Chapter 55

Ecosystems

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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Overview: Observing Ecosystems

- An **ecosystem** consists of all the organisms living in a community, as well as the abiotic factors with which they interact

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

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

Fig. 55-1

Fig. 55-2

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

- Ecologists study the transformations of energy and matter within their system

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

- 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

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

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
- 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)

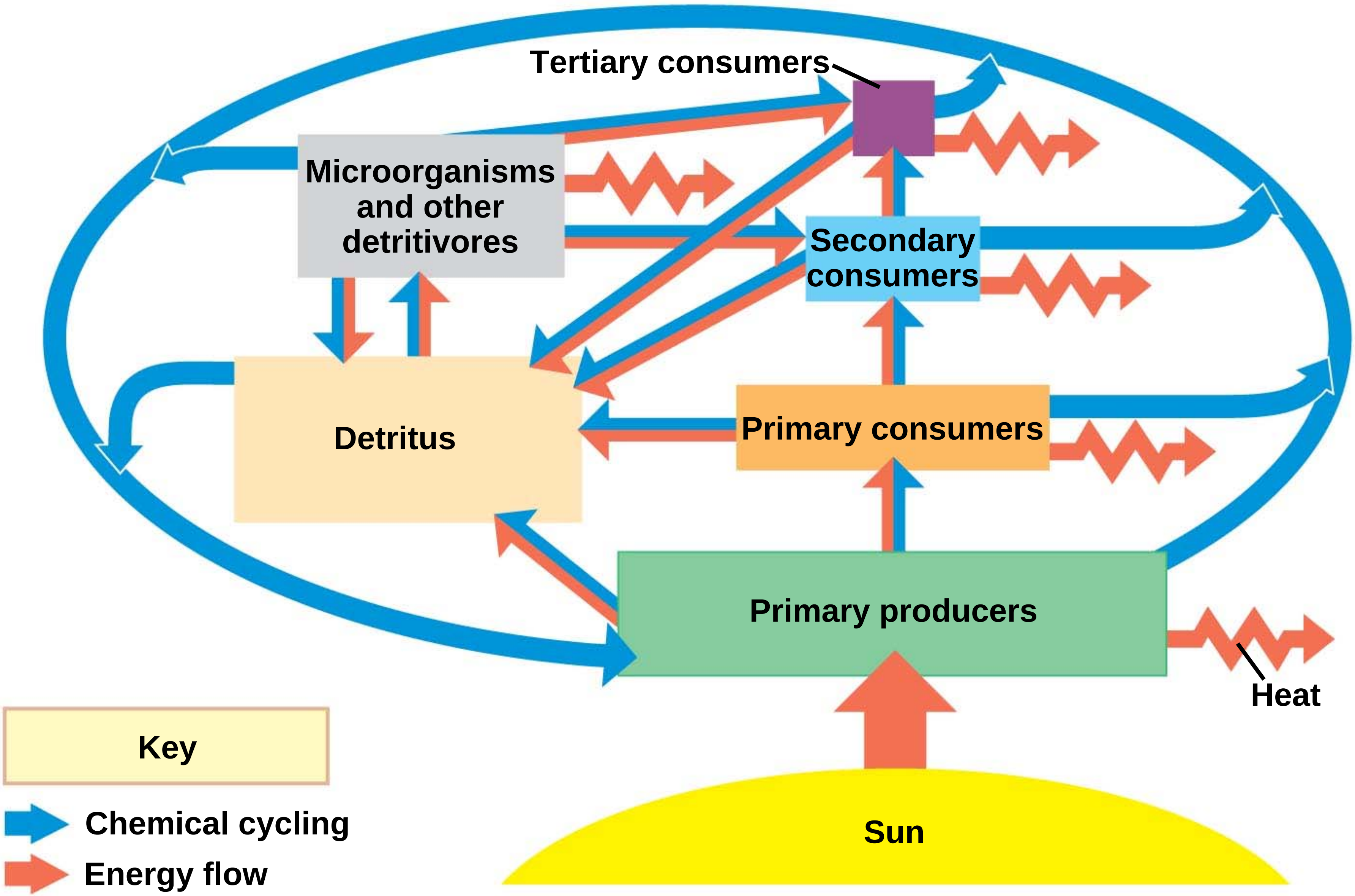
- **Detritivores,** or **decomposers**, are consumers that derive their energy from **detritus**, nonliving organic matter

- Prokaryotes and fungi are important detritivores

- Decomposition connects all trophic levels

Fig. 55-3

Fig. 55-4


Tertiary consumers
Microorganisms and other detritivores
Secondary consumers
Detritus
Primary consumers
Primary producers
Heat
Sun
Key
Chemical cycling
Energy flow

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

- **Primary production** in an ecosystem is the amount of light energy converted to chemical energy by autotrophs during a given time period

Ecosystem Energy Budgets

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

The Global Energy Budget

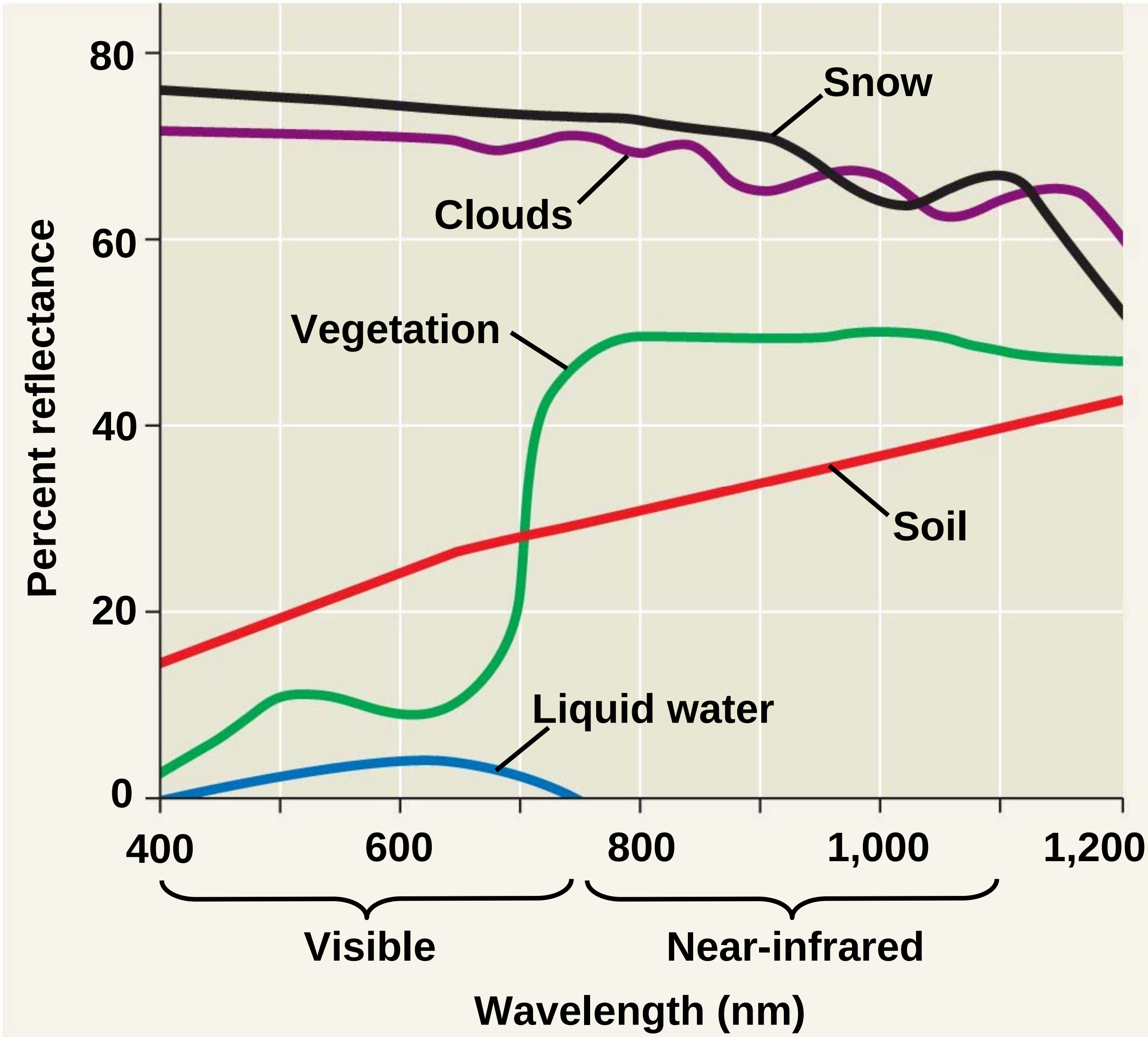
- The amount of solar radiation reaching the Earth's surface limits photosynthetic output of ecosystems
- Only a small fraction of solar energy actually strikes photosynthetic organisms, and even less is of a usable wavelength

Gross and Net Primary Production

- Total primary production is known as the ecosystem's **gross primary production (GPP)**
- **Net primary production (NPP)** is GPP minus energy used by primary producers for respiration
- Only NPP is available to consumers
- Ecosystems vary greatly in NPP and contribution to the total NPP on Earth
- *Standing crop* is the total biomass of photosynthetic autotrophs at a given time

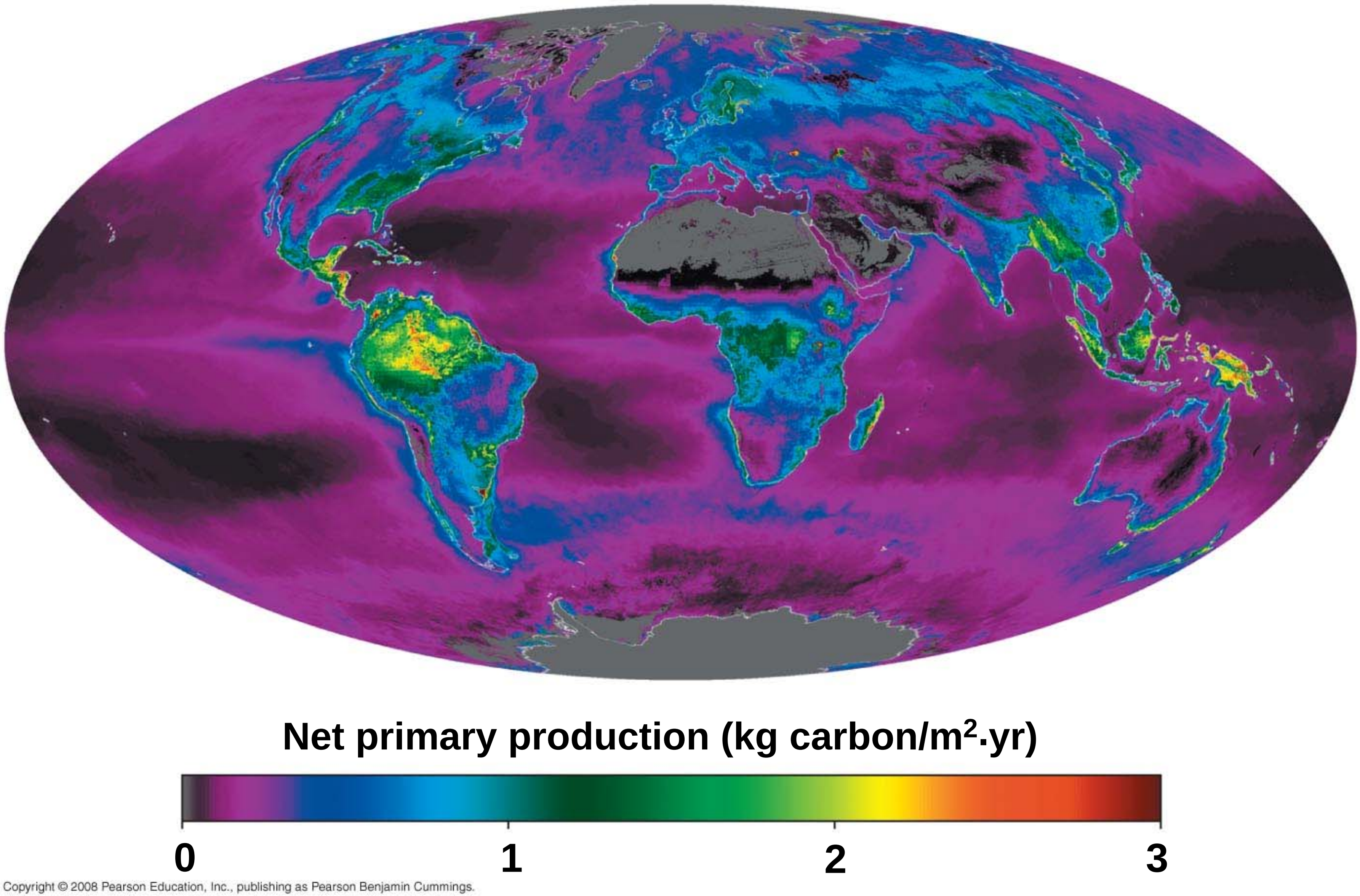
Fig. 55-5

TECHNIQUE



- 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

Fig. 55-6



Primary Production in Aquatic Ecosystems

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

Light Limitation

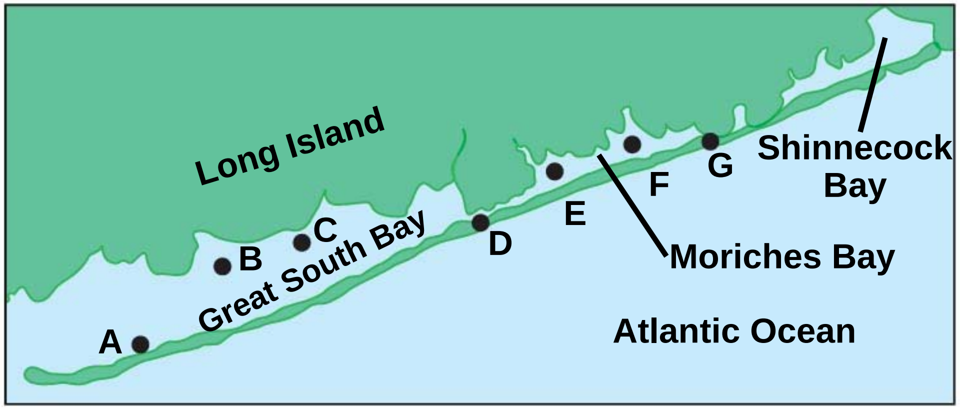
- Depth of light penetration affects primary production in the photic zone of an ocean or lake

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 typically 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

Fig. 55-7

EXPERIMENT



RESULTS

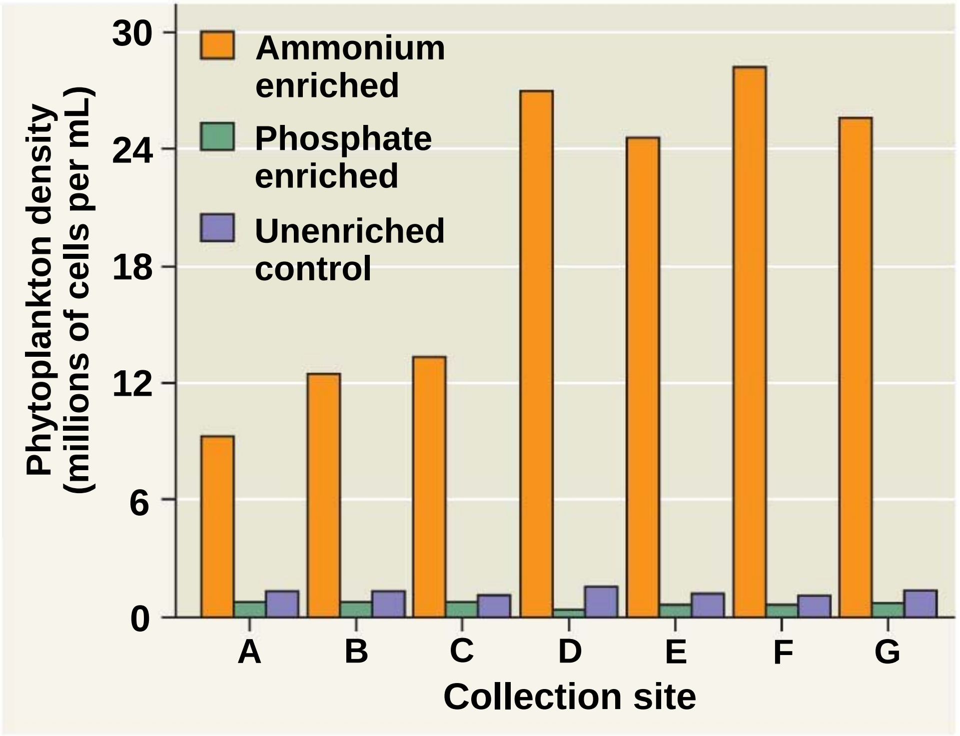


Fig. 55-7a

EXPERIMENT

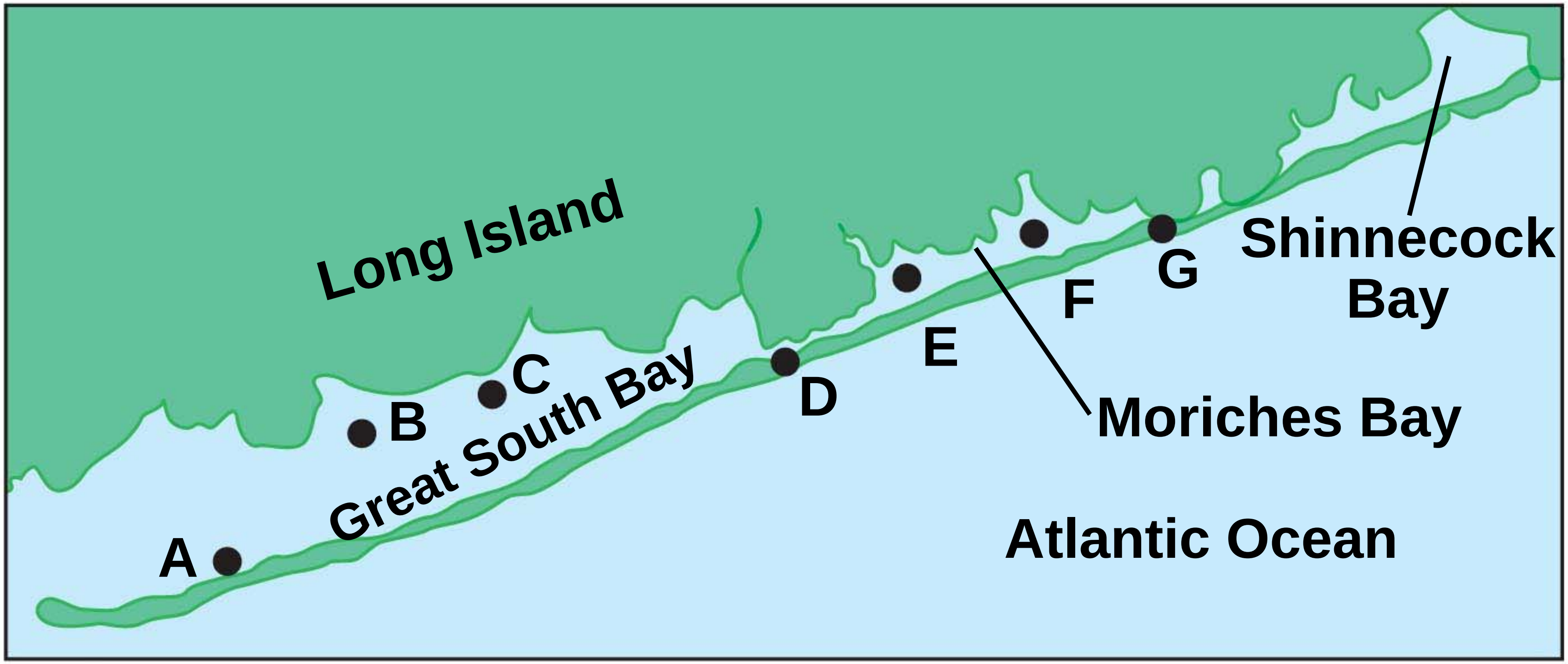
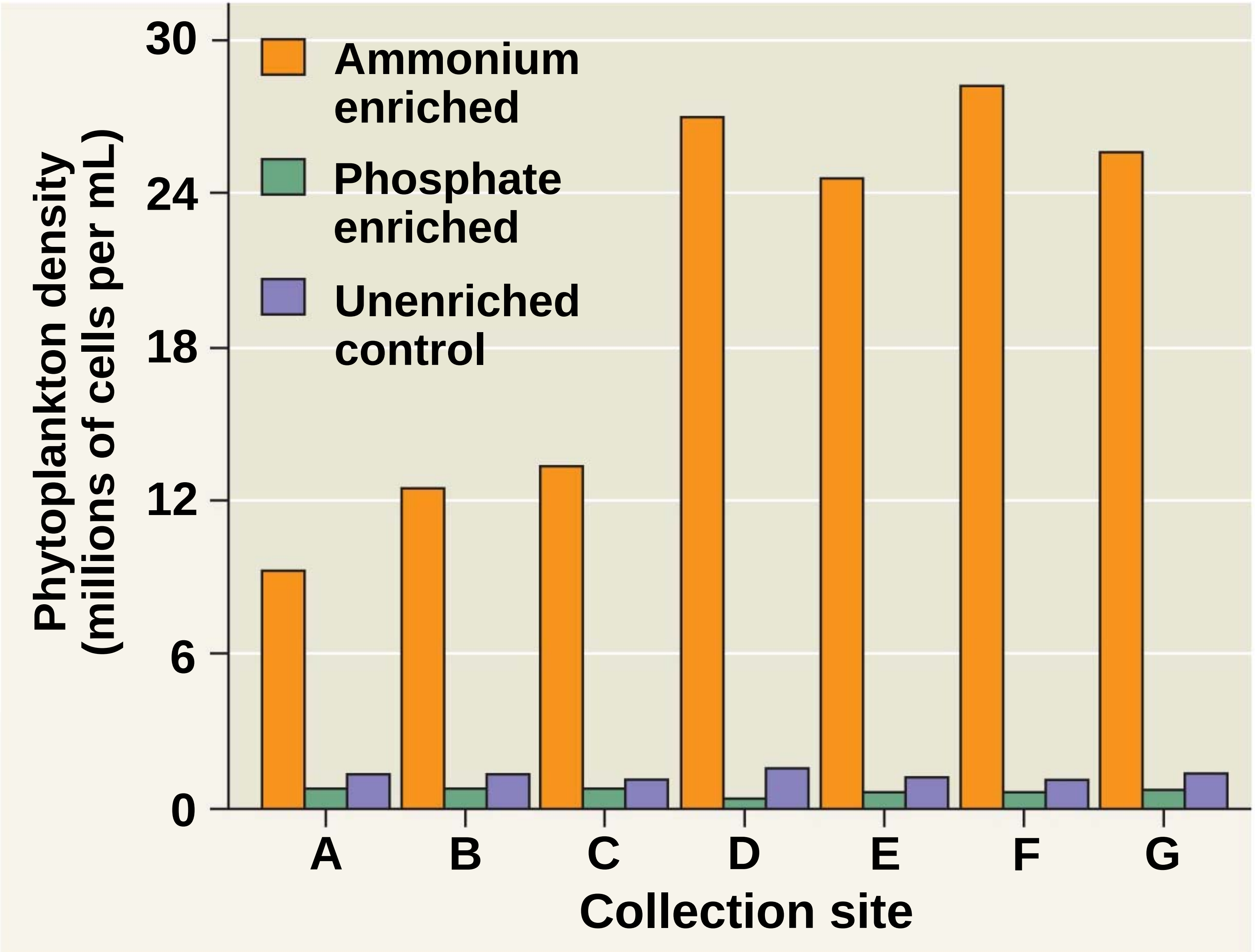


Fig. 55-7b

RESULTS



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

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).

- 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
- In some areas, sewage runoff has caused **eutrophication** of lakes, which can lead to loss of most fish species

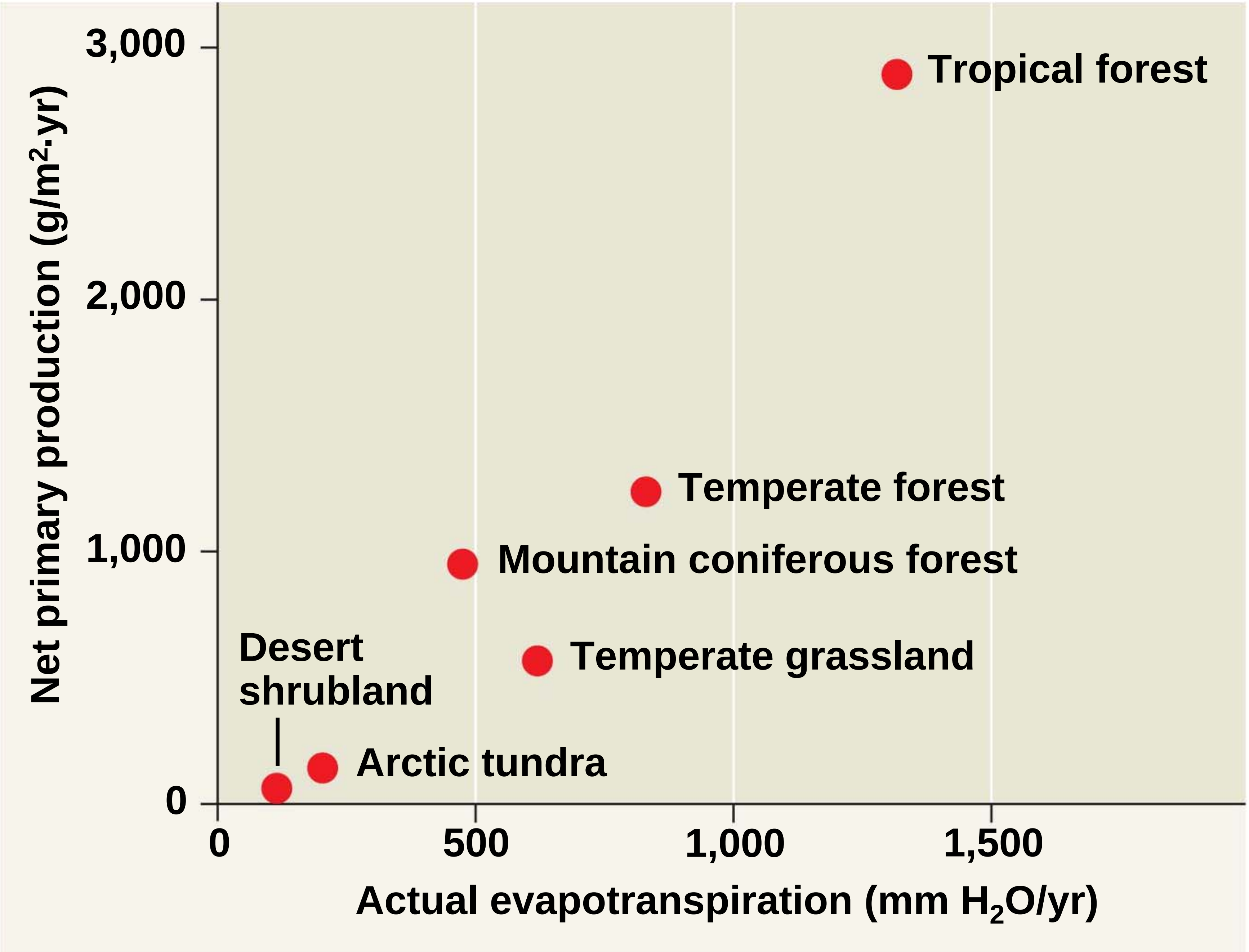
PLAY

Video: Cyanobacteria *(Oscillatoria)*

Primary Production in Terrestrial Ecosystems

- In terrestrial ecosystems, temperature and moisture affect primary production on a large scale
- Actual evapotranspiration can represent the contrast between wet and dry climates
- **Actual evapotranspiration** is the water annually transpired by plants and evaporated from a landscape
- It is related to net primary production

Fig. 55-8



3,000
2,000
1,000
0
Net primary production (g/m²·yr)
Tropical forest
Temperate forest
Mountain coniferous forest
Temperate grassland
Desert
shrubland
Arctic tundra
0
500
1,000
1,500
Actual evapotranspiration (mm H_2O/yr)

- On a more local scale, a soil nutrient is often the limiting factor in primary production

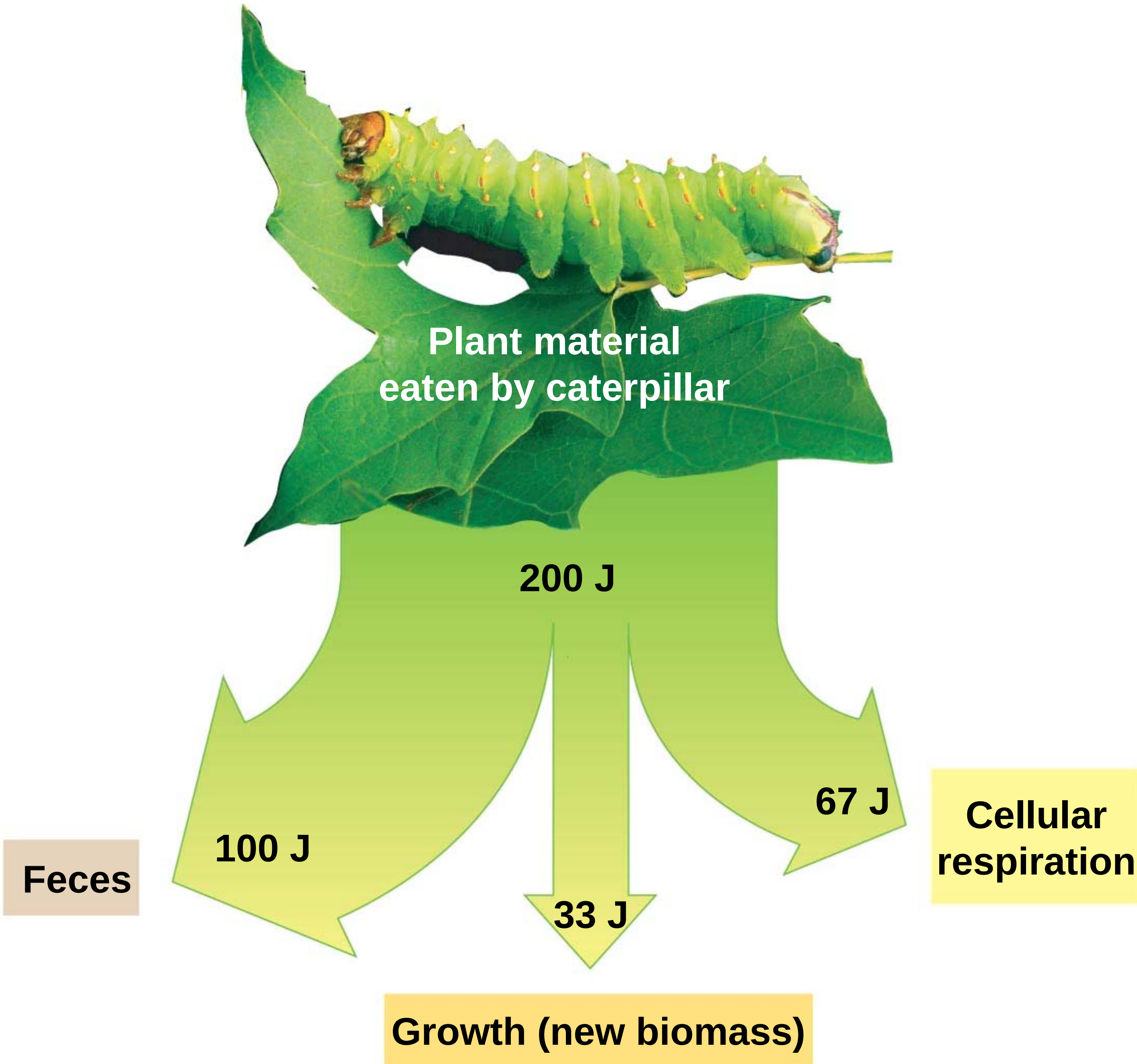
Concept 55.3: Energy transfer between trophic levels is typically only 10% efficient

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

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

Fig. 55-9



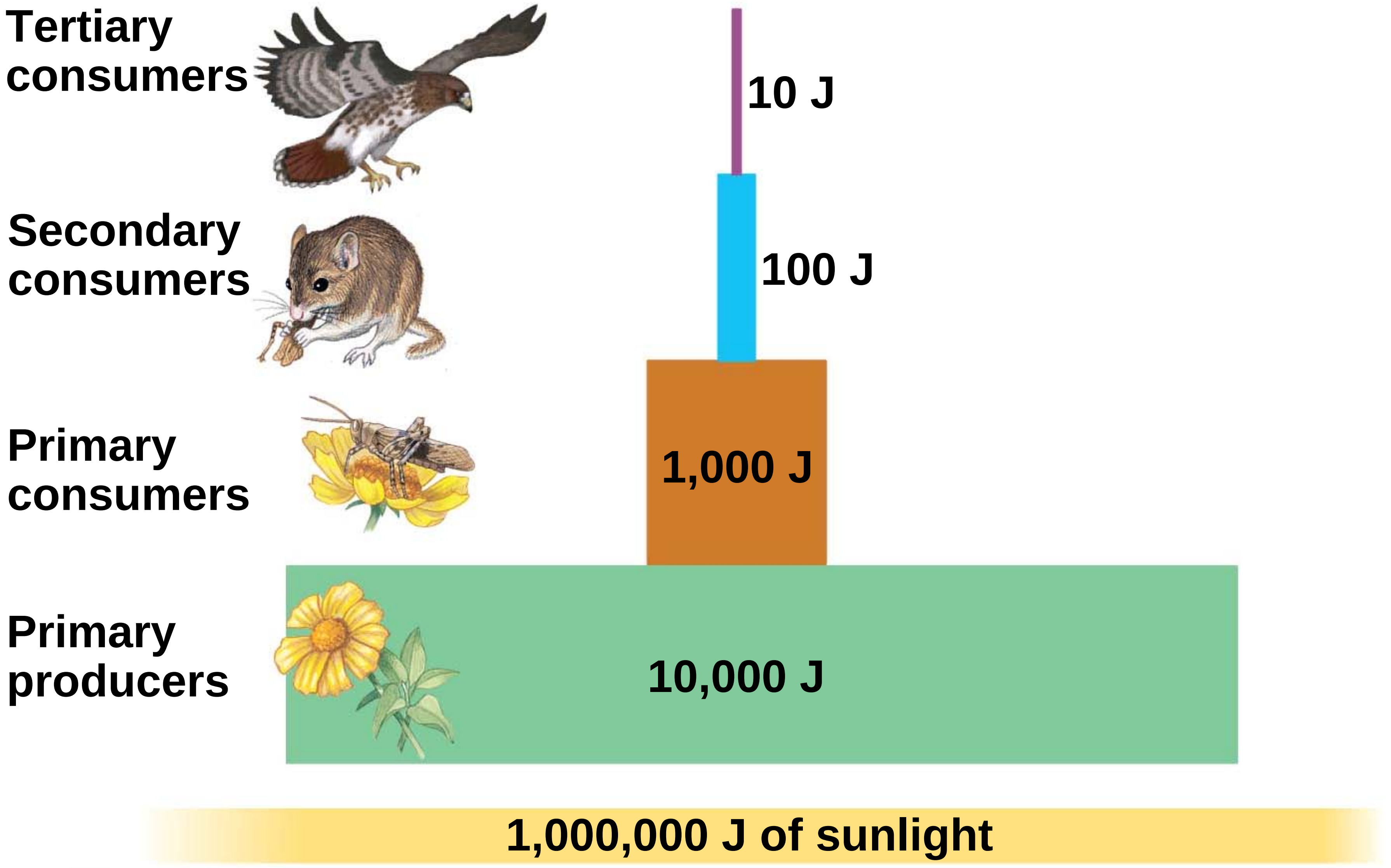
Plant material eaten by caterpillar
200 J
67 J
Cellular respiration
100 J
Feces
33 J
Growth (new biomass)

Trophic Efficiency and Ecological Pyramids

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

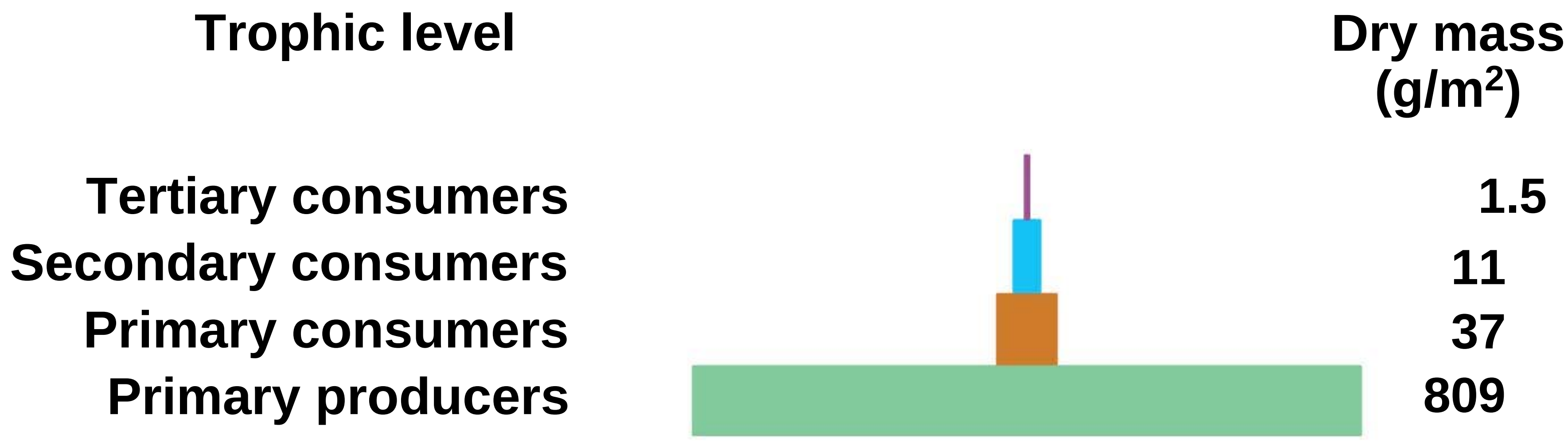
- Approximately 0.1% of chemical energy fixed by photosynthesis reaches a tertiary consumer
- A pyramid of net production represents the loss of energy with each transfer in a food chain

Fig. 55-10


Tertiary consumers
Secondary consumers
Primary consumers
Primary producers
10 J
100 J
1,000 J
10,000 J
1,000,000 J of sunlight

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

Fig. 55-11



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

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

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

- 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

The Green World Hypothesis

- Most terrestrial ecosystems have large standing crops despite the large numbers of herbivores

Fig. 55-12

- The **green world hypothesis** proposes several factors that keep herbivores in check:
  - Plant defenses
  - Limited availability of essential nutrients
  - Abiotic factors
  - Intraspecific competition
  - Interspecific interactions

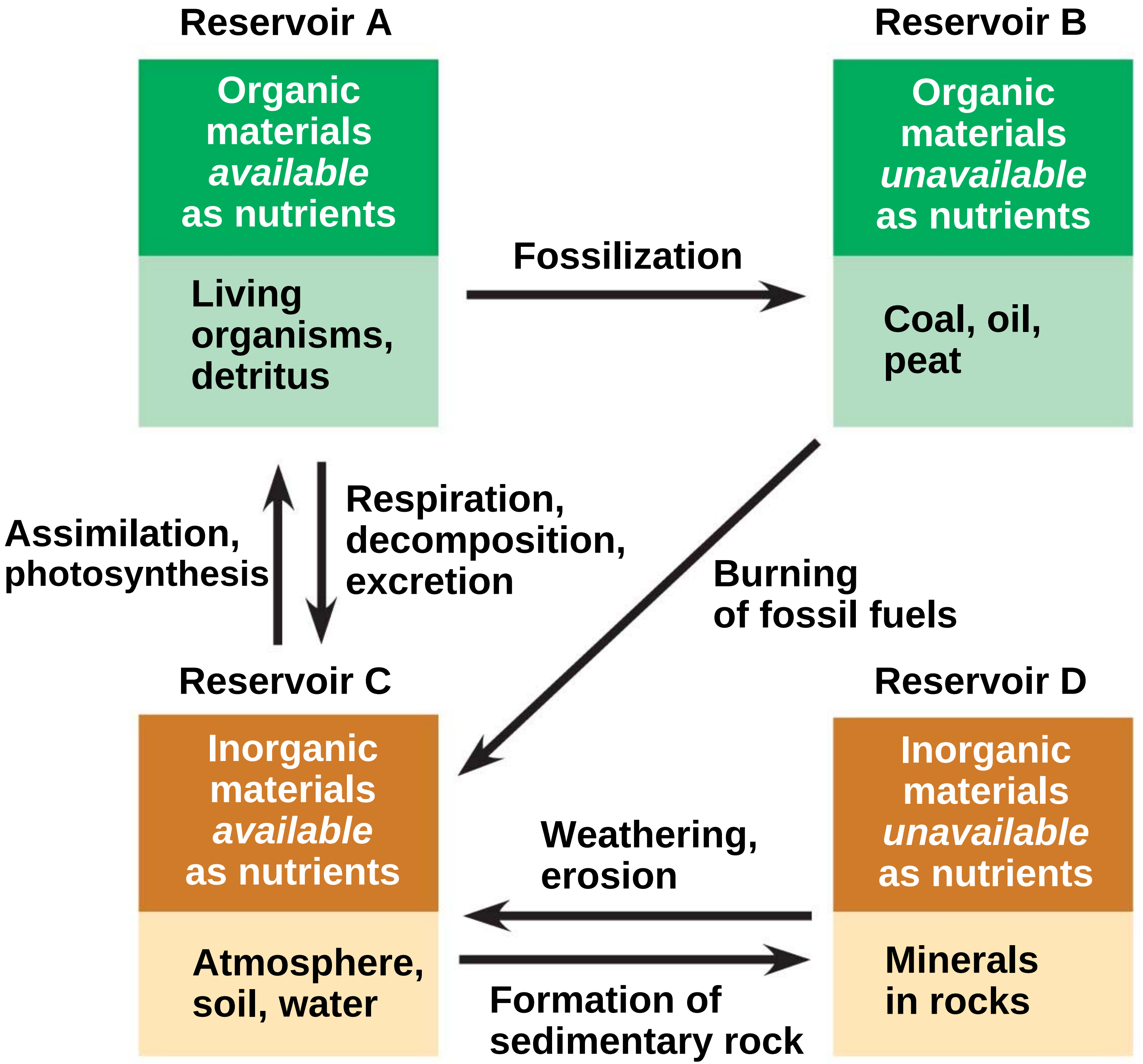
Concept 55.4: Biological and geochemical processes cycle nutrients between organic and inorganic parts of an ecosystem

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

Biogeochemical Cycles

- Gaseous carbon, oxygen, sulfur, and nitrogen occur in the atmosphere and cycle globally
- Less mobile elements such as phosphorus, potassium, and calcium cycle on a more local level
- 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

Fig. 55-13

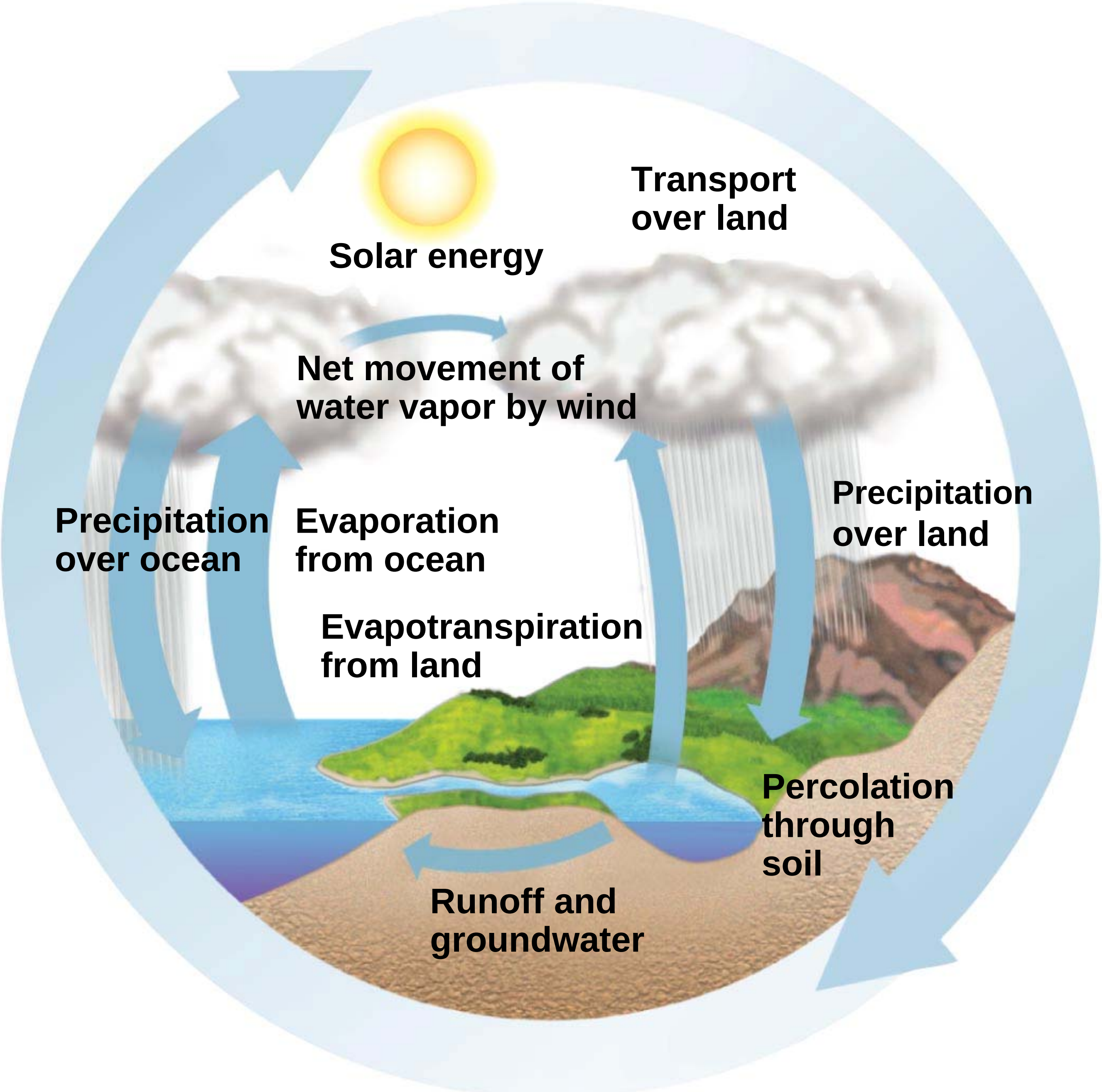

Reservoir A
Organic materials *available* as nutrients
Living organisms, detritus
Fossilization
Reservoir B
Organic materials *unavailable* as nutrients
Coal, oil, peat
Assimilation, photosynthesis
Respiration, decomposition, excretion
Burning of fossil fuels
Reservoir C
Inorganic materials *available* as nutrients
Atmosphere, soil, water
Weathering, erosion
Formation of sedimentary rock
Reservoir D
Inorganic materials *unavailable* as nutrients
Minerals in rocks

- 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

The Water Cycle

- Water is essential to all organisms
- 97% of the biosphere's water is contained in the oceans, 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

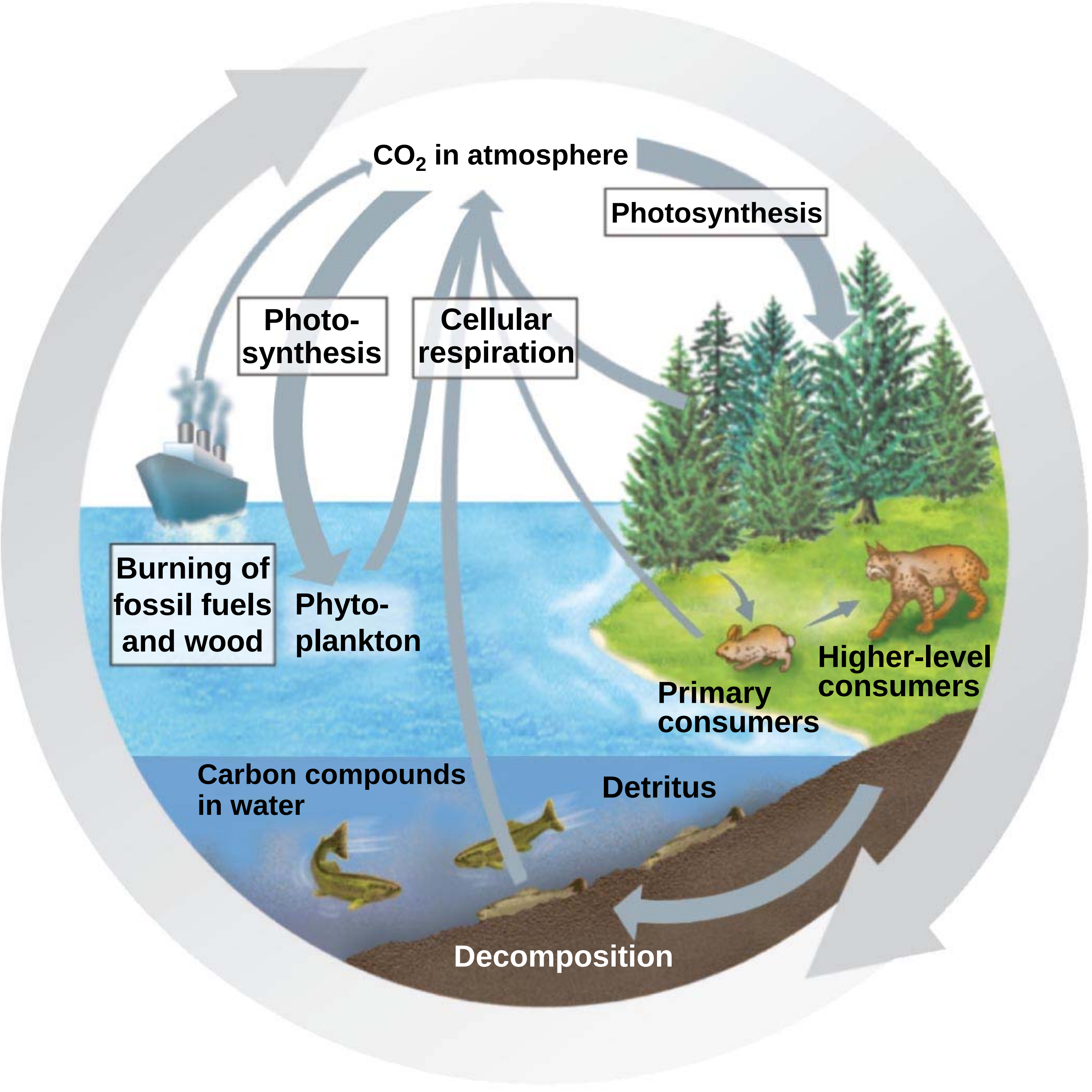
Fig. 55-14a


Transport
over land
Solar energy
Net movement of
water vapor by wind
Precipitation
over land
Precipitation
over ocean
Evaporation
from ocean
Evapotranspiration
from land
Percolation
through
soil
Runoff and
groundwater

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

Fig. 55-14b



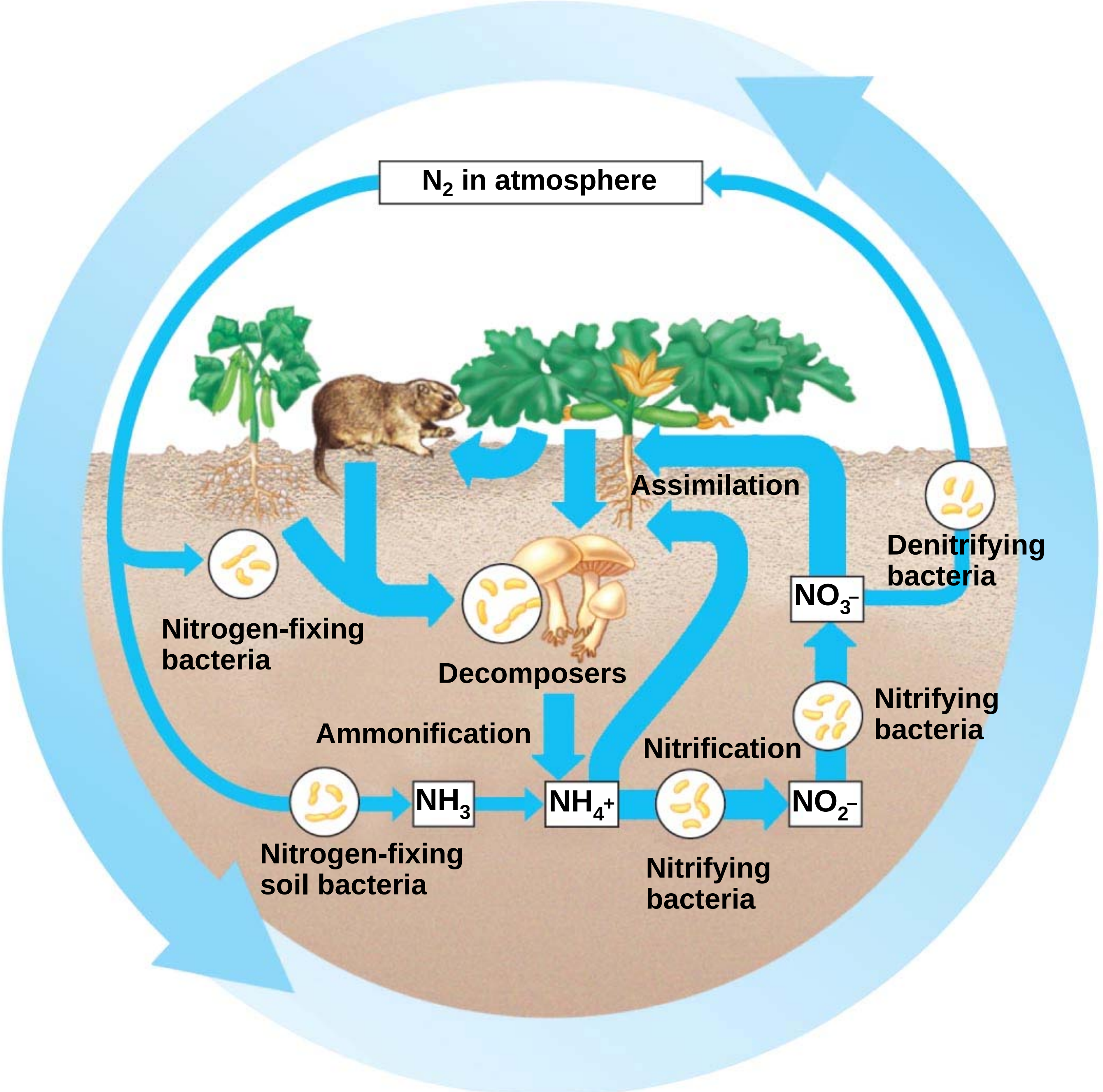
CO_2 in atmosphere
Photosynthesis
Photo-
synthesis
Cellular
respiration
Burning of
fossil fuels
and wood
Phyto-
plankton
Higher-level
consumers
Primary
consumers
Carbon compounds
in water
Detritus
Decomposition

The Terrestrial 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

- 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

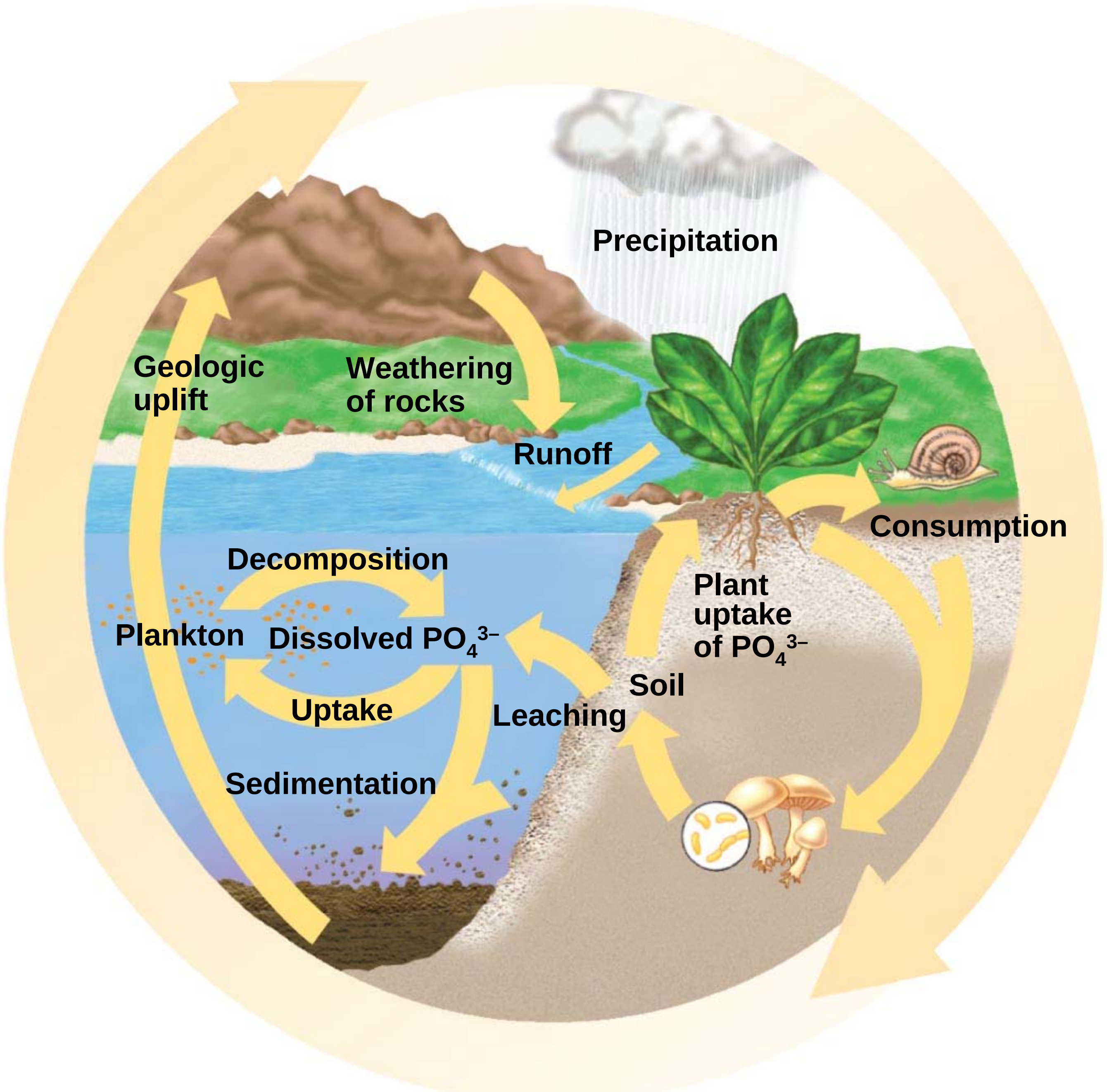
Fig. 55-14c


N_2 in atmosphere
Assimilation
Denitrifying bacteria
NO_3^-
Nitrogen-fixing bacteria
Decomposers
Nitrifying bacteria
Ammonification
Nitrification
NH_3
NH_4^+
NO_2^-
Nitrogen-fixing soil bacteria
Nitrifying bacteria

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

Fig. 55-14d

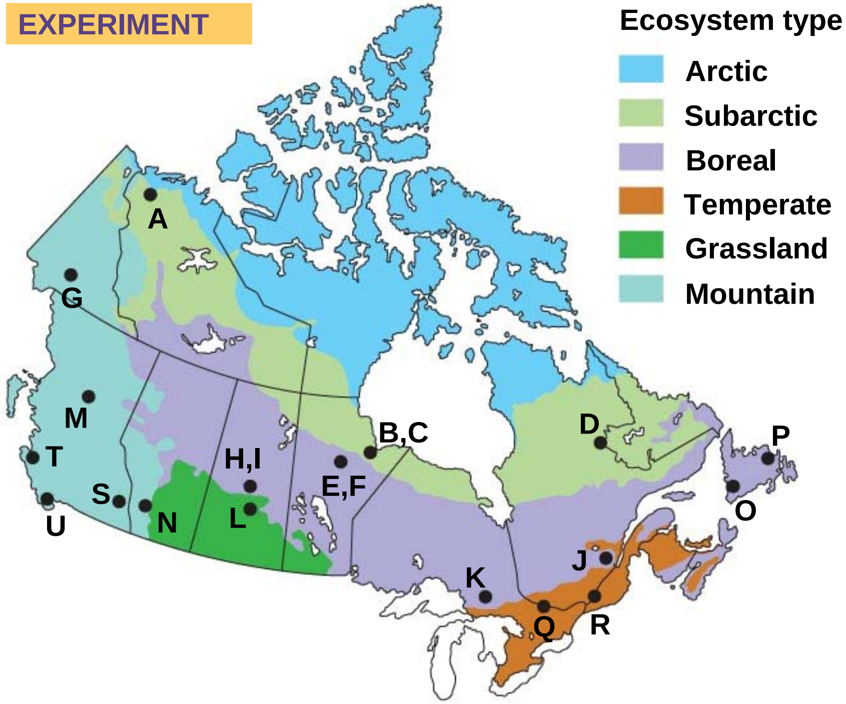

Precipitation
Geologic uplift
Weathering of rocks
Runoff
Consumption
Decomposition
Plant uptake of PO_4^{3-}
Plankton
Dissolved PO_4^{3-}
Soil
Uptake
Leaching
Sedimentation

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
- Rapid decomposition results in relatively low levels of nutrients in the soil

Fig. 55-15

EXPERIMENT



RESULTS

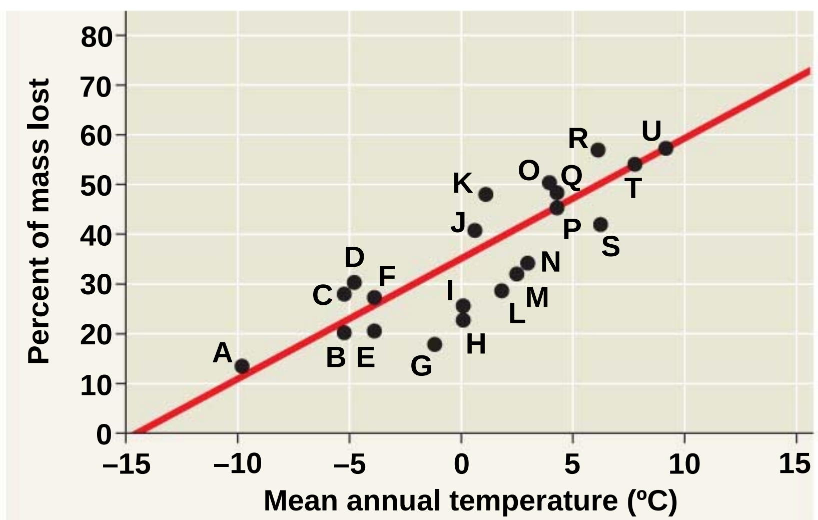


Fig. 55-15a

EXPERIMENT

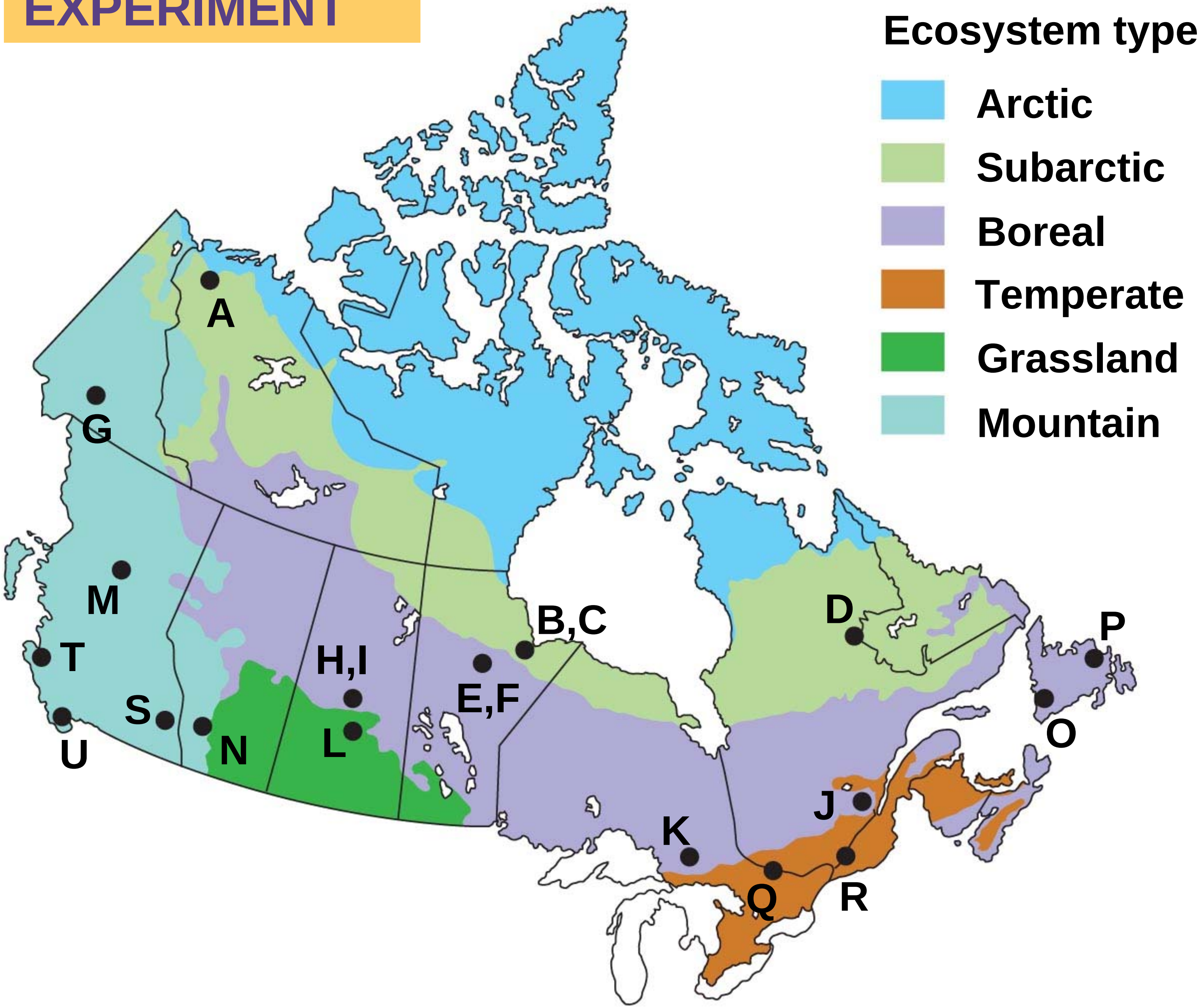
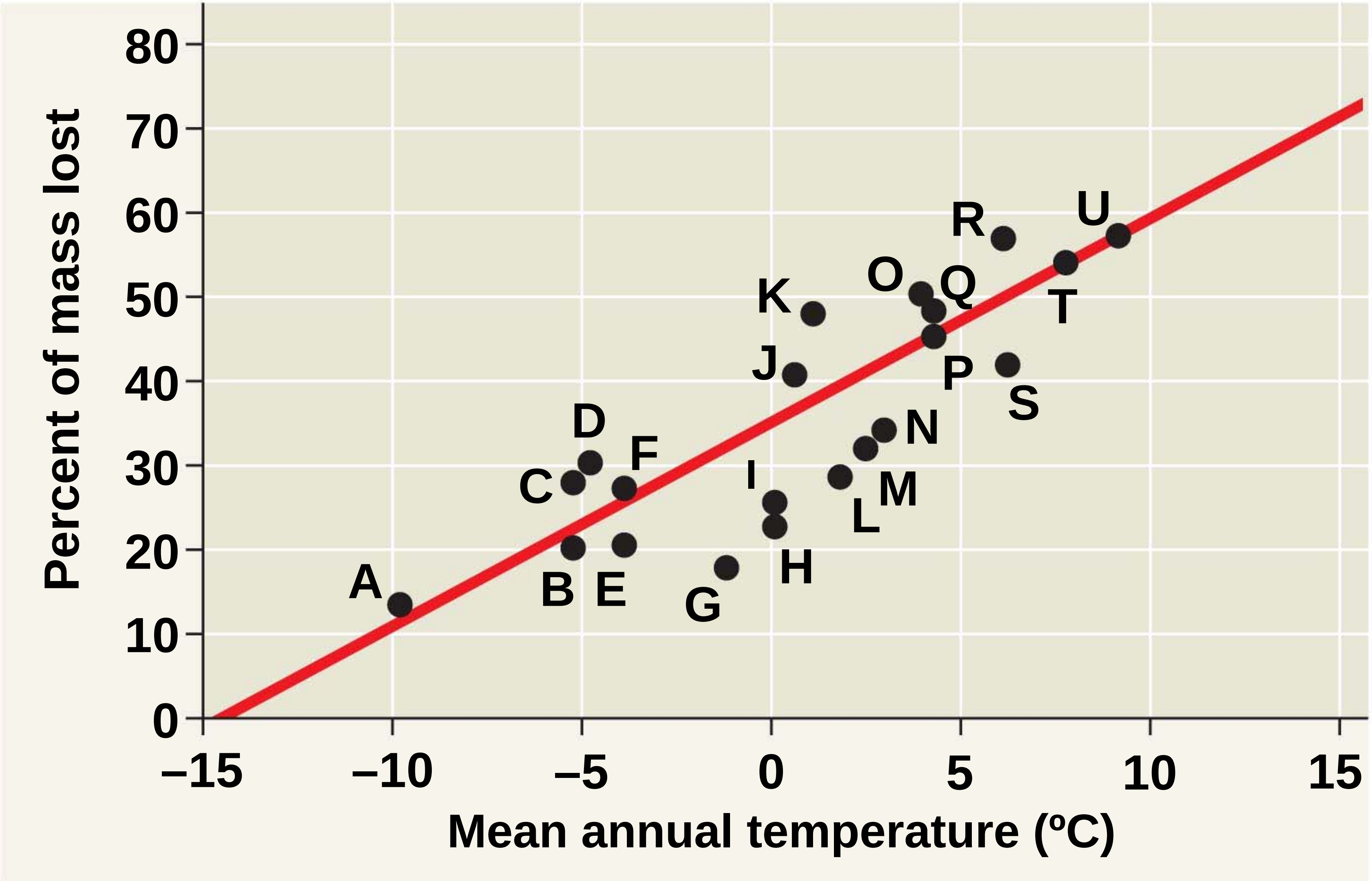


Fig. 55-15b

RESULTS



Case Study: Nutrient Cycling in the Hubbard Brook Experimental Forest

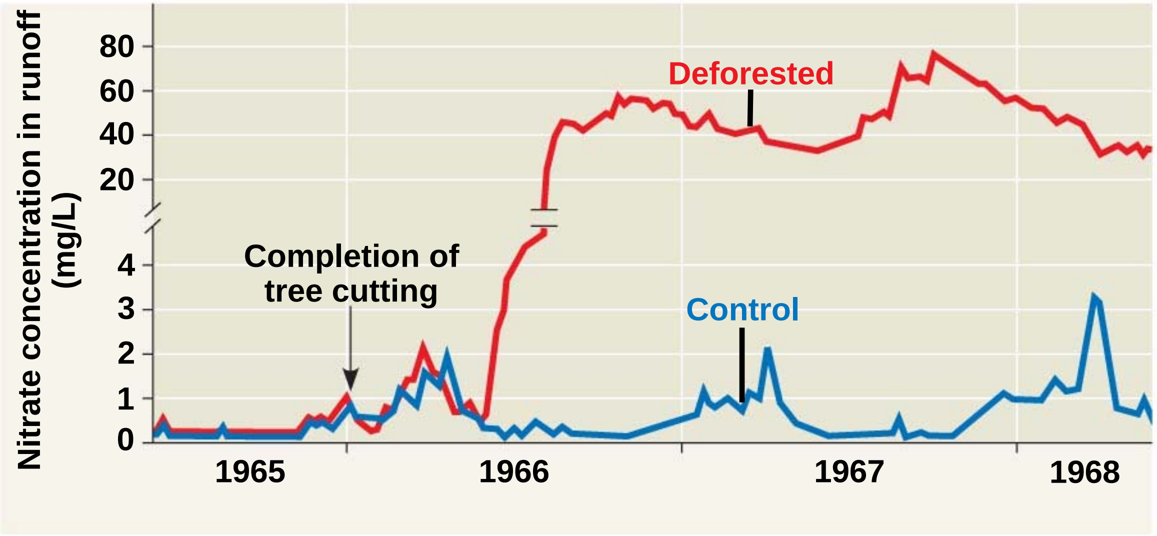
- Vegetation strongly regulates nutrient cycling
- Research projects monitor ecosystem dynamics over long periods
- The Hubbard Brook Experimental Forest has been used to study nutrient cycling in a forest ecosystem since 1963

- The research team constructed a dam on the site to monitor loss of water and minerals

Fig. 55-16


(a) Concrete dam and weir


(b) Clear-cut watershed



(c) Nitrogen in runoff from watersheds

Fig. 55-16a

(a) Concrete dam and weir

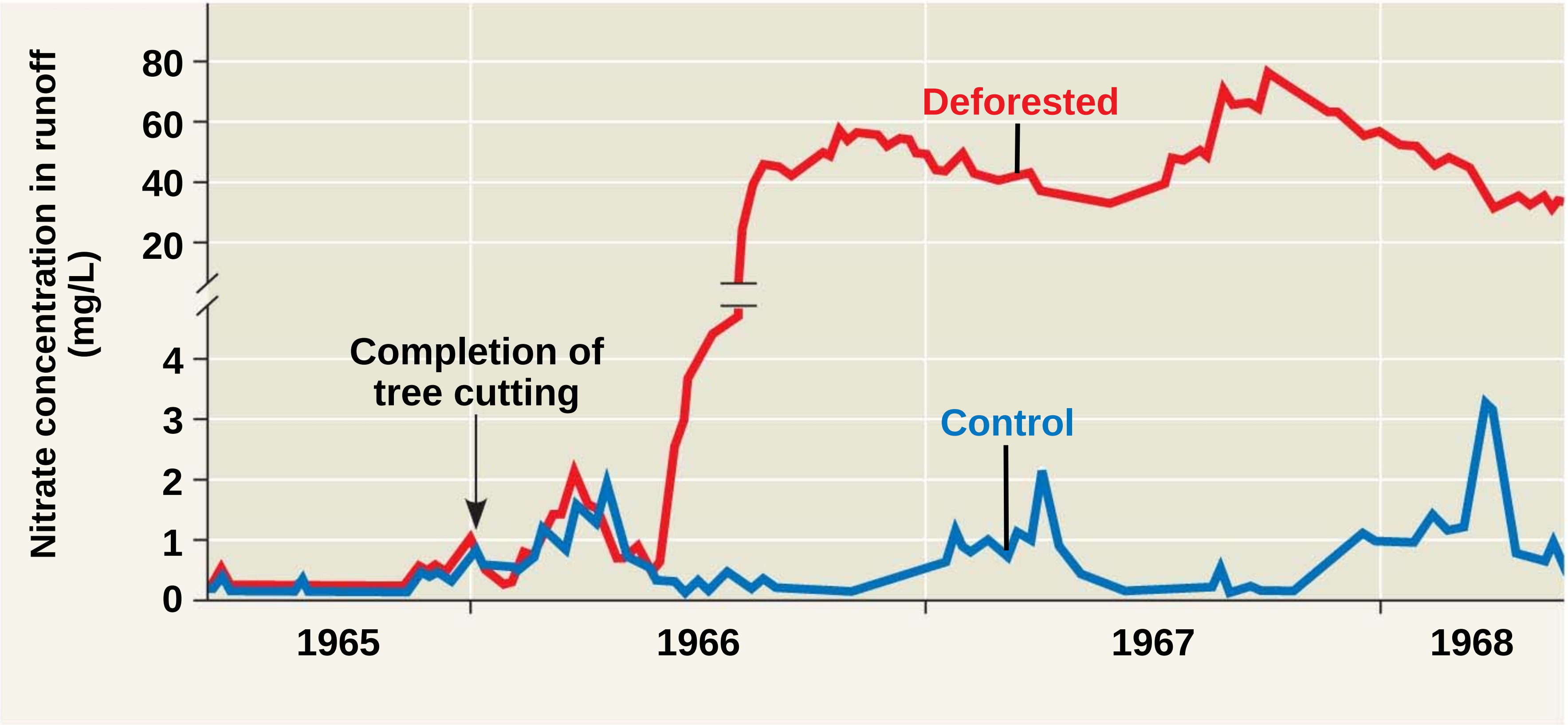
- In one experiment, the trees in one valley were cut down, and the valley was sprayed with herbicides

Fig. 55-16b

(b) Clear-cut watershed

- Net losses of water and minerals were studied and found to be greater than in an undisturbed area
- These results showed how human activity can affect ecosystems

Fig. 55-16c



(c) Nitrogen in runoff from watersheds

Concept 55.5: Human activities now dominate most chemical cycles on Earth

- As the human population has grown, our activities have disrupted the trophic structure, energy flow, and chemical cycling of many ecosystems

Nutrient Enrichment

- In addition to transporting nutrients from one location to another, humans have added new materials, some of them toxins, to ecosystems

Agriculture and Nitrogen Cycling

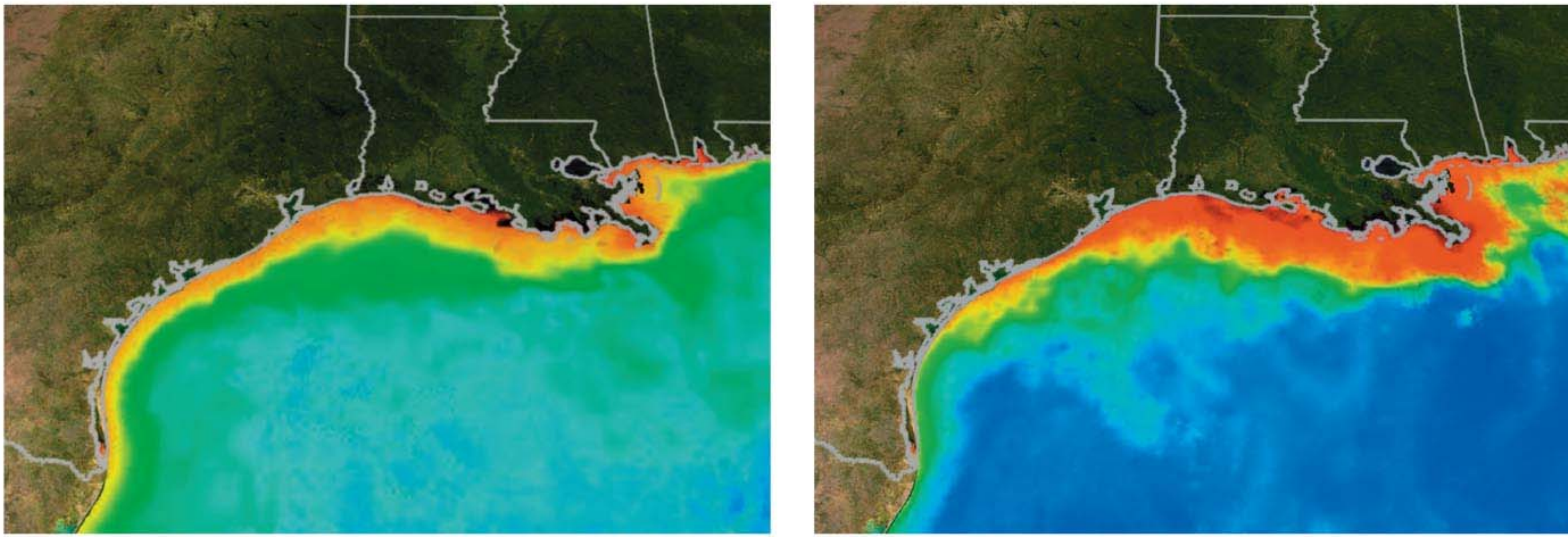
- The quality of soil varies with the amount of organic material it contains
- Agriculture removes from ecosystems nutrients that would ordinarily be cycled back into the soil
- Nitrogen is the main nutrient lost through agriculture; thus, agriculture greatly affects the nitrogen cycle
- Industrially produced fertilizer is typically used to replace lost nitrogen, but effects on an ecosystem can be harmful

Fig. 55-17

Contamination of Aquatic Ecosystems

- **Critical load** for a nutrient is the amount that plants can absorb without damaging the ecosystem
- When excess nutrients are added to an ecosystem, the critical load is exceeded
- Remaining nutrients can contaminate groundwater as well as freshwater and marine ecosystems
- Sewage runoff causes cultural eutrophication, excessive algal growth that can greatly harm freshwater ecosystems

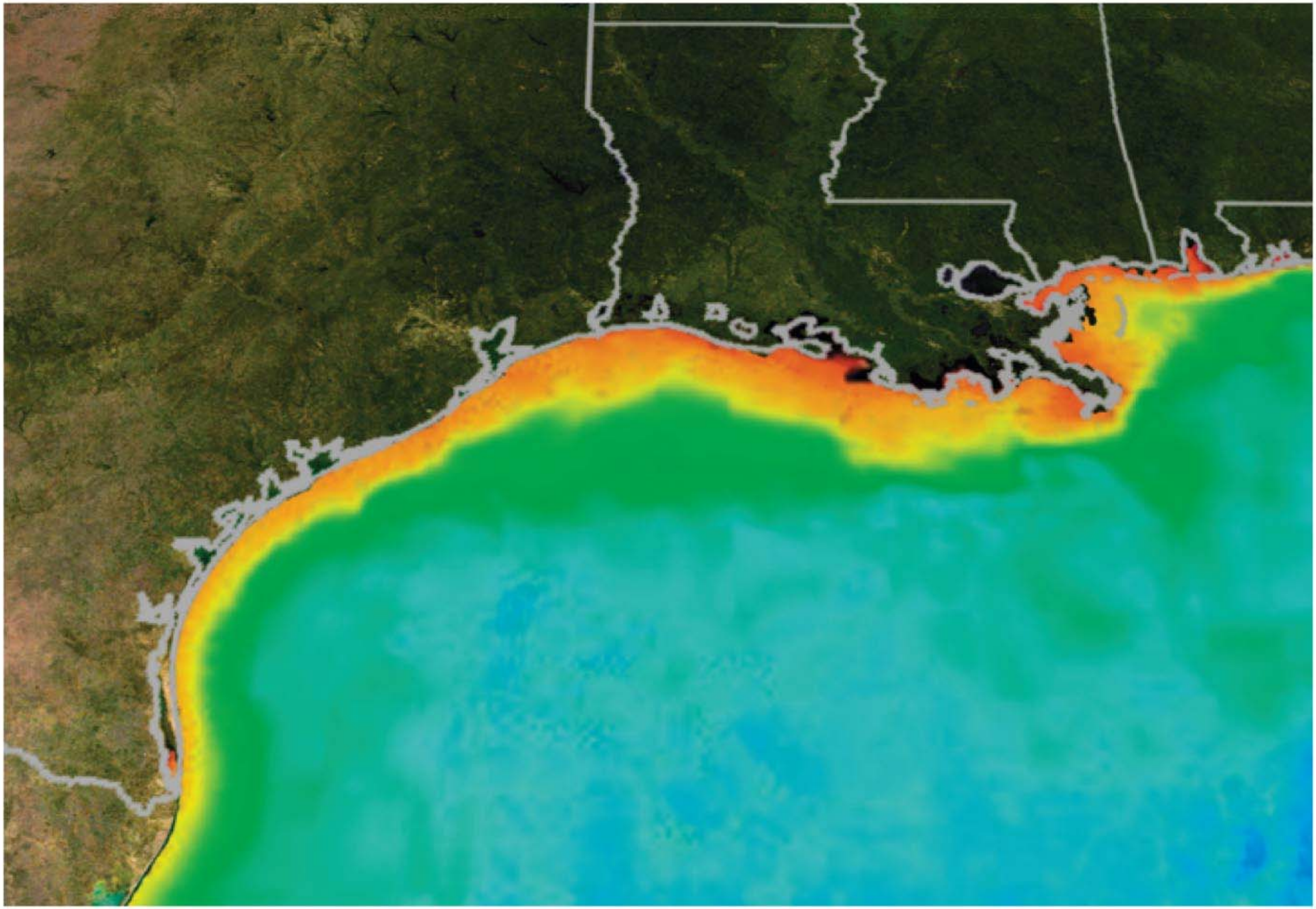
Fig. 55-18



Winter

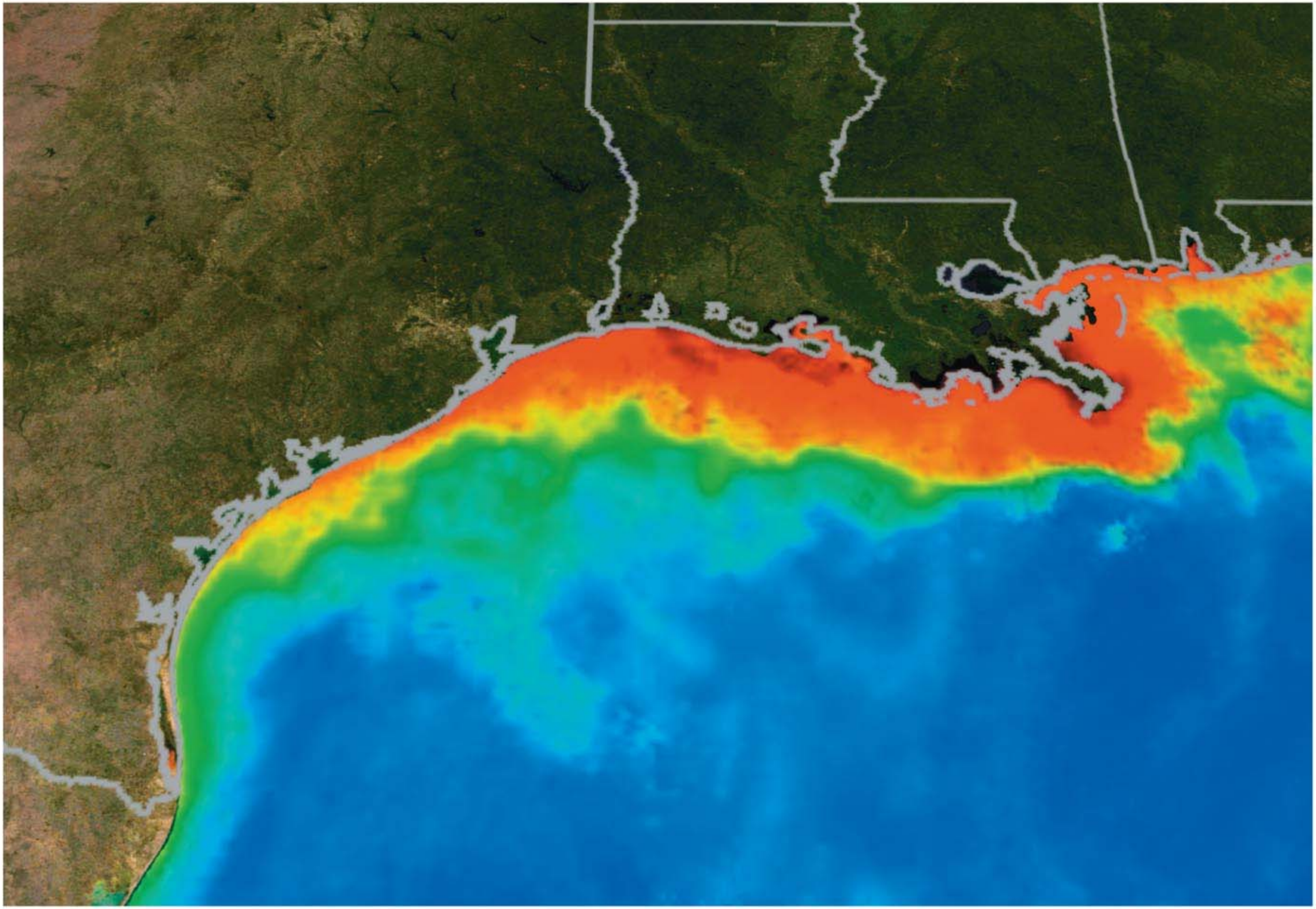
Summer

Fig. 55-18a



Winter

Fig. 55-18b



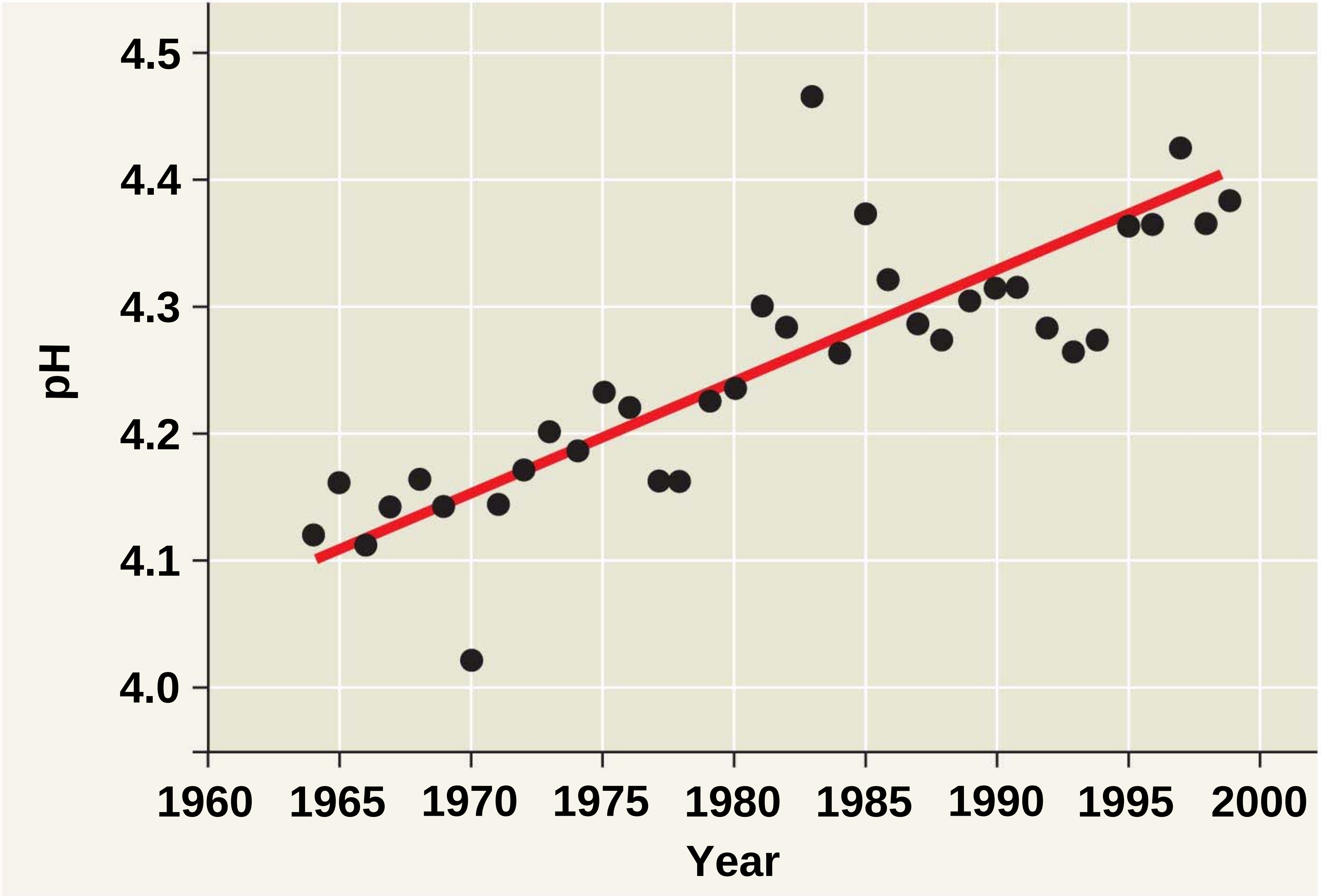
Summer

Acid Precipitation

- Combustion of fossil fuels is the main cause of acid precipitation
- North American and European ecosystems downwind from industrial regions have been damaged by rain and snow containing nitric and sulfuric acid
- Acid precipitation changes soil pH and causes leaching of calcium and other nutrients

- Environmental regulations and new technologies have allowed many developed countries to reduce sulfur dioxide emissions

Fig. 55-19

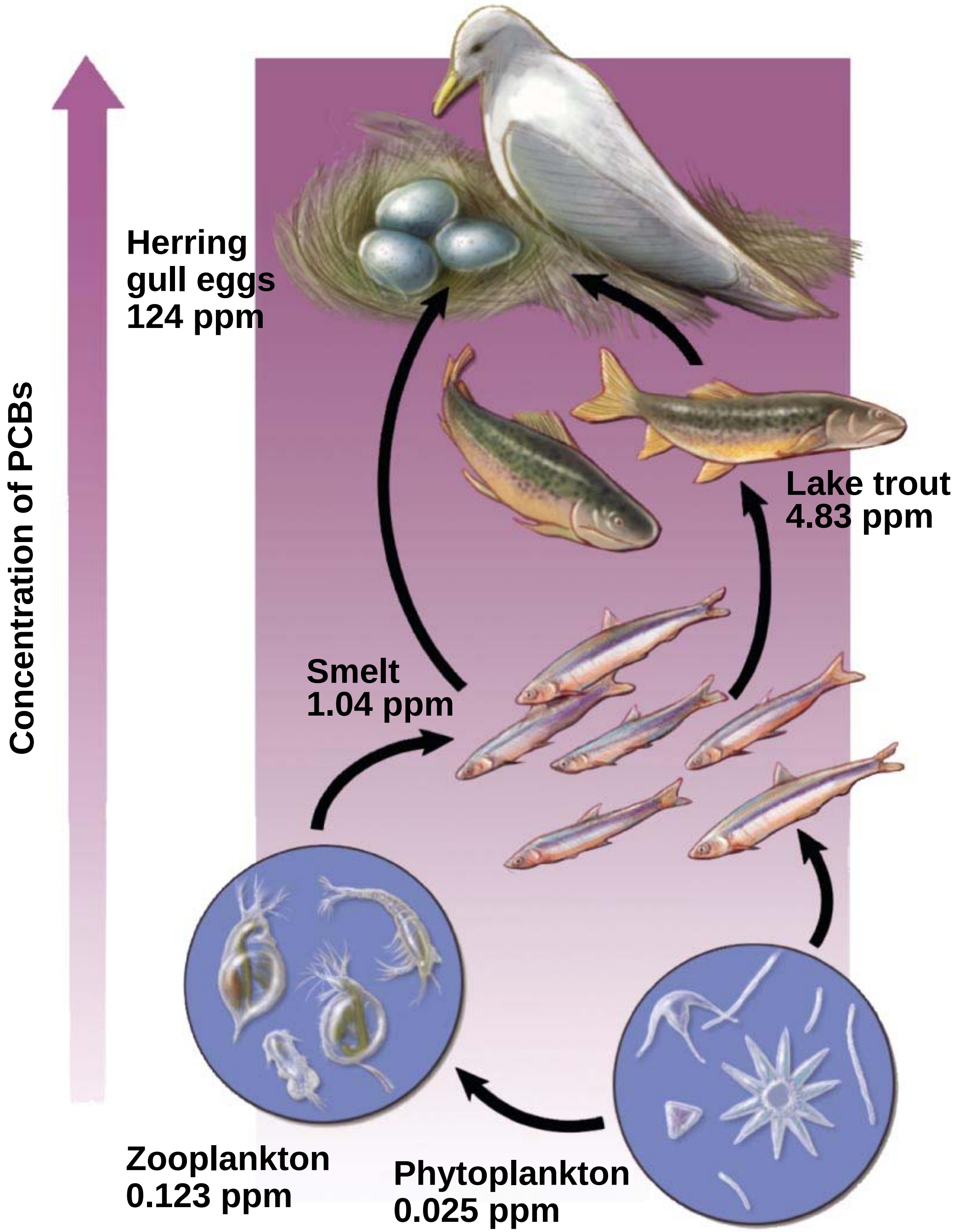

4.5
4.4
4.3
4.2
4.1
4.0
pH
1960
1965
1970
1975
1980
1985
1990
1995
2000
Year

Toxins in the Environment

- Humans release many toxic chemicals, including synthetics previously unknown to nature
- In some cases, harmful substances persist for long periods in an ecosystem
- One reason toxins are harmful is that they become more concentrated in successive trophic levels
- **Biological magnification** concentrates toxins at higher trophic levels, where biomass is lower

- PCBs and many pesticides such as DDT are subject to biological magnification in ecosystems
- In the 1960s Rachel Carson brought attention to the biomagnification of DDT in birds in her book *Silent Spring*

Fig. 55-20


Concentration of PCBs
Herring
gull eggs
124 ppm
Lake trout
4.83 ppm
Smelt
1.04 ppm
Zooplankton
0.123 ppm
Phytoplankton
0.025 ppm

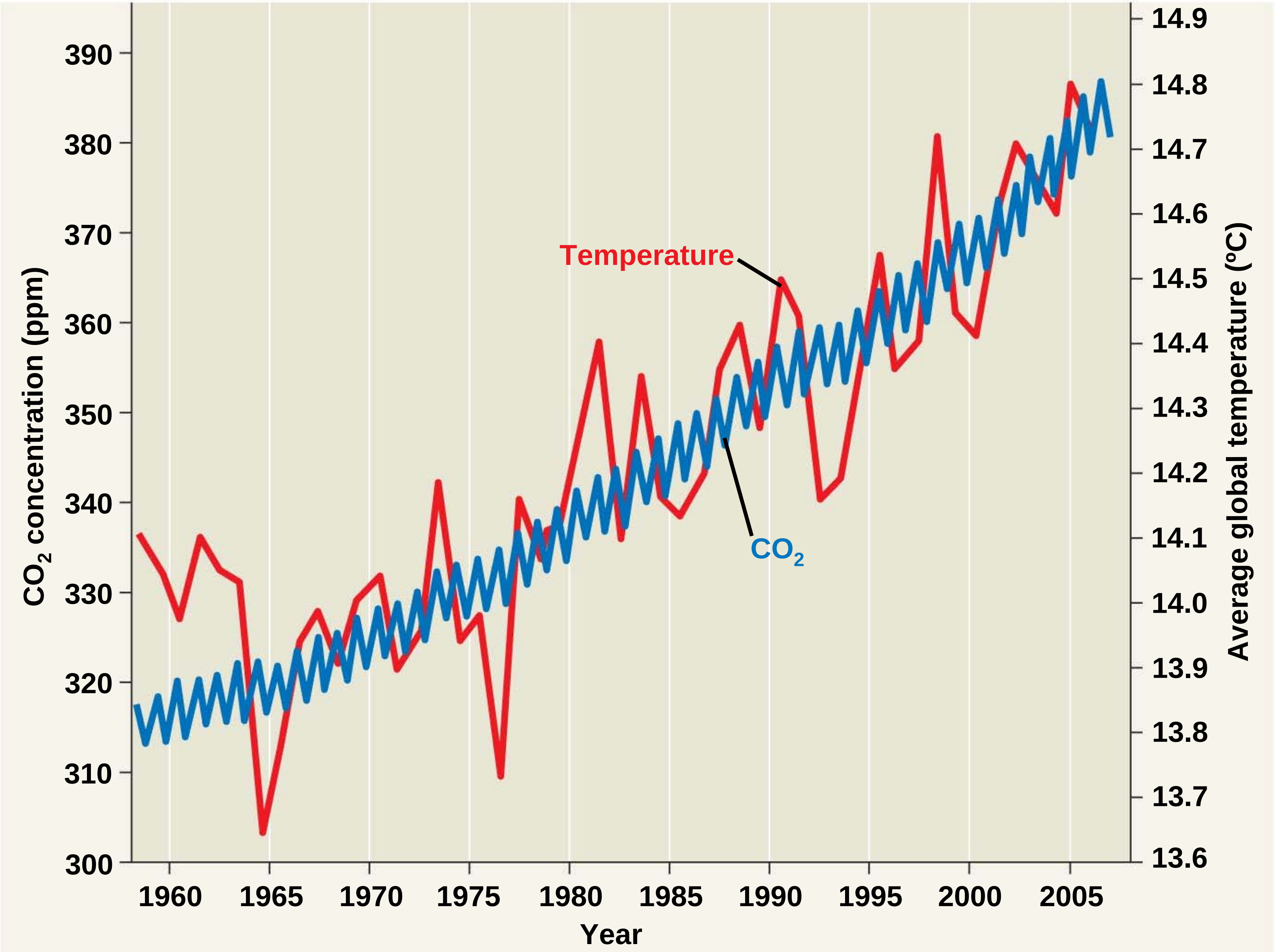
Greenhouse Gases and Global Warming

- One pressing problem caused by human activities is the rising level of atmospheric carbon dioxide

Rising Atmospheric CO_2 Levels

- Due to the burning of fossil fuels and other human activities, the concentration of atmospheric CO_2 has been steadily increasing

Fig. 55-21



Temperature
CO2
CO2 concentration (ppm)
390
380
370
360
350
340
330
320
310
300
Average global temperature (°C)
14.9
14.8
14.7
14.6
14.5
14.4
14.3
14.2
14.1
14.0
13.9
13.8
13.7
13.6
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year

How Elevated CO_2 Levels Affect Forest Ecology: The FACTS-I Experiment

- The FACTS-I experiment is testing how elevated CO_2 influences tree growth, carbon concentration in soils, and other factors over a ten-year period
- The CO_2-enriched plots produced more wood than the control plots, though less than expected
- The availability of nitrogen and other nutrients appears to limit tree growth and uptake of CO_2

Fig. 55-22

The Greenhouse Effect and Climate

- CO_2, water vapor, and other greenhouse gases reflect infrared radiation back toward Earth; this is the **greenhouse effect**
- This effect is important for keeping Earth’s surface at a habitable temperature
- Increased levels of atmospheric CO_2 are magnifying the greenhouse effect, which could cause global warming and climatic change

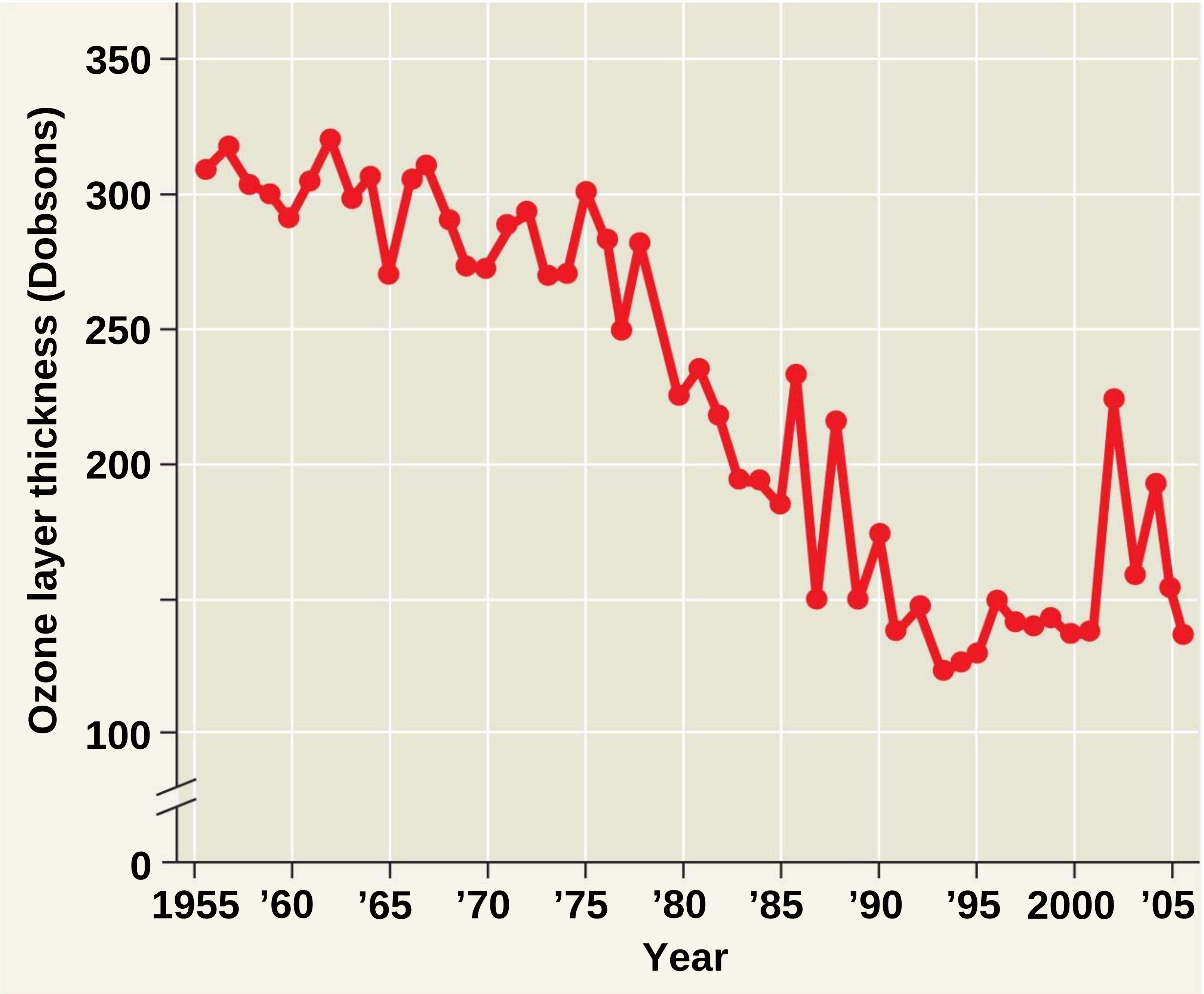
- Increasing concentration of atmospheric CO_2 is linked to increasing global temperature
- Northern coniferous forests and tundra show the strongest effects of global warming
- A warming trend would also affect the geographic distribution of precipitation

- Global warming can be slowed by reducing energy needs and converting to renewable sources of energy
- Stabilizing CO_2 emissions will require an international effort

Depletion of Atmospheric Ozone

- Life on Earth is protected from damaging effects of UV radiation by a protective layer of ozone molecules in the atmosphere
- Satellite studies suggest that the ozone layer has been gradually thinning since 1975

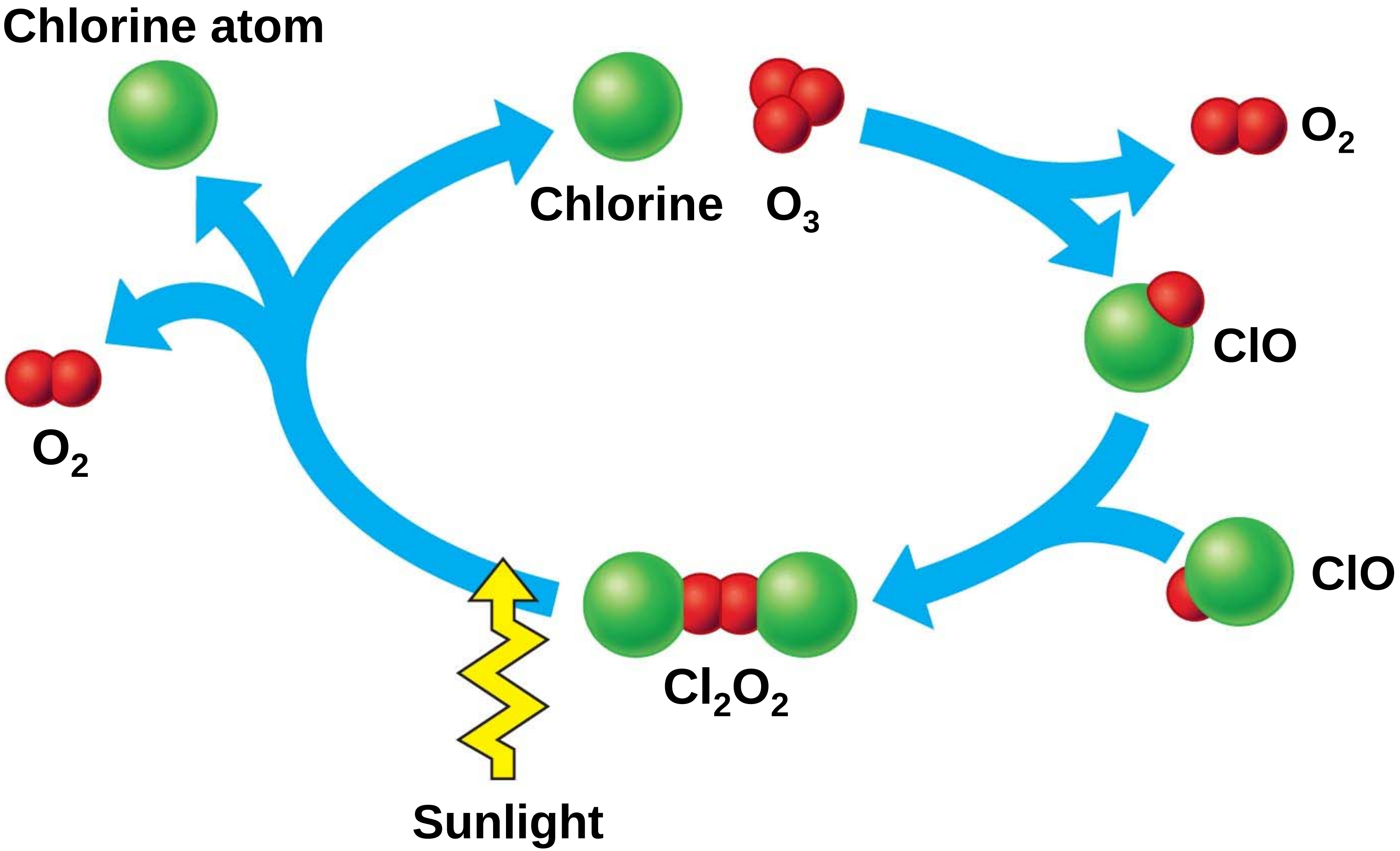
Fig. 55-23



350
300
250
200
100
0
Ozone layer thickness (Dobsons)
1955
’60
’65
’70
’75
’80
’85
’90
’95
2000
’05
Year

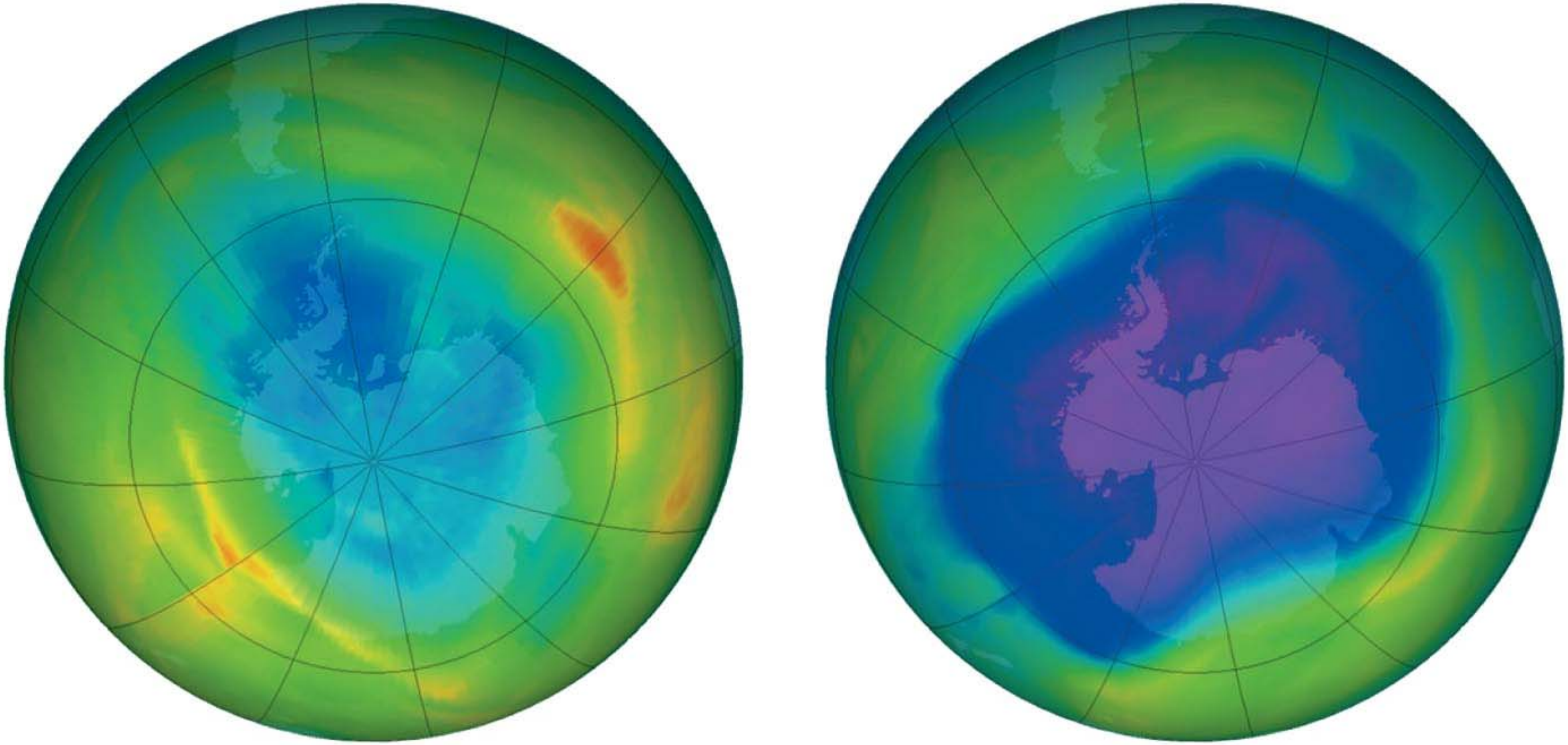
- Destruction of atmospheric ozone probably results from chlorine-releasing pollutants such as CFCs produced by human activity

Fig. 55-24



- Scientists first described an “ozone hole” over Antarctica in 1985; it has increased in size as ozone depletion has increased

Fig. 55-25



(a) September 1979 (b) September 2006

- Ozone depletion causes DNA damage in plants and poorer phytoplankton growth
- An international agreement signed in 1987 has resulted in a decrease in ozone depletion

Fig. 55-UN1

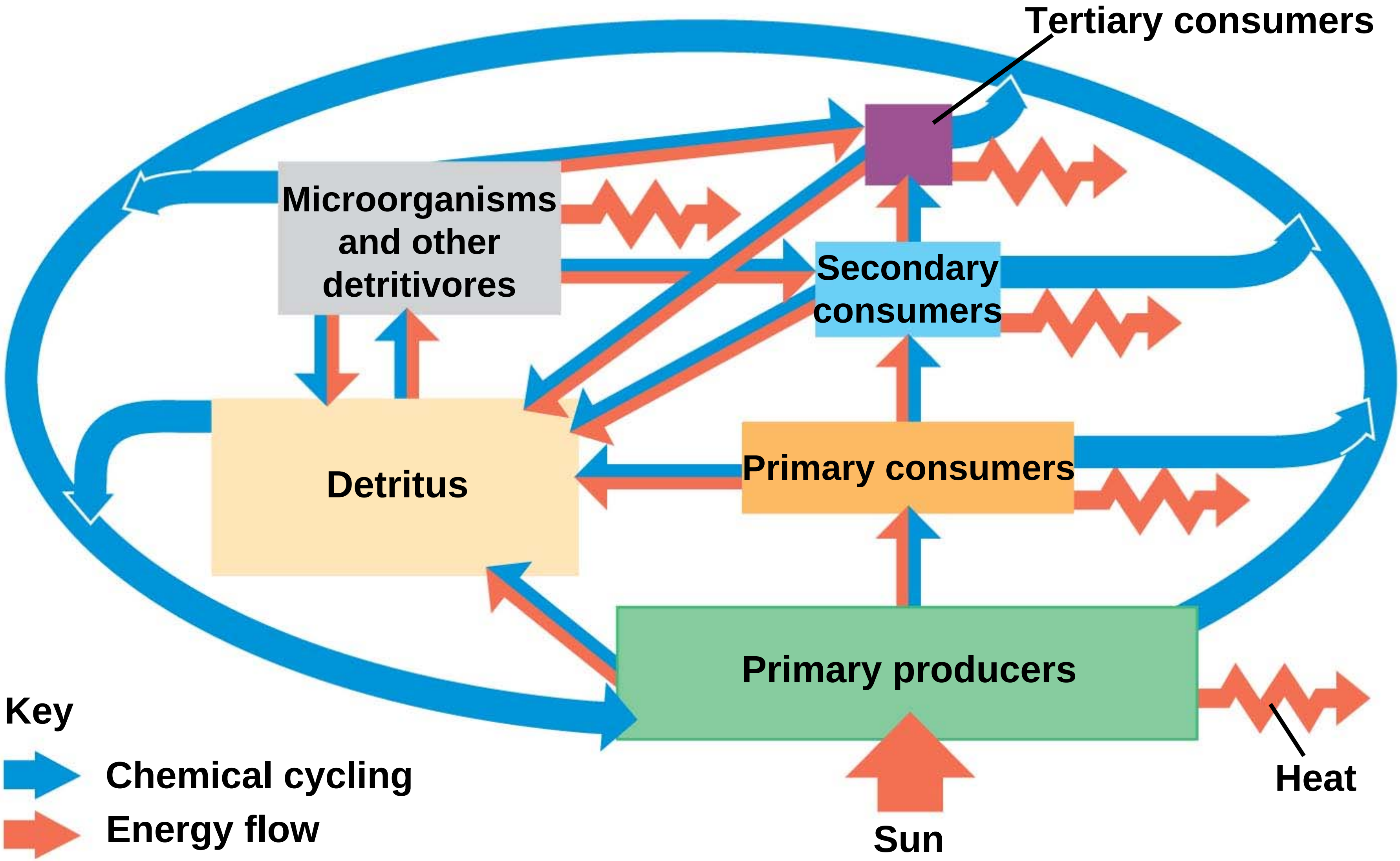
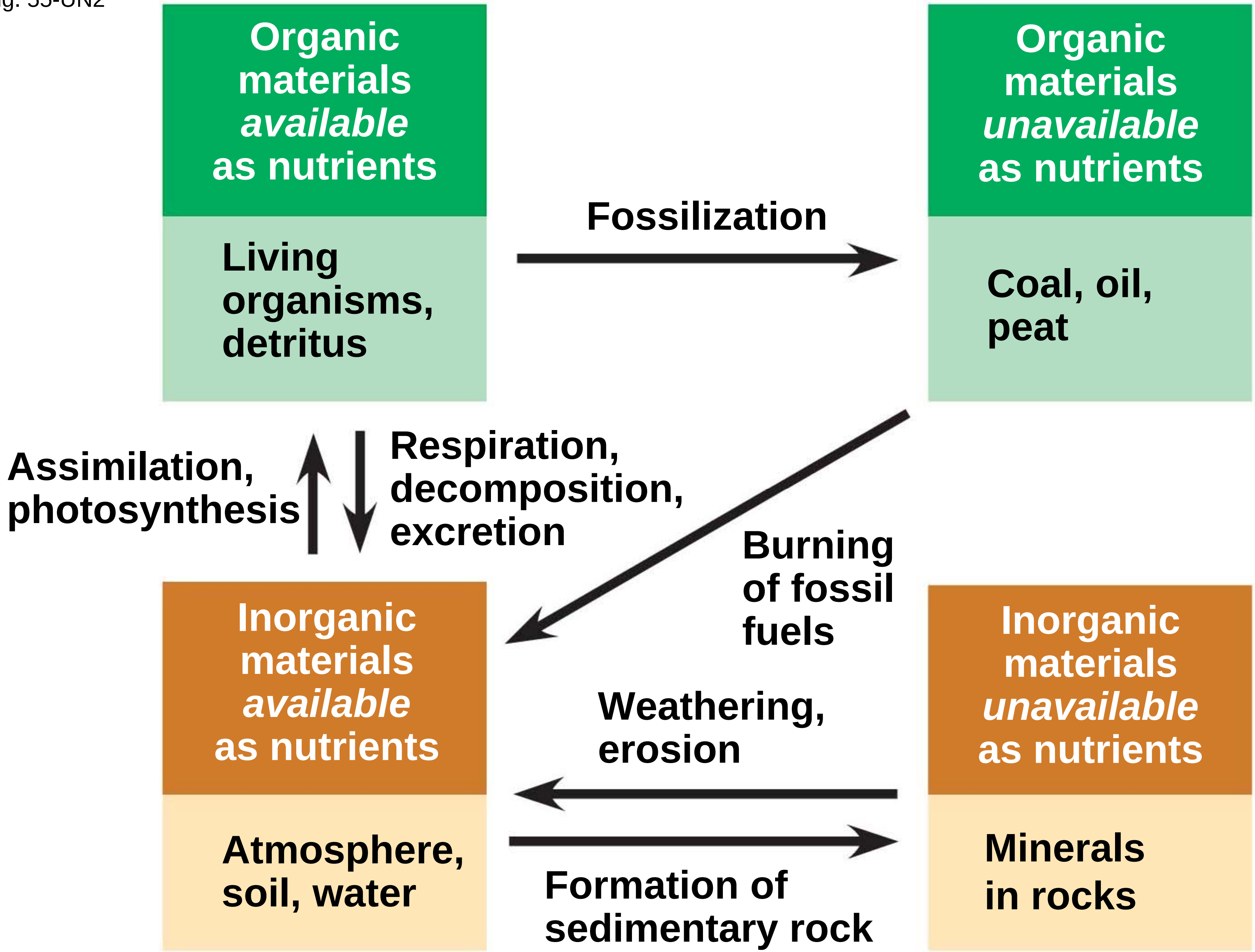
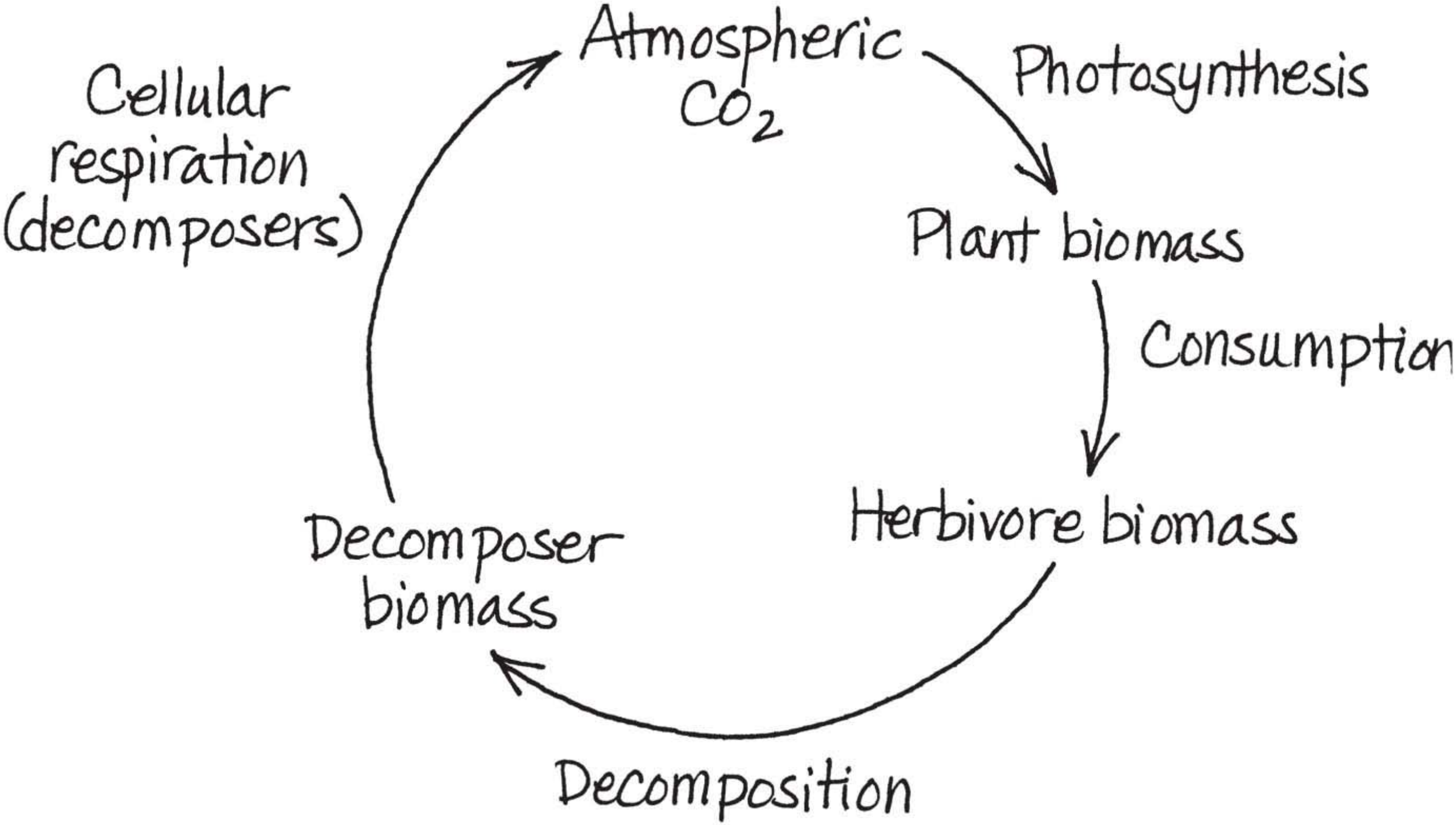

Tertiary consumers
Microorganisms and other detritivores
Secondary consumers
Detritus
Primary consumers
Primary producers
Key
Chemical cycling
Energy flow
Heat
Sun

Fig. 55-UN2



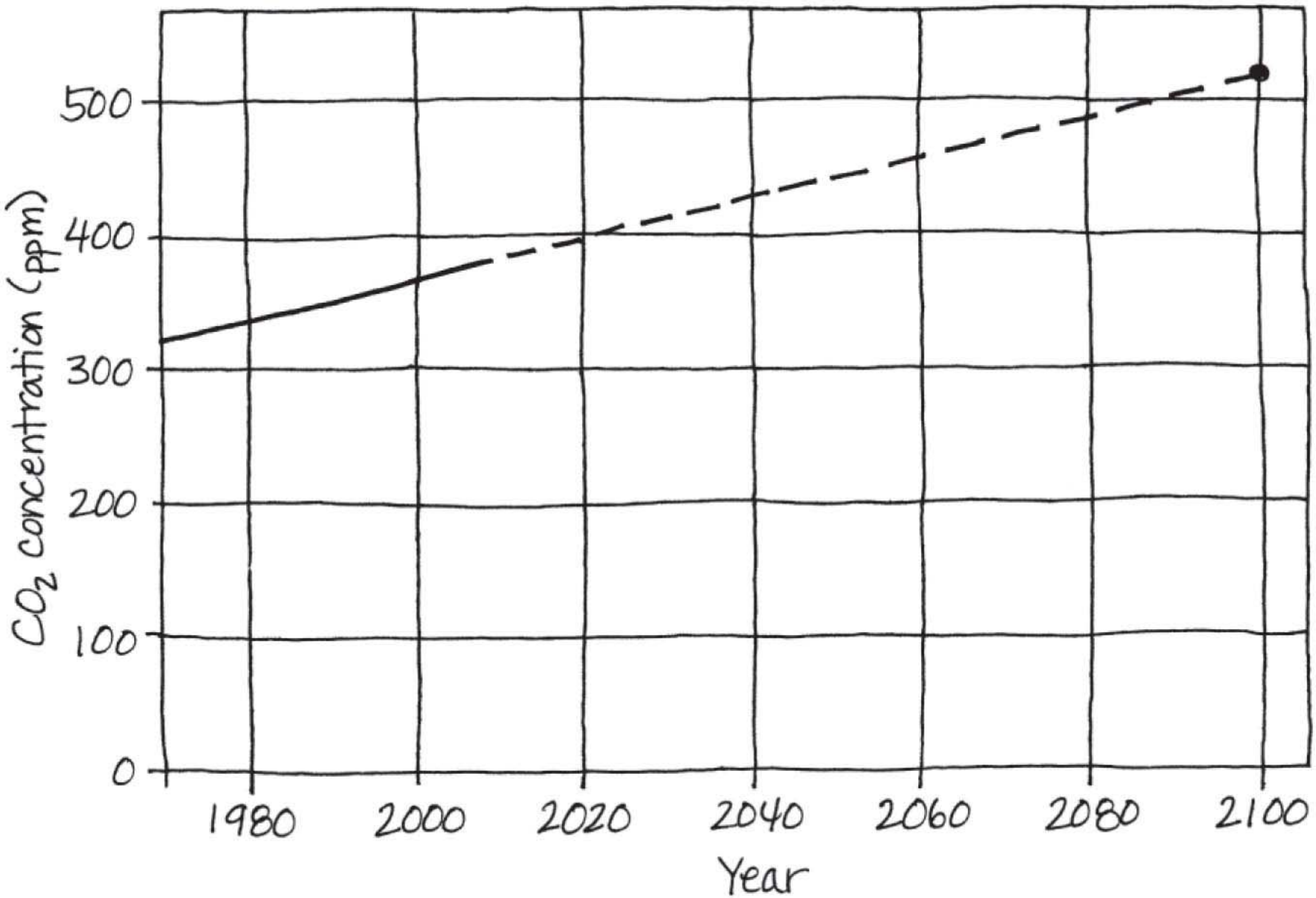
Organic materials *available* as nutrients
Living organisms, detritus
Fossilization
Organic materials *unavailable* as nutrients
Coal, oil, peat
Assimilation, photosynthesis
Respiration, decomposition, excretion
Burning of fossil fuels
Inorganic materials *available* as nutrients
Atmosphere, soil, water
Weathering, erosion
Formation of sedimentary rock
Inorganic materials *unavailable* as nutrients
Minerals in rocks

Fig. 55-UN3



Cycling of a carbon atom

Fig. 55-UN4



500
400
300
200
100
0
CO_2 concentration (ppm)
1980
2000
2020
2040
2060
2080
2100
Year

You should now be able to:

1. Explain how the first and second laws of thermodynamics apply to ecosystems
2. Define and compare gross primary production, net primary production, and standing crop
3. Explain why energy flows but nutrients cycle within an ecosystem
4. Explain what factors may limit primary production in aquatic ecosystems

5. Distinguish between the following pairs of terms: primary and secondary production, production efficiency and trophic efficiency
6. Explain why worldwide agriculture could feed more people if all humans consumed only plant material
7. Describe the four nutrient reservoirs and the processes that transfer the elements between reservoirs

8. Explain why toxic compounds usually have the greatest effect on top-level carnivores
9. Describe the causes and consequences of ozone depletion