

Environmental Science

Systems and Solutions

FOURTH EDITION

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Chapter 3

THE BIOSPHERE

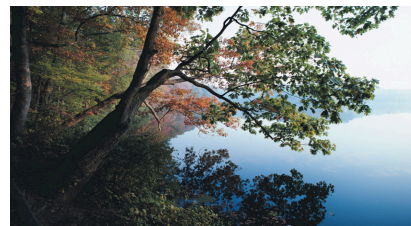
Populations, Communities, Ecosystems, and Biogeochemical Cycles

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Environmental Science *Systems and Solutions* FOURTH EDITION

Introduction

- **The environment is everything that surrounds you, including the air, the land, the oceans, and all living things.**
- **The natural environment is subdivided into two parts:**
 - the physical environment (nonliving matter) and
 - the biological environment, which includes all life forms (biosphere).



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Introduction

- **The physical environment is divided into three spheres, which have evolved together over the course of Earth's history on the basis of states of matter:**
 - The lithosphere (solid)
 - The hydrosphere liquid)
 - The atmosphere (gas)

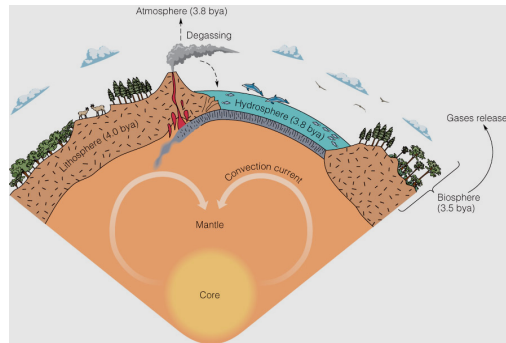


Figure 3-1 Spheres of the environment.

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Earth's Atmosphere

- **Earth's atmosphere is divided into layers on the basis of changing temperature gradients.**
- **The density of atmospheric gases decrease exponentially going away from the earth's surface.**
- **99% of the gases are found in the troposphere and stratosphere.**

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Adiabatic
Lapse rate:
Air cools
roughly
3 degrees F
Per 1000 ft

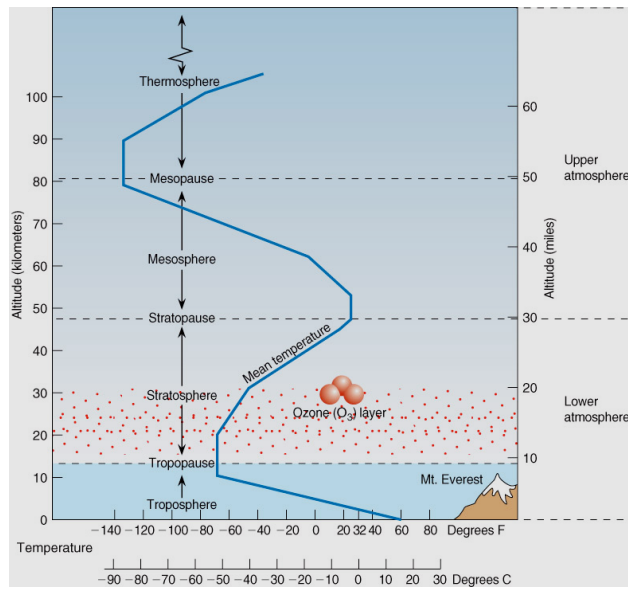


Figure 3-2: The structure of the Earth's atmosphere.

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Question

- ◆ Mount Palomar is about 6000 ft above sea level. If, on a winter day in San Diego (0 ft above sea level), it is 60 degrees out. What is a good guess as to the temperature on the mountain? (ALR=3°F/1000ft)

- A. 18 °F
- B. 42 °F
- C. 54 °F
- D. 60 °F
- E. 75 °F

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Cycle over days to weeks=weather
 Cycle over decades to millenia=climate
 Weather not very predictable: chaotic
 Climate easier to predict

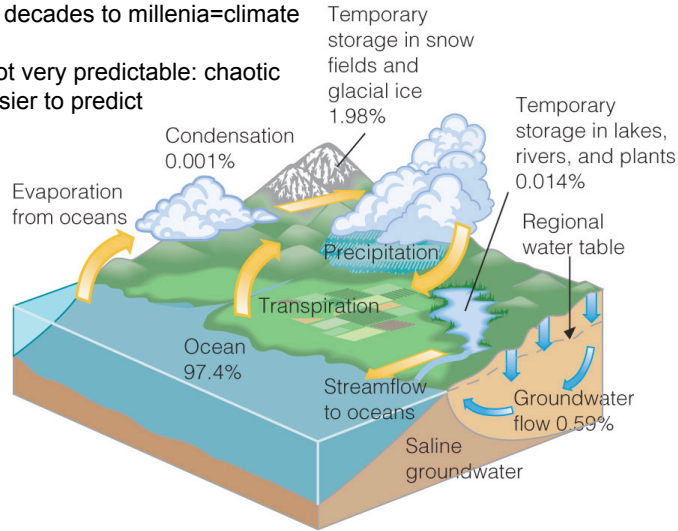


Figure 3-3 The hydrologic cycle.

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Hierarchy of Biosphere

- **Organisms, composed of atoms, molecules, and cells, are grouped into populations.**
- **Populations form communities, which then form ecosystems.**
- **Ecosystems comprise the biosphere, which includes all life on Earth.**

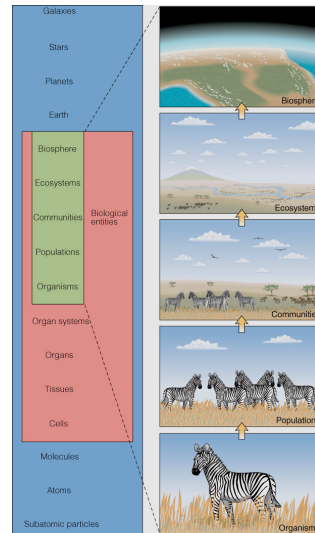


Figure 3-4 Organisms to biosphere.

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Ecology

- The science of ecology examines how organisms interact with each other and with the physical environment.
- Ecological principles have value in assessing how people are disturbing biological systems and in finding ways to minimize this disruption.
- But because of complexity including chaotic interactions, much is not understood. This science is at a beginning stage, and may not really even be a science yet!

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Biosphere Interactions Populations

- A population is a group of organisms of the same species living in the same area.
 - All populations undergo three distinct phases during their existence:
 - Growth
 - Stability
 - Decline
- [Fig. 3-5]

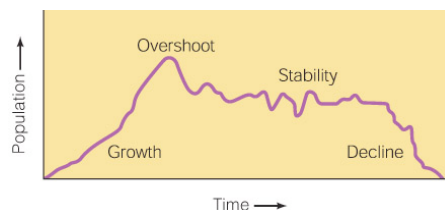


Figure 3-5 Growth, overshoot, stability, and decline; and finally extinction...

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Population Growth

- Birth rates, death rates, and the age structure affect its growth rate.

Population Stability

- Population growth is eventually limited by a complex interaction of many factors, including other species.
- **Carrying capacity** is the maximum population that can be sustained by an environment for a long time.

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Basic Abundance Controls

- Intrinsic rate of increase = birth rate - death rate; both must be considered since nature uses both
- Factors that limit the rates of reproduction and survival occur in both the physical and biological environment:
 - Physical limitations and law of the minimum
 - Competition: exploitative (early bird gets the work) and interference (coyotes vs. foxes)
 - Symbiosis
 - Predation

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Competitive Exclusion

- **Ecological niche:** what organism eats, what eats it, needed temperature, water, night vs. day, etc.
- **High niche overlap can exclude the less efficient competitor.**
- **Small niche overlap only limits abundance of both species.**
- **If one of competitors is removed others will increase; If all predators removed, prey will increase; people are currently major reason this happens (e.g. puma, bears)**



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Symbiotic Relations

TABLE 3-1		Symbolic Classification of Symbioses*	
Form of Symbiosis	Species A	Species B	
Mutualism	+	+	e.g. algae and coral; lichen
Predation and parasitism	+	-	
Commensalism	+	0	e.g. spanish moss on tree
Competition	-	-	
Amensalism	0	-	e.g. elephants and brush they crush!

* + = benefit, - = detriment, 0 = no effect

Figure 3-7 The wasp eggs on this tomato hornworm are parasitic.



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Figure 3.08: Commensal organisms, such as these barnacles, derive benefits from the turtle without harming it.

© Neville Coleman/Visuals Unlimited

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Human Impact on Population Size

- **People may cause population growth by removing previous limitations or population decline by imposing new limitations.**
- **People cause population increases by:**
 - An increase in available resources (e.g. pigeons)
 - Competitive release
 - Predator release
 - Introduction to new areas



Courtesy of Tracy Brooks-Mission Wolf/US Fish and Wildlife Service

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Human Impact on Population Size

- **People cause population decreases by:**
 - Habitat disruption
 - Introduction of new species
 - Overkill
 - Secondary extinctions



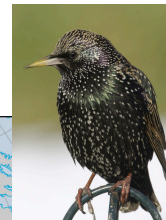
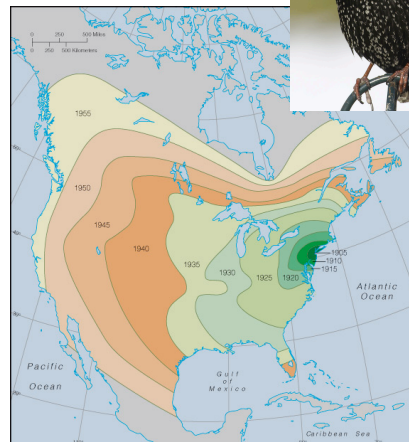
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Figure 3-16- The Verreaux's sifaka.

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Species Introduction

- **The introduction of nonnative (“exotic”) species like the European starling can have a large effect.**
- **Once the organism is established, population and range expansion can be quite rapid**



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Figure 3-11: The rapid migration of the European starling.

Source: Adapted from C. B. Cox and P. Moore, *Biogeography* [Cambridge, Mass.: Blackwell, 1993], p. 62.

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Can be quite subtle, e.g. eutrophication

- Nitrogen and Phosphorus are often “limiting” nutrient in plants (law of minimum)
- Human fertilizer runs off into sea and is rich in these nutrients => plants and algae increase greatly
- => Huge increase in dead plants => micro organisms that decompose dead plants greatly increase
- These use up all the oxygen in the water
- All the fish and other animals in the area die
- Remarkably, too much nutrient release causes huge “dead zones” off our coasts
- Other examples: deer, insect pests, etc.

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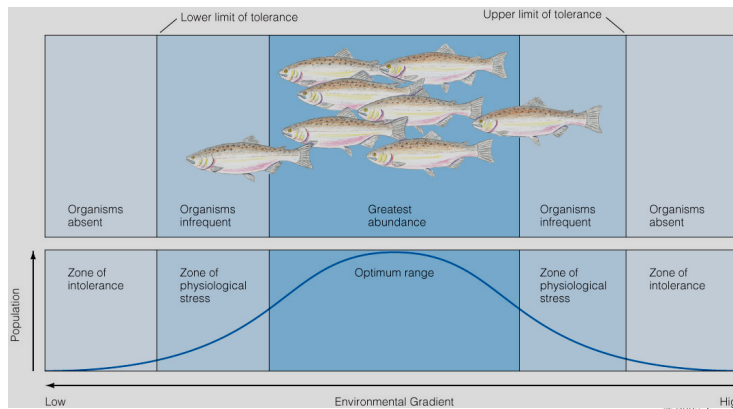
Figure 3.10: Lake eutrophication.

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Population Range

- Populations tend to have a maximum abundance near the center of their geographic range, which is the total area occupied by the population.
- The maximum occurs where the physical and biological factors that control abundance are most favorable.



Biosphere Interactions Communities and Ecosystems

- A community consists of all the populations that inhabit a certain area.
- The size of a community can range from very large to very small.
- An ecosystem is the community plus its physical environment.

Community Structure

- **Some communities are closed, with a sharp boundary (ecotone) separating different clusters of species.**
- **Most communities are open because of the overlapping ranges of their component populations.**



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Community Structure

- **Community diversity is important for resilience so that the community is less susceptible to environmental fluctuations. However, this importance level varies with the respective community.**

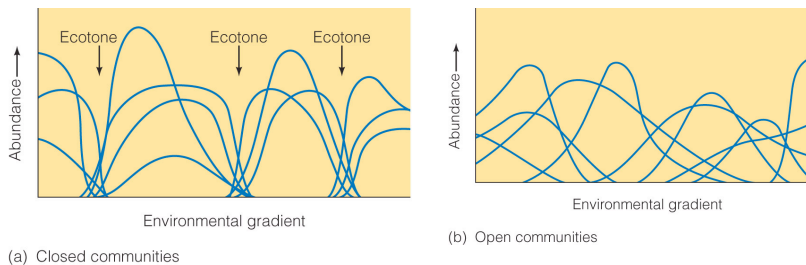


Figure 3-15 (a) In closed communities, the species boundaries tend to coincide. (b) In open communities, the species boundaries are more randomly distributed.

Adapted from R. E. Ricklefs, *Ecology* [New York: W. H. Freeman, 1990], p. 659.

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Question

◆ A place where species range boundaries coincide is called

- A. A zone of intolerance
- B. A closed community
- C. An environmental gradient
- D. An ecotone
- E. A water/land boundary

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Community Succession

- **Succession is the sequential replacement of species in a community by immigration of new species and local extinction of old ones.**
- **Pioneer species colonize a site that was opened by disturbance. These populations are replaced by intermediate species, which are eventually replaced by a climax community.**
- **Happens after disturbance: volcanic eruption, fire, bulldozing/development/road building: climax community is destroyed and pioneer species then thrive**
- **Many plants and animals you see are pioneer species!**

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Community Succession

- Succession occurs because each community, pioneer to climax, prepares the way for the stage that follows by altering environmental traits.
- Succession is characterized by several trends:
 - Decreasing productivity
 - Increasing diversity
 - Increasing biomass

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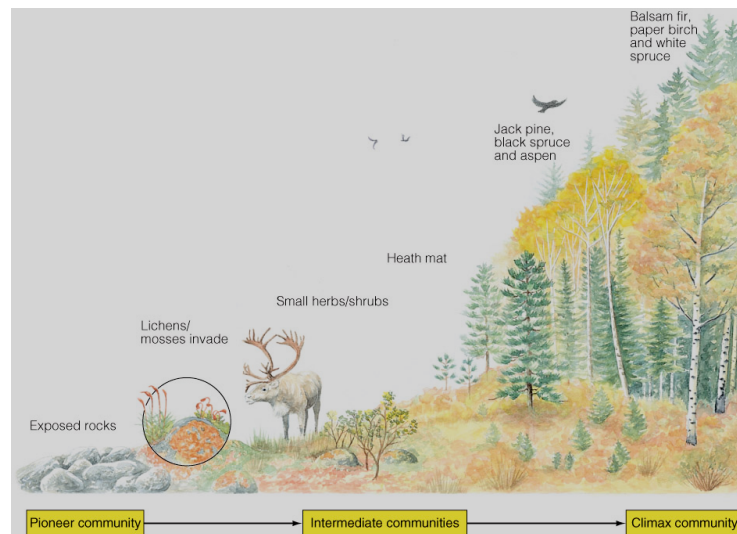


Figure 3-17 Ecological succession.

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Ecosystem and Community Function

- **Communities vary in structure but are alike in that they all carry out basic processes. (Remember we are looking for basic truths that can guide us through enormous complexities)**
- **The most basic processes are:**
 - Energy flow
 - Matter cycling
- **All organisms eat to stay alive, causing energy and matter to move through the community.**

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Ecosystem and Community Function

- **All energy and matter ultimately come from, and return to, the physical environment.**
- **People are altering the structure of many community and ecosystem functioning through various human activities such as land use change, etc.**

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Food Web (food chain)

- Energy flows are routed through feeding relationships in the ecosystem. Why do things eat? To get energy and matter.
- A food web describes the complex interrelationships by which organisms consume other organisms.

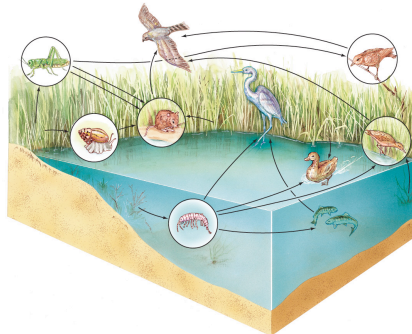


Figure 3-20 A food web showing the interaction between aquatic and land organisms.

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Biomass Pyramids

- Biomass is the weight of living matter.
- The first trophic (feeding) level is the producers, which capture energy from the non-living environment.
- Consumers derive energy from the chemical energy stored in the bodies of producers or other consumers.

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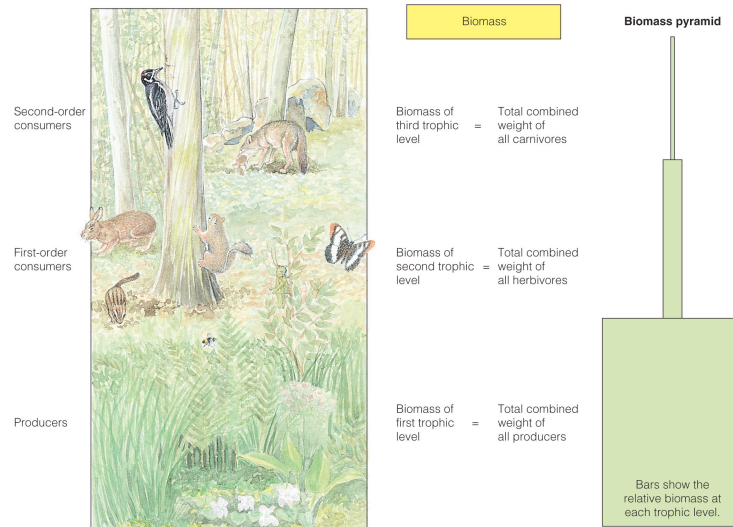


Figure 3-21 A biomass pyramid.

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Question

◆ A rodent in a forest mates in the spring, eats plants, and is active only at night. This describes the rodent's

- A. habitat
- B. niche
- C. tolerance range
- D. zone of limitation
- E. productivity

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Participation credit: Please write
answer on piece of paper and hand to
T.A. (One paper per person!)

- What topics in environmental science are you most interested in? For example: population, consumption, water, atmosphere, energy, evolution, biodiversity, climate change, fossil fuels, alternative energy, parks and preserves, biology, land use, pollution, toxics, sustainability, forests, organic vs. chemical based agriculture, extinctions, etc. etc.
-

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Question

- ◆ Only 5% to 20% efficiency in transfer of energy/mass to each higher trophic level explains
 - A. Why plants use more energy than animals
 - B. Why there are so few top level carnivores
 - C. Why deer eat plants and wolves eat deer
 - D. Why the biomass pyramid is a pyramid
 - E. None of the above

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Energy Flows

- **Biomass declines with each higher trophic level because progressively less food is available.**
- **In general, 80-95% of the energy is lost in the transfer between each level.**

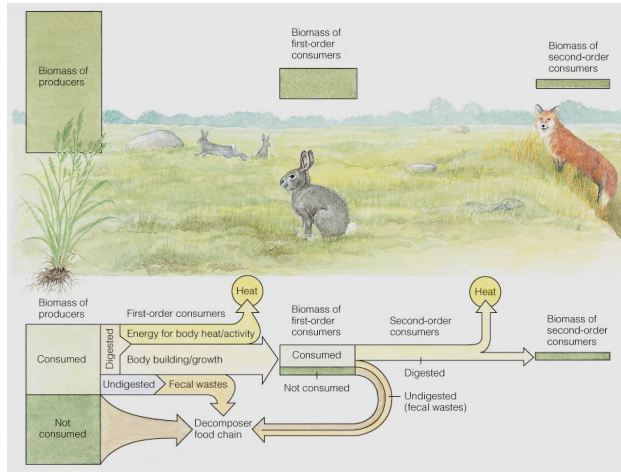


Figure 3-23 Flow of biomass and energy through a food pyramid.

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Ecosystem Productivity

- **Ecosystem productivity varies greatly with the ecosystem, the term NPP (Net Primary Productivity) is the rate at which producers can create biomass. The term NSP (Net Secondary Productivity) is the rate at which consumer and decomposer biomass is produced.**

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TABLE 3-5 Ecosystems and Productivity

Ecosystem Type	Area (10 ⁶ km ²) [†]	Net Primary Productivity, Per Unit Area Per Year (g/m ² or t/km ² per year)*		World Net Primary Production (10 ⁹ t per year) [‡]
		Normal Range	Mean	
Tropical rainforest	17.0	1,000–3,500	2,200	37.4
Tropical seasonal forest	7.5	1,000–2,500	1,600	12.0
Temperate evergreen forest	5.0	600–2,500	1,300	6.5
Temperate deciduous forest	7.0	600–2,500	1,200	8.4
Boreal northern forest	12.0	400–2,000	800	9.6
Woodland and shrubland	8.5	250–1,200	700	6.0
Savanna	15.0	200–2,000	900	13.5
Temperate grassland	9.0	200–1,500	600	5.4
Tundra and alpine	8.0	10–400	140	1.1
Desert and semidesert shrub	18.0	10–250	90	1.6
Extreme desert, rock, sand, and ice	24.0	0–10	3	0.07
Cultivated land	14.0	100–3,500	650	9.1
Swamp and marsh	2.0	800–3,500	2,000	4.0
Lake and stream	2.0	100–1,500	250	0.5
Total continental	149		773	115
Open ocean	332.0	2–400	125	41.5
Upwelling zones	0.4	400–1,000	500	0.2
Continental shelf	26.6	200–600	360	9.6
Reefs	0.6	500–4,000	2,500	1.6
Estuaries	1.4	200–3,500	1,500	2.1
Total marine	361		152	55.0
Full total	510		333	170

*t/km² = g/m² = metric tons/km² = approximately 2.85 tons per square mile.
[†]10⁶ t = 1 billion metric tons = approximately 1.102 billion tons.
[‡]10⁹ km² = approximately 386,000 square miles.
 Source: Begon M, Harper J, Townsend C. *Ecology*, 2d ed. Cambridge, MA: Blackwell, 1990. Reprinted by permission of Blackwell Science, Inc.

TBL03_05: Ecosystems and productivity.

Productivity = tons of biomass per square mile per year (or metric: tonnes/km²/yr

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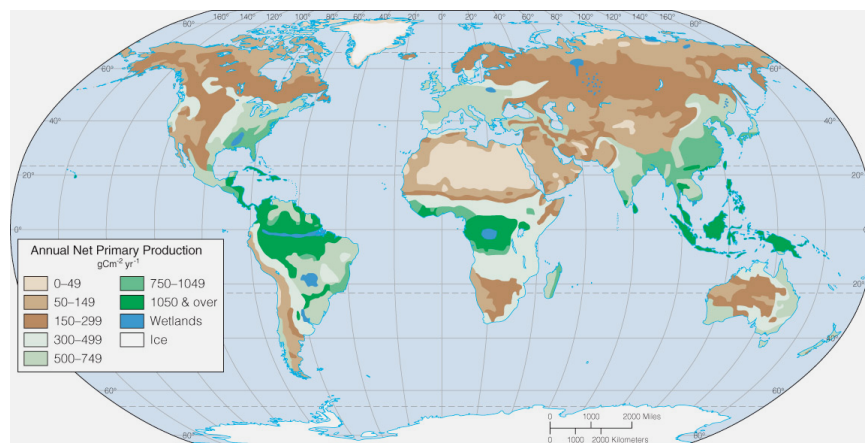


Figure 3-24 Annual net primary productivity (NPP) on the Earth's land surface.

Source: Adapted from J. M. Melillo, et al., *Nature* 363 [1993]: p. 237.

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Biogeochemical Cycles

- **The six most important biogeochemical cycles are those that transport the essential elements that comprise the majority of atoms in living things:**
 - Carbon (C)
 - Hydrogen (H)
 - Oxygen (O)
 - Nitrogen (N)
 - Phosphorus (P)
 - Sulfur (S)

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TABLE 3-7

The Relative Abundance by Weight of Some Chemical Elements in the Earth's Crust

Element (Chemical Symbol)	Relative Abundance
Oxygen (O)	46.6%
Silicon (Si)	27.7
Aluminum (Al)	8.1
Iron (Fe)	5.0
Calcium (Ca)	3.6
Sodium (Na)	2.8
Potassium (K)	2.6
Magnesium (Mg)	2.1
Phosphorus (P)	0.07
Carbon (C)	0.03
Nitrogen (N)	Trace

TBL03_07: Relative abundance of some elements in the Earth's crust.

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TABLE 3-6		Atomic Composition by Weight of Three Representative Organisms		
Element	Human	Alfalfa	Bacterium	
Oxygen	62.81%	77.90%	73.68%	
Carbon	19.37	11.34	12.14	
Hydrogen	9.31	8.72	9.94	
Nitrogen	5.14	0.83	3.04	
Phosphorus	0.63	0.71	0.60	
Sulfur	0.64	0.10	0.32	
Total	97.90	99.60	99.72	

TBL03_06: Atomic composition by weight of three representative organisms.

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Matter Cycling

- A classic example of matter cycling is the carbon cycle.

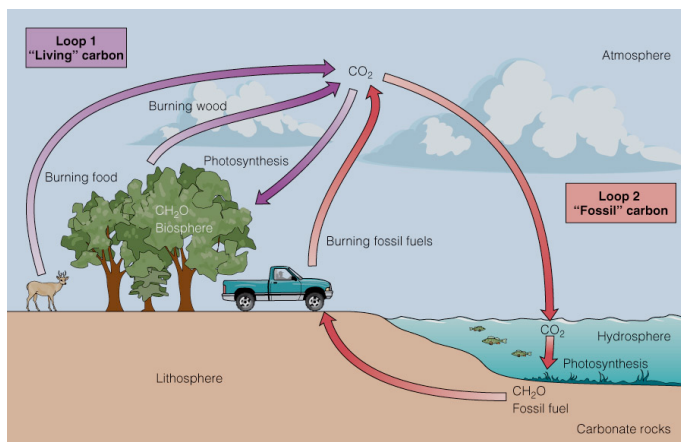


Figure 3.25: The carbon cycle: Loop 1 is "living" carbon and Loop 2 is "fossil" carbon.

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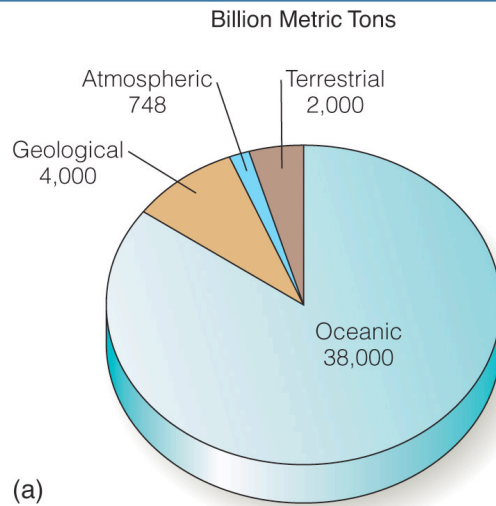


Figure 3.27a: Major reservoirs of the carbon cycle, in billion tons of carbon.

Source: Adapted from W. M. Post, et al., "The Global Carbon Cycle," *American Scientist* 78 [1990]: 315.

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(b)

Figure 3.27b: Limestone is a reservoir for the carbon cycle.

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Matter Cycling

- **Matter is cycled over and over within a typical healthy ecosystem.**

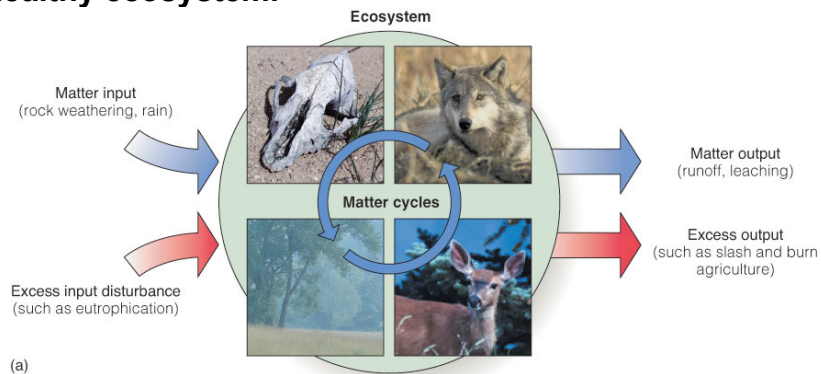


Figure 3-26a A healthy ecosystem cycles most of its matter through the food web.

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Carbon Storage

- **Carbon is withdrawn from the atmosphere by photosynthesis.**
 - $\text{CO}_2 + \text{H}_2\text{O} + \text{energy} \rightarrow \text{CH}_2\text{O} + \text{O}_2$
- **Carbon is returned to the atmosphere by combustion (burning fuel and by respiration (digesting food)).**
 - $\text{CH}_2\text{O} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{energy}$



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Biogeochemical Cycles

- It is important to pay attention to the cycle's pathways, rates of cycling, and degree to which they are being disturbed by human activities.
- Scientists focus on the cycles of chemical elements when observing the cycles of matter within and among the spheres.

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Nitrogen Cycle

Haber-Bosch process, forms NH_3 (ammonia) from atmospheric N_2 and H (from natural gas) under high pressure. NH_3 can be converted to fertilizer (and explosives (nitroglycerin)). Large fraction of agriculture depends on this.

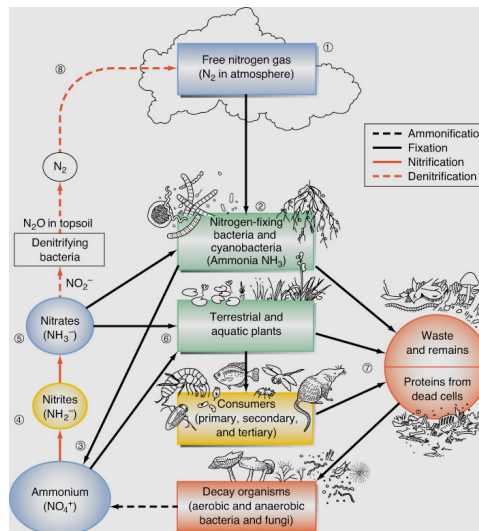


Fig. 3-28

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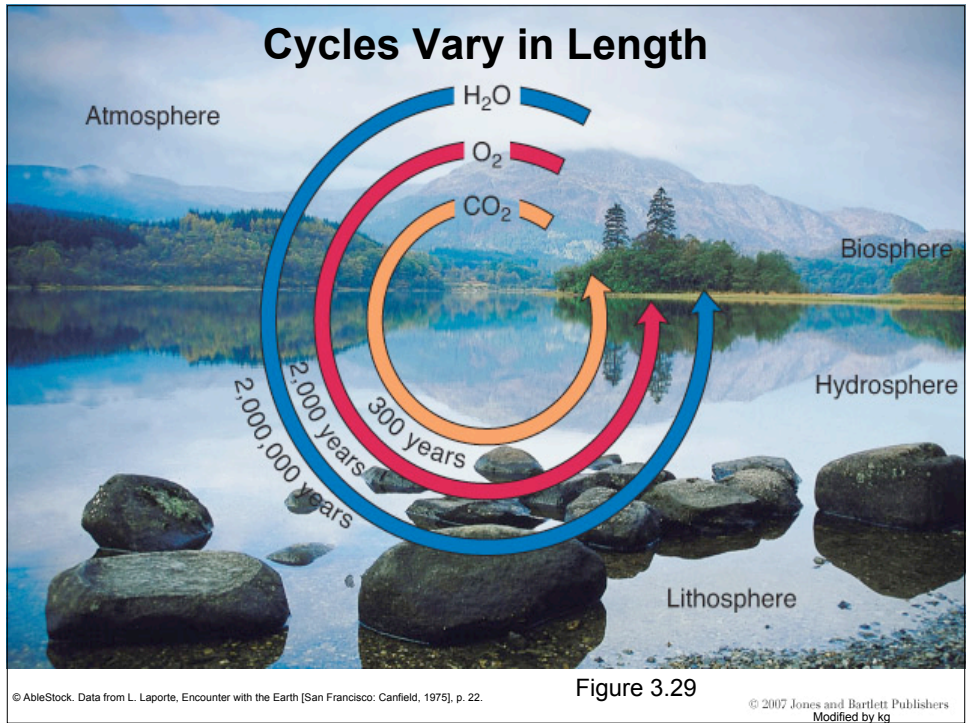
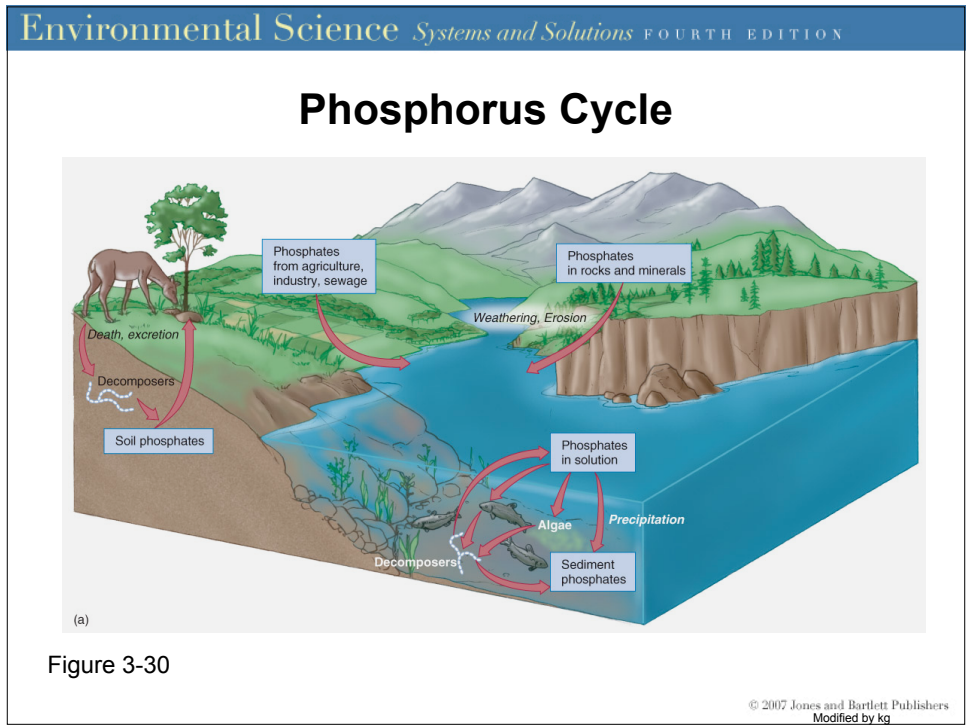


Figure 3.29



Human Impact on Cycles

- **Biogeochemical cycles are crucial to life but are being greatly disturbed by human activity.**
- **Most of the cycles are being accelerated, causing both depletion of resources and pollution.**
- **Major consequences are likely to occur but no one knows how drastic or how dangerous the effects will be.**



Figure 3-30b
A phosphate mine.

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Carbon Emissions

- **Carbon is a major example of human impact on biogeochemical cycles.**
- **Carbon released from the burning of fossil fuels has increased exponentially over the last century.**

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Atmospheric CO₂

- **Plant life and the oceans are absorbing only about half of the carbon being emitted into the atmosphere by fossil fuel combustion.**
- **The rest is accumulating in the atmosphere as carbon dioxide.**
- **This accumulation in the atmosphere has many potential consequences, notably global climate change.**

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Energy Flows

- **The first law of thermodynamics says that energy cannot be created or destroyed, but can be transformed.**
- **The second law of thermodynamics says that when energy is transformed from one kind to another, it is degraded.**
- **Entropy is the amount of low-quality energy in a system.**
- **Some energy transformations are more efficient than others.**

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Energy Transformation

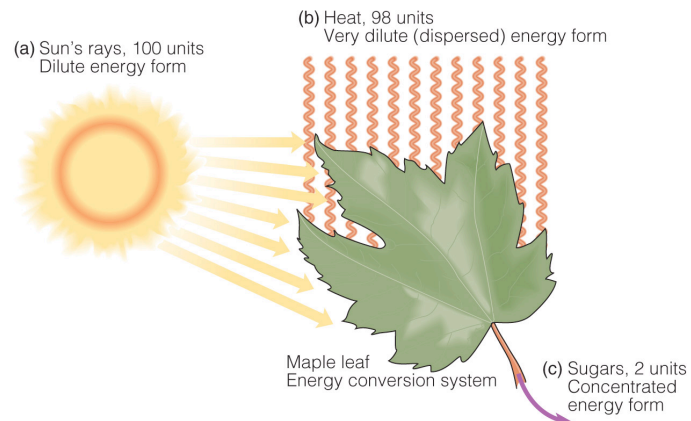


Figure 3-31 The two laws of thermodynamics.

Source: Adapted from E. P. Odum, *Ecology and Our Endangered Life-Support Systems* (Sunderland, Mass.: Sinauer 1989), p. 70.)

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Human Use of Energy Flows

- **Modern civilization is built upon fossil fuels, which are fossilized plant materials that stored solar energy millions of years ago as chemical energy.**
- **Fossil fuels are nonrenewable resources that will be used up if rates of use continue to rise:**
 - Oil within the next 100 years
 - Coal within the next 300-400 years

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Human Use of Energy Flows

- The burning of fossil fuel causes most air pollution (acid rain, smog, carbon monoxide, greenhouse gases).
- It would be more sustainable and less damaging to use renewable energy (such as solar and tidal).

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Question

- ◆ There is a species of trout that is endemic to Germany. This means it is
 - A. Becoming extinct
 - B. Evolving quickly
 - C. Localized in this area
 - D. Losing population
 - E. diseased

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