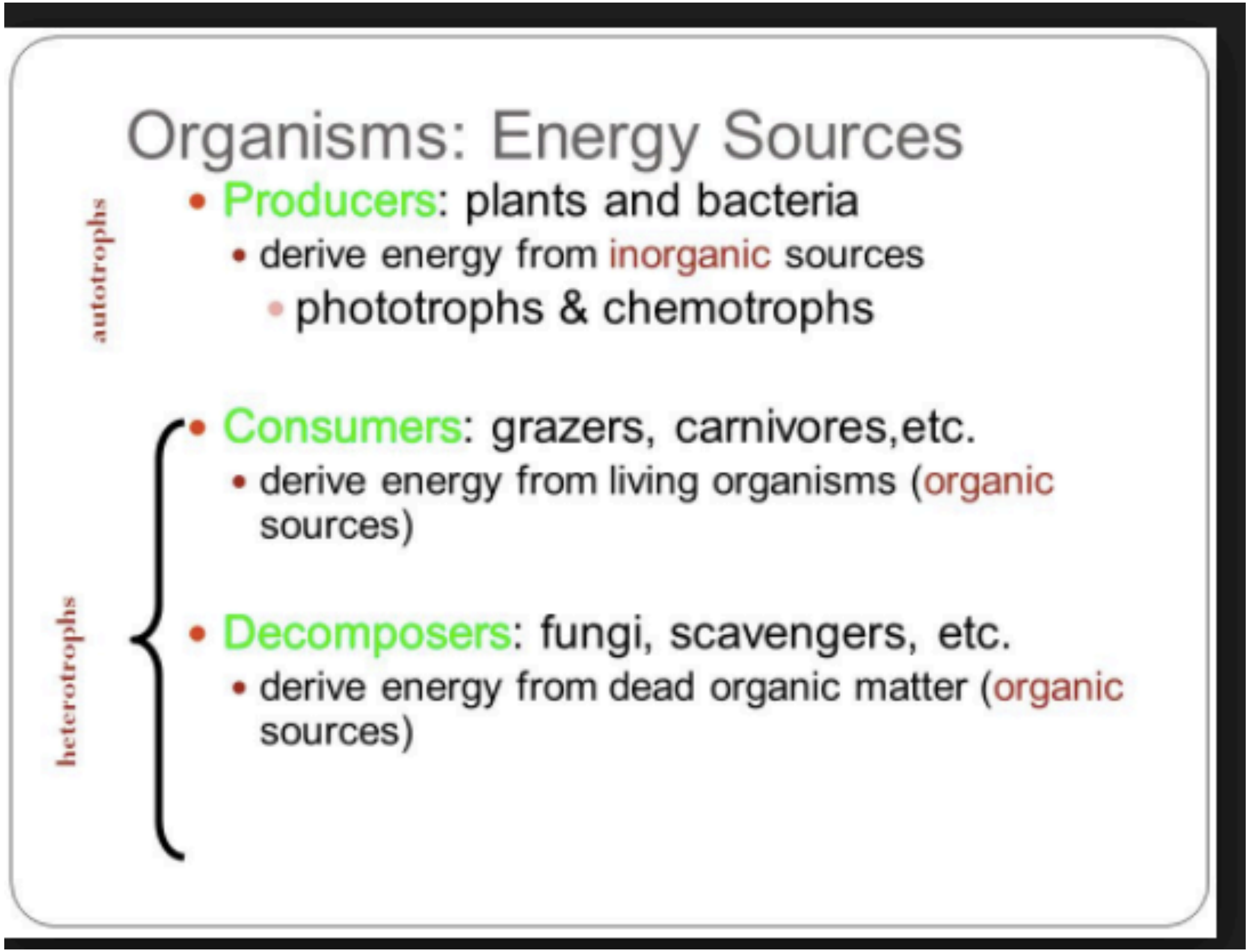
Perspectives of Ecologists: Biosphere Approach

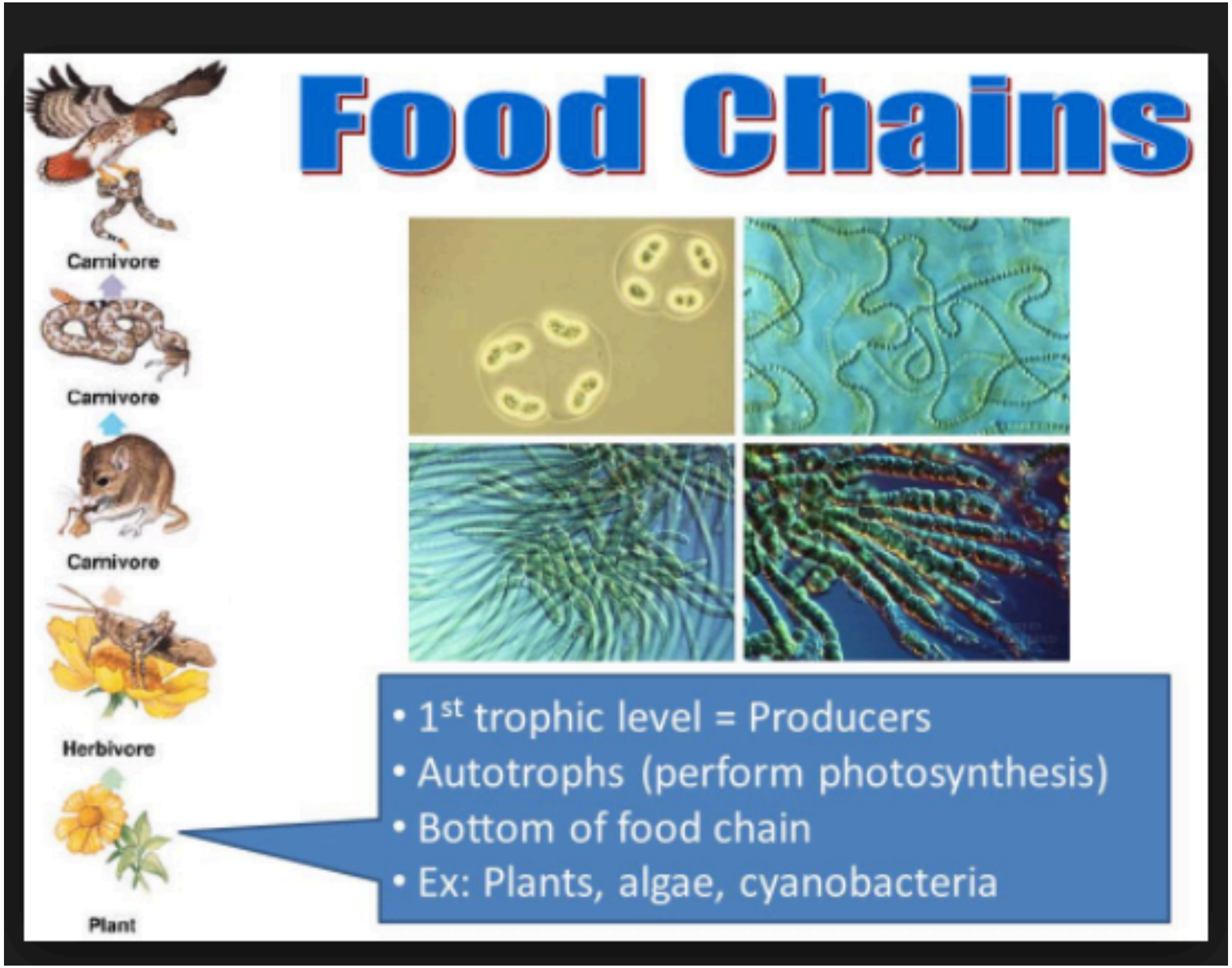
- How can we understand the global movements of air and water, and the energy and chemical elements they contain?
- Focus is on the global circulation of matter and energy, affecting:
  - distributions of organisms
  - changes in populations
  - composition of communities
  - productivity of ecosystems

? – climate change ?!

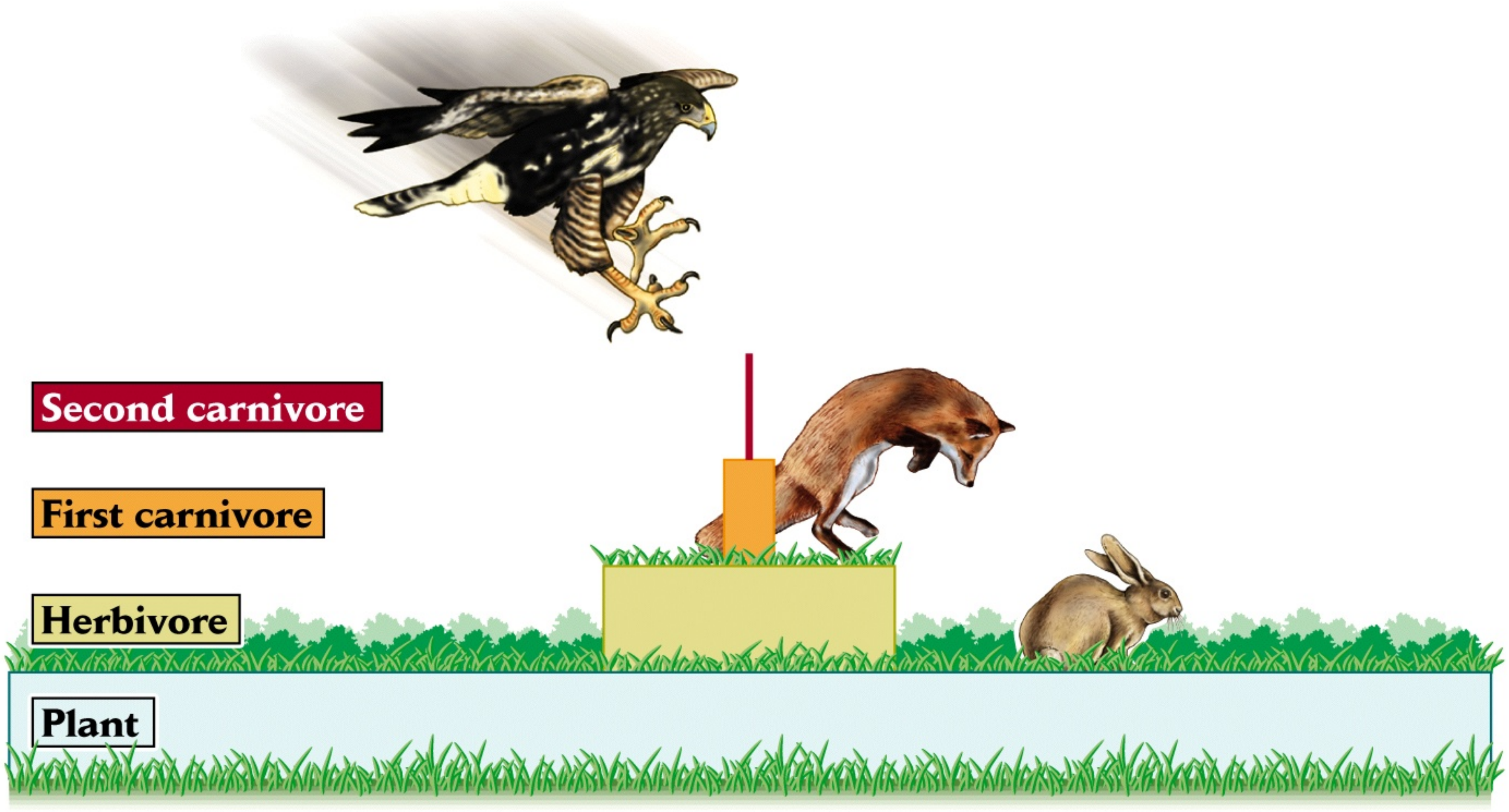
Ecosystems, trophic levels, laws of thermodynamics

- Trophic level: feeding level
- Producers
- Consumers
  - Primary, secondary..
  - Herbivores, Omnivores, Carnivores…
- Decomposers
  - Detritus feeders




Food Chains
Carnivore
Carnivore
Carnivore
Herbivore
Plant
• 1st trophic level = Producers
• Autotrophs (perform photosynthesis)
• Bottom of food chain
• Ex: Plants, algae, cyanobacteria

An ecological pyramid of energy



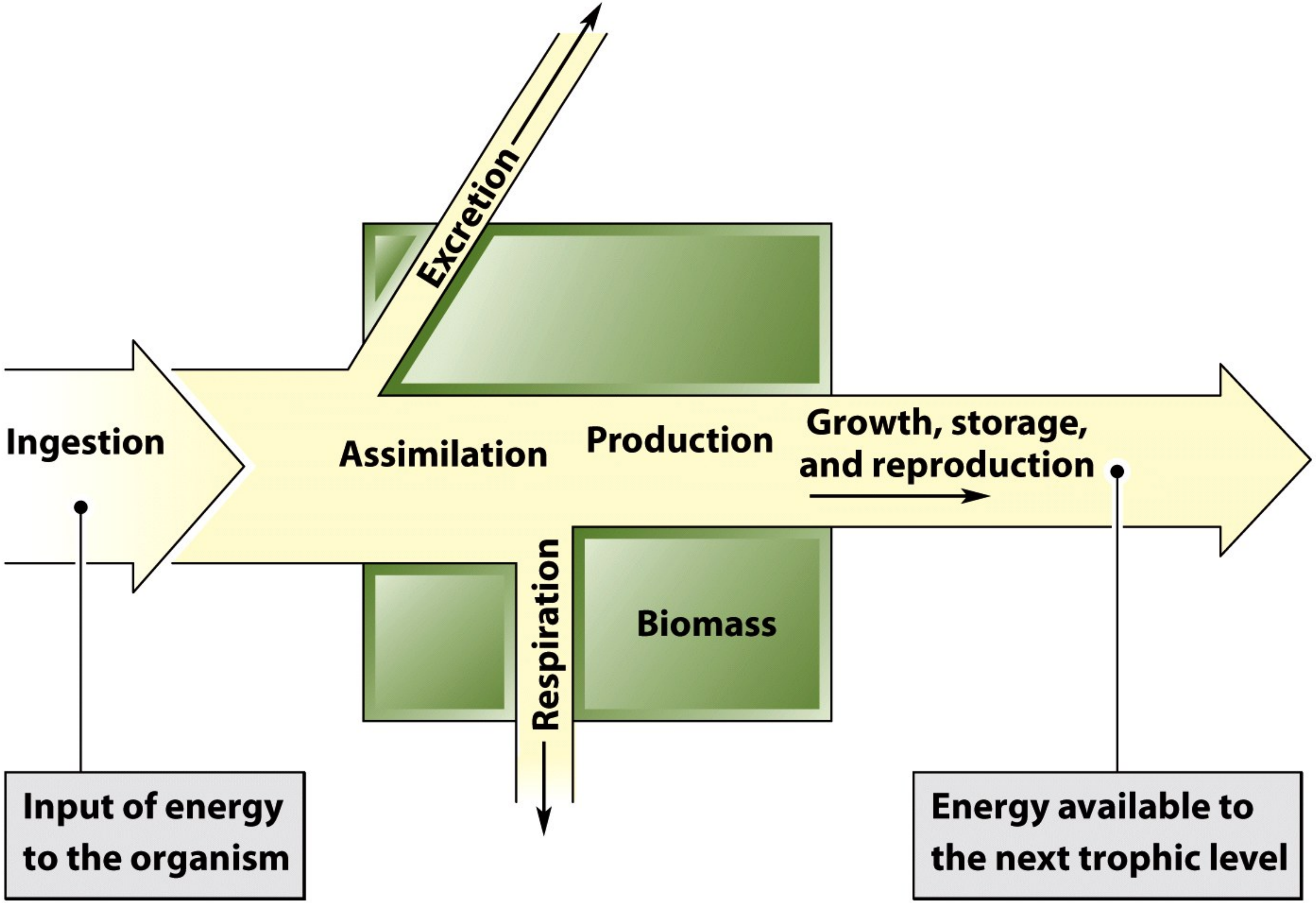
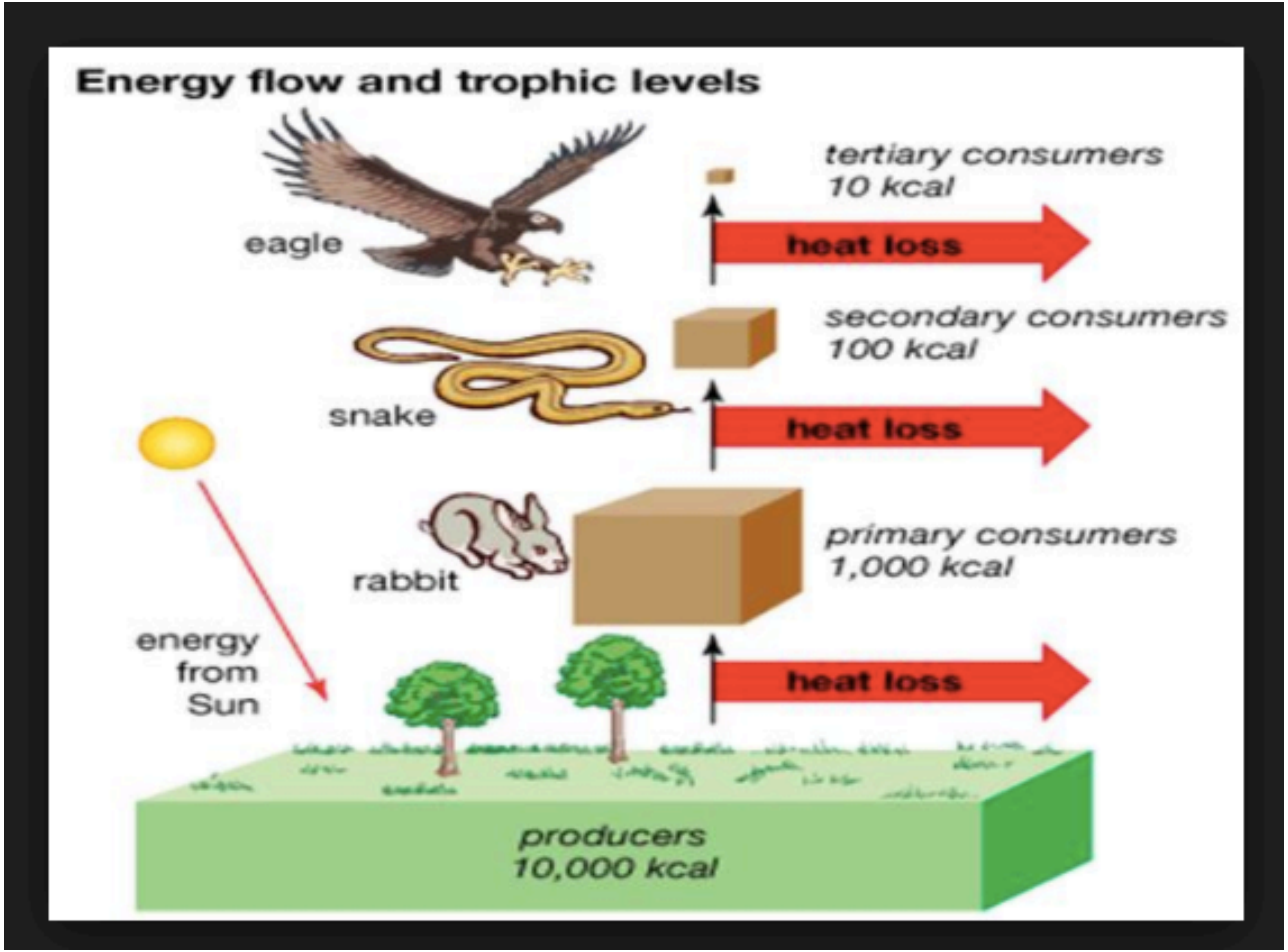


Figure 22.2
The Economy of Nature, Sixth Edition

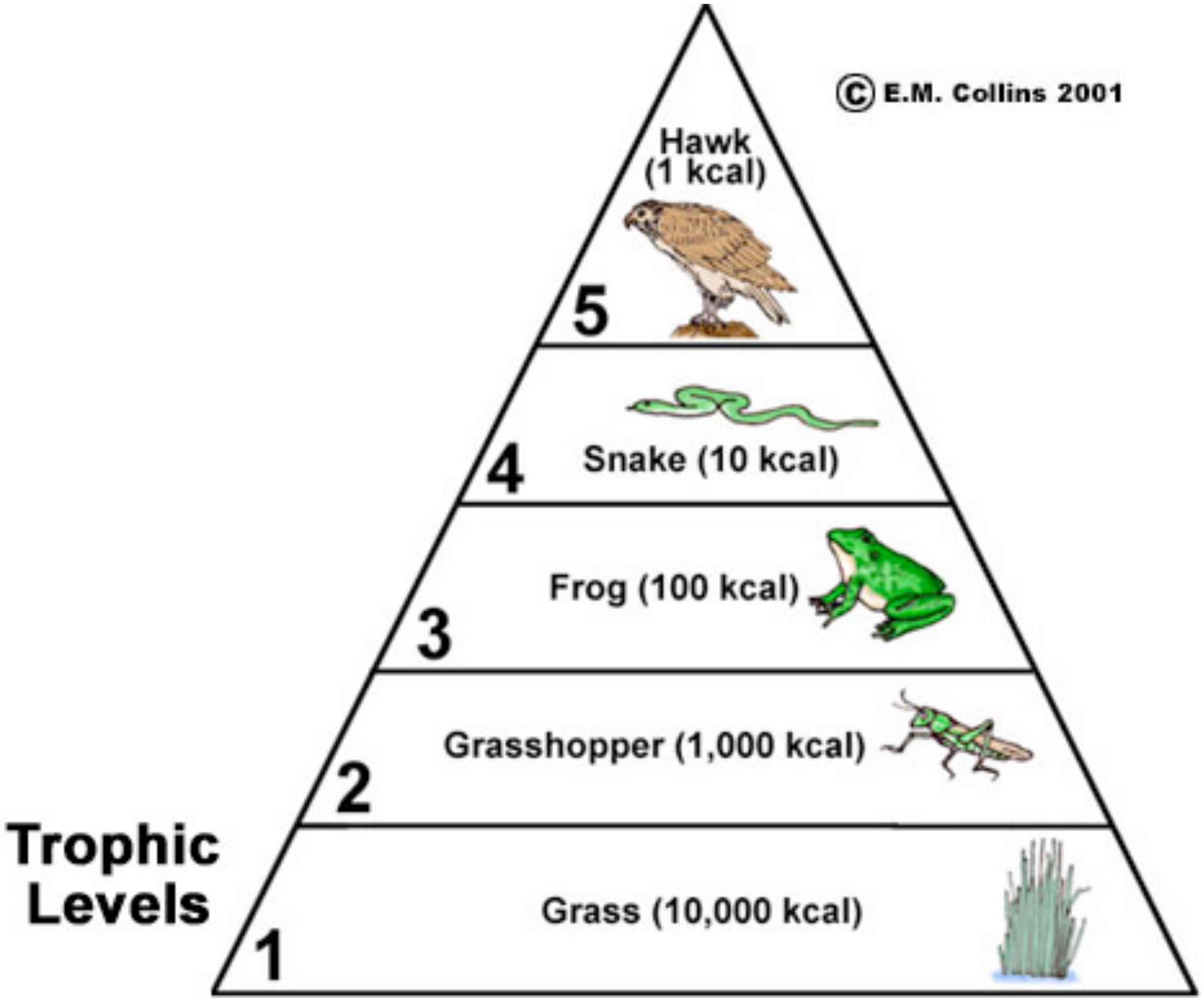
Only 5% to 20% of energy passes between trophic levels.

- Energy reaching each trophic level depends on:
  - net primary production (base of food chain)
  - efficiencies of transfers between trophic levels

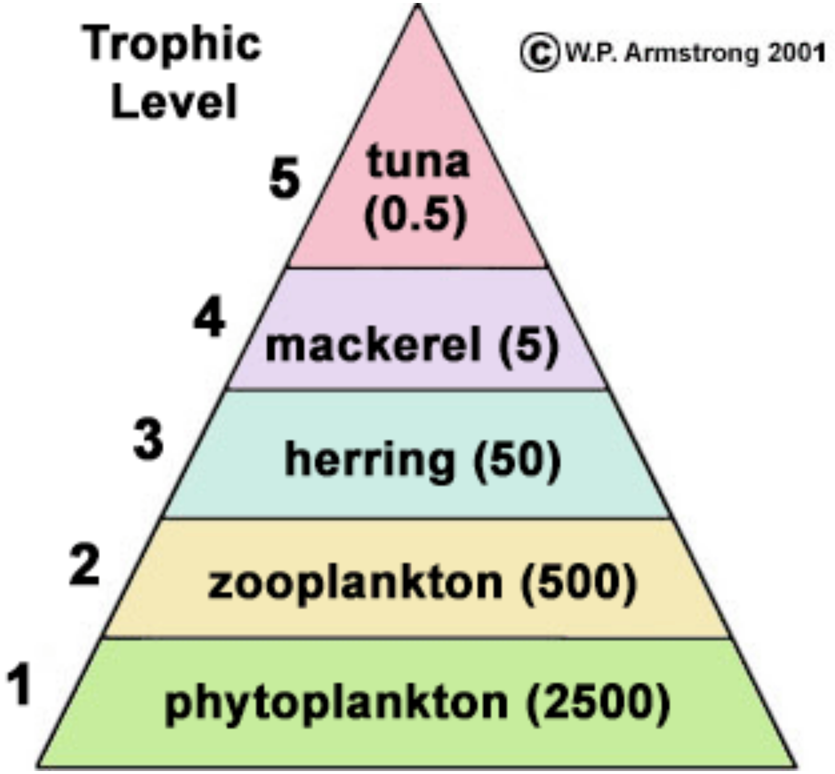
  - More on this later -
- Plant use between 15% and 70% of light energy assimilated for maintenance – thus that portion is unavailable to consumers
- Herbivores and carnivores expend more energy on maintenance than do plants: **production of each trophic level is only 5% to 20% that of the level below it**.


Energy flow and trophic levels
tertiary consumers
10 kcal
eagle
heat loss
secondary consumers
100 kcal
snake
heat loss
primary consumers
1,000 kcal
rabbit
energy
from
Sun
heat loss
producers
10,000 kcal

Energy: how many lbs of grass to support one hawk

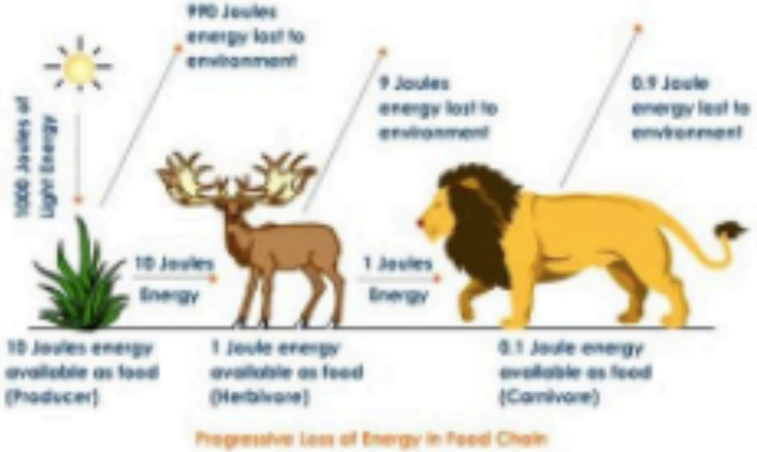


Ocean food pyramid – roughly 2500 lbs/1136 kg of phytoplankton to support 0.5lb/0.23 kg of tuna



ECOSYSTEMS & ENERGY

- Due to the 2nd Law of Thermodynamics, energy is not equally passed through a food chain
- Plants only convert 1-2% of the energy they receive into stored sugars
- In general only about 10% of the energy is passed from 1 trophic level to the next (the rest is used in metabolism, to do work, an as heat loss)
- Less and less energy is available as you move up a food chain



http://images.tutorvista.com/

Primary production varies among ecosystems.

- Primary production is maximum under favorable combinations of:
  - intense sunlight
  - warm temperatures
  - abundant rainfall
  - ample nutrients
- On land, production is highest in humid tropics, lowest in tundra and desert.

Primary Production:

- **Primary production** is the process whereby plants, algae, and some bacteria (**primary producers**) capture the energy of light and transform it into the energy of chemical bonds in carbohydrate:
- The rate of primary production determines the rate of energy supply to the rest of the ecosystem:
  - **gross primary production** = total energy assimilated by primary producers
  - **net primary production** = energy accumulated (in stored form) by primary producers
  - gross - net = **respiration**, the energy consumed by producers for maintenance and biosynthesis

  - The planet's NPP ultimately limits the number of consumers that can survive on earth

NPP highest in humid tropics

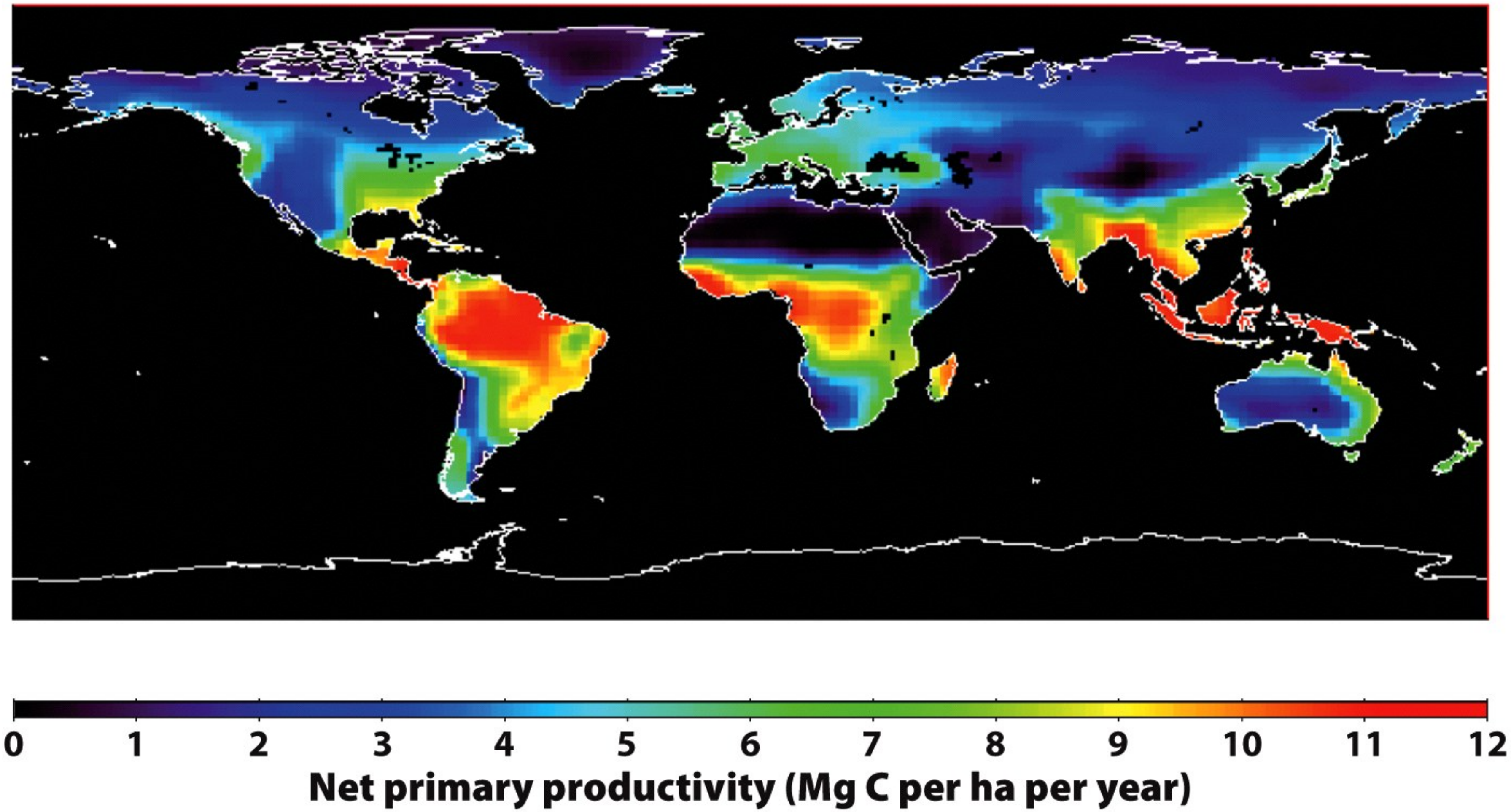
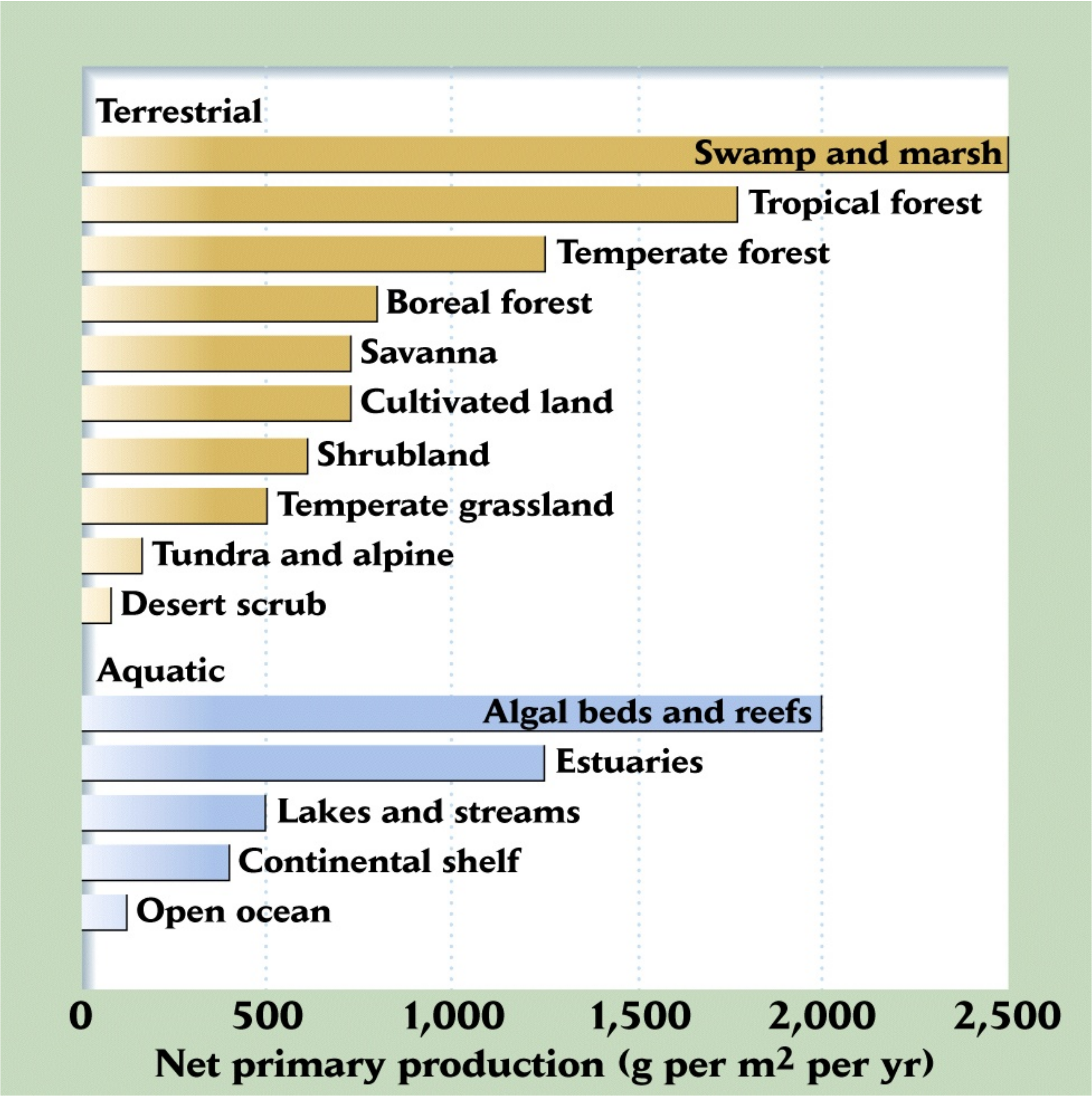


Figure 22.10
The Economy of Nature, Sixth Edition

NPP among ecosystems



Credit: © Richard Herrmann/Visuals Unlimited

205379

Pickelweed saltmarsh.

Credit: © Theo Allofs/Visuals Unlimited

283044

Temperate Rainforest showing moss-covered trees and ferns, Olympic National Park, Washington.

Credit: © Adam Jones/Visuals Unlimited

212904

Fall foliage and view of Mt. LeConte, Great Smokey Mountains National Park, Tennessee.

Credit: © Beth Davidow/Visuals Unlimited

301419

Northern Boreal Forest of Spruce and Aspens and tundra ponds.

Credit: © Joe McDonald/Visuals Unlimited

300241

African Lioness (*Panthera leo*) and African Elephants, Masai Mara Game Reserve, Kenya.

Credit: © Richard Herrmann/Visuals Unlimited

205342

Chaparral vegetation.

Credit: © Steve Maslowski/Visuals Unlimited

210424

A Bison herd on the prairie.

Credit: © Patrick J. Endres/Visuals Unlimited

301450

Arctic tundra biome in summer, Alaska Range Mountains, Denali National Park, Alaska.

Credit: © Richard Thom/Visuals Unlimited

307010

Sonoran Desert scene with Creosote Bush, Saguaro, Cholla, and Paloverde.

Only 5% to 20% of energy passes between trophic levels.

- Energy reaching each trophic level depends on:
  - net primary production (base of food chain)
  - efficiencies of transfers between trophic levels
- Plant use between 15% and 70% of light energy assimilated for maintenance – thus that portion is unavailable to consumers
- Herbivores and carnivores expend more energy on maintenance than do plants: **production of each trophic level is only 5% to 20% that of the level below it**.

Ecological Efficiency

- **Ecological efficiency** (**food chain efficiency**) is the percentage of energy transferred from one trophic level to the next:
  - range of 5% to 20% is typical, as we've seen
  - to understand this more fully, we must study the use of energy within a trophic level

Undigested plant fibers in elephant dung

Intratrophic Energy Transfers

- Intratrophic transfers involve several components:
  - **ingestion** (energy content of food ingested)
  - **egestion** (energy content of indigestible materials regurgitated or defecated) *(the elephant dung)*
  - **assimilation** (energy content of food digested and absorbed)
  - **excretion** (energy content of organic wastes)
  - **respiration** (energy consumed for maintenance)
  - **production** (residual energy content for growth and reproduction)

Fundamental Energy Relationships

- Components of an animal's energy budget are related by:
  - ingested energy - egested energy = assimilated energy
  - assimilated energy - respiration - excretion = production

Assimilation Efficiency

- **Assimilation efficiency** = assimilation/ingestion
- primarily a function of food quality:
  - seeds: 80%
  - young vegetation: 60-70%
  - plant foods of grazers, browsers: 30-40%
  - decaying wood: 15%
  - animal foods: 60-90%

Net Production Efficiency

- **Net production efficiency** = production/assimilation
- depends largely on metabolic activity:
  - birds: <1%
  - small mammals: <6%
  - sedentary, cold-blooded animals: as much as 75%
- **Gross production efficiency** = assimilation efficiency x net production efficiency = production/ingestion, ranges from below 1% (birds and mammals) to >30% (aquatic animals).

Active, warm-blooded animals – low net production efficiencies; hummingbird: <1%

Production Efficiency in Plants

- The concept of production efficiency is somewhat different for plants because plants do not digest and assimilate food:
  - **net production efficiency** = net production/gross production; varies between 30% and 85%
  - rapidly growing plants in temperate zone have net production efficiencies of 75-85%; their counterparts in the tropics are 40-60% efficient

Detritus Food Chains

- Ecosystems support two parallel food chains:
  - **herbivore-based** (relatively large animals feed on leaves, fruits, seeds)
  - **detritus-based** (microorganisms and small animals consume dead remains of plants and indigestible excreta of herbivores)
  - herbivores consume:
    - 1.5-2.5% of net primary production in temperate forests
    - 12% in old-field habitats
    - 60-99% in plankton communities

Exploitation Efficiency

- When production and consumption are not balanced, energy may accumulate in the ecosystem (as organic sediments).
- **Exploitation efficiency** = ingestion by one trophic level/production of the trophic level below it.
- To the extent that exploitation efficiency is <100%, ecological efficiency = exploitation efficiency x gross production efficiency.

Energy moves through ecosystems at different rates.

- Other indices address how rapidly energy cycles through an ecosystem:
  - **residence time** measures the average time a packet of energy resides in storage:
    - residence time (yr) = energy stored in biomass/net productivity
  - **biomass accumulation ratio** is a similar index based on biomass rather than energy:
    - biomass accumulation ratio (yr) = biomass/rate of biomass production

Residence Time for Litter

- Decomposition of litter is dependent on conditions of temperature and moisture.
- Index is **residence time** = mass of litter accumulation/rate of litter fall:
  - 3 months in humid tropics
  - 1-2 yr in dry and montane tropics
  - 4-16 yr in southeastern US
  - >100 yr in boreal ecosystems

Some General Rules

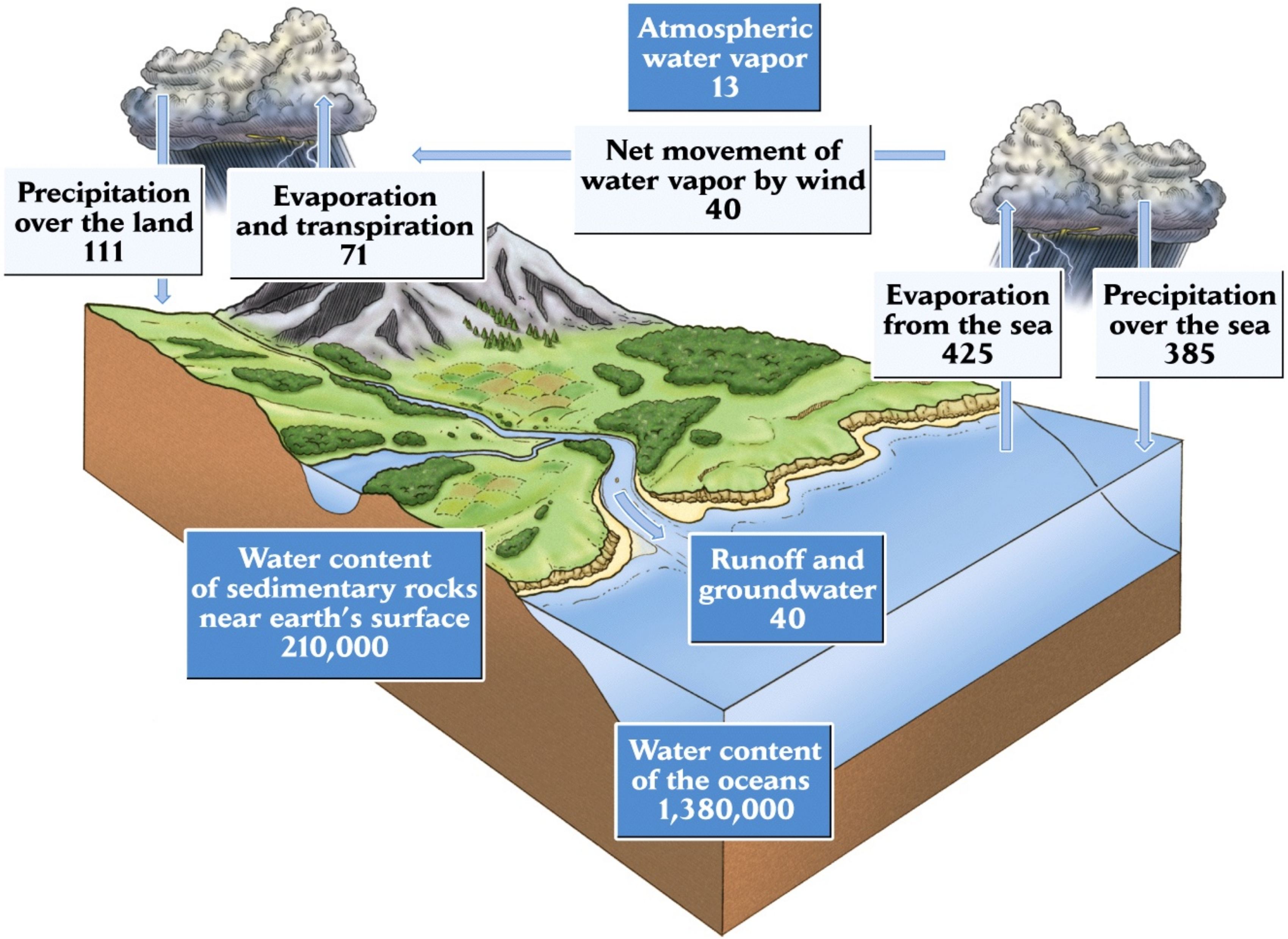
- Assimilation efficiency increases at higher trophic levels.
- Net and gross production efficiencies decrease at higher trophic levels.
- Ecological efficiency averages about 10%.
- About 1% of net production of plants ends up as production on the third trophic level: the pyramid of energy narrows quickly.
- To increase human food supplies means eating lower on food chain!

- Rewilding video

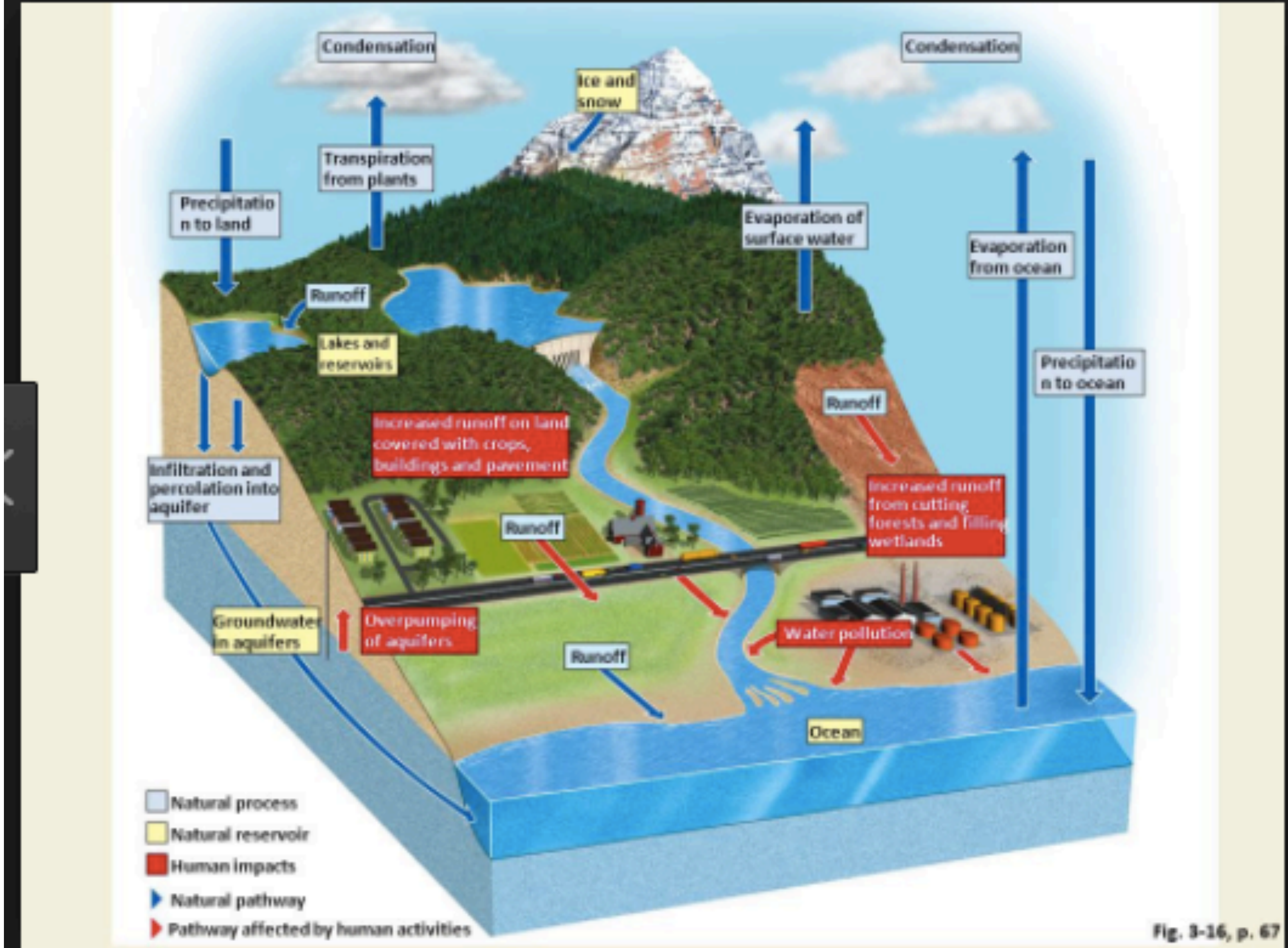
Nutrient cycling…

- Water cycle
- Carbon cycle
- Nitrogen cycle
- Phosphorus cycle
- Sulfur cycle

Water cycle



Atmospheric water vapor 13
Net movement of water vapor by wind 40
Precipitation over the land 111
Evaporation and transpiration 71
Evaporation from the sea 425
Precipitation over the sea 385
Water content of sedimentary rocks near earth's surface 210,000
Runoff and groundwater 40
Water content of the oceans 1,380,000


Condensation
Condensation
Ice and snow
Transpiration from plants
Precipitatio n to land
Evaporation of surface water
Evaporation from ocean
Runoff
Lakes and reservoirs
Precipitatio n to ocean
Runoff
Increased runoff on land covered with crops, buildings and pavement
Infiltration and percolation into aquifer
Increased runoff from cutting forests and filling wetlands
Runoff
Groundwater in aquifers
Overpumping of aquifers
Water pollution
Runoff
Ocean
Natural process
Natural reservoir
Human impacts
Natural pathway
Pathway affected by human activities
Fig. 3-16, p. 67

Human activities

Human activities that alter the water cycle include:

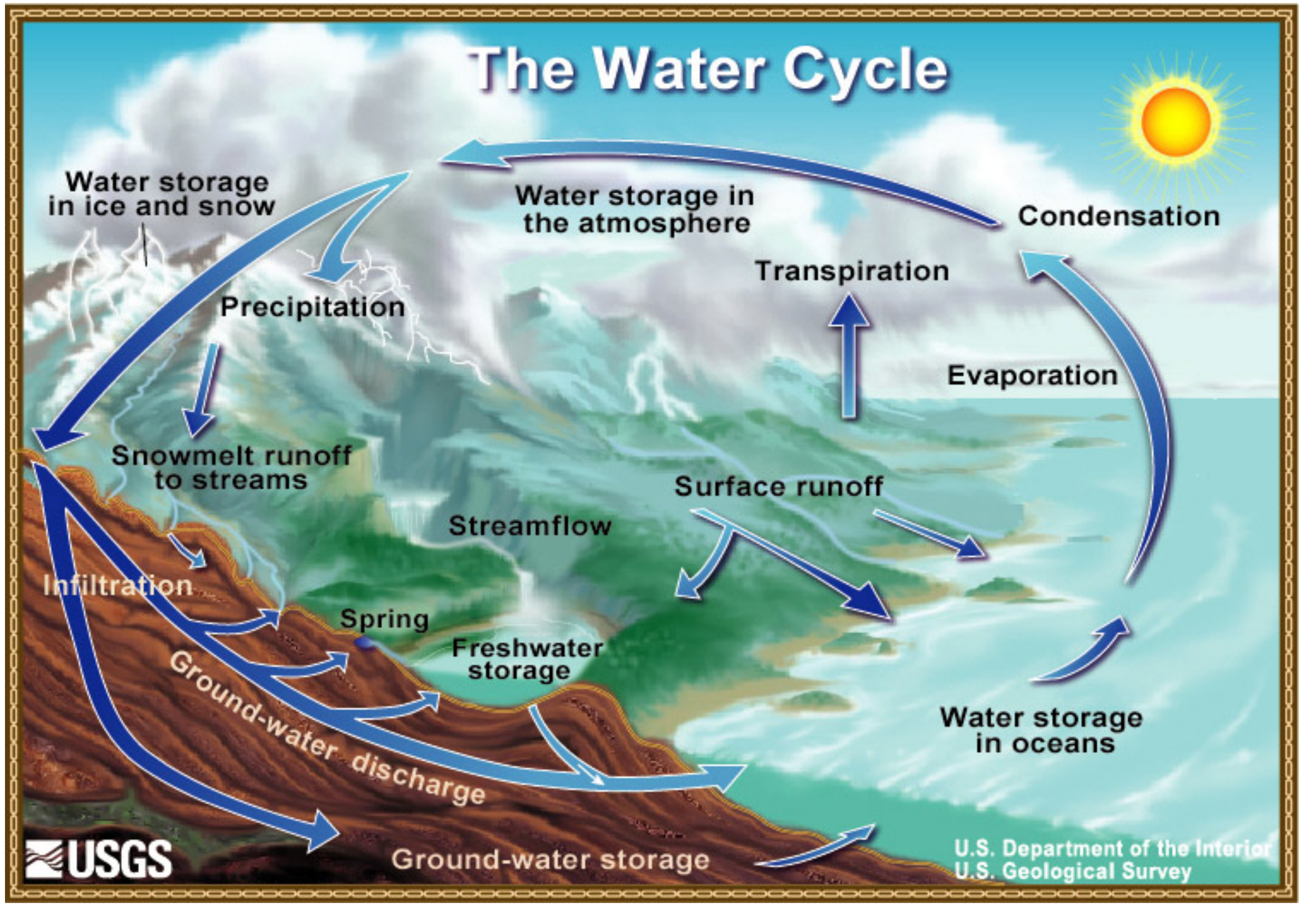
- agriculture
- industry
- alteration of the chemical composition of the atmosphere
- construction of dams
- deforestation and afforestation
- removal of groundwater from wells
- urbanization

Climate Change

- 1827 – Fourier said atmosphere will allow solar radiation to enter uninhibited but traps thermal radiation from the Earth's surface
- 1861 – Tyndal said thermal radiation trapping is not due to major gases (N_2 and O_2) but to trace gases
- Major greenhouse gases
  - CO_2
  - Water vapor, H_2O
  - Others (CH_4, N_2O)
- Mechanisms of climate change will not be discussed here, only impact on hydrology

Climate Change & water

- Earth's water cycle encompasses the salt water of the oceans, the fresh water of rivers and lakes, and frozen icecaps and glaciers. It includes water flows within and between the oceans, atmosphere, and land, in the form of evaporation, precipitation, storms and weather. The water cycle contains enormous energy flows that shape Earth's climate, temperature trends, and surface features. Water effects are orders of magnitude larger than the feared effects of carbon dioxide.
- Eg: Oceans can hold 1,000 times the heat energy than the mass of the atmsophere

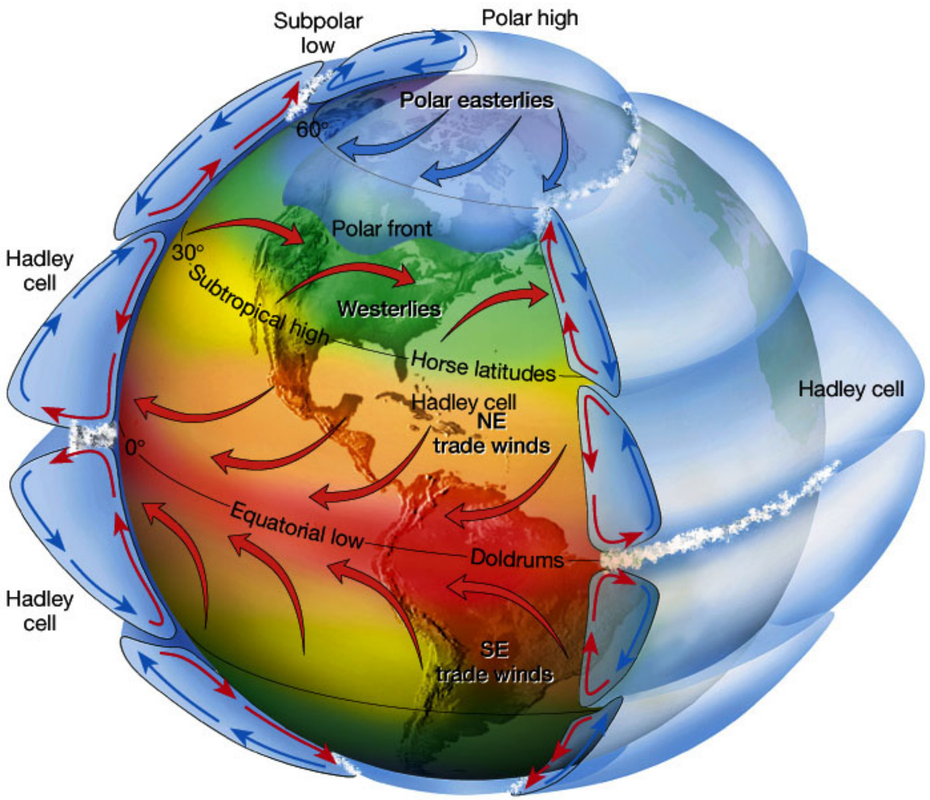


Climate Change – Water Vapor

- The atmosphere can hold more water vapor at higher temperatures
- This produces more clouds which warm the surface in infrared (longwave, thermal) radiation but cool the surface in shortwave (solar) radiation (Boer, 1993)
- Therefore, increased water vapor in the atmosphere *may* further act to increase surface temperature and evaporation. This will further increase atmospheric water vapor concentrations
- Result: possible "runaway greenhouse" effect

Climate Change – Runoff

- Current precipitation trends controlled by wind circulation
- These trends intensify due to climate change, so dry areas become drier and wet areas become wetter



Source: Maidment CE 394K.2 class notes, 2008

Climate change and hydrological cycle

- Increasing the hydrological cycle
- What does that mean?
- Wet areas are getting wetter and dry areas are getting drier.
- Why?
- A warmer atmosphere can absorb more water vapor, and what goes up must come down — and thanks to prevailing winds, it won’t come down in the same place.
- But it’s happening about twice as fast as anyone thought. Why this disconnect? Previously: data taken from land and not from oceans. Look at what in oceans?
- Salinity. Why? When water evaporates from the surface of the ocean, it leaves the salt behind. That makes increased saltiness a good proxy for drought. When fresh water rains back down on the ocean, it dilutes the seawater, so decreased saltiness is the equivalent of a land-based flood.

Lebanon and water

- "The effect of climate change on water resources is expected to be significant as a result of decrease in precipitation and projected changes in its spatial and temporal distribution, in addition to an increase in evapotranspiration. Droughts are predicted to occur 15 days to 1 month earlier, which will negatively affect the existing water shortage due to urbanization and population growth. The already dry regions such as the Bekaa, Hermel and the South will be mostly affected. A reduction of 6 to 8% of the total volume of water resources is expected with an increase of 1° C and 12 to 16% for an increase of 2° C. In addition, a decline in total and active precipitation is forecasted as well as a shift in rainfall consisting of higher precipitation in November and December, and a steep reduction from January onward.
- Climate change will induce a reduction of 40% of the snow cover of Lebanon with an increase of 2° C in temperature and will reach 70% decrease in snow cover with an increase of 4° C. This will have adverse impacts on rivers and groundwater recharge, especially that snow melt will occur in early spring, which does not coincide with high demand for irrigation water such as the summer season. In addition, snow will shift from 1,500 m to 1,700 m by 2050 and to 1,900 m by 2090, affecting the recharge of most springs. The change in rainfall regimes will increase the manifestation of extreme events: winter floods can increase up to 30%, and hot summer days and tropical nights can last at least two months longer. This combination of significantly less wet and substantially warmer conditions will result in an extended hot and dry climate and in an intensification of the temperature extremes."
- Lebanon National Communication Plan - 2011

Carbon cycle

Natural Capital: Carbon Cycle with Major Harmful Impacts of Human Activities

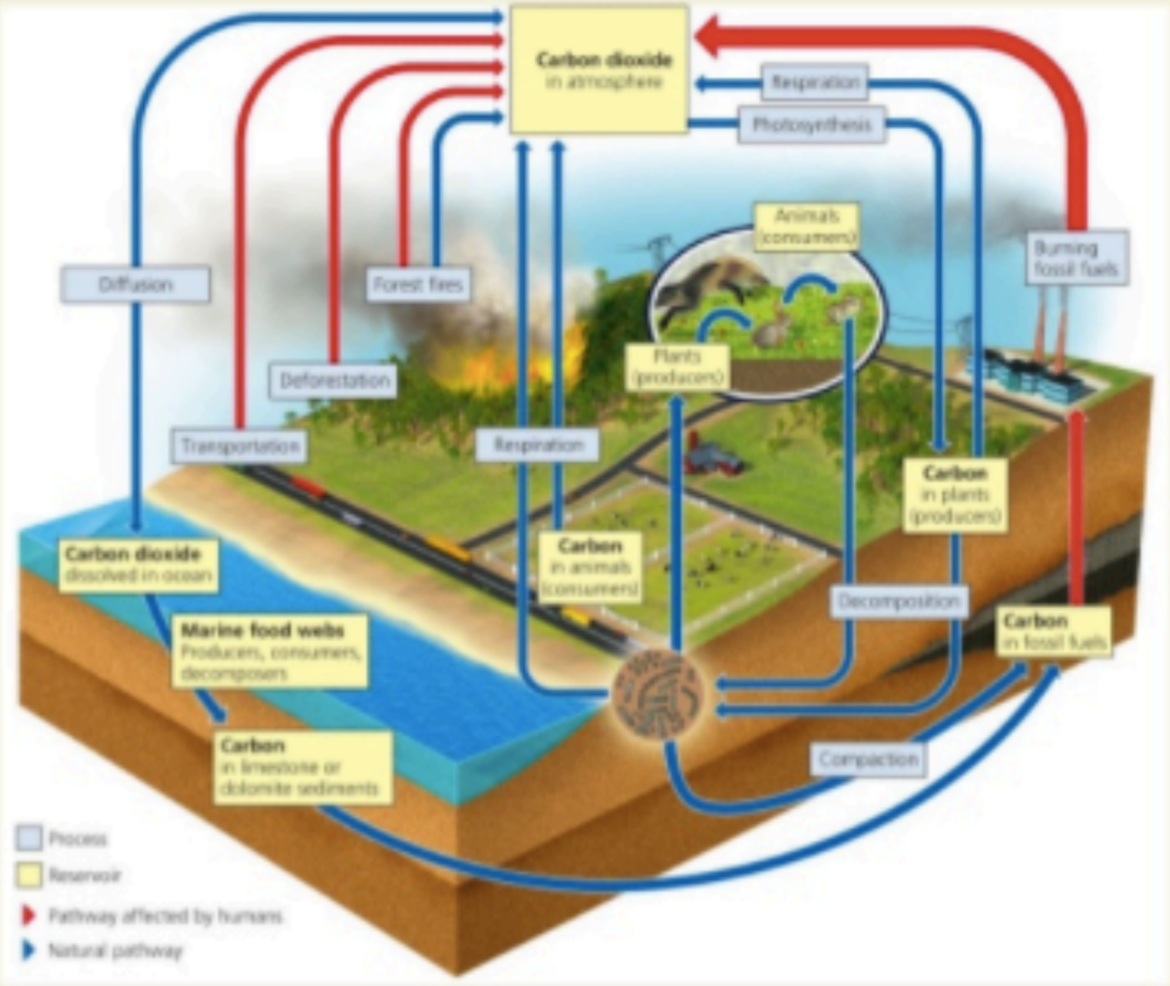


Fig. 3-19, p. 70

Changes in the Carbon Cycle Over Time

- Atmospheric CO_2 concentrations have varied considerably over earth's history:
  - during the early Paleozoic era (550-400 Mya), concentrations were 15-20 X those at present
  - concentrations declined to ca. present level by 300 Mya (during which saw development of forests on land), then increased again to 5 X present level through the early Mesozoic era (250-150 Mya) and have declined gradually since
  - early Paleozoic and early Mesozoic eras were extreme greenhouse times (hot temperatures), unlikely to be equaled by effects of current human enhancement of atmospheric CO_2

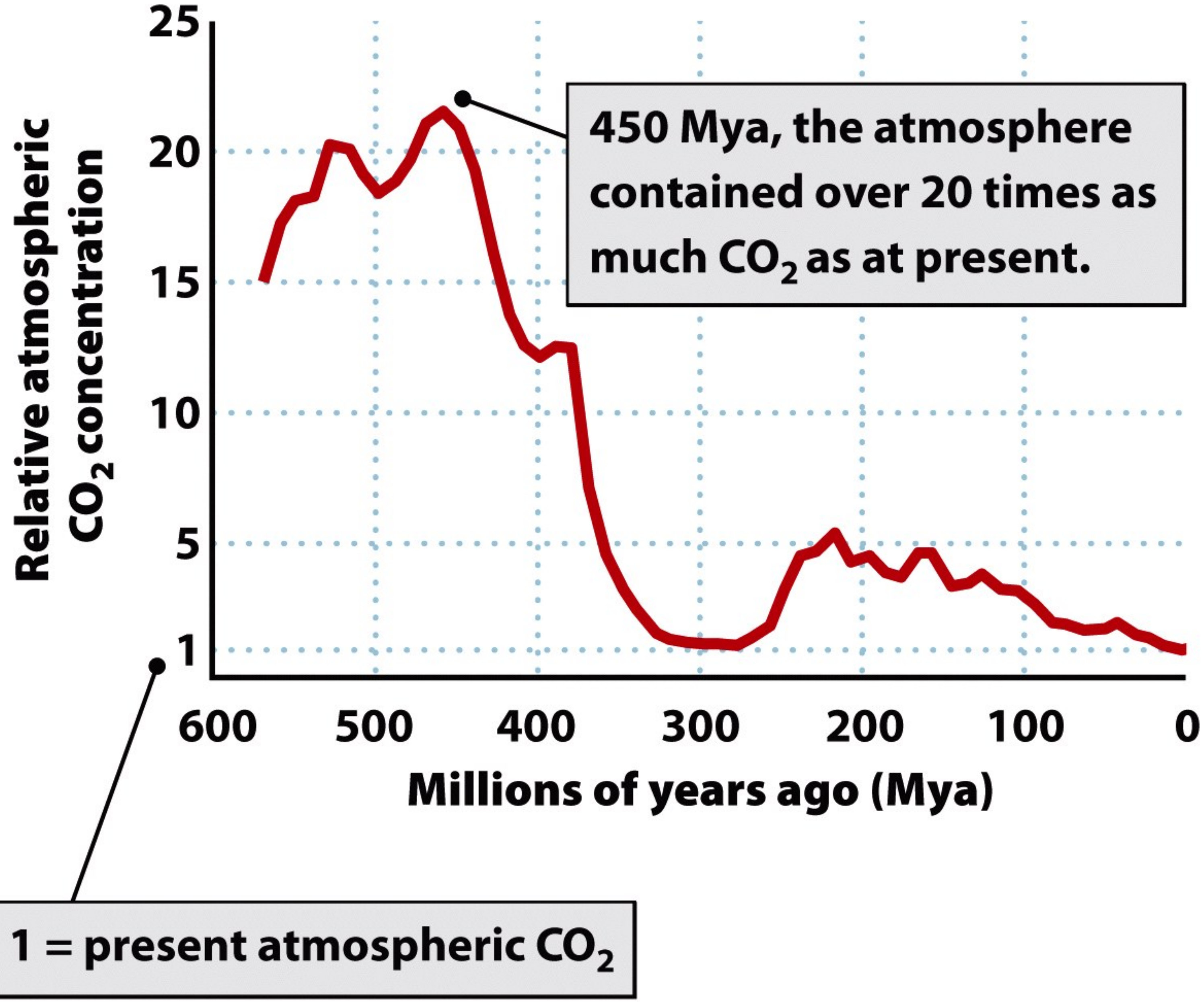
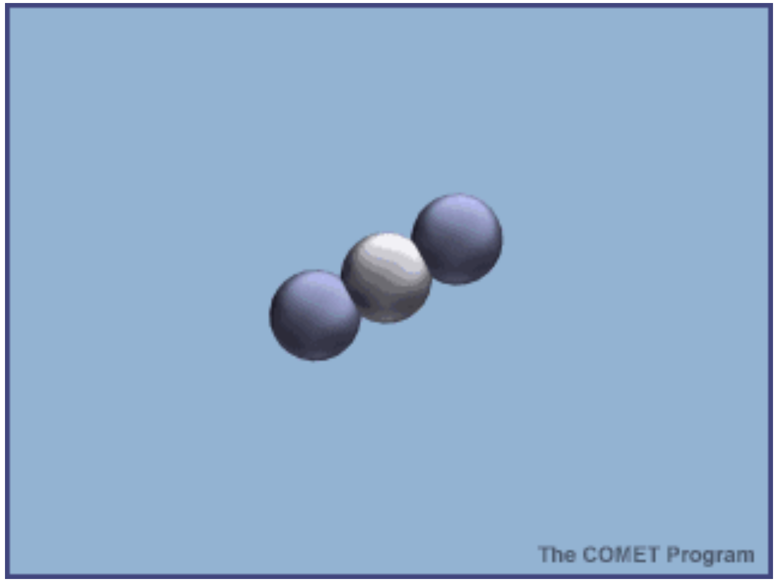


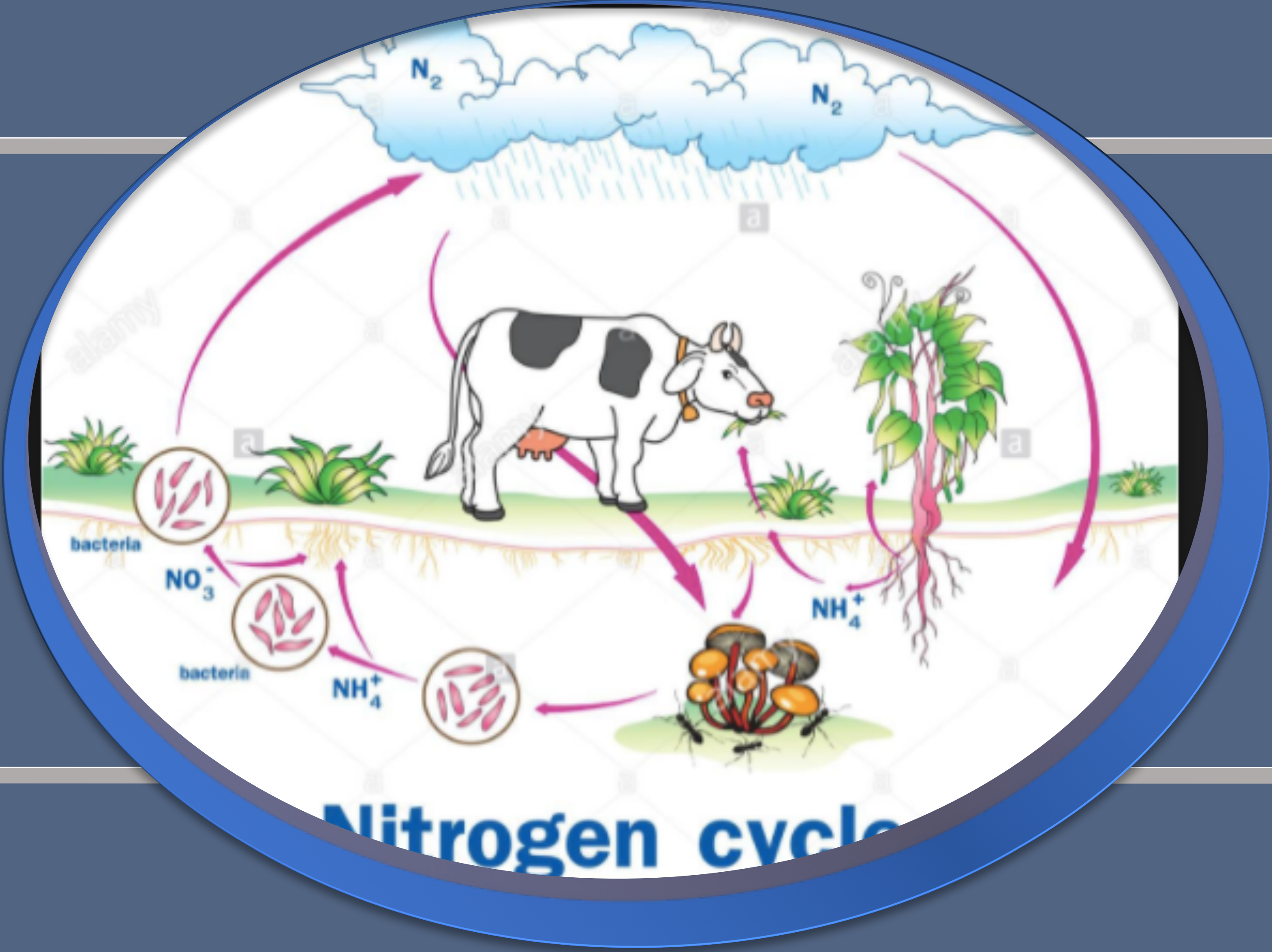
Figure 23.9
The Economy of Nature, **Sixth Edition**

Reminder: Climate Change – CO_2

- CO_2 concentration from 1900-1920 was300 ppm
- CO_2 concentration at present day is 403 ppm (as of Sept 2017) (source: https://www.co2.earth/)
- CO_2 concentration to melt all permanent polar ice is 1200 ppm (Pierrehumbert, 2002)
- Most climate models investigate doubling of CO_2 to roughly 700 ppm and find an increase in temperature of 2-4 °C



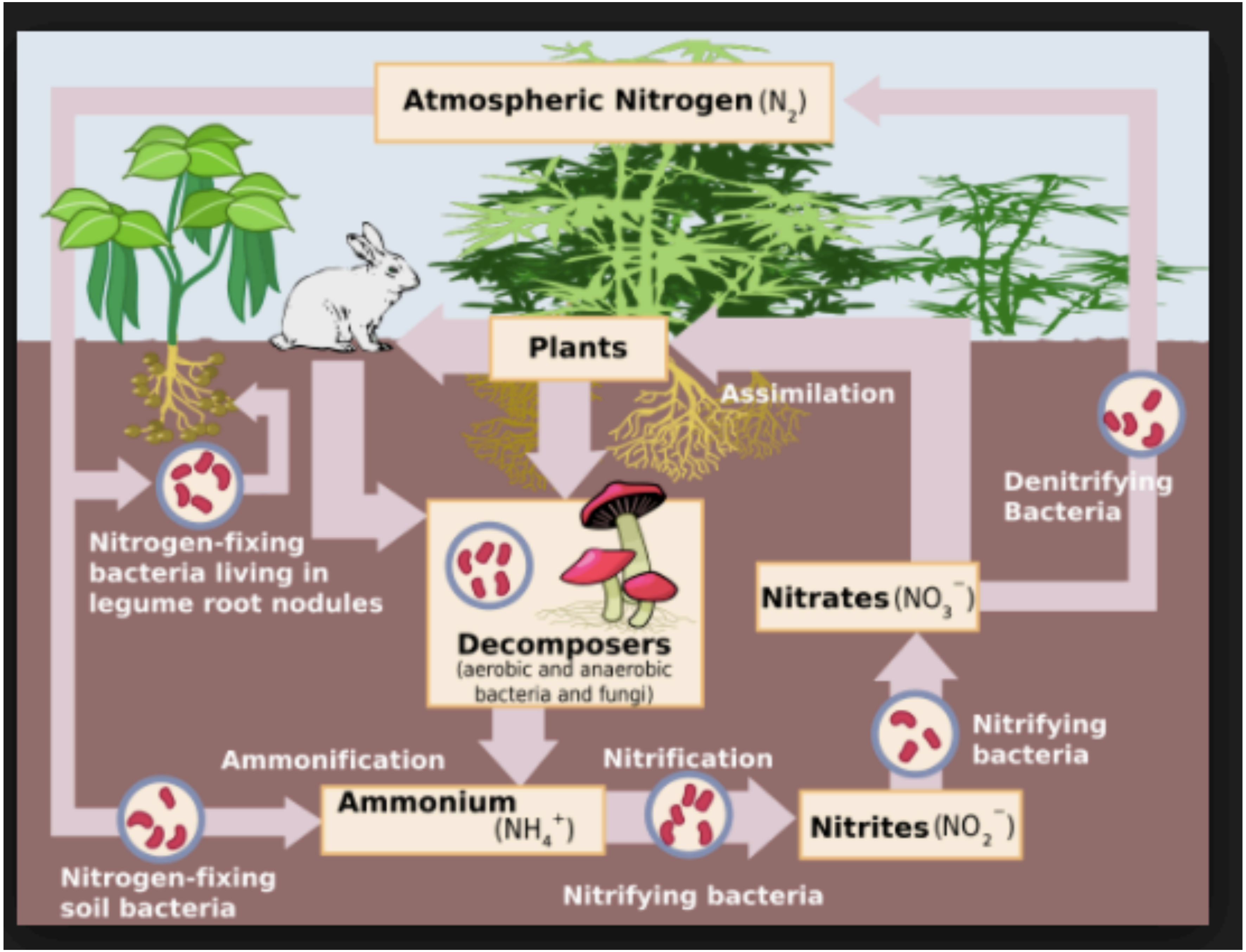
Source: Maidment CE 394K.2 class notes, 2008



Nitrogen cycle

Nitrogen - A Most Versatile Element!

- Ultimate source (largest reservoir) of this essential element is molecular N_2 gas in the atmosphere, which can also dissolve in water to some extent.
- Nitrogen is absent from native rock.
- Nitrogen enters biological pathways through nitrogen fixation:
  - these pathways are more complicated than those of the carbon cycle because nitrogen has more oxidized and reduced forms than carbon


Atmospheric Nitrogen (N_2)
Plants
Assimilation
Denitrifying Bacteria
Nitrogen-fixing bacteria living in legume root nodules
Decomposers
(aerobic and anaerobic bacteria and fungi)
Nitrates (NO_3^-)
Nitrifying bacteria
Ammonification
Nitrification
Ammonium (NH_4^+)
Nitrites (NO_2^-)
Nitrogen-fixing soil bacteria
Nitrifying bacteria

Nitrogen Cycle in a Terrestrial Ecosystem with Major Harmful Human Impacts

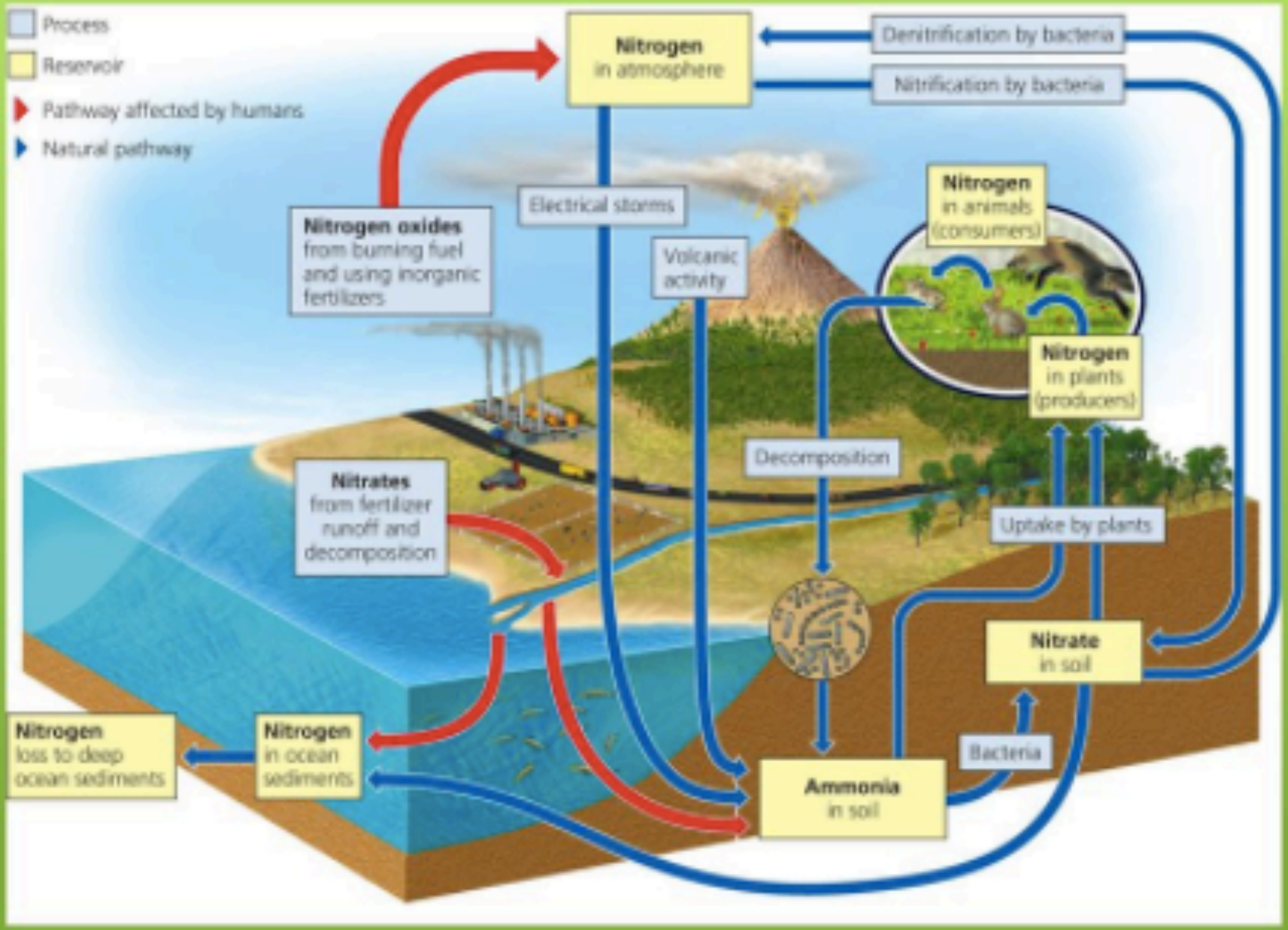


Fig. 3-20, p. 71

Nitrogen and us

- human beings have more than doubled the annual transfer of nitrogen into biologically available forms
  - Chemical fertilizers
  - Pollution from vehicles and industrial plants

  - N2O has risen in the atmosphere as a result of agricultural fertilization, biomass burning, cattle and feedlots, and other industrial sources

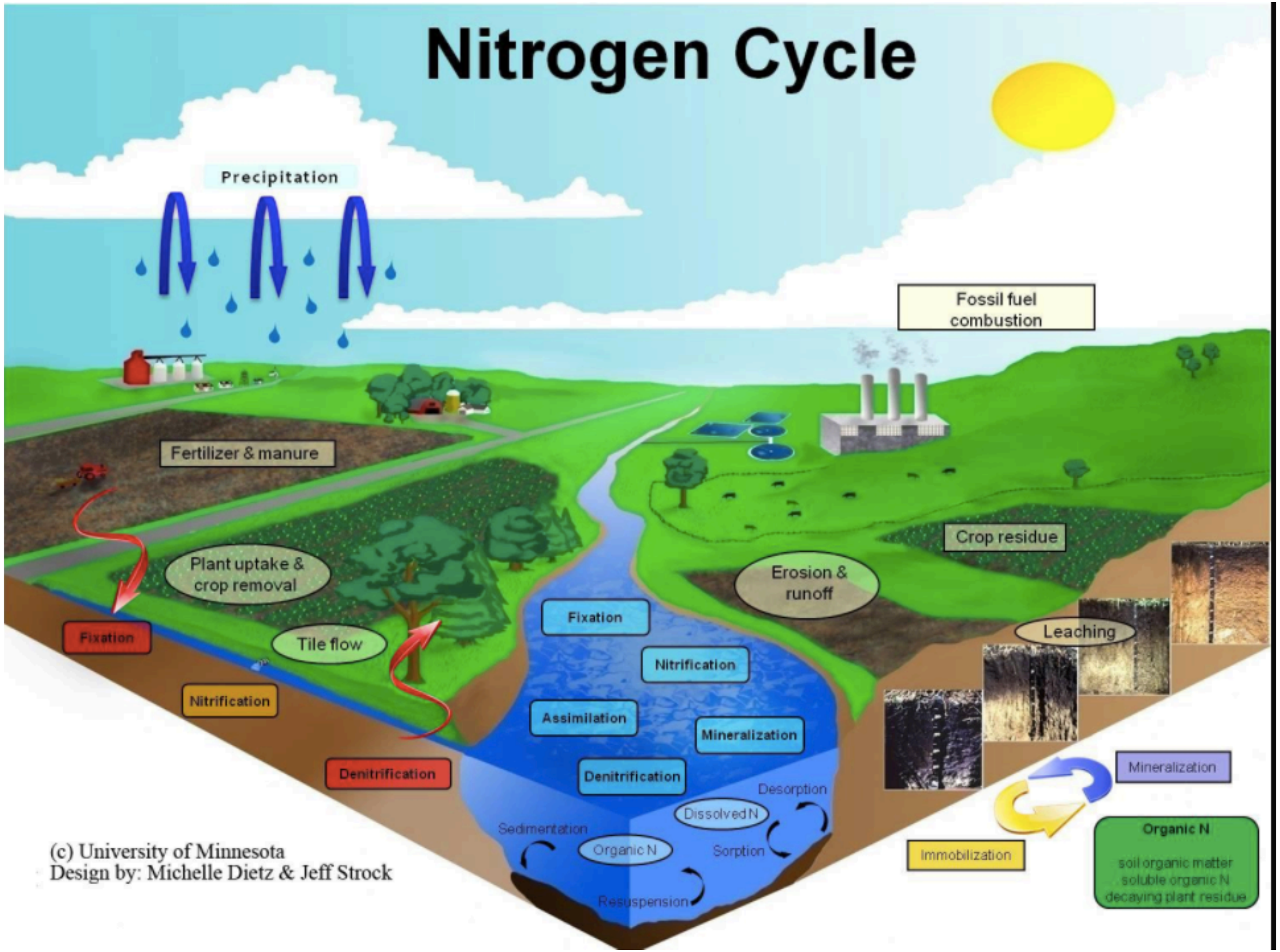
Human activities

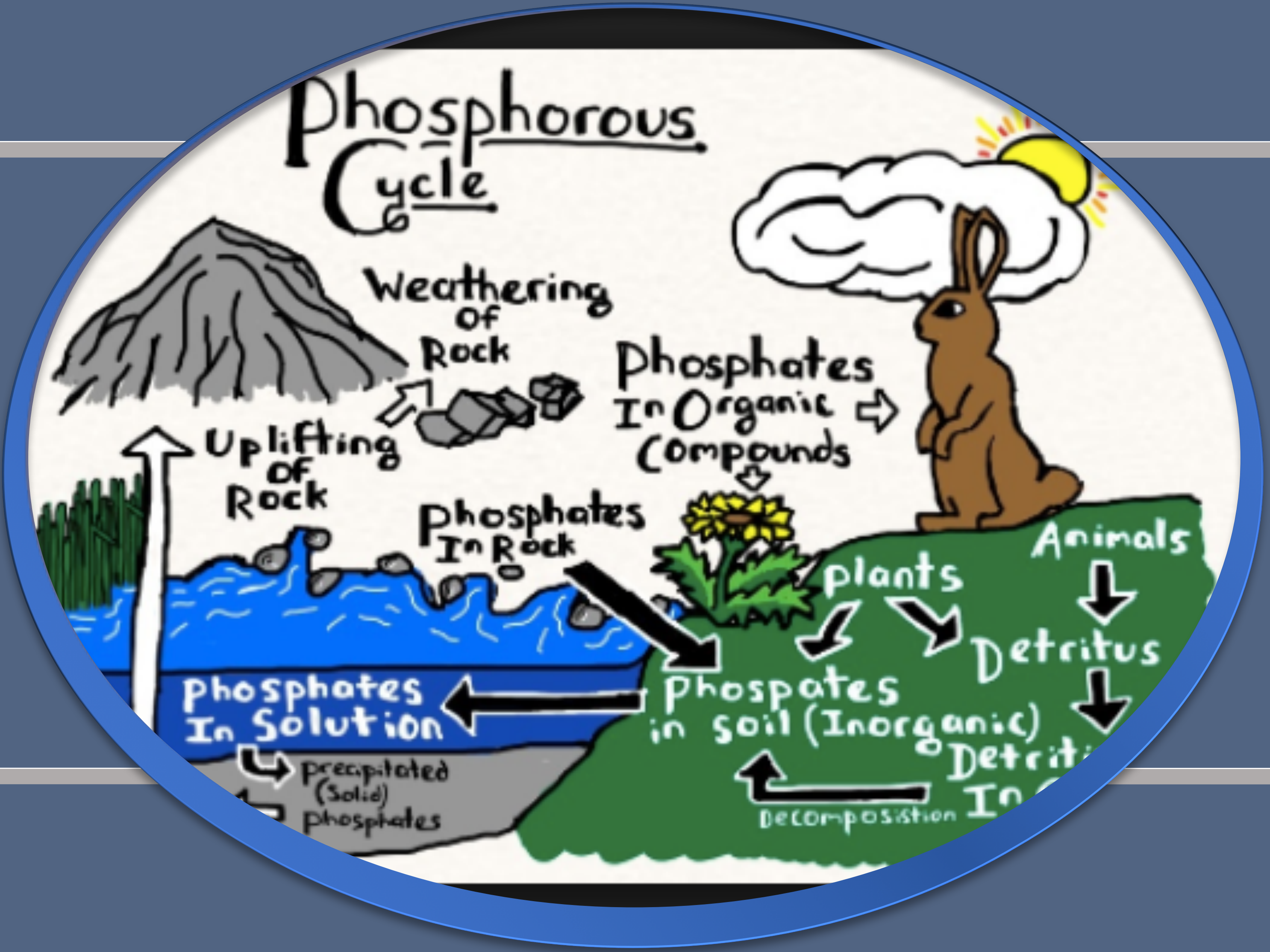
- The impacts of human domination of the nitrogen cycle that we have identified with certainty include:
  - Increased global concentrations of nitrous oxide (N2O), a potent greenhouse gas, in the atmosphere as well as increased regional concentrations of other oxides of nitrogen (including nitric oxide, NO) that drive the formation of photochemical smog;
  - Losses of soil nutrients such as calcium and potassium that are essential for long-term soil fertility;
  - Substantial acidification of soils and of the waters of streams and lakes in several regions;
  - Greatly increased transport of nitrogen by rivers into estuaries and coastal waters where it is a major pollutant.

Consequences

human alterations of the nitrogen cycle have:

- * Accelerated losses of biological diversity, especially among plants adapted to low-nitrogen soils, and subsequently, the animals and microbes that depend on these plants;
- * Caused changes in the plant and animal life and ecological processes of estuarine and nearshore ecosystems, and contributed to long-term declines in coastal marine fisheries.


Nitrogen Cycle
Precipitation
Fossil fuel combustion
Fertilizer & manure
Plant uptake & crop removal
Crop residue
Erosion & runoff
Leaching
Tile flow
Fixation
Nitrification
Denitrification
Fixation
Nitrification
Assimilation
Mineralization
Denitrification
Desorption
Dissolved N
Sedimentation
Organic N
Sorption
Resuspension
Mineralization
Immobilization
Organic N
soil organic matter
soluble organic N
decaying plant residue
(c) University of Minnesota
Design by: Michelle Dietz & Jeff Strock



Phosphorus cycle

The Phosphorus Cycle

- Phosphorous is an essential element, constituent of nucleic acids, cell membranes, energy transfer systems, bones, and teeth.
- Phosphorus may limit productivity:
  - in aquatic systems, sediments act as a phosphorus sink unless oxygen-depleted
  - in soils, phosphorus is only readily available between pH of 6 and 7

Phosphorus Transformations

- Phosphorus undergoes relatively few transformations:
  - plants assimilate P as phosphate (PO_4^{3-}) and incorporate this into organic compounds
  - animals and phosphatizing bacteria break down organic forms of phosphorus and release the phosphorus as phosphate
  - phosphorus does not:
    - undergo oxidation-reduction reactions in the ecosystem
    - circulate through the atmosphere, except as dust

Impacts

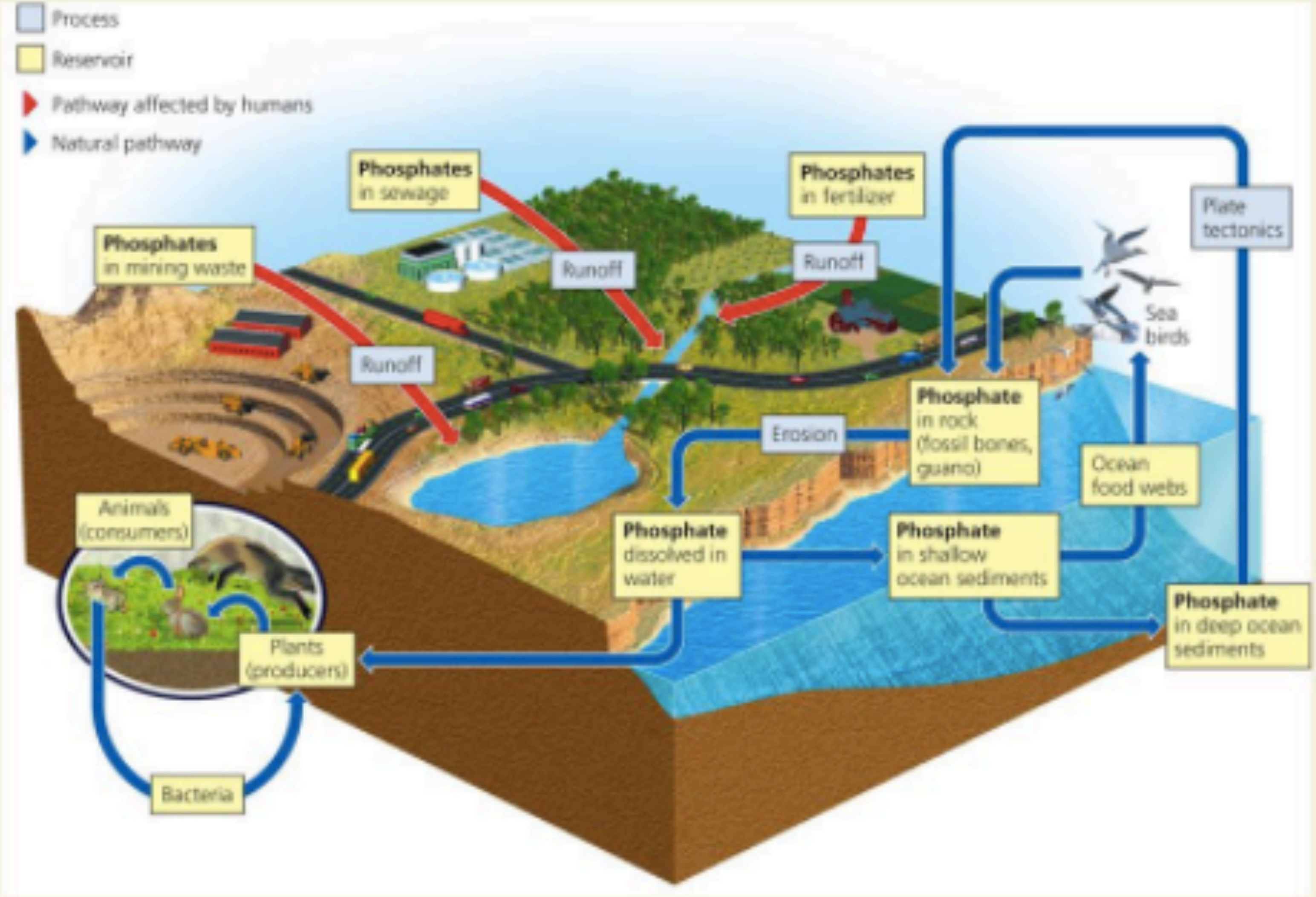
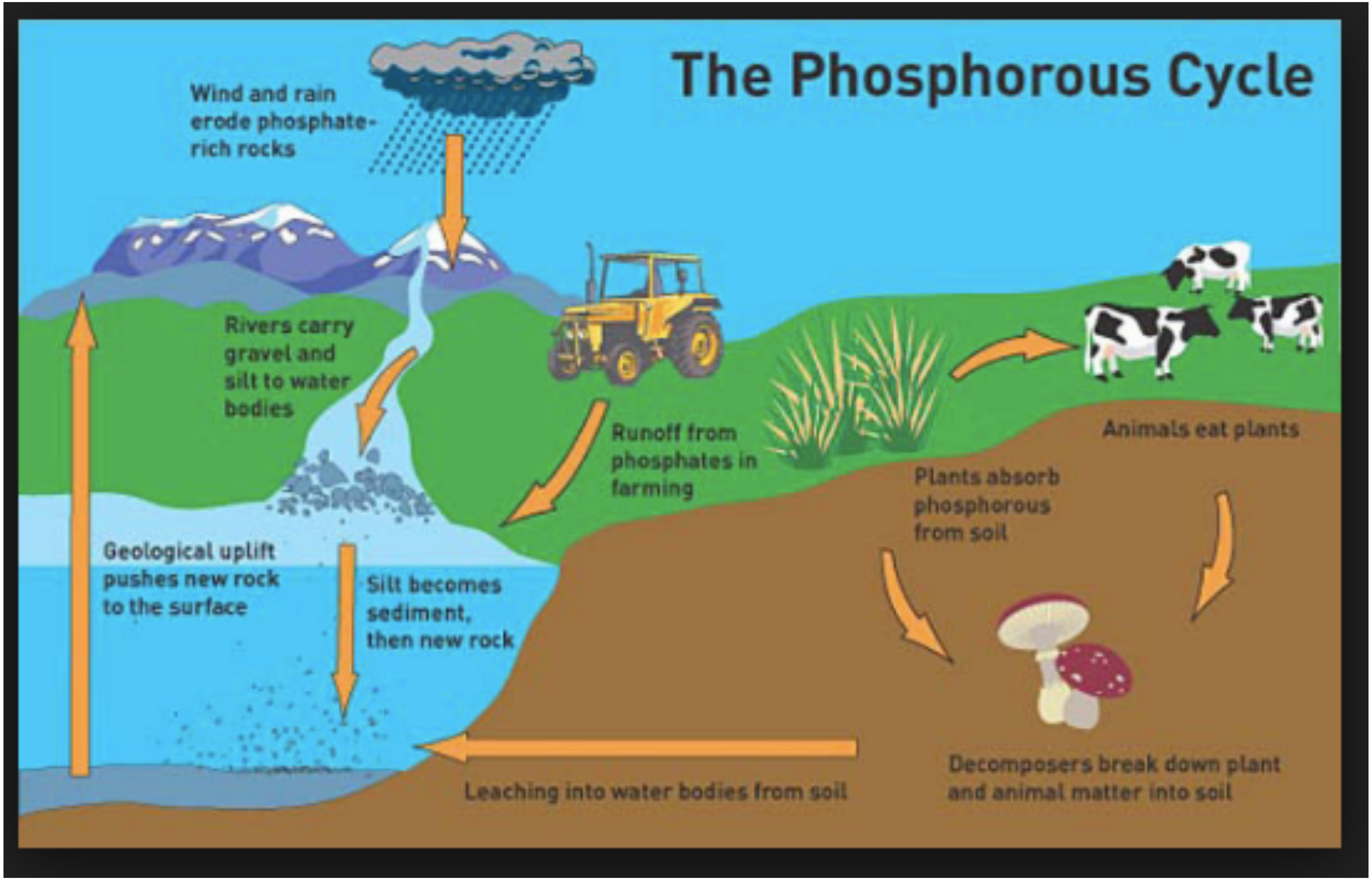


Fig. 3-21, p. 73


The Phosphorous Cycle
Wind and rain erode phosphate-rich rocks
Rivers carry gravel and silt to water bodies
Runoff from phosphates in farming
Plants absorb phosphorous from soil
Animals eat plants
Geological uplift pushes new rock to the surface
Silt becomes sediment, then new rock
Decomposers break down plant and animal matter into soil
Leaching into water bodies from soil

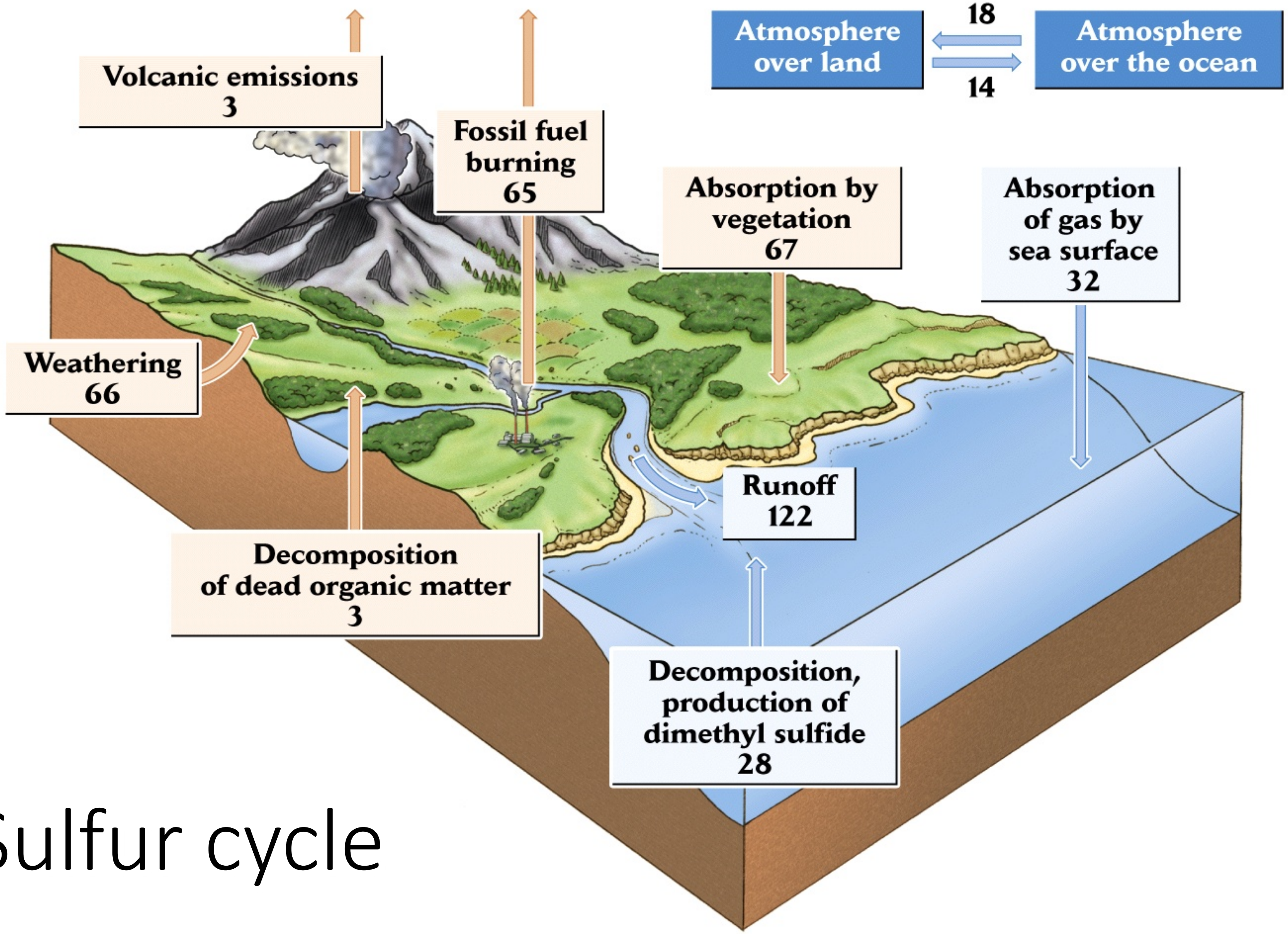
Sulfur cycle

The Sulfur Cycle

- Sulfur is an essential element and, like nitrogen, has many oxidation states and follows complex chemical pathways.
- Sulfur reduction reactions include:
  - assimilatory sulfate reduction to organic forms and dissimilatory oxidation back to sulfate by many organisms
  - reduction of sulfate when used as an oxidizer for respiration by heterotrophic bacteria in anaerobic environments
- Sulfur oxidation reactions include:
  - oxidation of reduced sulfur when used as an electron donor (in place of oxygen in water) by photosynthetic bacteria
  - oxidation of sulfur by chemoautotrophic bacteria that use the energy thus obtained for assimilation of CO_2

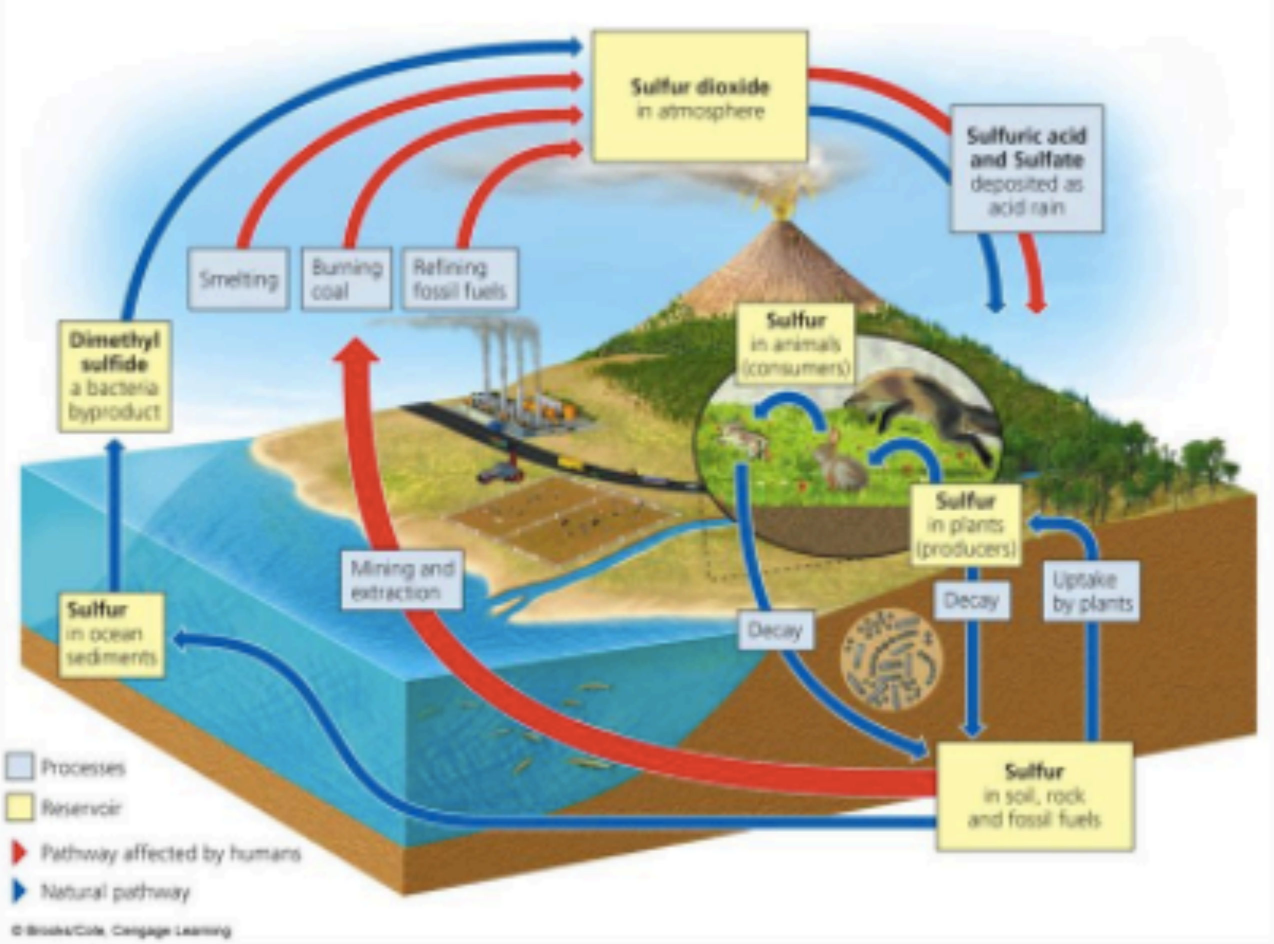
Sulfur in Coal and Oil Deposits

- Iron sulfide (FeS) commonly associated with coal and oil deposits can result in environmental problems:
  - oxidation of sulfides in mine wastes to sulfate, which combines with water to form sulfuric acid, associated with acid mine drainage
  - oxidation of sulfides in coal and oil releases sulfates into atmosphere, which then form sulfuric acid, a component of acid rain



Sulfur cycle

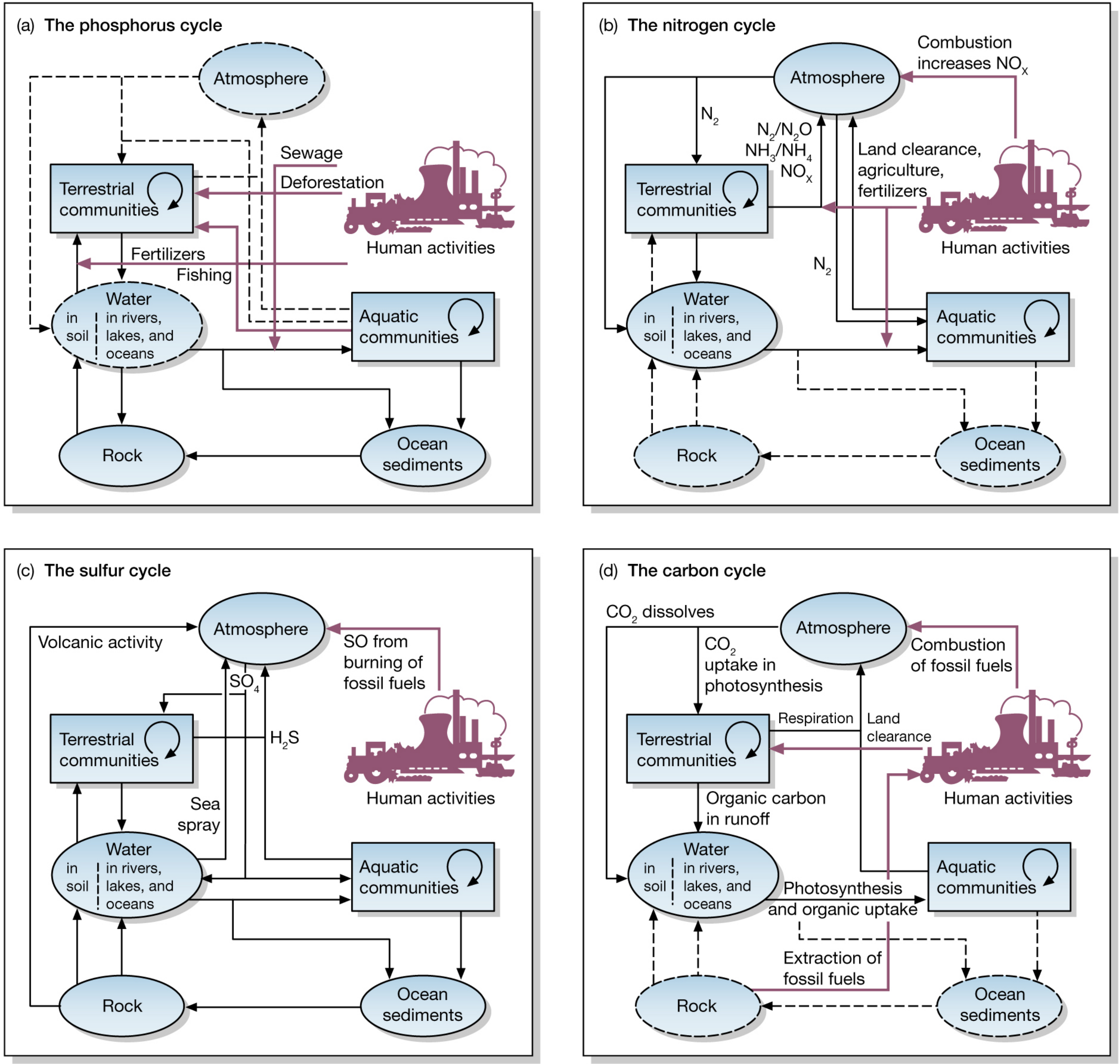
Natural Capital: Sulfur Cycle with Major Harmful Impacts of Human Activities



Acidic streams from refuse of coal mines (Pennsylvania)

Acid Rain and Forest Decline

The figures simplified



(a) The phosphorus cycle
Atmosphere
Sewage
Deforestation
Terrestrial communities
Human activities
Fertilizers
Fishing
Water
in soil
in rivers, lakes, and oceans
Aquatic communities
Rock
Ocean sediments
(b) The nitrogen cycle
Atmosphere
Combustion increases NO_X
N_2
N_2/N_2O
NH_3/NH_4
NO_X
Land clearance, agriculture, fertilizers
Terrestrial communities
Human activities
N_2
Water
in soil
in rivers, lakes, and oceans
Aquatic communities
Rock
Ocean sediments
(c) The sulfur cycle
Volcanic activity
Atmosphere
SO from burning of fossil fuels
SO_4
Terrestrial communities
H_2S
Human activities
Sea spray
Water
in soil
in rivers, lakes, and oceans
Aquatic communities
Rock
Ocean sediments
(d) The carbon cycle
CO_2 dissolves
Atmosphere
CO_2 uptake in photosynthesis
Combustion of fossil fuels
Respiration
Land clearance
Terrestrial communities
Human activities
Organic carbon in runoff
Water
in soil
in rivers, lakes, and oceans
Photosynthesis and organic uptake
Aquatic communities
Extraction of fossil fuels
Rock
Ocean sediments