LECTURE PRESENTATIONS
For CAMPBELL BIOLOGY, NINTH EDITION
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Chapter 55

Ecosystems and Restoration Ecology

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Overview: Cool Ecosystem

- An **ecosystem** consists of all the organisms living in a community, as well as the abiotic factors with which they interact
- An example is the unusual community of organisms, including chemoautotrophic bacteria, living below a glacier in Antarctica

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- Ecosystems range from a microcosm, such as an aquarium, to a large area, such as a lake or forest

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- Regardless of an ecosystem’s size, its dynamics involve two main processes: energy flow and chemical cycling
- Energy flows through ecosystems, whereas matter cycles within them

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Concept 55.1: Physical laws govern energy flow and chemical cycling in ecosystems

- Ecologists study the transformations of energy and matter within ecosystems

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Conservation of Energy

- Laws of physics and chemistry apply to ecosystems, particularly energy flow
- The first law of thermodynamics states that energy cannot be created or destroyed, only transformed
- Energy enters an ecosystem as solar radiation, is conserved, and is lost from organisms as heat

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- The second law of thermodynamics states that every exchange of energy increases the entropy of the universe
- In an ecosystem, energy conversions are not completely efficient, and some energy is always lost as heat

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Conservation of Mass

- The **law of conservation of mass** states that matter cannot be created or destroyed
- Chemical elements are continually recycled within ecosystems
- In a forest ecosystem, most nutrients enter as dust or solutes in rain and are carried away in water
- Ecosystems are open systems, absorbing energy and mass and releasing heat and waste products

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Energy, Mass, and Trophic Levels

- Autotrophs build molecules themselves using photosynthesis or chemosynthesis as an energy source
- Heterotrophs depend on the biosynthetic output of other organisms

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- Energy and nutrients pass from **primary producers** (autotrophs) to **primary consumers** (herbivores) to **secondary consumers** (carnivores) to **tertiary consumers** (carnivores that feed on other carnivores)

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- **Detritivores,** or **decomposers**, are consumers that derive their energy from **detritus**, nonliving organic matter
- Prokaryotes and fungi are important detritivores
- Decomposition connects all trophic levels

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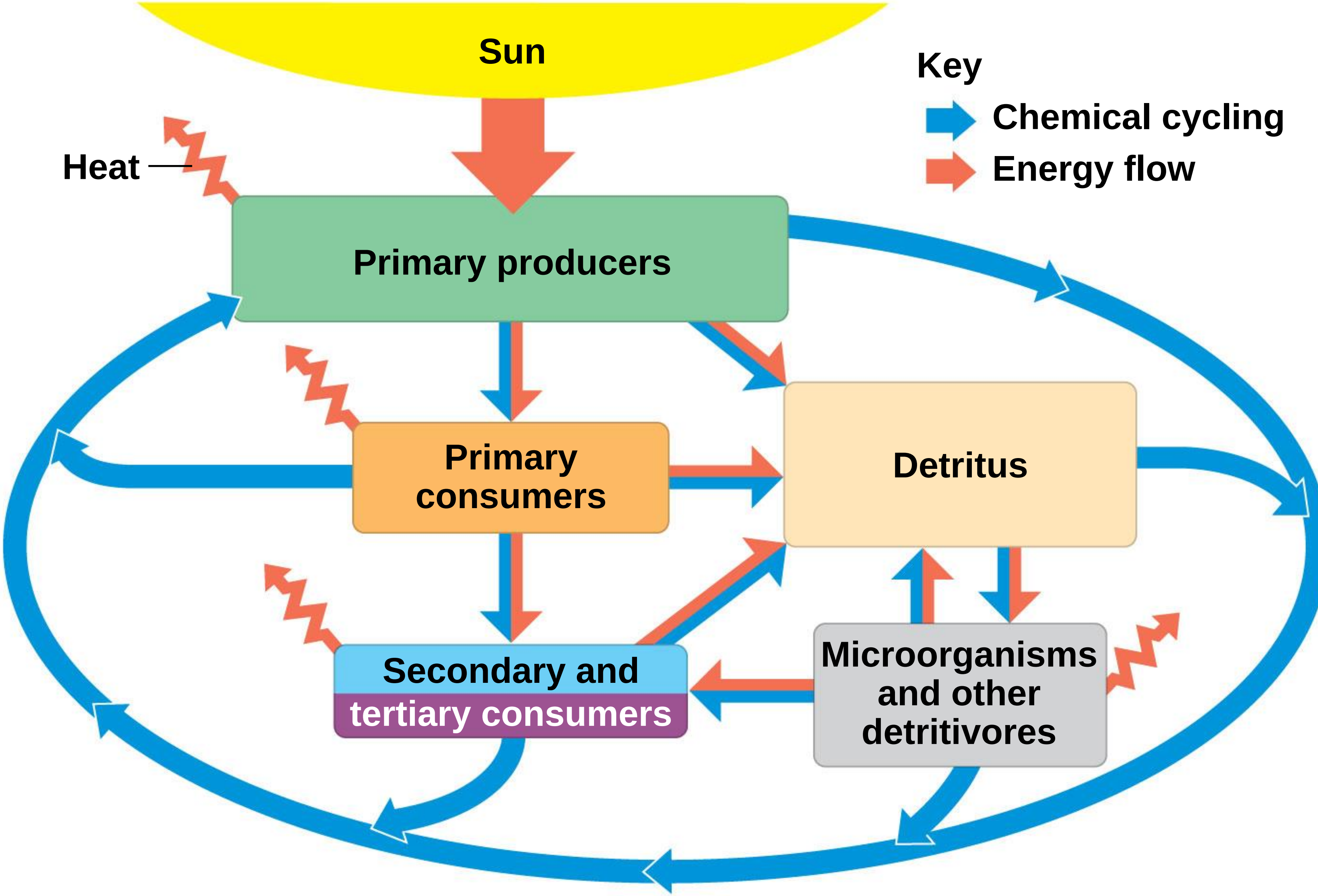
Figure 55.4



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Concept 55.2: Energy and other limiting factors control primary production in ecosystems

- In most ecosystems, **primary production** is the amount of light energy converted to chemical energy by autotrophs during a given time period
- In a few ecosystems, chemoautotrophs are the primary producers

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Ecosystem Energy Budgets

- The extent of photosynthetic production sets the spending limit for an ecosystem's energy budget

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The Global Energy Budget

- The amount of solar radiation reaching Earth's surface limits the photosynthetic output of ecosystems
- Only a small fraction of solar energy actually strikes photosynthetic organisms, and even less is of a usable wavelength

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Gross and Net Production

- Total primary production is known as the ecosystem's **gross primary production (GPP)**
- GPP is measured as the conversion of chemical energy from photosynthesis per unit time
- **Net primary production (NPP)** is GPP minus energy used by primary producers for respiration
- NPP is expressed as
  - Energy per unit area per unit time ($J/m^2 \cdot yr$), or
  - Biomass added per unit area per unit time ($g/m^2 \cdot yr$)

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- NPP is the amount of new biomass added in a given time period
- Only NPP is available to consumers
- Standing crop is the total biomass of photosynthetic autotrophs at a given time
- Ecosystems vary greatly in NPP and contribution to the total NPP on Earth

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- Tropical rain forests, estuaries, and coral reefs are among the most productive ecosystems per unit area
- Marine ecosystems are relatively unproductive per unit area but contribute much to global net primary production because of their volume

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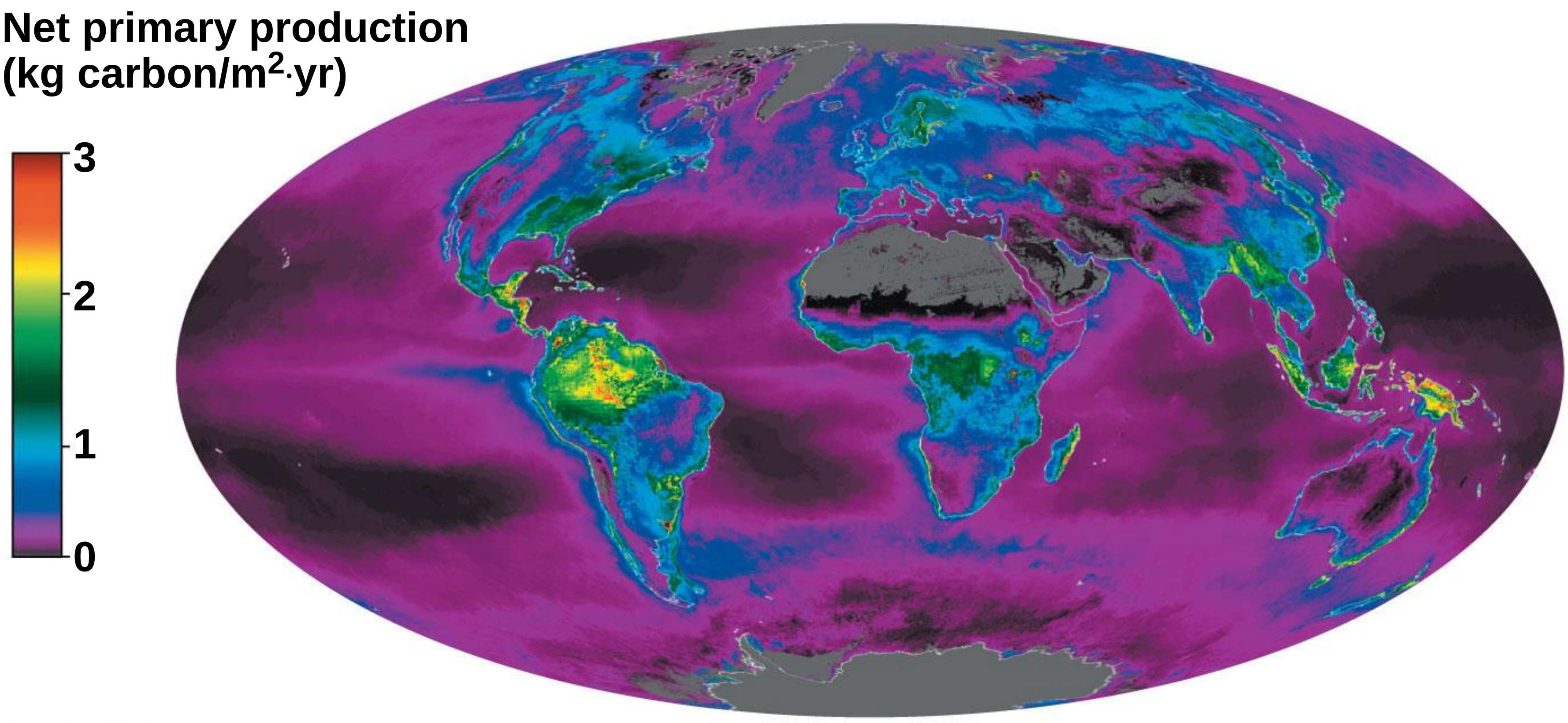
Figure 55.6



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- **Net ecosystem production (NEP)** is a measure of the total biomass accumulation during a given period
- NEP is gross primary production minus the total respiration of all organisms (producers and consumers) in an ecosystem
- NEP is estimated by comparing the net flux of CO_2 and O_2 in an ecosystem, two molecules connected by photosynthesis
- The release of O_2 by a system is an indication that it is also storing CO_2

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Primary Production in Aquatic Ecosystems

- In marine and freshwater ecosystems, both light and nutrients control primary production

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Light Limitation

- Depth of light penetration affects primary production in the photic zone of an ocean or lake

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Nutrient Limitation

- More than light, nutrients limit primary production in geographic regions of the ocean and in lakes
- A **limiting nutrient** is the element that must be added for production to increase in an area
- Nitrogen and phosphorous are the nutrients that most often limit marine production
- Nutrient enrichment experiments confirmed that nitrogen was limiting phytoplankton growth off the shore of Long Island, New York

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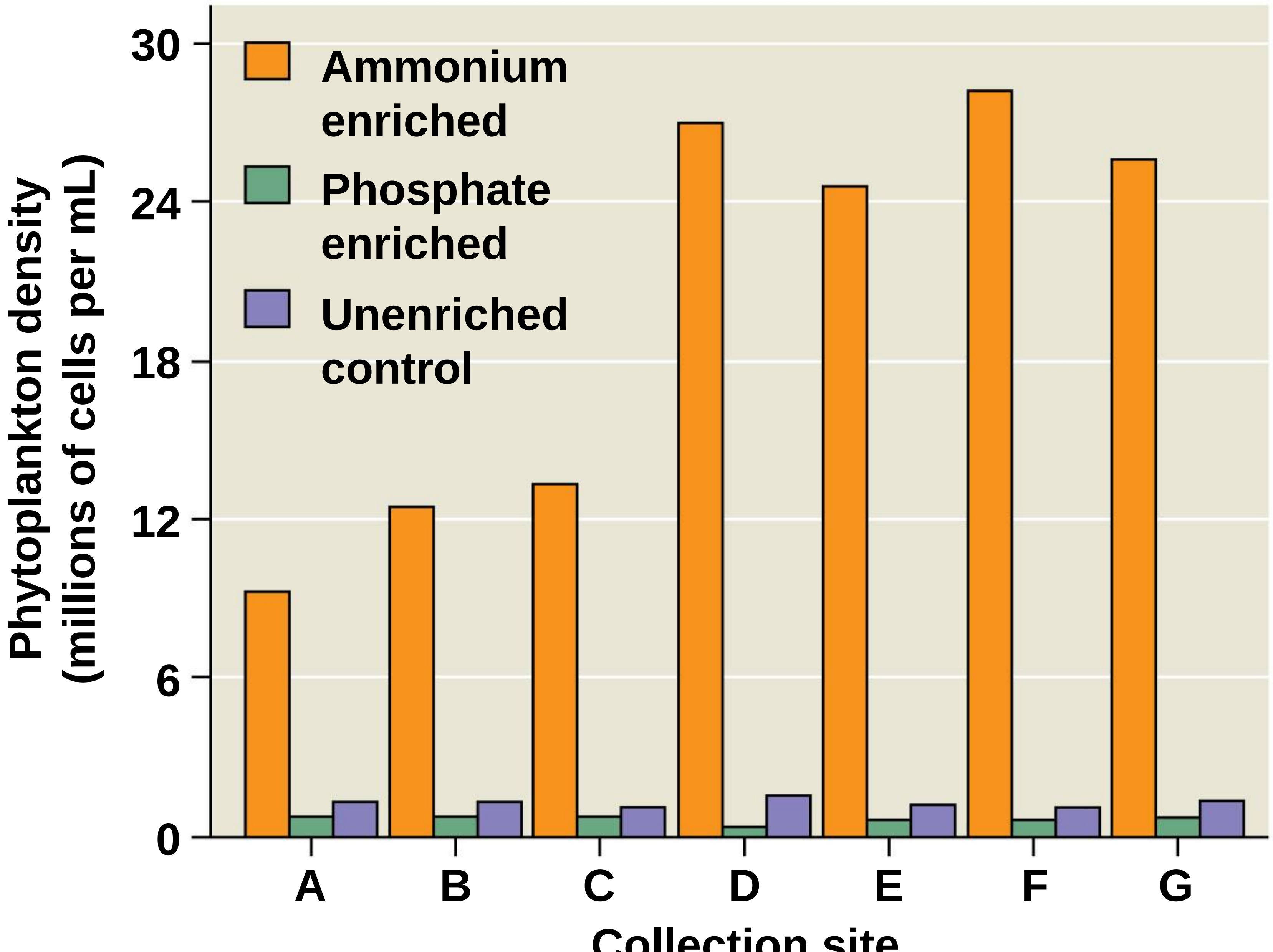
Figure 55.8

RESULTS



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- Experiments in the Sargasso Sea in the subtropical Atlantic Ocean showed that iron limited primary production

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Table 55.1

Table 55.1 Nutrient Enrichment Experiment for Sargasso Sea Samples

Nutrients Added to Experimental Culture	Relative Uptake of ^{14}C by Cultures*
None (controls)	1.00
Nitrogen (N) + phosphorus (P) only	1.10
N + P + metals (excluding iron)	1.08
N + P + metals (including iron)	12.90
N + P + iron	12.00

*^{14}C uptake by cultures measures primary production.

Source: D. W. Menzel and J. H. Ryther, Nutrients limiting the production of phytoplankton in the Sargasso Sea, with special reference to iron, *Deep Sea Research* 7:276–281 (1961).

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- Upwelling of nutrient-rich waters in parts of the oceans contributes to regions of high primary production
- The addition of large amounts of nutrients to lakes has a wide range of ecological impacts

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- In some areas, sewage runoff has caused **eutrophication** of lakes, which can lead to loss of most fish species
- In lakes, phosphorus limits cyanobacterial growth more often than nitrogen
- This has led to the use of phosphate-free detergents

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Primary Production in Terrestrial Ecosystems

- In terrestrial ecosystems, temperature and moisture affect primary production on a large scale
- Primary production increases with moisture

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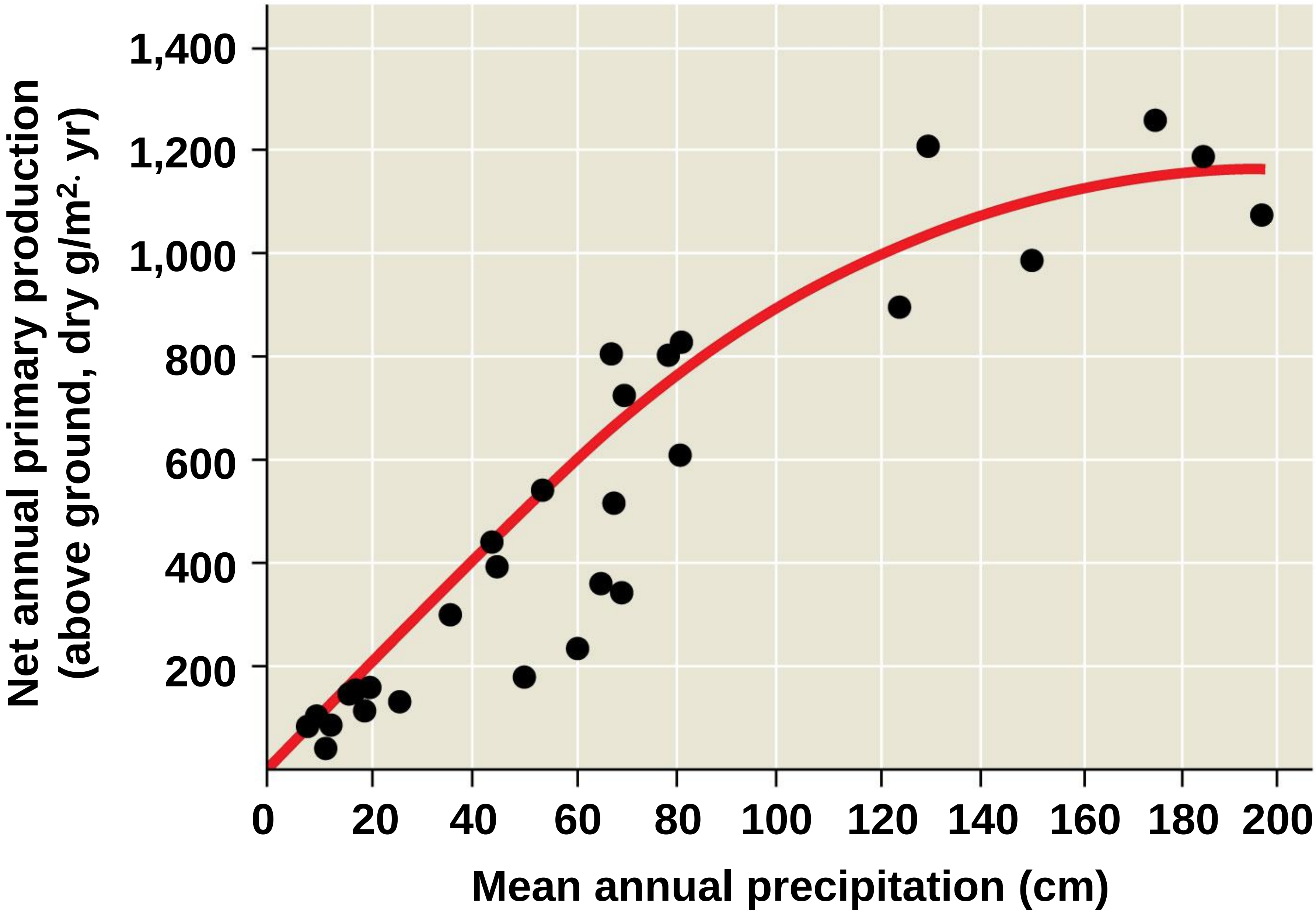
Figure 55.9



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- Actual evapotranspiration is the water transpired by plants and evaporated from a landscape
- It is affected by precipitation, temperature, and solar energy
- It is related to net primary production

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Nutrient Limitations and Adaptations That Reduce Them

- On a more local scale, a soil nutrient is often the limiting factor in primary production
- In terrestrial ecosystems, nitrogen is the most common limiting nutrient
- Phosphorus can also be a limiting nutrient, especially in older soils

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- Various adaptations help plants access limiting nutrients from soil
  - Some plants form mutualisms with nitrogen-fixing bacteria
  - Many plants form mutualisms with mycorrhizal fungi; these fungi supply plants with phosphorus and other limiting elements
  - Roots have root hairs that increase surface area
  - Many plants release enzymes that increase the availability of limiting nutrients

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Concept 55.3: Energy transfer between trophic levels is typically only 10% efficient

- **Secondary production** of an ecosystem is the amount of chemical energy in food converted to new biomass during a given period of time

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Production Efficiency

- When a caterpillar feeds on a leaf, only about one-sixth of the leaf's energy is used for secondary production
- An organism's **production efficiency** is the fraction of energy stored in food that is not used for respiration

$$\text{Production efficiency} = \frac{\text{Net secondary production} \times 100\%}{\text{Assimilation of primary production}}$$

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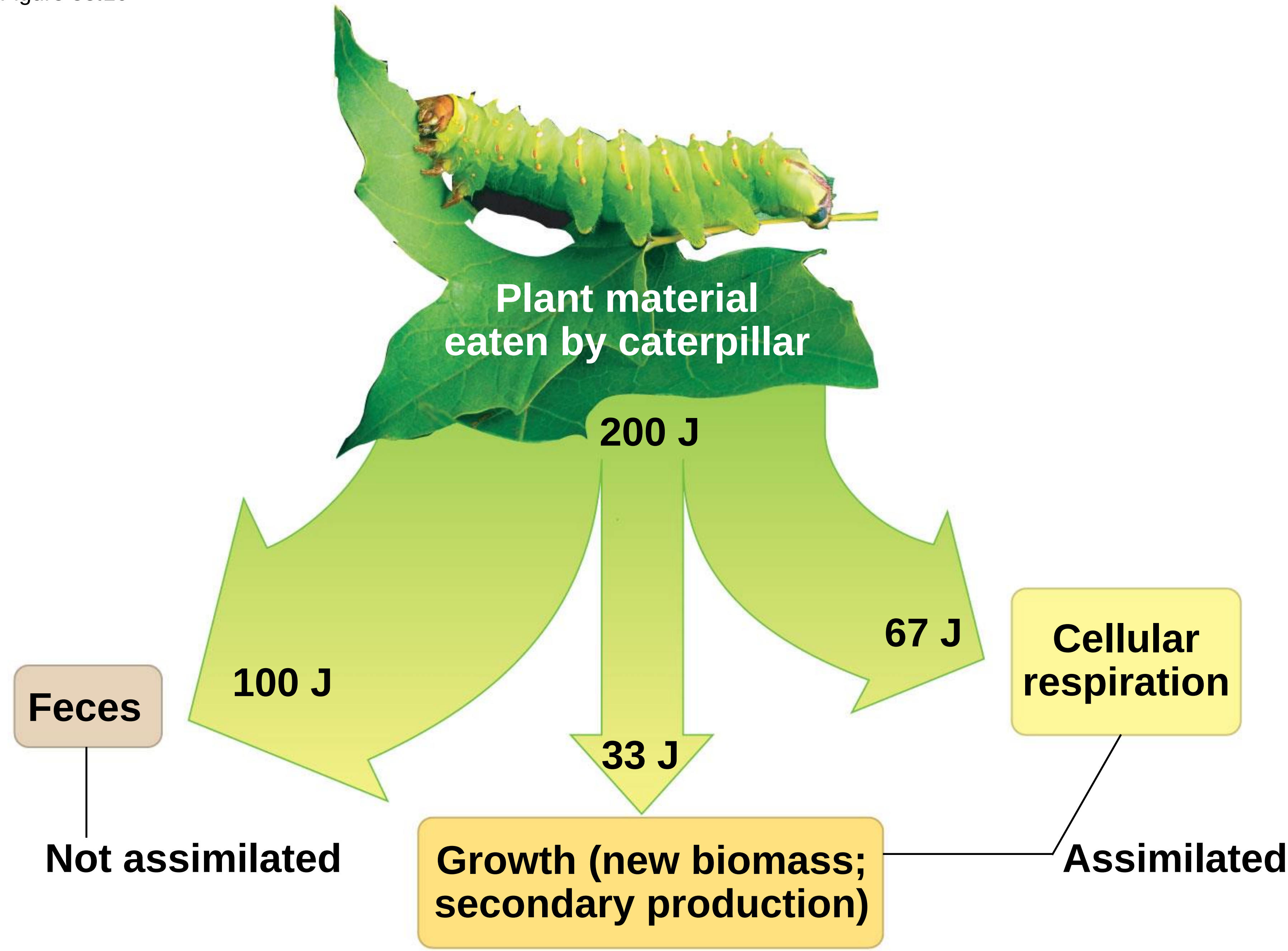
Figure 55.10



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- Birds and mammals have efficiencies in the range of 1–3% because of the high cost of endothermy
- Fishes have production efficiencies of around 10%
- Insects and microorganisms have efficiencies of 40% or more

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Trophic Efficiency and Ecological Pyramids

- **Trophic efficiency** is the percentage of production transferred from one trophic level to the next
- It is usually about 10%, with a range of 5% to 20%
- Trophic efficiency is multiplied over the length of a food chain

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- Approximately 0.1% of chemical energy fixed by photosynthesis reaches a tertiary consumer
- A pyramid of net production represents the loss of energy with each transfer in a food chain

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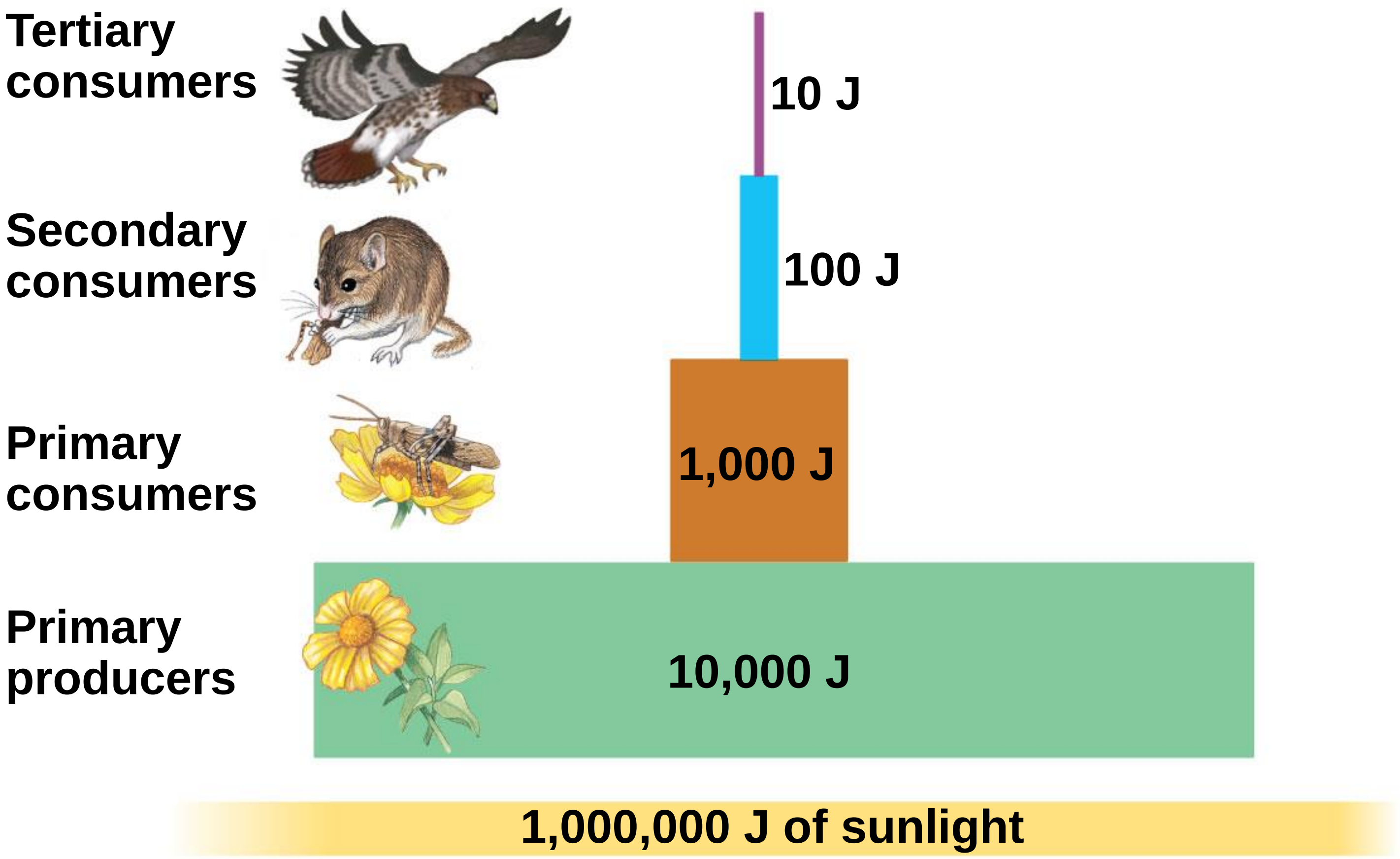
Figure 55.11



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- In a biomass pyramid, each tier represents the dry mass of all organisms in one trophic level
- Most biomass pyramids show a sharp decrease at successively higher trophic levels

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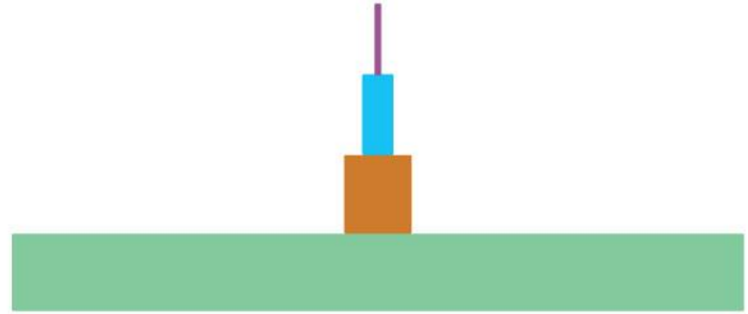
Figure 55.12



Trophic level	Dry mass (g/m^2)
Tertiary consumers	1.5
Secondary consumers	11
Primary consumers	37
Primary producers	809

(a) Most ecosystems (data from a Florida bog)

Trophic level	Dry mass (g/m^2)
Primary consumers (zooplankton)	21
Primary producers (phytoplankton)	4

(b) Some aquatic ecosystems (data from the English Channel)

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- Certain aquatic ecosystems have inverted biomass pyramids: producers (phytoplankton) are consumed so quickly that they are outweighed by primary consumers
- **Turnover time** is the ratio of the standing crop biomass to production

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- Dynamics of energy flow in ecosystems have important implications for the human population
- Eating meat is a relatively inefficient way of tapping photosynthetic production
- Worldwide agriculture could feed many more people if humans ate only plant material

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Concept 55.4: Biological and geochemical processes cycle nutrients and water in ecosystems

- Life depends on recycling chemical elements
- Nutrient cycles in ecosystems involve biotic and abiotic components and are often called **biogeochemical cycles**

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Biogeochemical Cycles

- Gaseous carbon, oxygen, sulfur, and nitrogen occur in the atmosphere and cycle globally
- Less mobile elements include phosphorus, potassium, and calcium
- These elements cycle locally in terrestrial systems but more broadly when dissolved in aquatic systems

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- A model of nutrient cycling includes main reservoirs of elements and processes that transfer elements between reservoirs
- All elements cycle between organic and inorganic reservoirs

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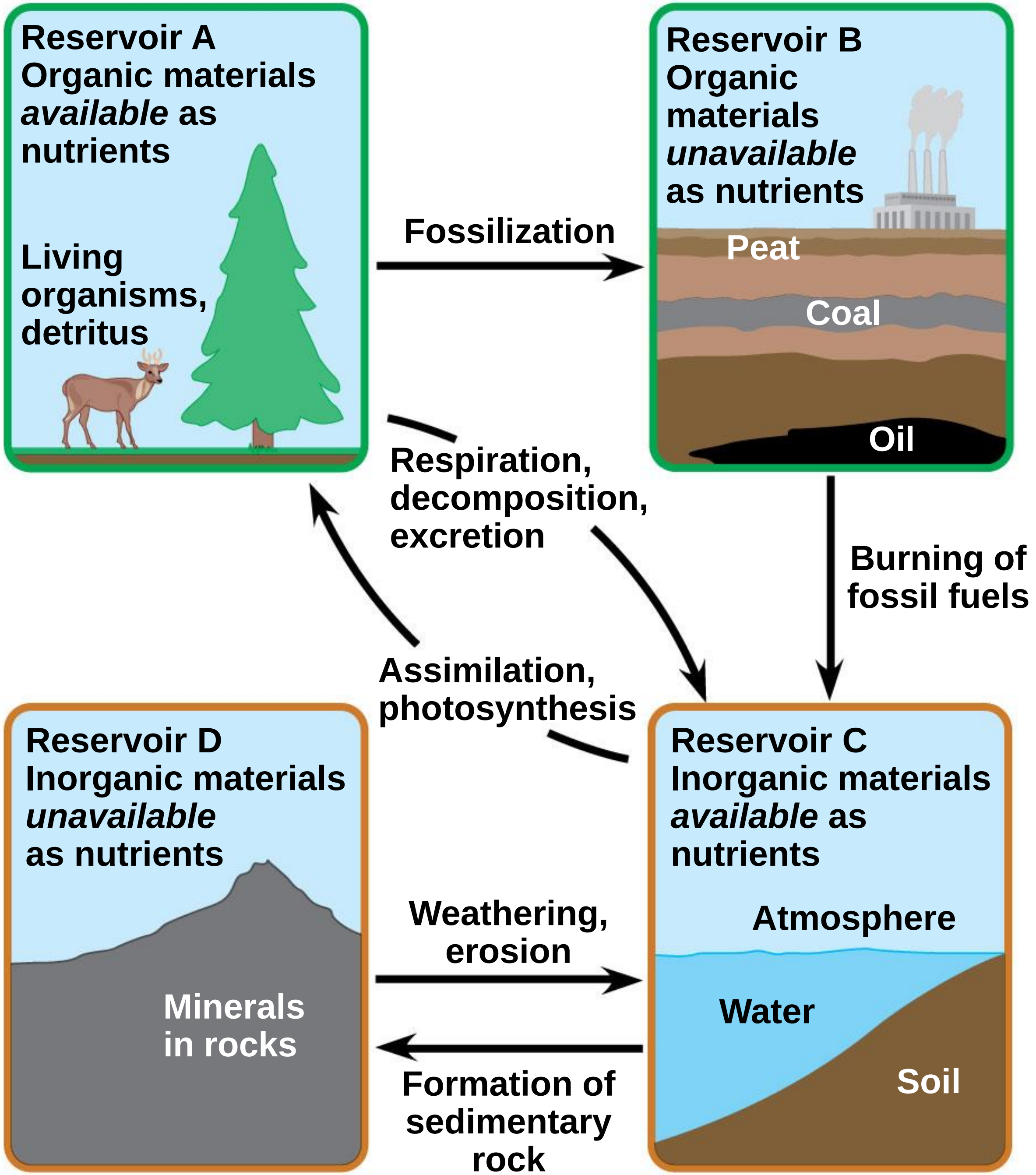
Figure 55.13



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- In studying cycling of water, carbon, nitrogen, and phosphorus, ecologists focus on four factors
  - Each chemical’s biological importance
  - Forms in which each chemical is available or used by organisms
  - Major reservoirs for each chemical
  - Key processes driving movement of each chemical through its cycle

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The Water Cycle

- Water is essential to all organisms
- Liquid water is the primary physical phase in which water is used
- The oceans contain 97% of the biosphere's water; 2% is in glaciers and polar ice caps, and 1% is in lakes, rivers, and groundwater
- Water moves by the processes of evaporation, transpiration, condensation, precipitation, and movement through surface and groundwater

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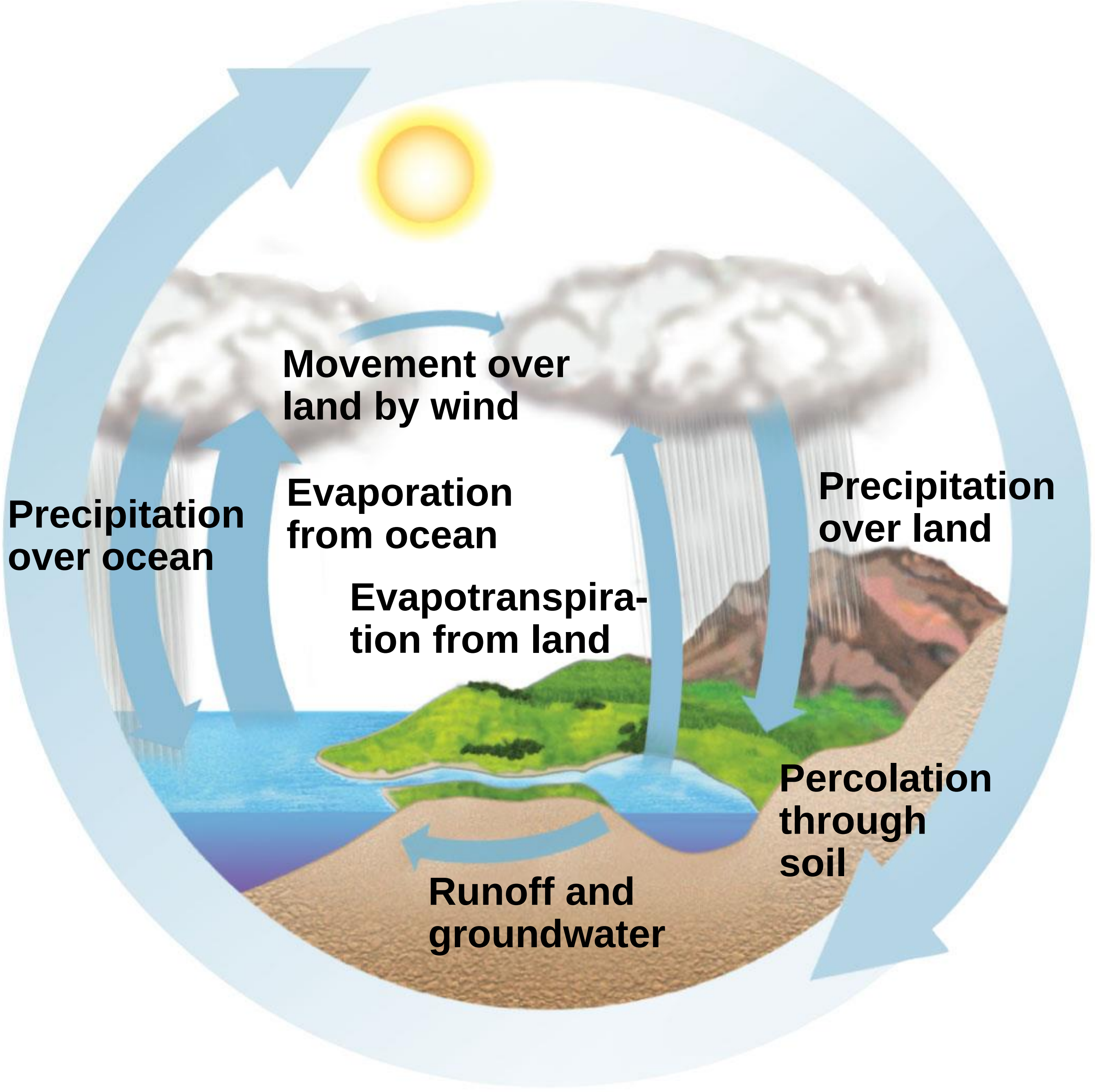
Figure 55.14a



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The Carbon Cycle

- Carbon-based organic molecules are essential to all organisms
- Photosynthetic organisms convert CO_2 to organic molecules that are used by heterotrophs
- Carbon reservoirs include fossil fuels, soils and sediments, solutes in oceans, plant and animal biomass, the atmosphere, and sedimentary rocks

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- CO_2 is taken up and released through photosynthesis and respiration; additionally, volcanoes and the burning of fossil fuels contribute CO_2 to the atmosphere

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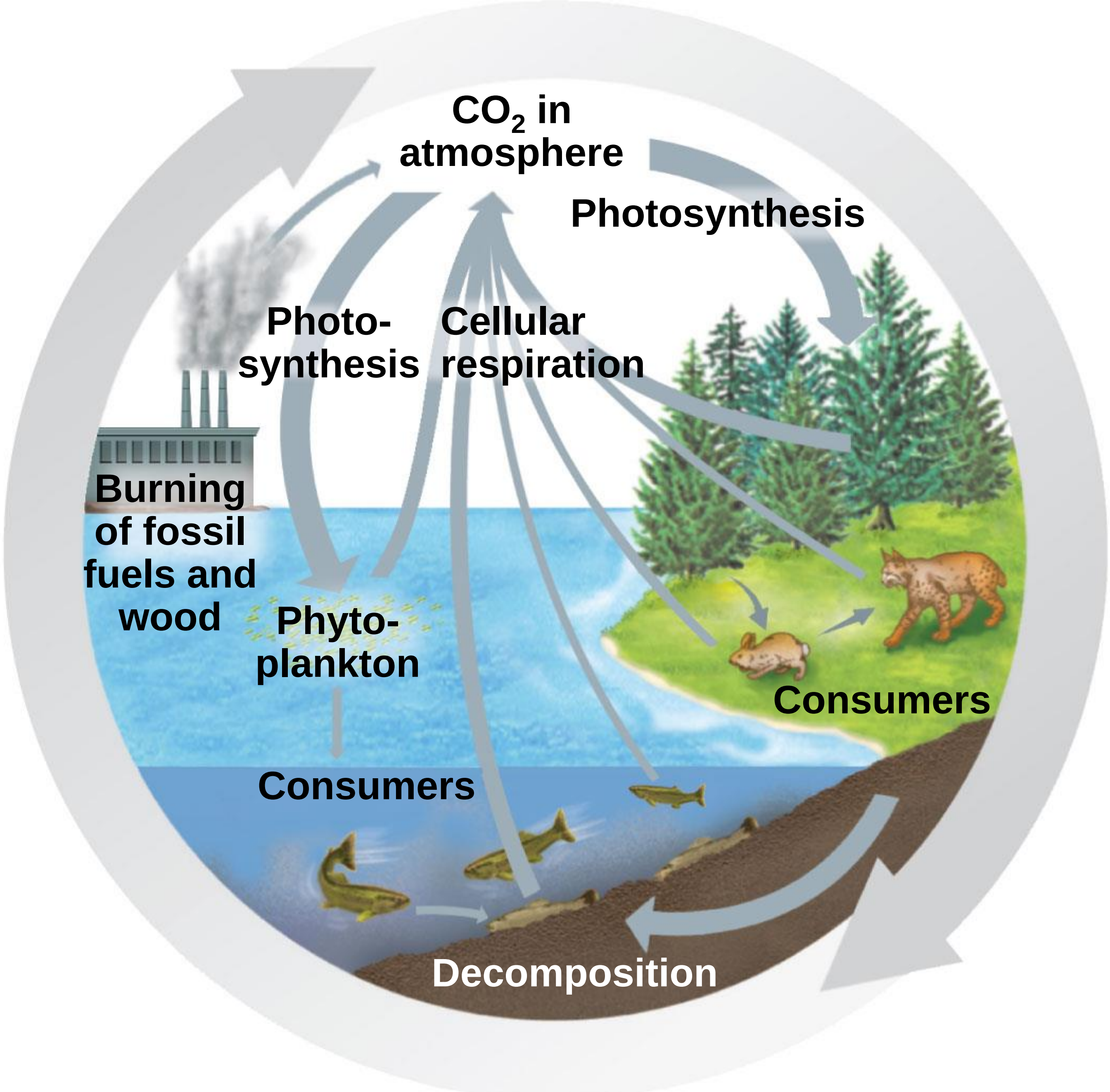
Figure 55.14b



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The Nitrogen Cycle

- Nitrogen is a component of amino acids, proteins, and nucleic acids
- The main reservoir of nitrogen is the atmosphere (N_2), though this nitrogen must be converted to NH_4^+ or NO_3^- for uptake by plants, via nitrogen fixation by bacteria

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- Organic nitrogen is decomposed to NH_4^+ by ammonification, and NH_4^+ is decomposed to NO_3^- by nitrification
- Denitrification converts NO_3^- back to N_2

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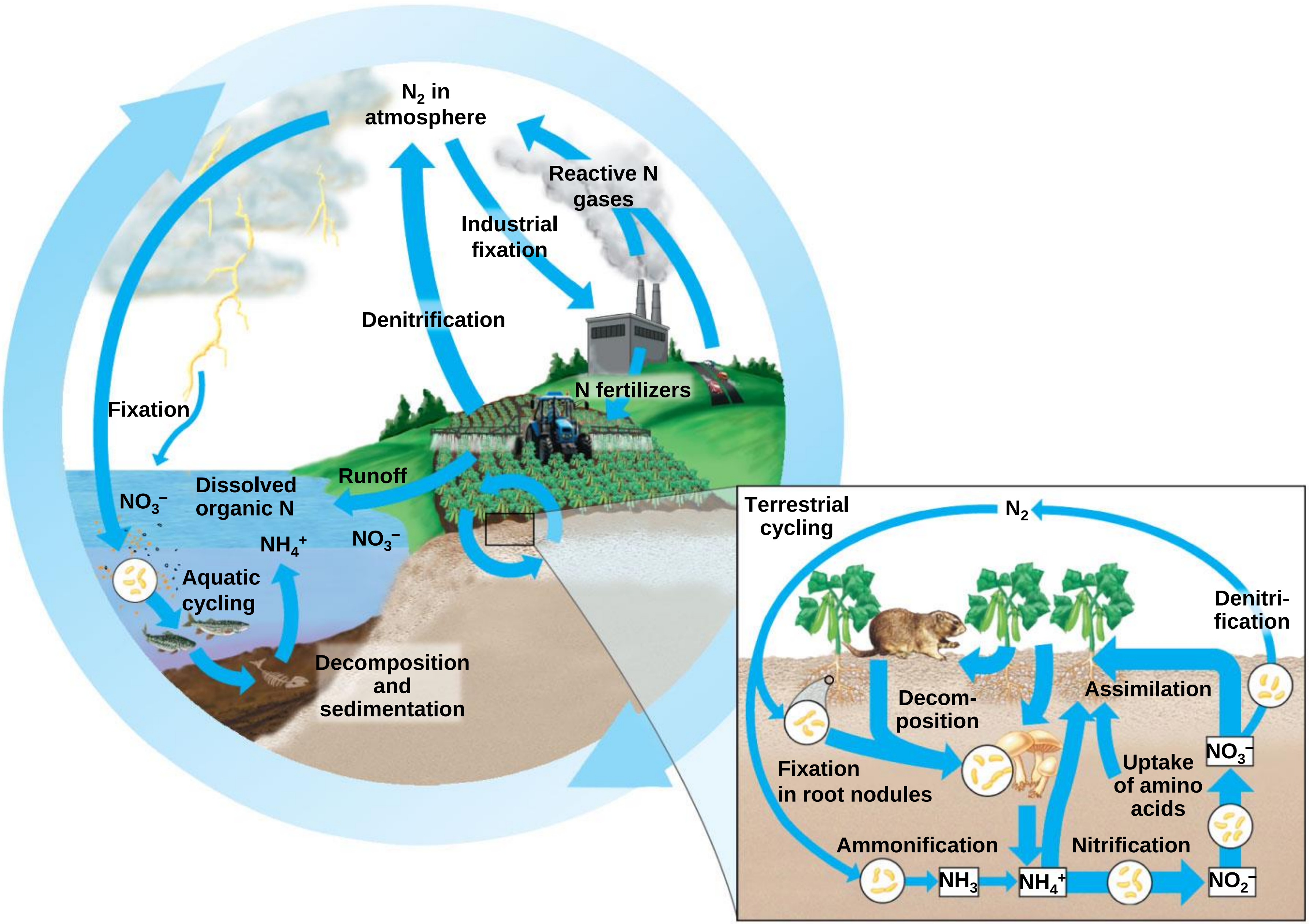
Figure 55.14c



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The Phosphorus Cycle

- Phosphorus is a major constituent of nucleic acids, phospholipids, and ATP
- Phosphate (PO_4^{3-}) is the most important inorganic form of phosphorus
- The largest reservoirs are sedimentary rocks of marine origin, the oceans, and organisms
- Phosphate binds with soil particles, and movement is often localized

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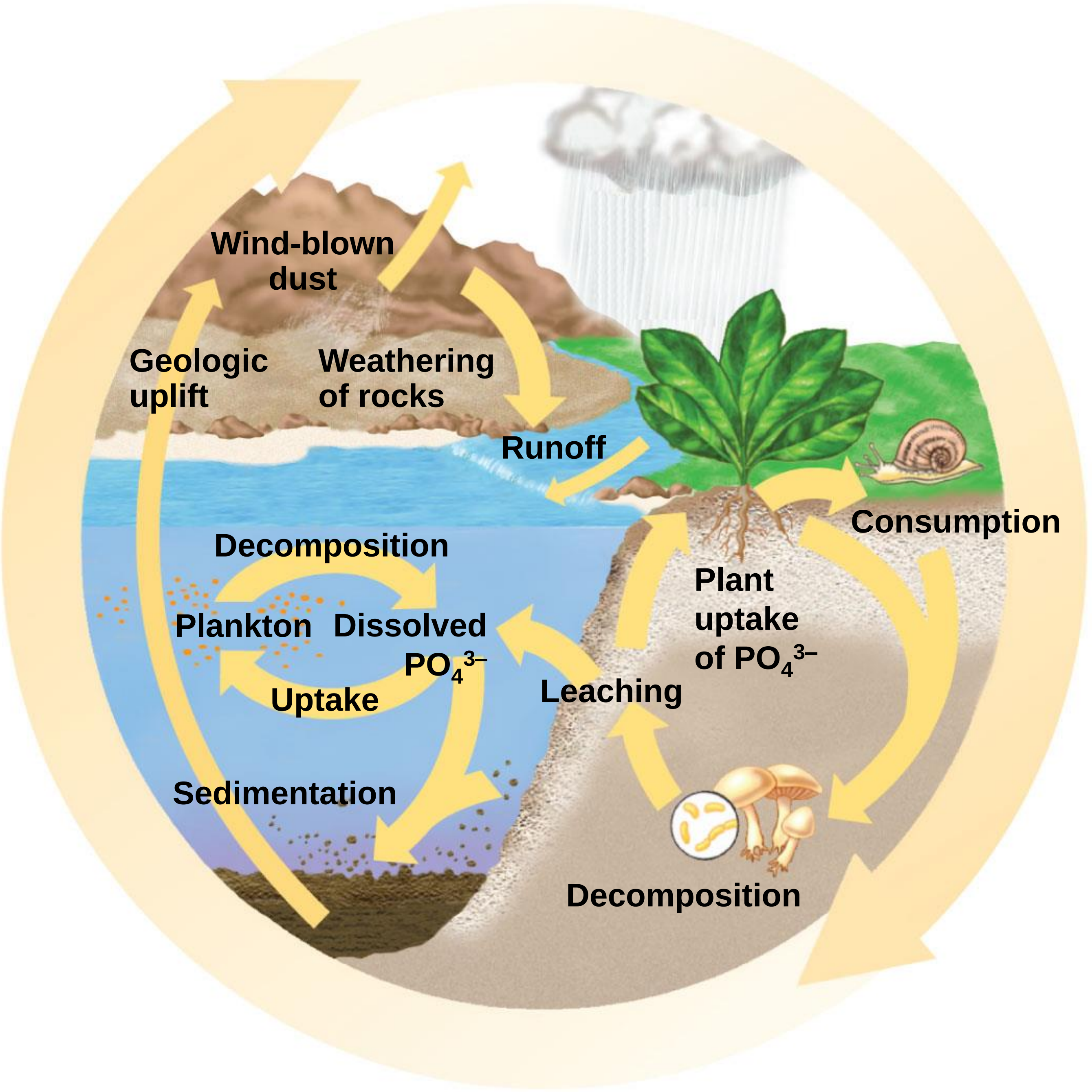
Figure 55.14d



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Decomposition and Nutrient Cycling Rates

- Decomposers (detritivores) play a key role in the general pattern of chemical cycling
- Rates at which nutrients cycle in different ecosystems vary greatly, mostly as a result of differing rates of decomposition
- The rate of decomposition is controlled by temperature, moisture, and nutrient availability

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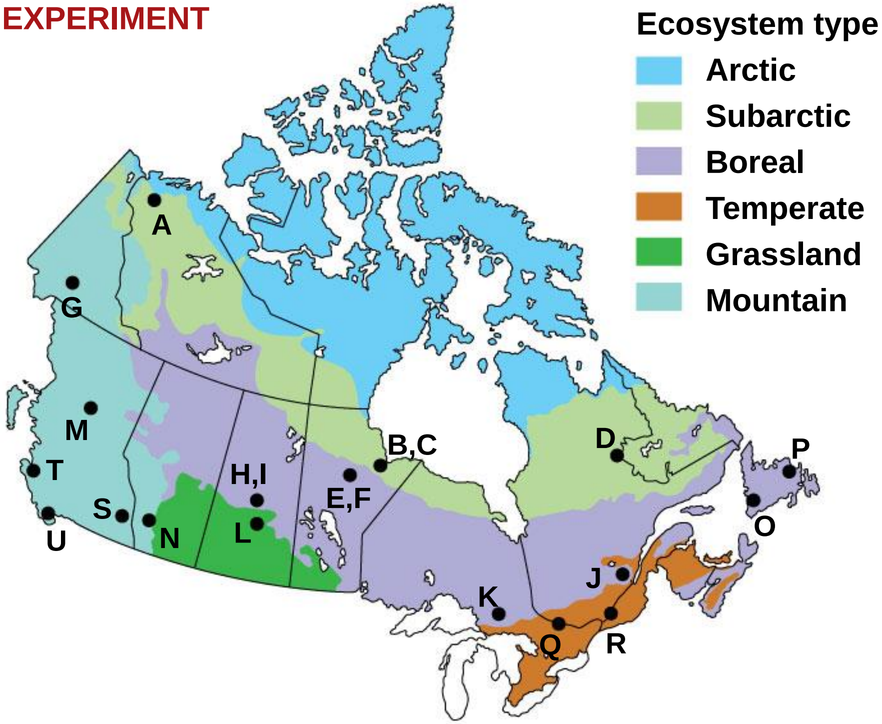
Figure 55.15

EXPERIMENT



RESULTS

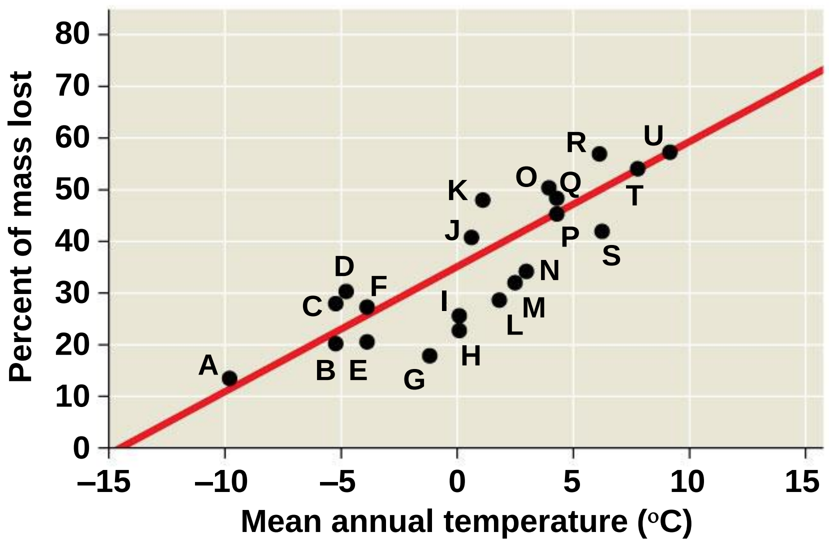


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Figure 55.15a

EXPERIMENT

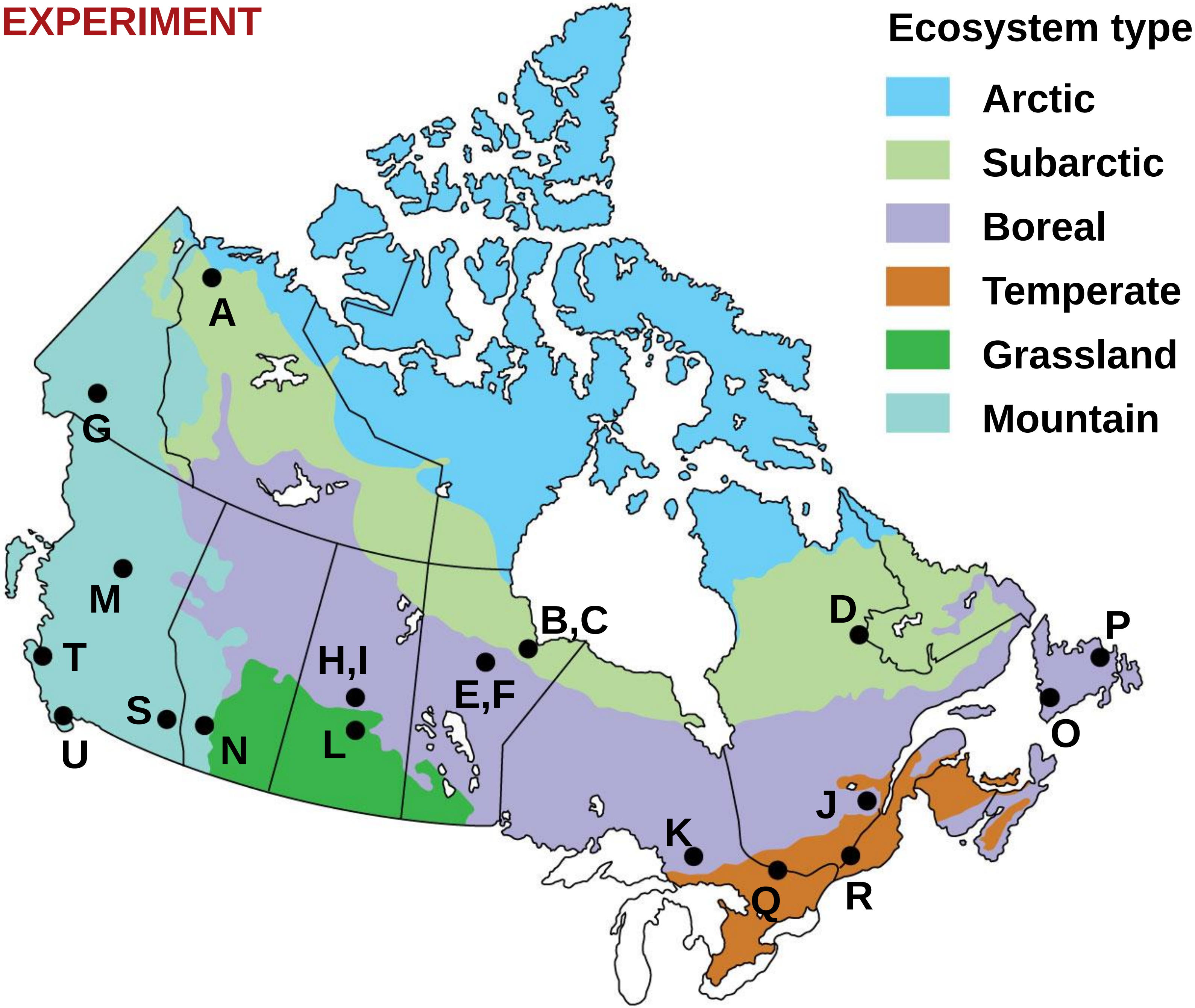

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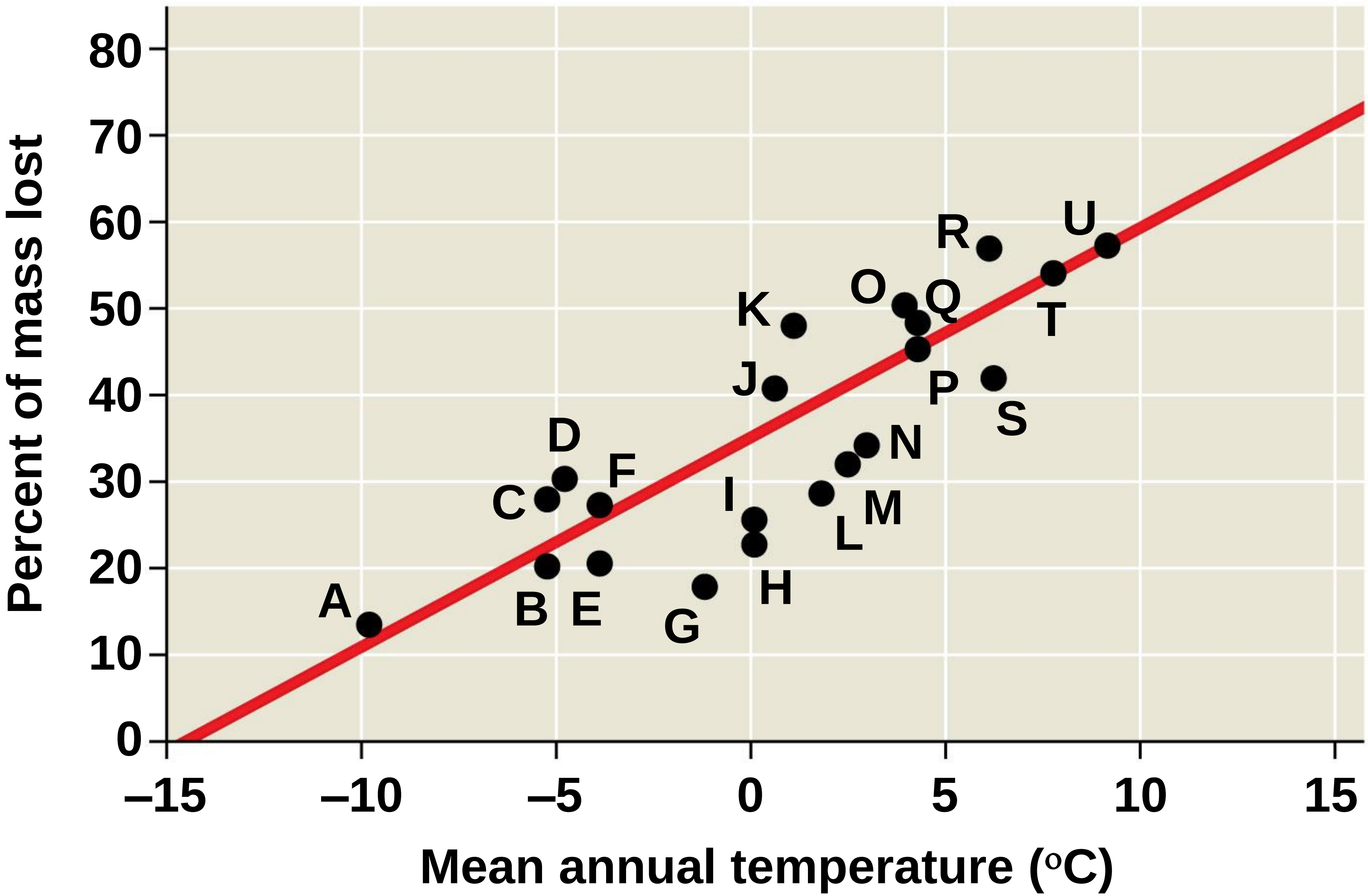
Figure 55.15b

RESULTS



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- Rapid decomposition results in relatively low levels of nutrients in the soil
  - For example, in a tropical rain forest, material decomposes rapidly, and most nutrients are tied up in trees other living organisms
- Cold and wet ecosystems store large amounts of undecomposed organic matter as decomposition rates are low
- Decomposition is slow in anaerobic muds

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Case Study: Nutrient Cycling in the Hubbard Brook Experimental Forest

- The Hubbard Brook Experimental Forest has been used to study nutrient cycling in a forest ecosystem since 1963
- The research team constructed a dam on the site to monitor loss of water and minerals
- They found that 60% of the precipitation exits through streams and 40% is lost by evapotranspiration

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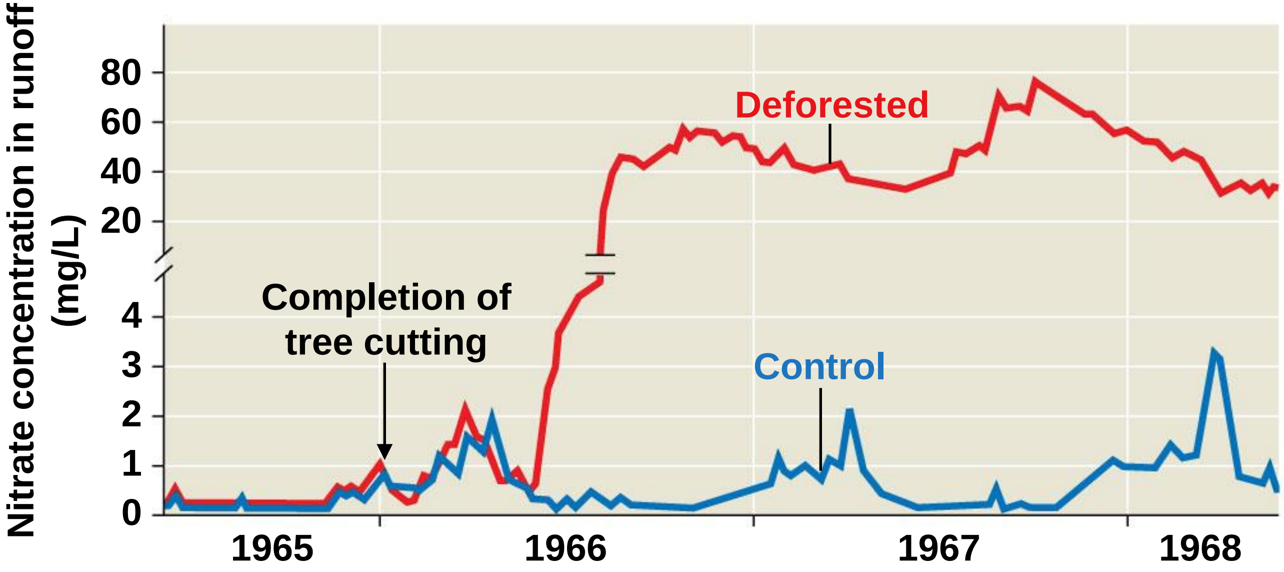
Figure 55.16

(a) Concrete dam and weir

(b) Clear-cut watershed



(c) Nitrate in runoff from watersheds

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- In one experiment, the trees in one valley were cut down, and the valley was sprayed with herbicides

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- Net losses of water were 30–40% greater in the deforested site than the undisturbed (control) site
- Nutrient loss was also much greater in the deforested site compared with the undisturbed site
  - For example, nitrate levels increased 60 times in the outflow of the deforested site
- These results showed how human activity can affect ecosystems

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Concept 55.5: Restoration ecologists help return degraded ecosystems to a more natural state

- Given enough time, biological communities can recover from many types of disturbances
- Restoration ecology seeks to initiate or speed up the recovery of degraded ecosystems
- Two key strategies are bioremediation and augmentation of ecosystem processes

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Figure 55.17

(a) In 1991, before restoration

(b) In 2000, near the completion of restoration

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Bioremediation

- **Bioremediation** is the use of organisms to detoxify ecosystems
- The organisms most often used are prokaryotes, fungi, or plants
- These organisms can take up, and sometimes metabolize, toxic molecules
  - For example, the bacterium *Shewanella oneidensis* can metabolize uranium and other elements to insoluble forms that are less likely to leach into streams and groundwater

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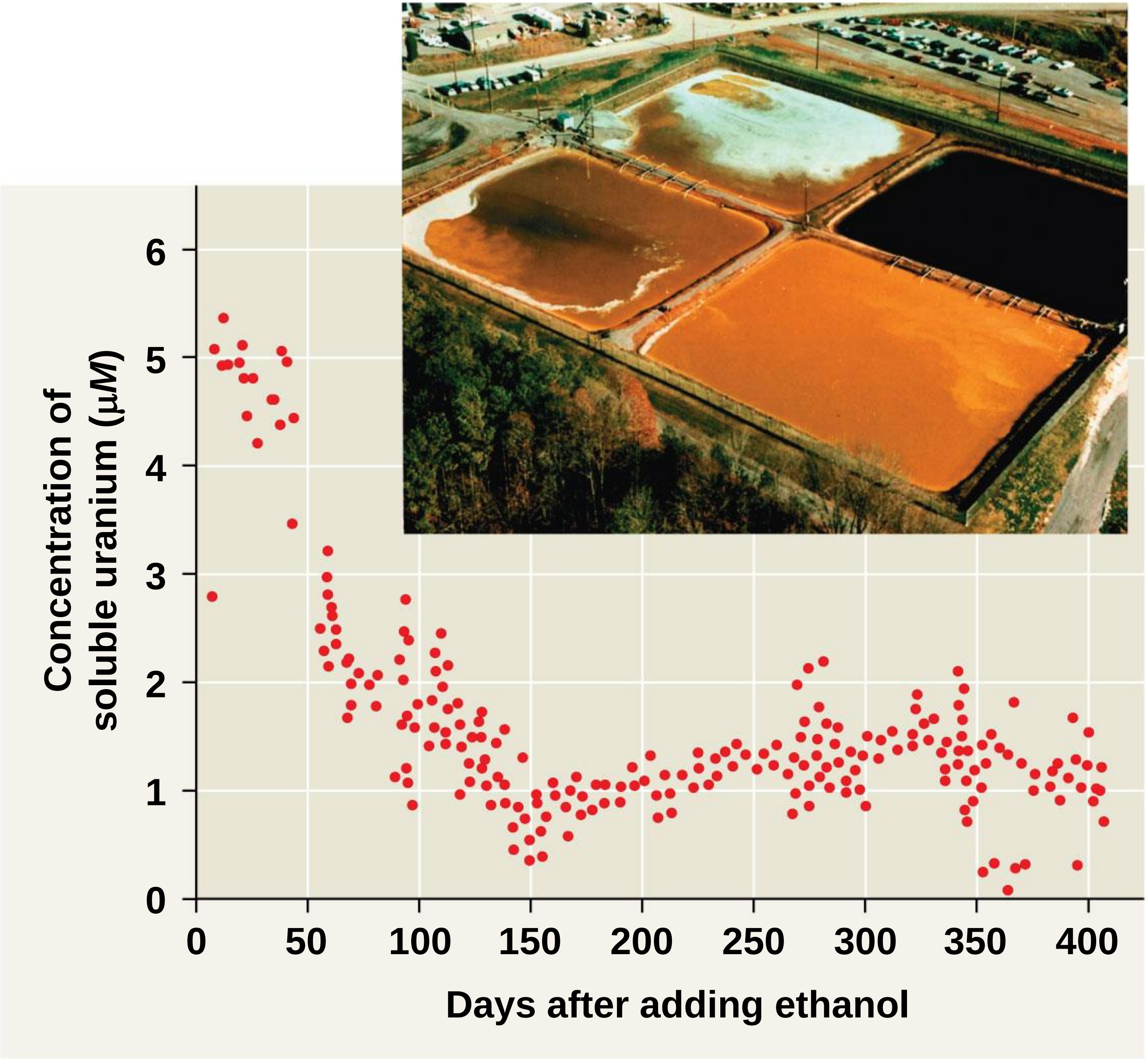
Figure 55.18



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Biological Augmentation

- **Biological augmentation** uses organisms to add essential materials to a degraded ecosystem
  - For example, nitrogen-fixing plants can increase the available nitrogen in soil
  - For example, adding mycorrhizal fungi can help plants to access nutrients from soil

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Restoration Projects Worldwide

- The newness and complexity of restoration ecology require that ecologists consider alternative solutions and adjust approaches based on experience

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Figure 55.UN02

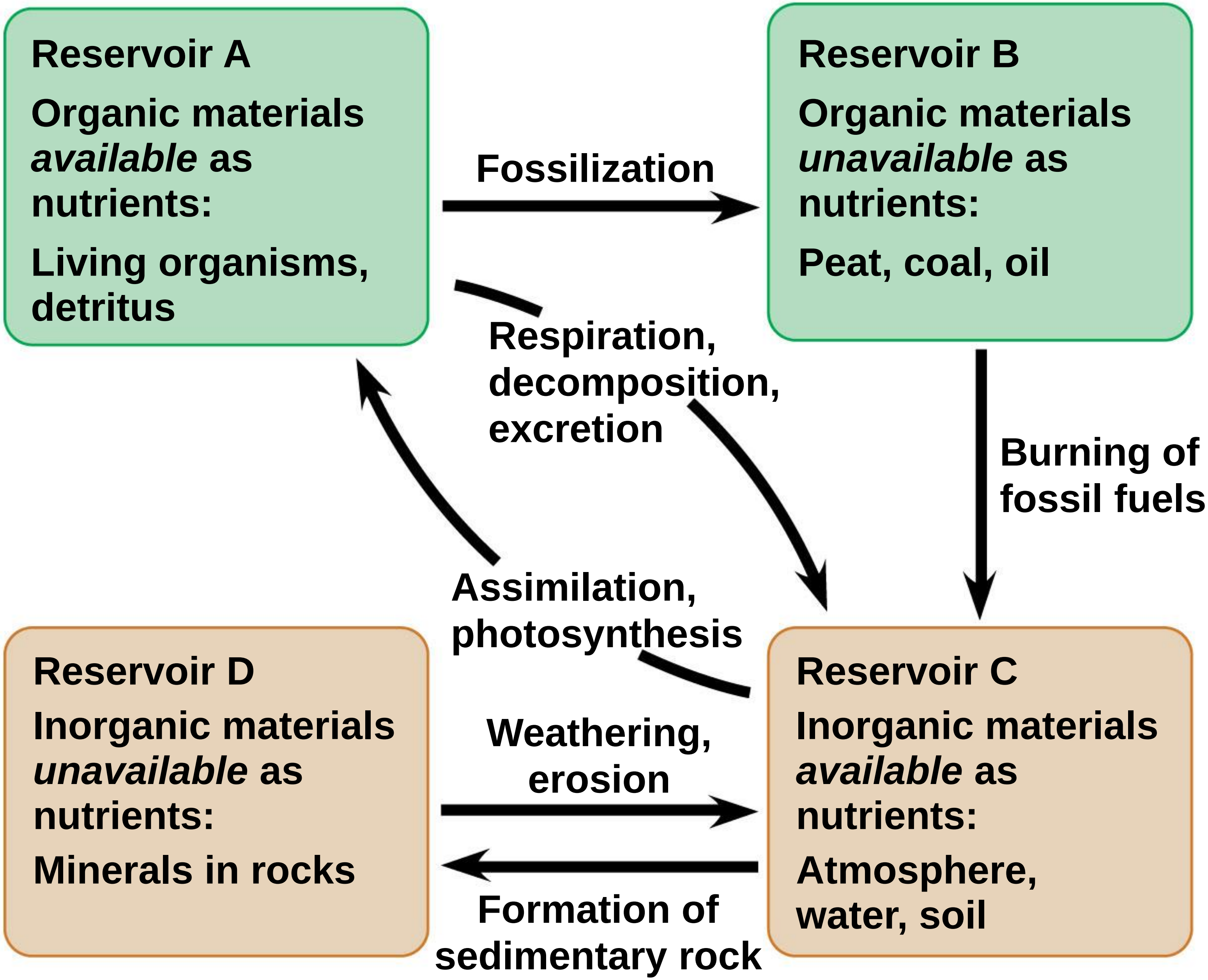

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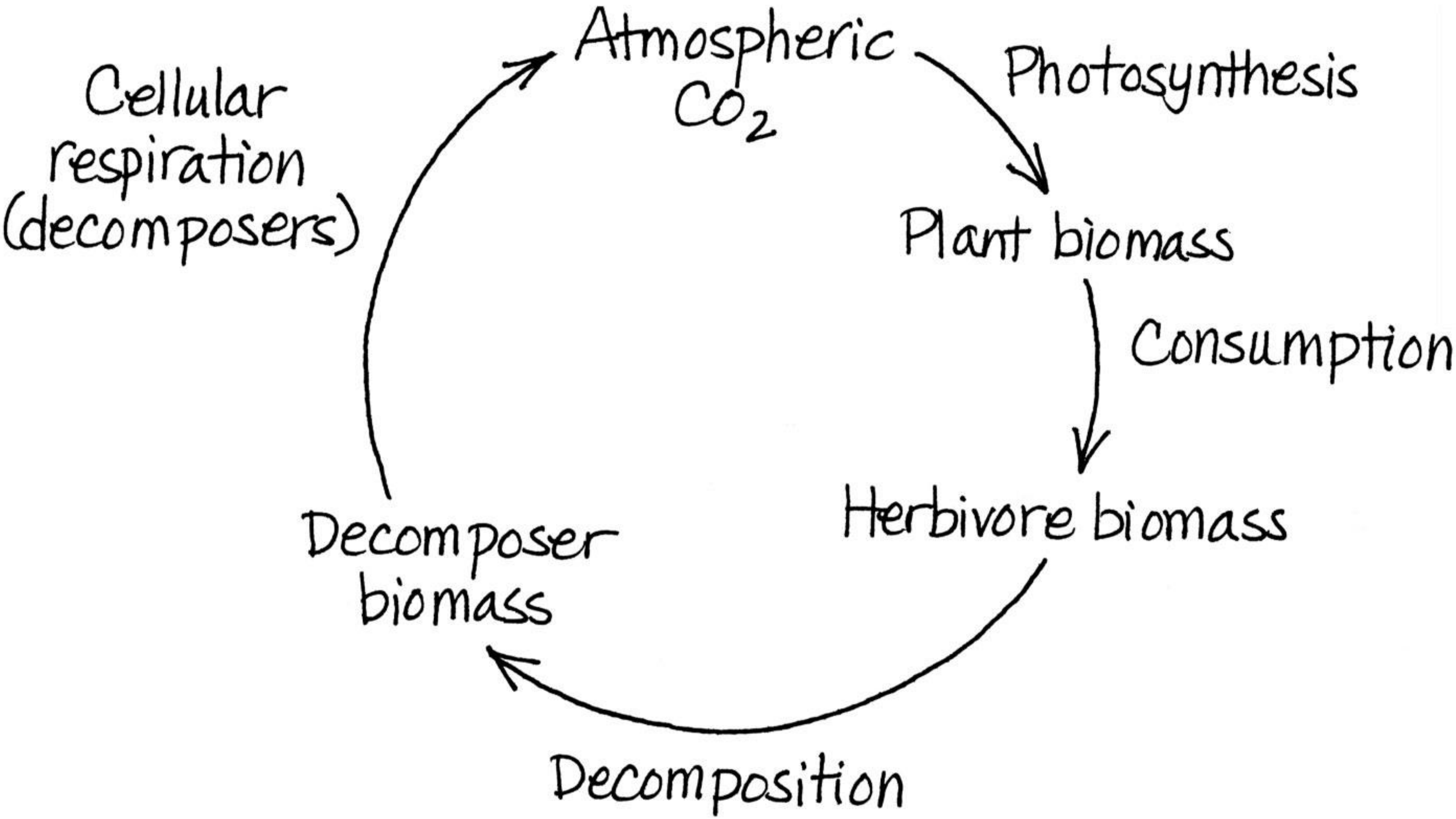
Figure 55.UN03



Cycling of a carbon atom

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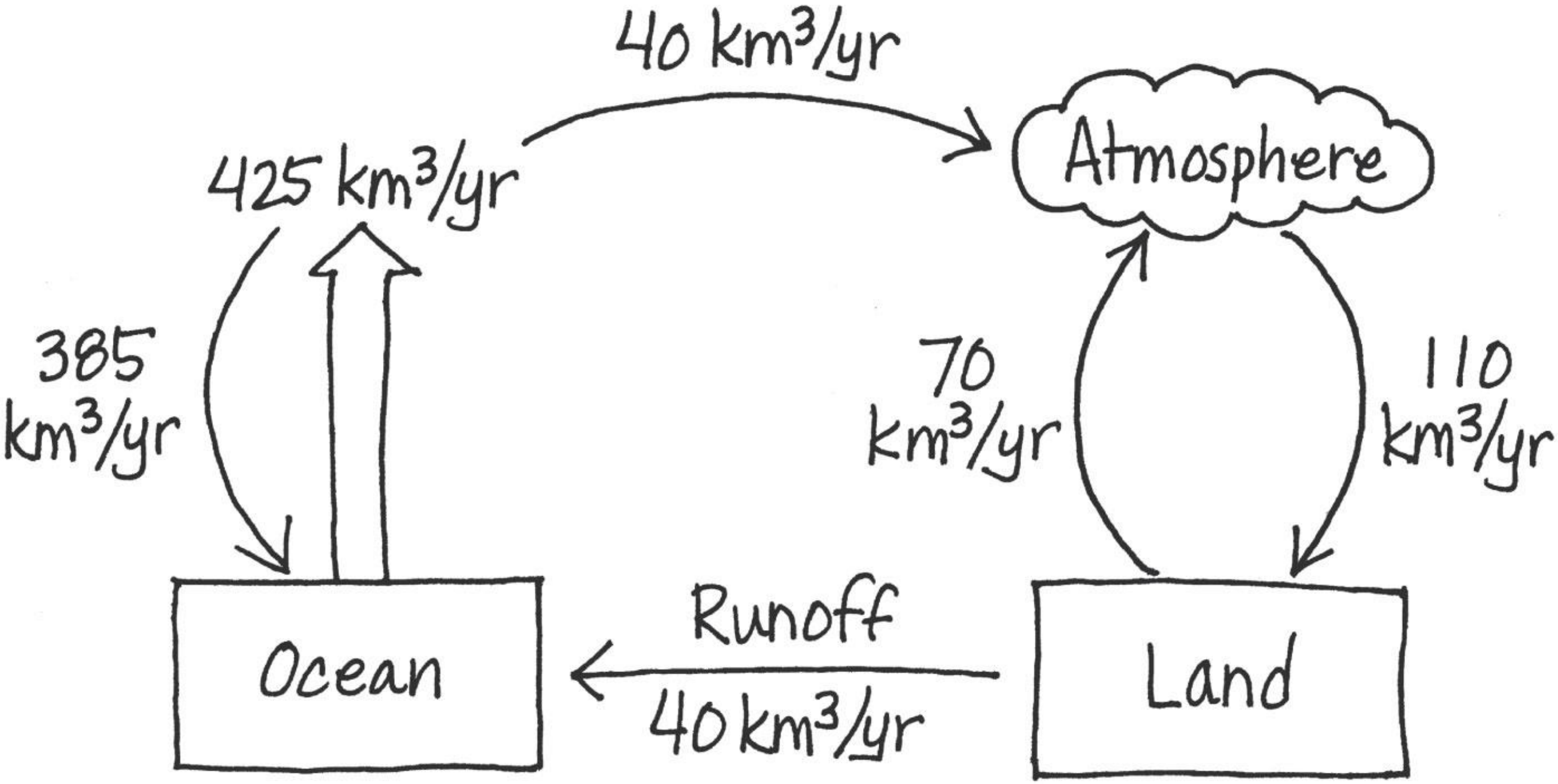
Figure 55.UN04



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