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Global Ecology

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Case Study: Dust in the Wind and the Decline of Coral

Coral reefs are home to millions of marine species, including commercially important fish.

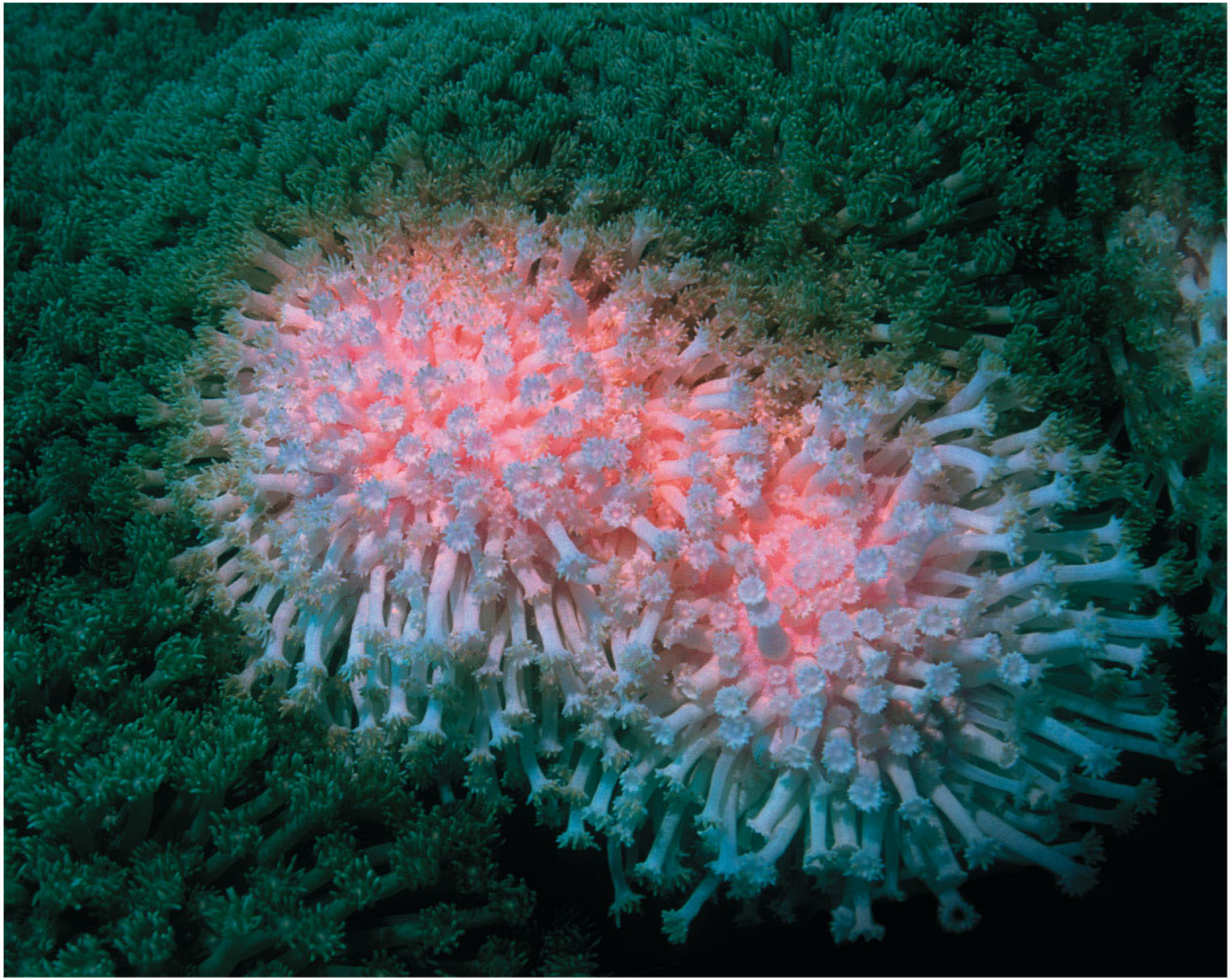
The unique habitat of calcium carbonate formations created by the coral, and the high energy supply based on high net rates of primary production, support tremendous biodiversity.

Case Study: Dust in the Wind and the Decline of Coral

Corals require a narrow range of temperatures, clear water, and high salinity.

Coral reefs throughout the world are experiencing increasing rates of disease, loss of symbiotic algae (bleaching), and mortality.

Figure 24.1 A Decline in Coral Reefs

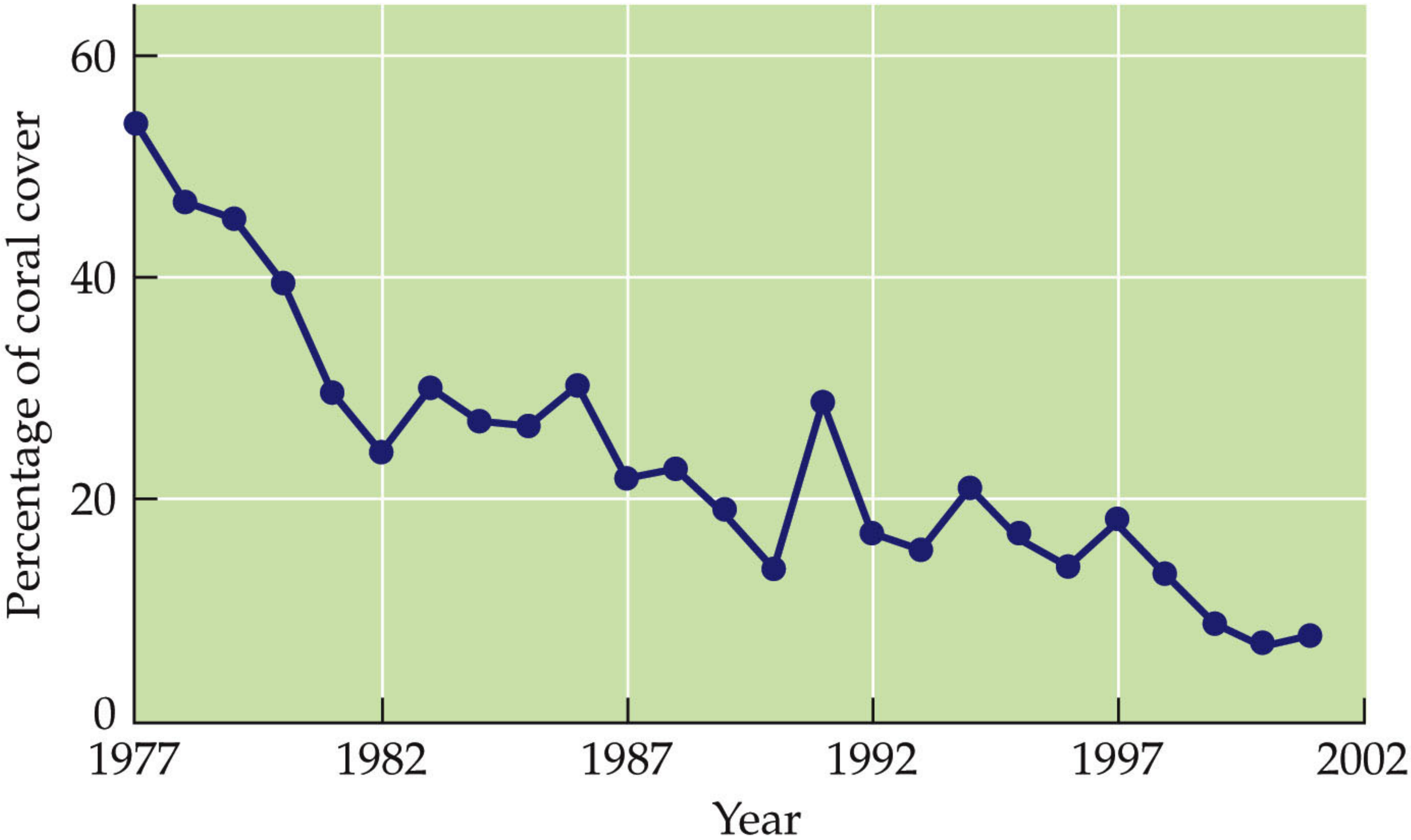


Case Study: Dust in the Wind and the Decline of Coral

Reef decline is associated with human activities: Erosion of sediments from terrestrial ecosystems, water pollution, and overharvesting, including keystone predators and dynamite fishing.

But these factors do not explain the widespread nature of coral decline over their entire range.

Figure 24.2 A Record of Coral Reef Decline



ECOLOGY, Figure 24.2

Case Study: Dust in the Wind and the Decline of Coral

Hints of a potential cause came from the study of coral diseases.

One of the most common, aspergillosis, is caused by a widespread terrestrial fungus, *Aspergillus sydowii*.

Garrison et al. (2003) proposed that windblown dust carries fungal spores from distant terrestrial ecosystems to reef ecosystems.

This research poses many questions:

- Where does the dust come from and why has it become more important?
- How can the fungus survive in the atmosphere?
- Is it the primary cause of disease, or is a secondary infection killing the corals?
- How else might dust deposition affect corals?

Introduction

Movements of biologically important elements are linked at a global scale that transcends ecological boundaries.

Ecological processes at the ecosystem scale (e.g., net primary production, decomposition) influence global phenomena (e.g., greenhouse gases).

Introduction

Humans are increasingly changing the physical and chemical environment at a global scale.

Atmospheric emissions of pollutants, dust, and greenhouse gases have caused widespread environmental problems.

A major focus of global ecology is the study of the environmental effects of human activities.

Concept 24.1: Elements move among geological, atmospheric, and biological pools at a global scale.

The global cycling of carbon, nitrogen, phosphorus, and sulfur are emphasized because of their importance to biological activity, and their roles in the human alteration of the global environment.

Global Biogeochemical Cycles

Pools, or reservoirs, are where the elements occur.

Fluxes are the rates of movement between pools.

Example: Terrestrial plants would be a pool for carbon, while photosynthesis would represent a flux.

The Carbon Cycle:

Carbon is critical for biological activity, for energy transfer and the structure of organisms.

C is a dynamic element, moving between different pools over time scales of weeks to decades.

Changes in the global C cycle are influencing Earth's climate.

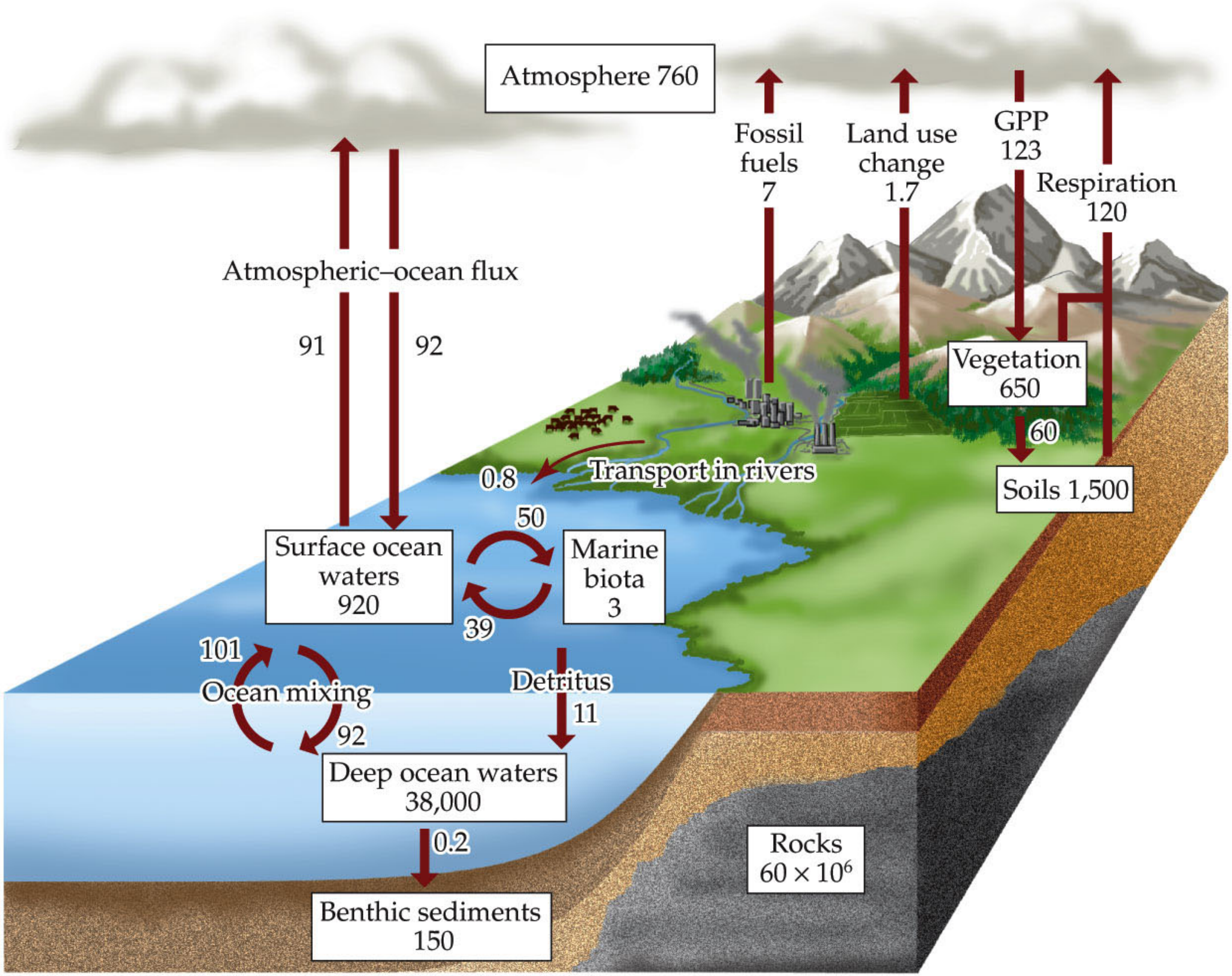
C in the atmosphere occurs primarily as carbon dioxide (CO_2) and methane (CH_4).

Both are greenhouse gases that influence atmospheric absorption and retention of infrared radiation.

The major pools of C: Atmosphere, oceans, land surface (includes soils and vegetation), and sediments and rock.

99% of global C is in sediments and rock; the most stable pool, it takes up and releases C on geological time scales.

Figure 24.3 The Global Carbon Cycle



ECOLOGY, Figure 24.3

Ocean surface water takes up CO_2 from the atmosphere by diffusion.

C is transferred to deeper water mostly as organic detritus and carbonate shells.

Upwellings bring C-rich water to the surface, releasing CO_2 to the atmosphere.

Terrestrial pool: Soils contain twice as much C as plants.

CO_2 is exchanged with atmosphere mostly by photosynthesis and respiration.

Prior to the Industrial Revolution, these two fluxes were roughly equal, with no net change in atmospheric CO_2.

Anthropogenic release of C to the atmosphere results from *land-use-change*—mostly deforestation (20%) and burning fossil fuels (80%).

Removing the forest canopy warms the soil, increasing rates of decomposition and respiration. Burning trees also releases CO_2, and small amounts of CO and CH_4 to the atmosphere.

Anthropogenic emissions of CO_2 doubled from 1970 to 2005.

About half is taken up by the oceans and terrestrial biota. However, this proportion will decrease because the fluxes of terrestrial ecosystem and ocean uptake will not keep pace with the rate of atmospheric increase.

Higher concentrations of CO_2 may stimulate photosynthesis.

But experiments have shown that increased photosynthetic rates may be short lived, and plants will acclimate to higher concentrations.

For forest trees, increased CO_2 uptake may be sustained longer.

One method of testing effects of elevated CO_2 levels uses free-air CO_2 enrichment, or FACE.

CO_2 is injected into the air through vertical pipes that surround a stand of trees. Rate of injection is controlled to achieve a particular concentration of CO_2.

Figure 24.4 A FACE Experiment

ECOLOGY, Figure 24.4

An experiment using FACE with loblolly pines measured tree basal area to estimate aboveground NPP and soil cores to estimate fine root growth and belowground NPP (DeLucia et al. 1999).

Elevated CO_2 levels increased the overall NPP of the forest by 25%.

Input of C into the soil also increased, both from litter and fine root turnover.

Forests may be an important sink for anthropogenic CO_2.

But this forest may represent the upper limit of potential CO_2 uptake. Older forests, or ones with less nutrients and water, may not have as great a capacity for CO_2 uptake.

Atmospheric CO_2 affects pH of the oceans by diffusing in and forming carbonic acid.

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2\,H^+ + CO_3^{2-}$$

Significant increases in ocean acidity have been forecast by model simulations.

Many marine organisms form shells of carbonate.

Increasing acidity will dissolve existing shells and lower carbonate concentrations will decrease the ability to synthesize new shells.

Anthropogenic emissions of CO_2 therefore have potential to tremendously alter the diversity and function of marine ecosystems.

CH_4 levels are much lower than CO_2 in the atmosphere but CH_4 is a much more effective greenhouse gas.

CH_4 is emitted naturally by anaerobic methanogenic bacteria that live in wetlands and shallow marine sediments, and the rumens of ruminant animals.

Anthropogenic sources of CH_4 result from processing and burning of fossil fuels, agricultural development (primarily rice, which is grown in flooded fields), burning of forests and crops, and livestock production.

Over geologic time, atmospheric C concentrations have changed with geological and climatic changes.

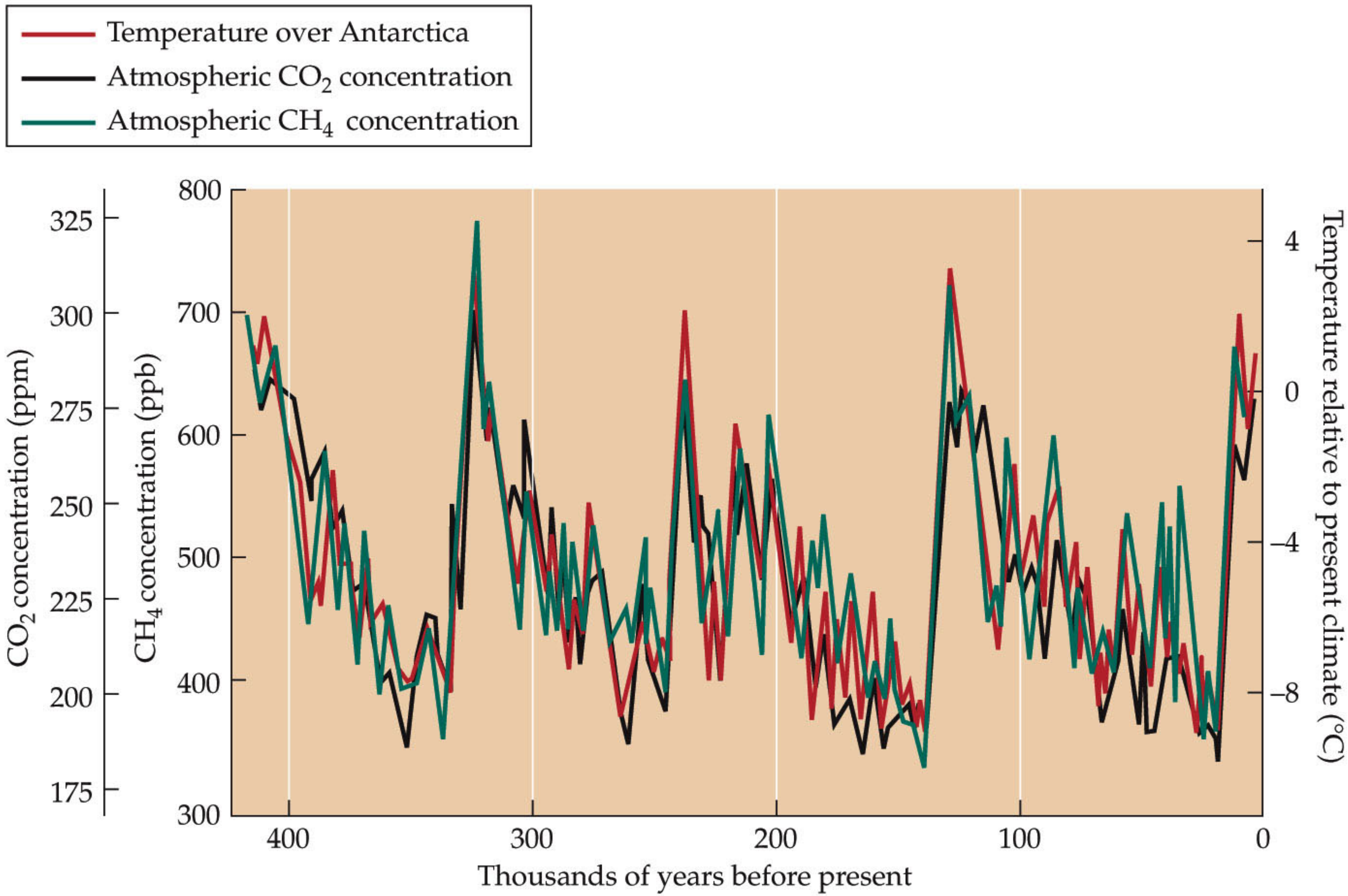
Concentrations have ranged from 3000 ppm 60 million years ago to less than 200 ppm 140,000 years ago.

Concentration of CO_2 and CH_4 can be measured in tiny bubbles preserved in polar ice.

The concentrations are correlated with glacial–interglacial cycles.

Lowest concentrations correlate with glacial periods.

Figure 24.5 Temporal Changes in Atmospheric CO_2 and CH_4



ECOLOGY, Figure 24.5

Since the mid-19th century, concentrations have increased at a rate faster than at any other time over the past 400,000 years, reaching 380 ppm in 2005.

Even if CO_2 emissions are reduced dramatically, CO_2 levels will remain high due to a time lag (decades to centuries) in ocean uptake.

The Nitrogen Cycle:

N is a constituent of enzymes and proteins, and often limits primary productivity.

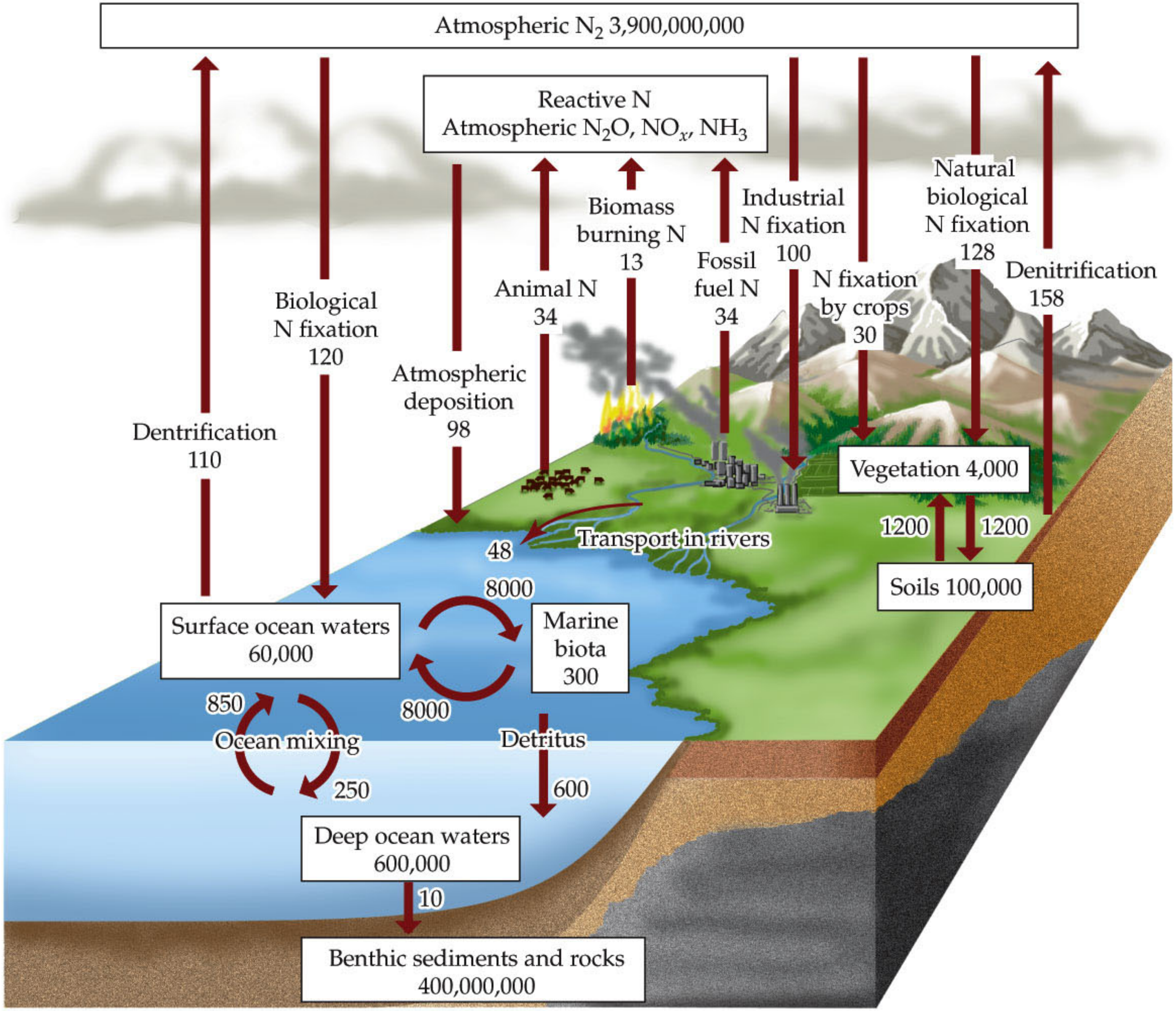
Cycles of N and C are tightly coupled through the processes of photosynthesis and decomposition.

Most N in the atmosphere is N_2, which is not available to most organisms.

N-fixing bacteria are able to convert it to a useable form.

Terrestrial N-fixers supply 12% of the annual biological N demand. The rest comes from decomposition.

Figure 24.6 The Global Nitrogen Cycle



ECOLOGY, Figure 24.6

Flux of N between terrestrial and oceanic pools via rivers is tiny, but it enhances primary production in estuaries and salt marshes.

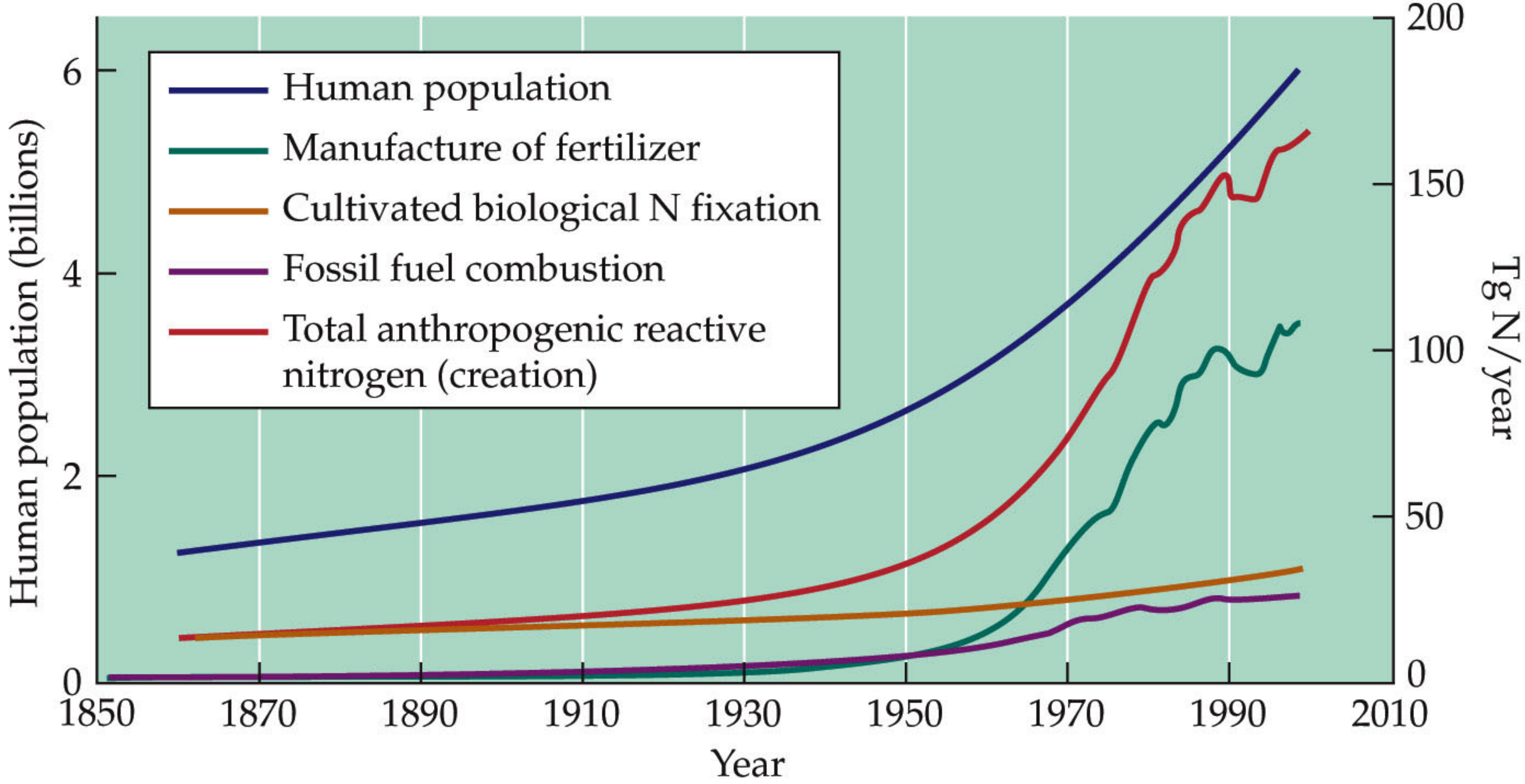
Denitrification results in movement of N (as N_2) from terrestrial and marine ecosystems to the atmosphere.

Anthropogenic fluxes are now the dominant components of the N cycle.

The rate of fixation of atmospheric N_2 by humans now exceeds natural terrestrial biological rates.

Emissions of N from industrial and agricultural activities cause widespread environmental changes, including acid precipitation.

Figure 24.7 Changes in Anthropogenic Fluxes in the Global N Cycle



ECOLOGY, Figure 24.7

Fertilizers are made using the Haber–Bosch process: N_2 from air is combined with H_2 under high pressure and temperature to form ammonium.

This was responsible for major increases in food supplies in the 20th century.

Growing N-fixing crops such as soybeans and alfafa has significantly increased biological fixation.

Flooding fields for rice crops increases N-fixation by cyanobacteria.

Anthropogenic emissions include NO_x (NO, NO_2, HNO_3, and NO_3^-), N_2O, NH_3, and peroxyacetyl nitrate (PAN), mostly from fossil fuel combustion.

These reactive forms of N are returned to Earth's surface through atmospheric deposition.

The Phosphorus Cycle:

P can be limiting for primary productivity in some terrestrial ecosystems, as well as aquatic ecosystems.

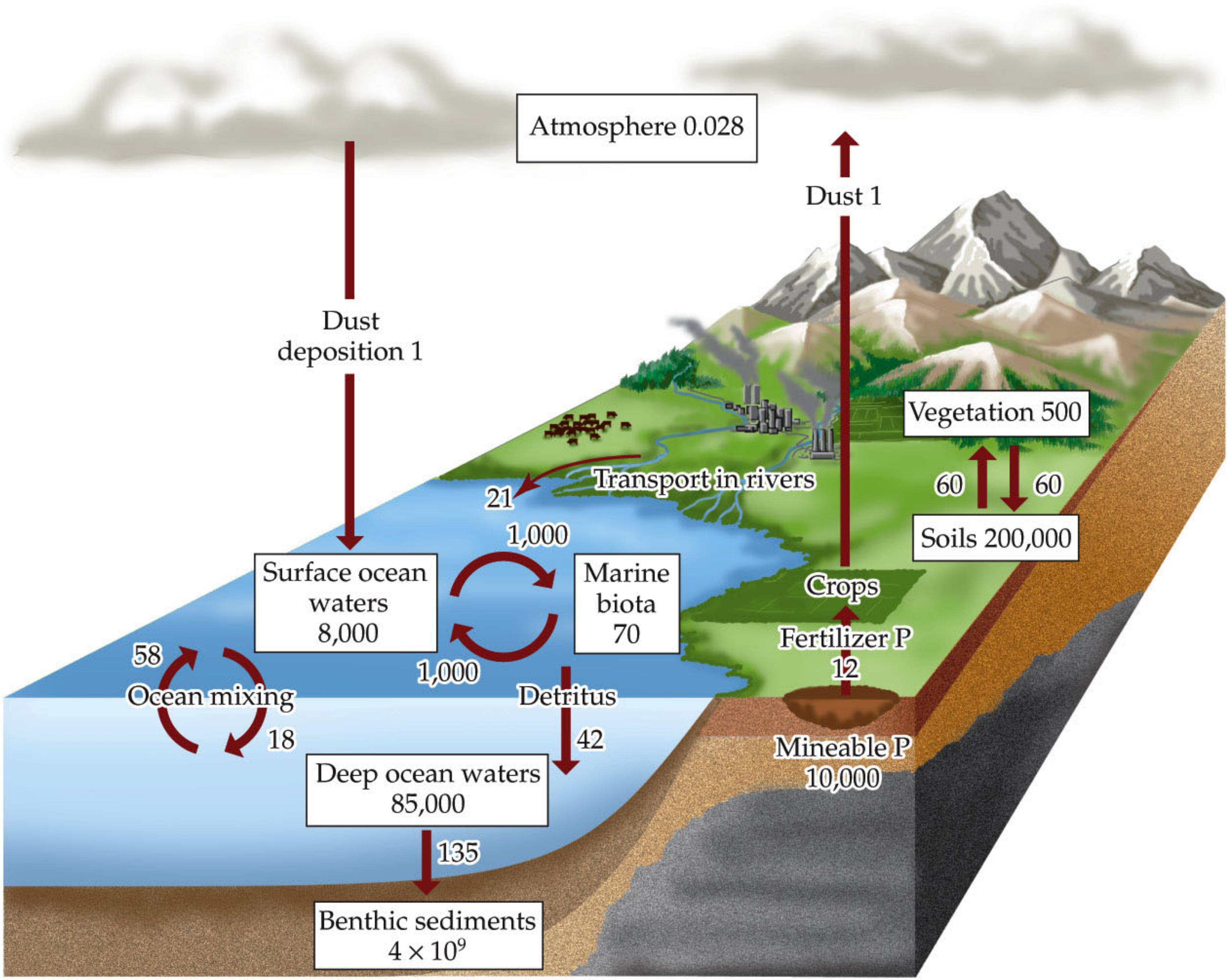
P availability can control the rate of N-fixation, which has a high metabolic demand for P.

The C, N, and P cycles are linked to one another through photosynthesis and NPP, decomposition, and N_2 fixation.

P has essentially no atmospheric pool, except as dust.

The largest pools are in terrestrial soils and marine sediments.

Figure 24.8 The Global Phosphorus Cycle



ECOLOGY, Figure 24.8

P is internally cycled in ecosystems between uptake by plants and microorganisms and release by decomposition.

In terrestrial ecosystems, most P loss is associated with occlusion (transformation to insoluble, biologically unavailable forms).

P in aquatic systems is lost to the sediments. This is cycled again with tectonic uplift and weathering of rocks.

Anthropogenic effects on the P cycle include agricultural fertilizers, sewage and industrial wastes, and increases in terrestrial erosion.

P fertilizers are made from marine sedimentary deposits.

Mining releases four times more P annually than natural rock weathering.

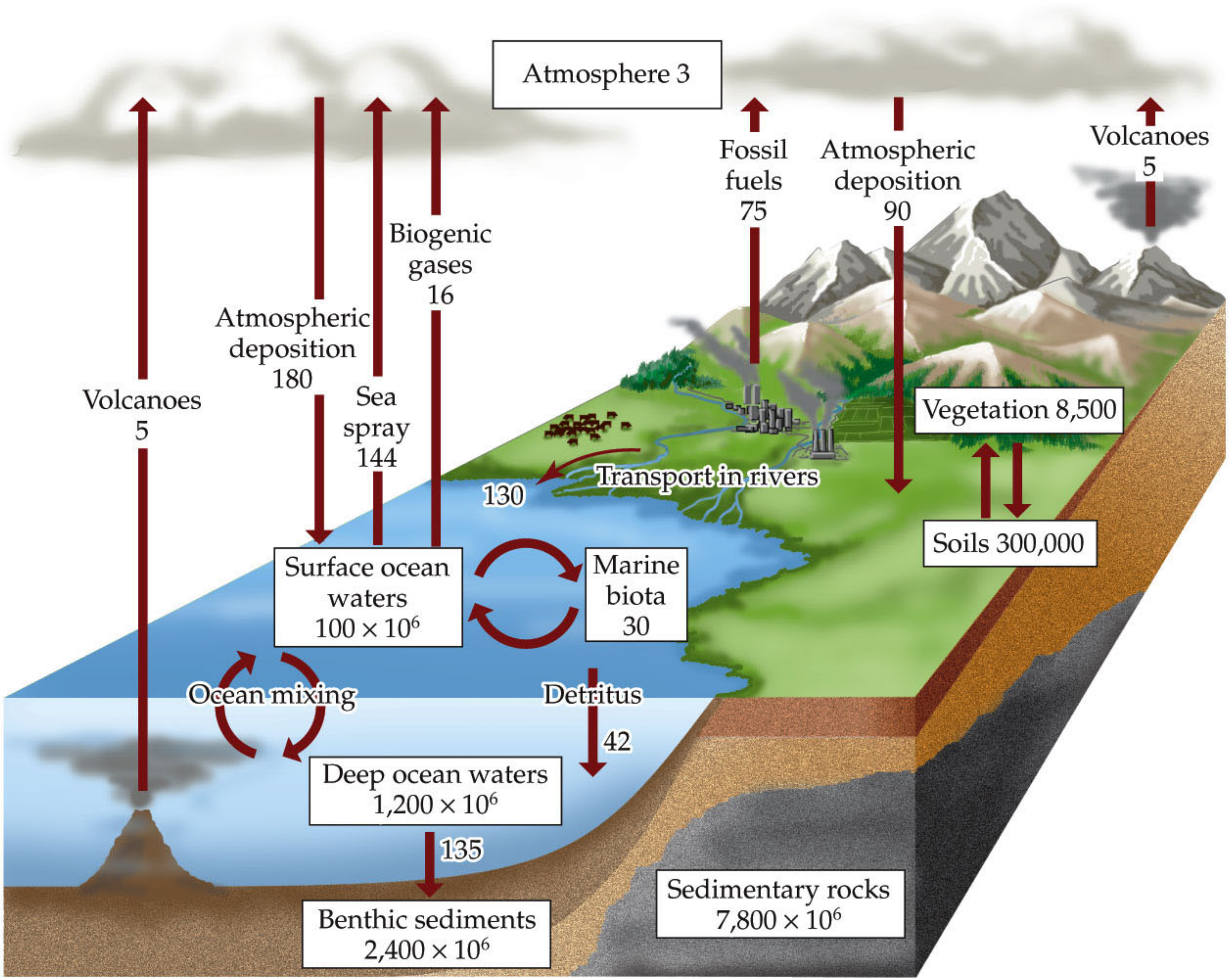
Flux of anthropogenic P from terrestrial to aquatic ecosystems has significant potential for negative environmental effects such as eutrophication.

The Sulfur Cycle:

S is a constituent of some amino acids and DNA and RNA, but it is probably never limiting to growth.

Pools of S are in rocks, sediments, and the ocean, which contains a large pool of dissolved sulfate (SO_4^{2-}).

Figure 24.9 The Global Sulfur Cycle



ECOLOGY, Figure 24.9

Fluxes of S among the global pools can occur in gaseous, dissolved, or solid forms.

Volcanic eruptions emit substantial amounts of sulfur dioxide (SO_2) into the atmosphere.

Bacteria and archaea in anaerobic soils emit S-containing gases such as H_2S (biogenic emissions).

Most gaseous S compounds in the atmosphere undergo transformation to SO_4^{2-} and H_2SO_4 (sulfuric acid), which are removed quickly by precipitation.

Anthropogenic emissions have quadrupled since the Industrial Revolution. Most come from burning S-containing coal and oil.

Concept 24.2: Earth is warming at an unprecedented rate due to anthropogenic emissions of greenhouse gases.

Change in frequency of extreme events (droughts, storms) or temperatures will have profound effects on ecosystems.

Extreme events result in significant mortality, and have a major role in determining species' geographic ranges.

Weather is the current state of the atmosphere around us at any given time.

Climate is the long term description of weather, including average conditions and the full range of variation.

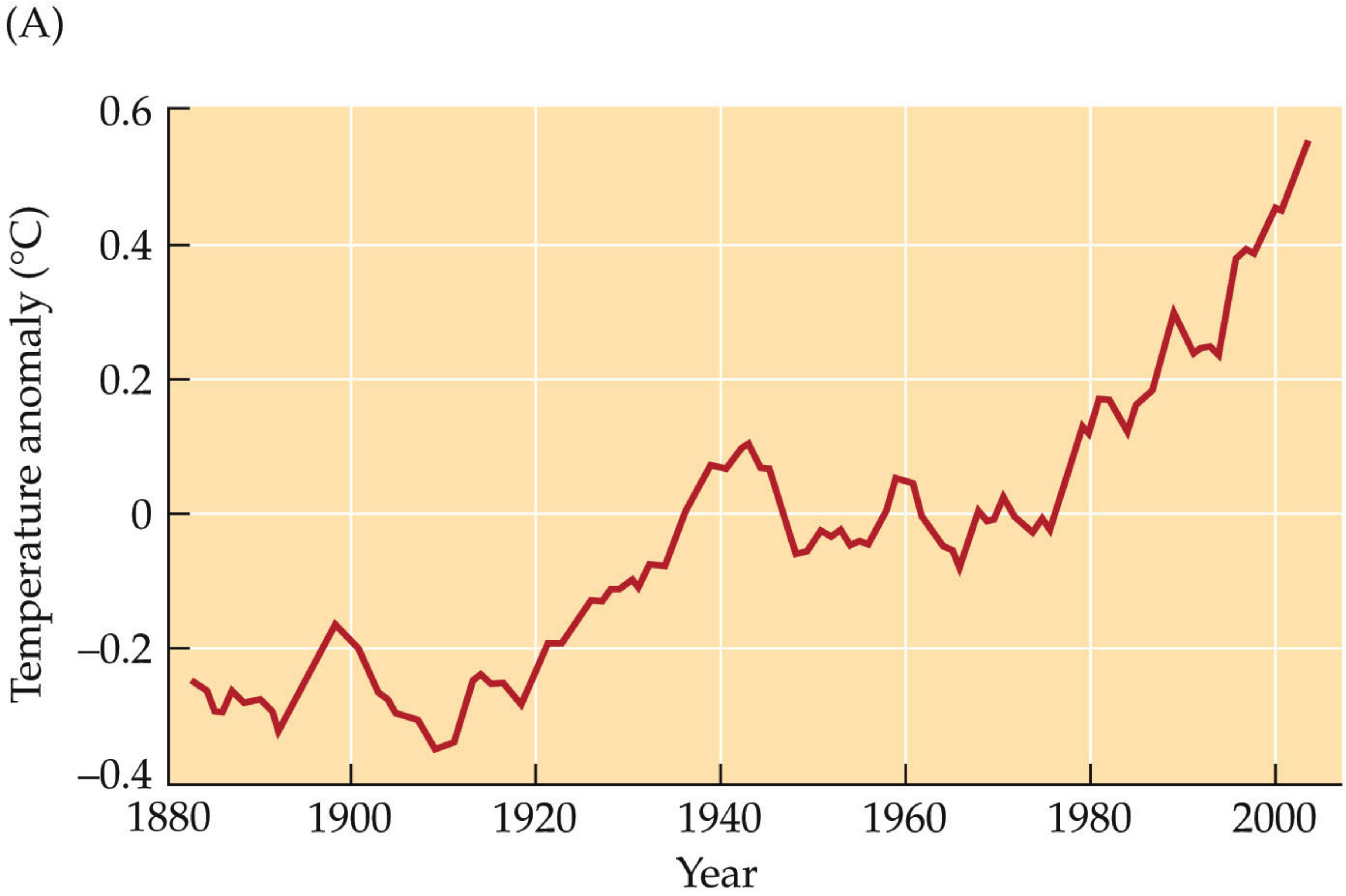
Climatic variation occurs at a multitude of time scales—from daily and seasonal to decadal.

Climate change refers to directional change in climate over a period of several decades.

Earth is currently experiencing a significant change in climate (IPCC 2007).

Average global surface temperature increased 0.6°C (± 0.2°C) during the 20th century.

Figure 24.10 A Changes in Global Temperature and Precipitation



Global Climate Change

The 1990s was the warmest decade of the previous 1,000 years, and 2005 was the warmest year in over a century (IPCC 2007).

Concurrently, there has been widespread retreat of mountain glaciers, thinning of the polar ice caps and melting of permafrost, and a 15 cm rise in sea level since 1900.

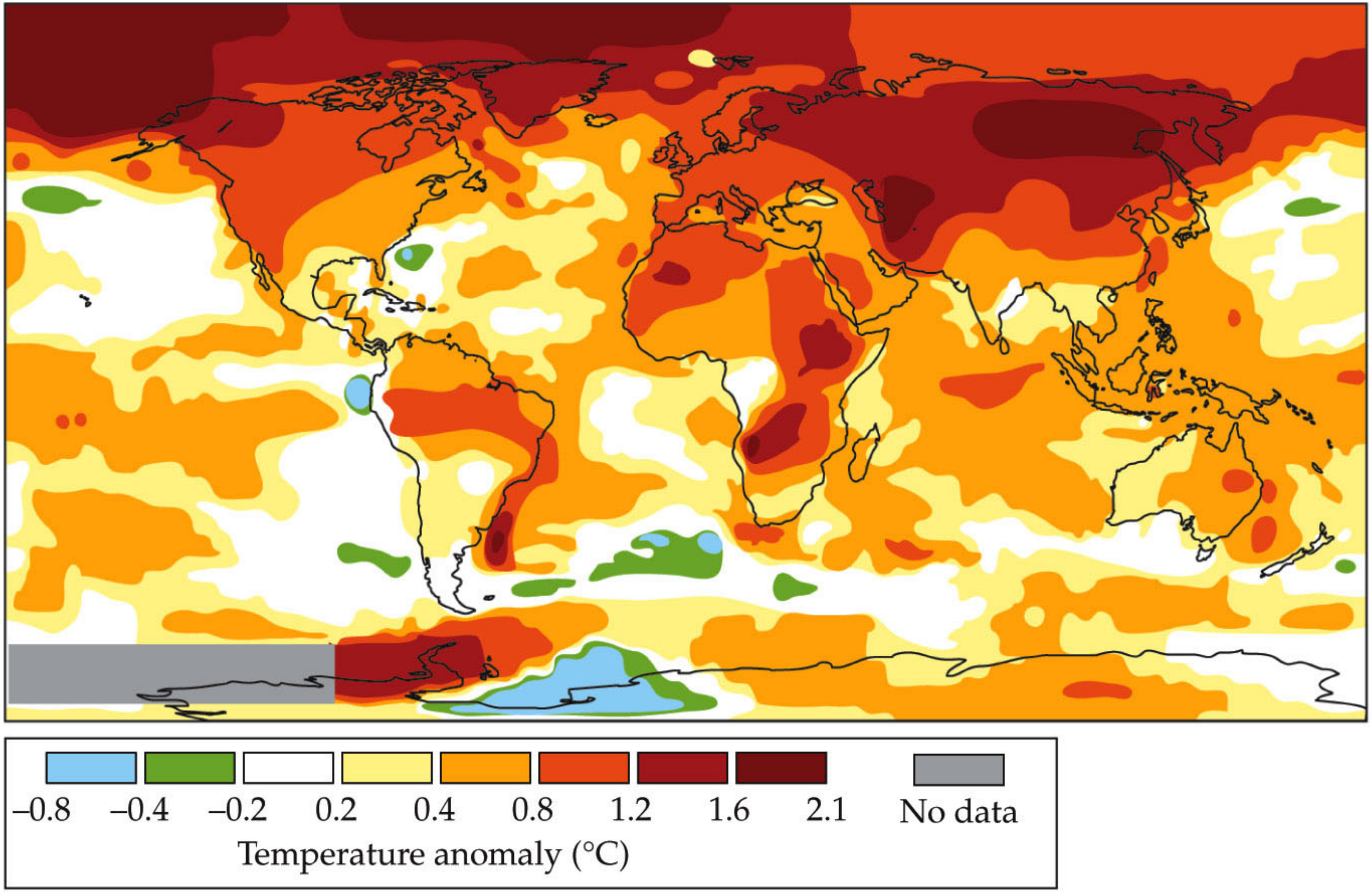
Global Climate Change

The warming trend has not been consistent around the globe.

Some regions have seen significant warming, especially mid- to high latitudes in the Northern Hemisphere.

Figure 24.10 B Changes in Global Temperature and Precipitation

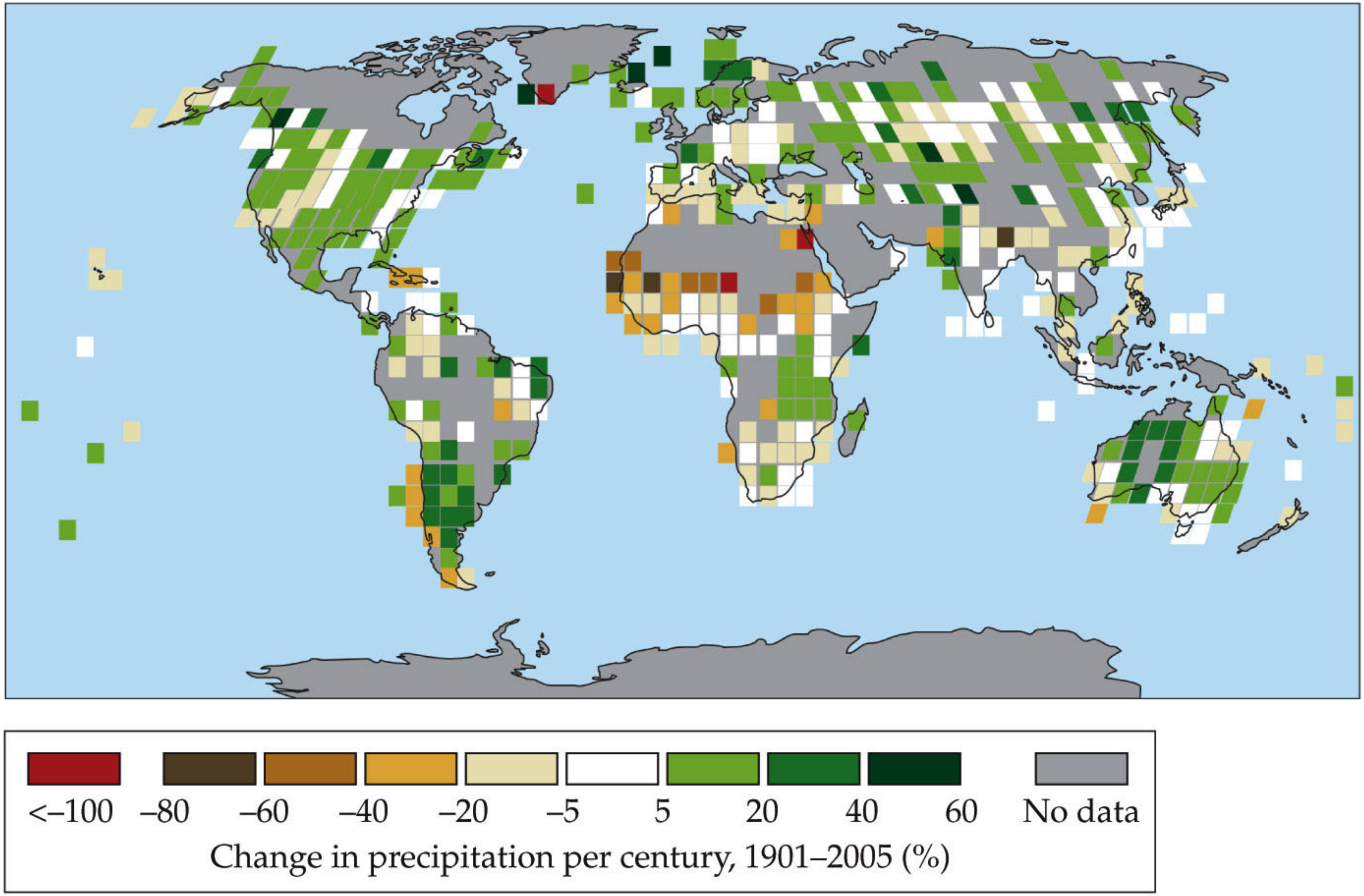
(B) 2001–2005 mean surface temperature anomaly (°C)



Changes in precipitation have also occurred, with more precipitation in the high latitudes of the Northern Hemisphere and drier weather in the subtropics and tropics.

There is also a trend of increasing frequency of extreme weather such as hurricanes and heat waves.

(C)



ECOLOGY, Figure 24.10 (Part 3)

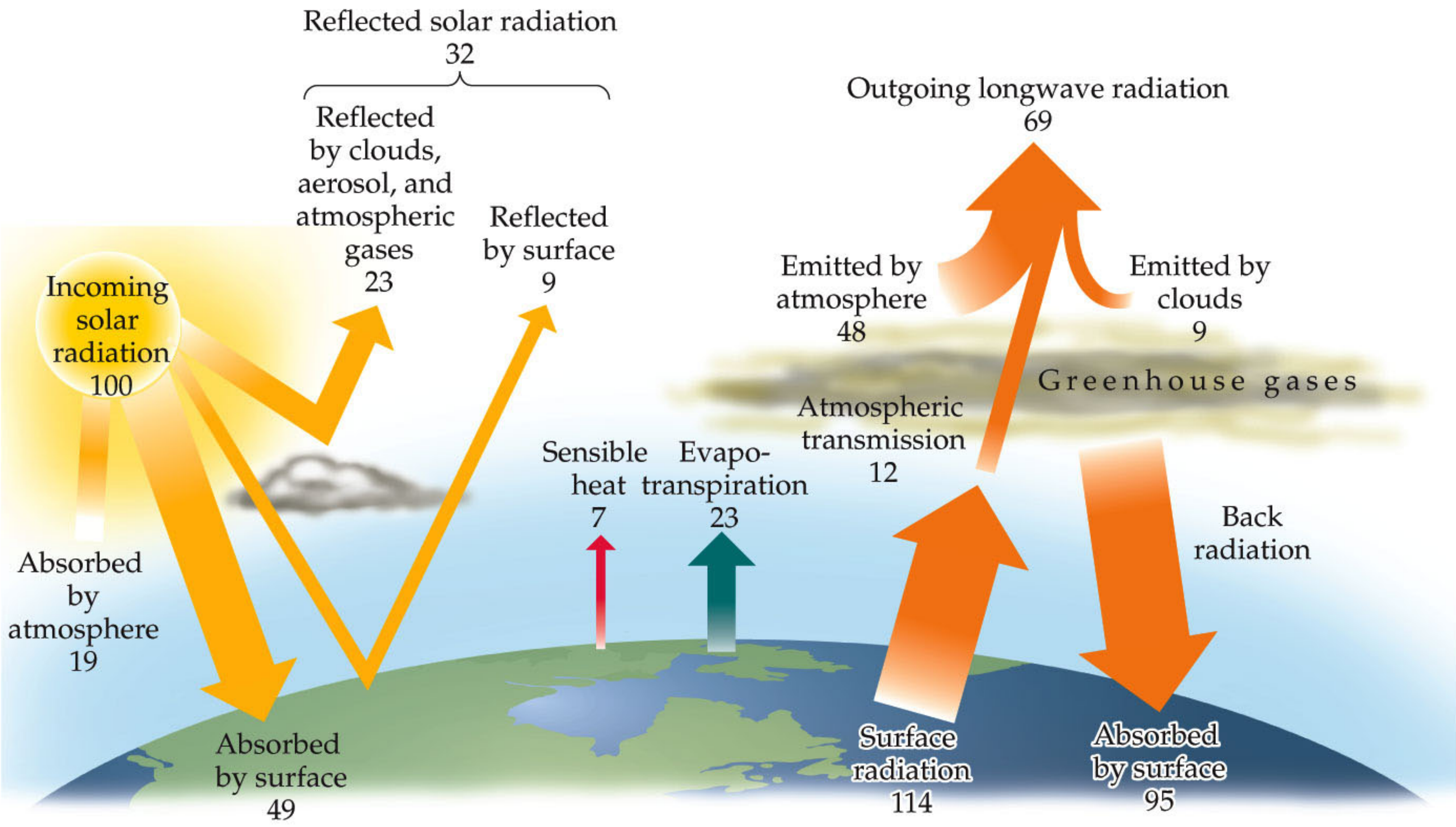
Climate change may result from changes in the amount of solar radiation absorbed by Earth's surface.

This is associated with variation in the amount of radiation emitted by the sun, in Earth's position relative to the sun, or in the reflection of solar radiation by clouds or surfaces with high reflectivity (albedo), such as snow and ice.

Greenhouse effect—warming of Earth by atmospheric absorption and reradiation of infrared radiation emitted by Earth's surface.

This is due to **greenhouse gases** in the atmosphere, primarily water vapor, CO_2, CH_4, and N_2O.

Figure 2.4 Earth's Radiation Balance



ECOLOGY, Figure 2.4

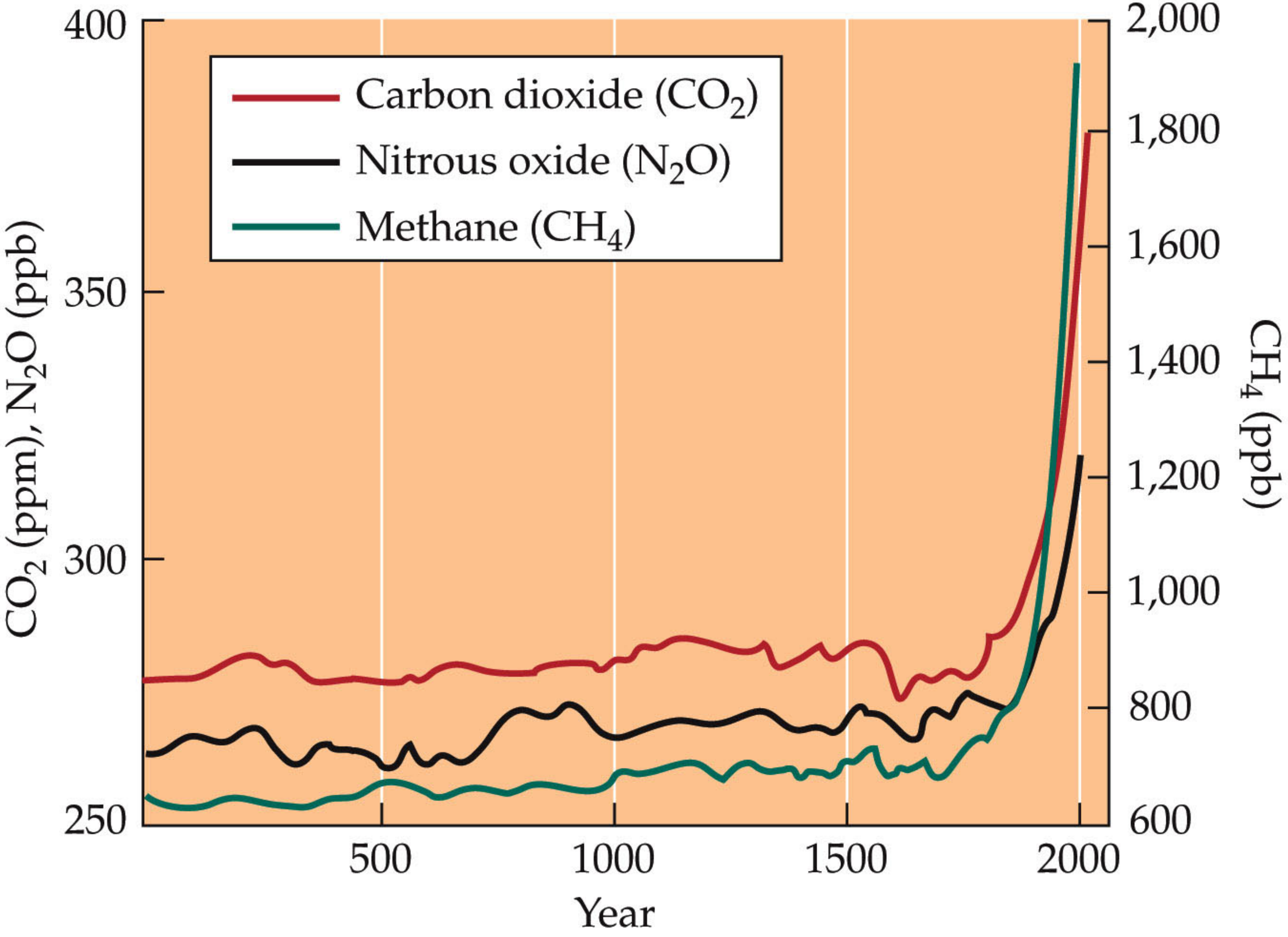
Effect of the different gases depends on their concentration and chemical properties.

Water vapor contributes the most to greenhouse warming, but its concentration varies regionally, and changes in average concentration have been small.

CH_4 has a greater effect per molecule than CO_2, but its concentration is much lower.

Atmospheric concentrations of CO_2, CH_4, and N_2O are increasing substantially, primarily as a result of fossil fuel combustion and land use change.

Figure 24.11 Increases in Greenhouse Gases



ECOLOGY, Figure 24.11

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988.

The panel includes experts in atmospheric and climatic science from around the world.

They use sophisticated modeling and analysis of data from the scientific literature to evaluate underlying causes of observed climate change, and scenarios for the future.

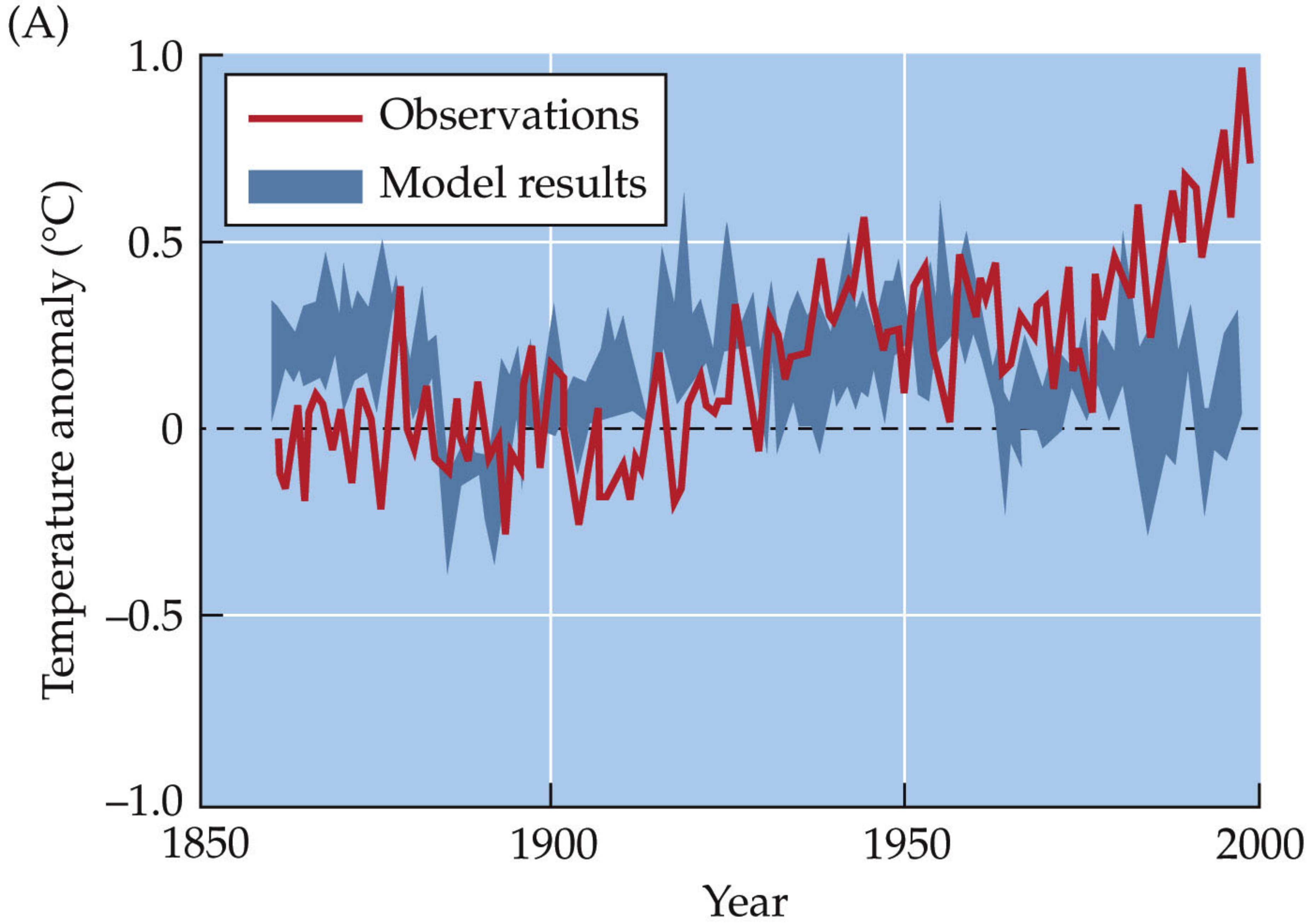
The IPCC releases assessment reports to promote understanding of climate change among scientists, policymakers, and the general public.

In recognition of their efforts to spread "knowledge about man-made climate change," the IPCC was awarded the Nobel Peace Prize in 2007.

In its third report (2001), the IPCC concluded that the majority of the observed global warming is attributable to human activities.

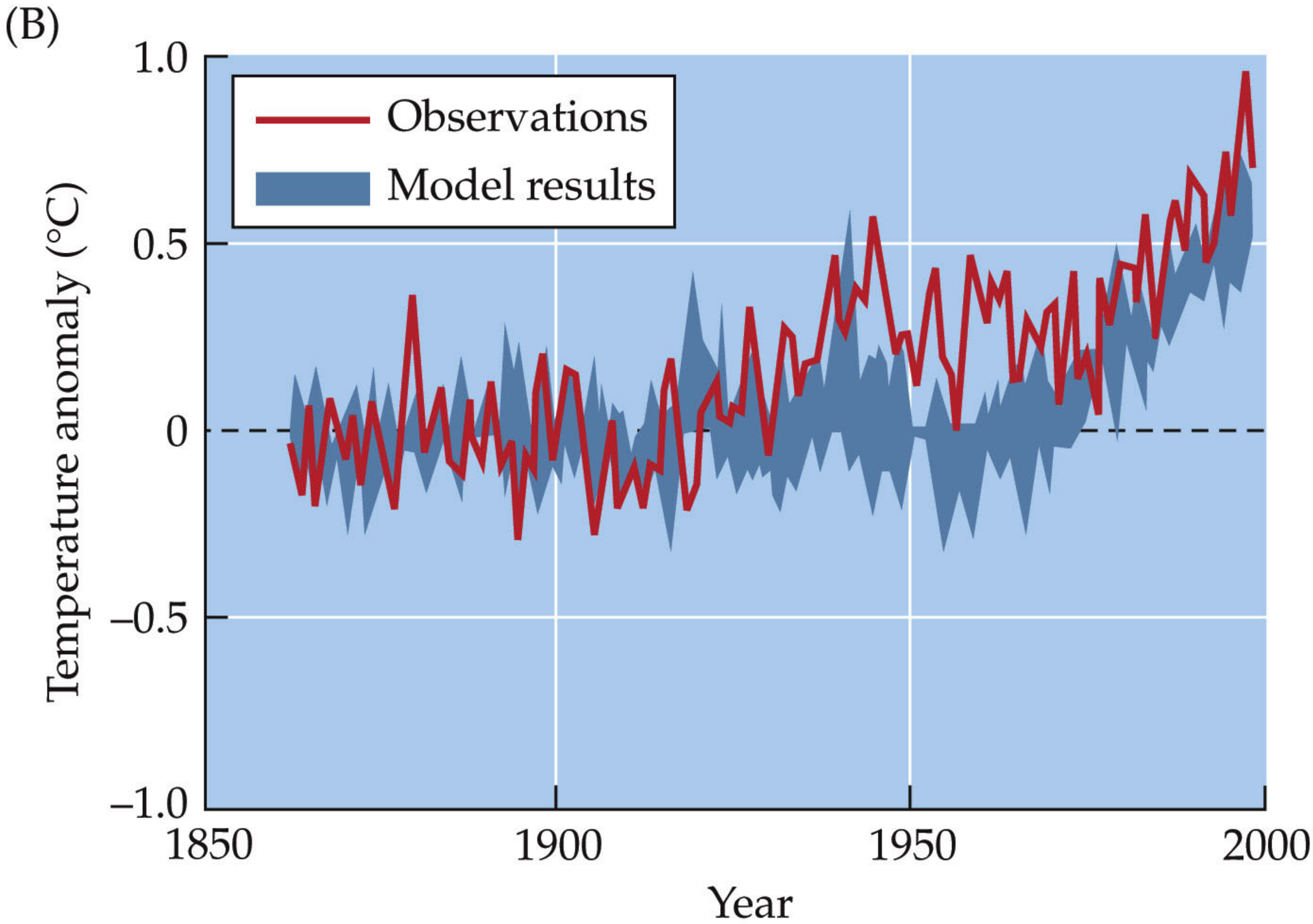
While this conclusion is debated in the political arena, it is backed by the majority of the world's leading atmospheric scientists.

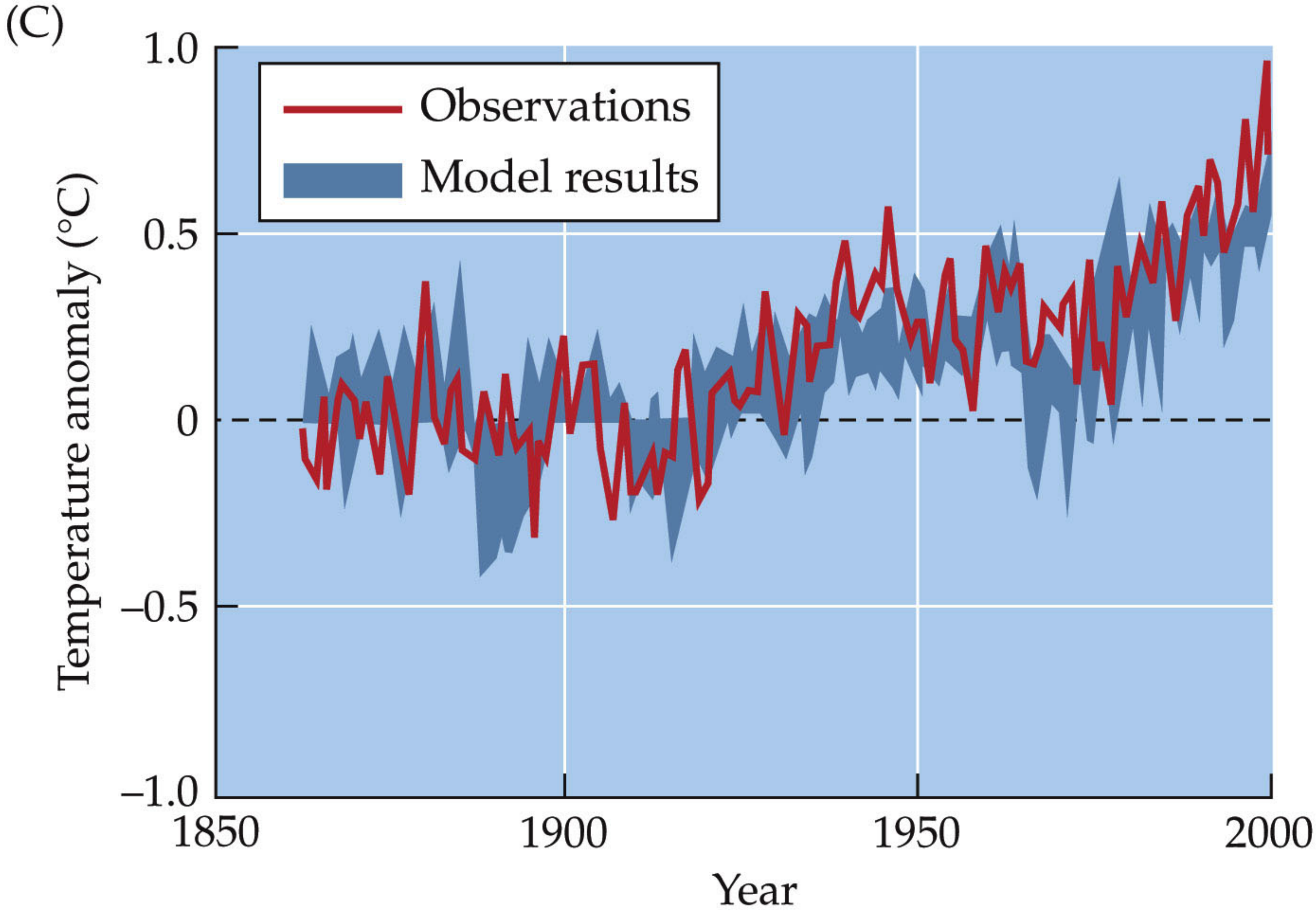
Figure 24.12 Contributors to Global Temperature Change (Part 1)



ECOLOGY, Figure 24.12 (Part 1)

Figure 24.12 Contributors to Global Temperature Change (Part 2)




(C)
Observations
Model results
1.0
0.5
0
–0.5
–1.0
Temperature anomaly (°C)
1850
1900
1950
2000
Year

Paul Crutzen has suggested that we have entered a new geological period, which he called the *Anthropocene epoch* to indicate the extensive impact of humans on our environment.

William Ruddiman has suggested that human influence on the climate system began 5,000 years ago with the advent of agriculture.

He compared observed trends in atmospheric concentrations of CO_2 and CH_4 with those expected based on repeated glacial–interglacial patterns over the past 400,000 years.

About 8,000 and 5,000 years ago, the trends in CO_2 and CH_4 concentrations deviated from the natural trend (what had been observed in previous cycles).

Humans were developing agriculture about this time, clearing forests and starting irrigation.

Figure 24.13 A Delayed Ice Age? (Part 1)

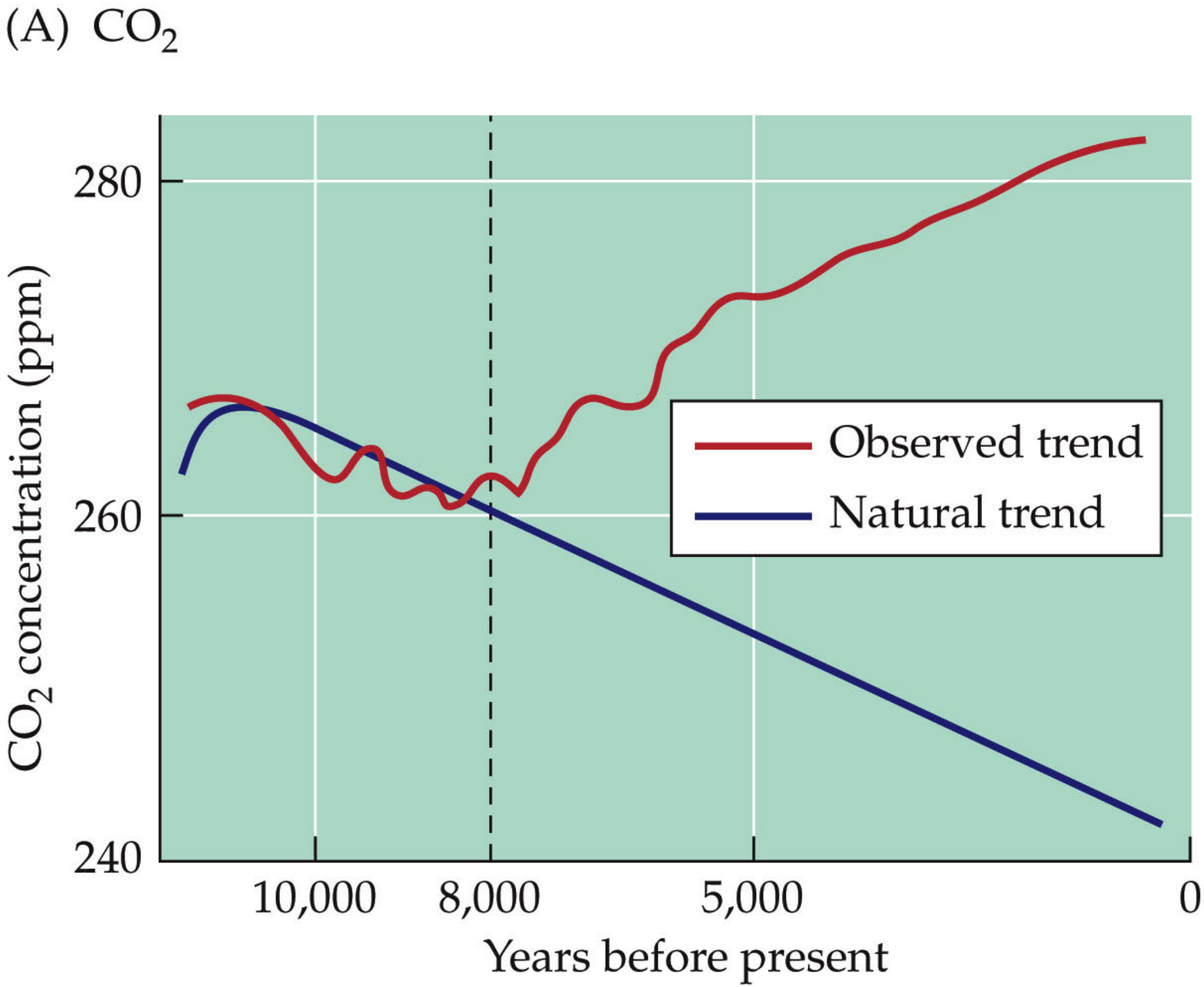
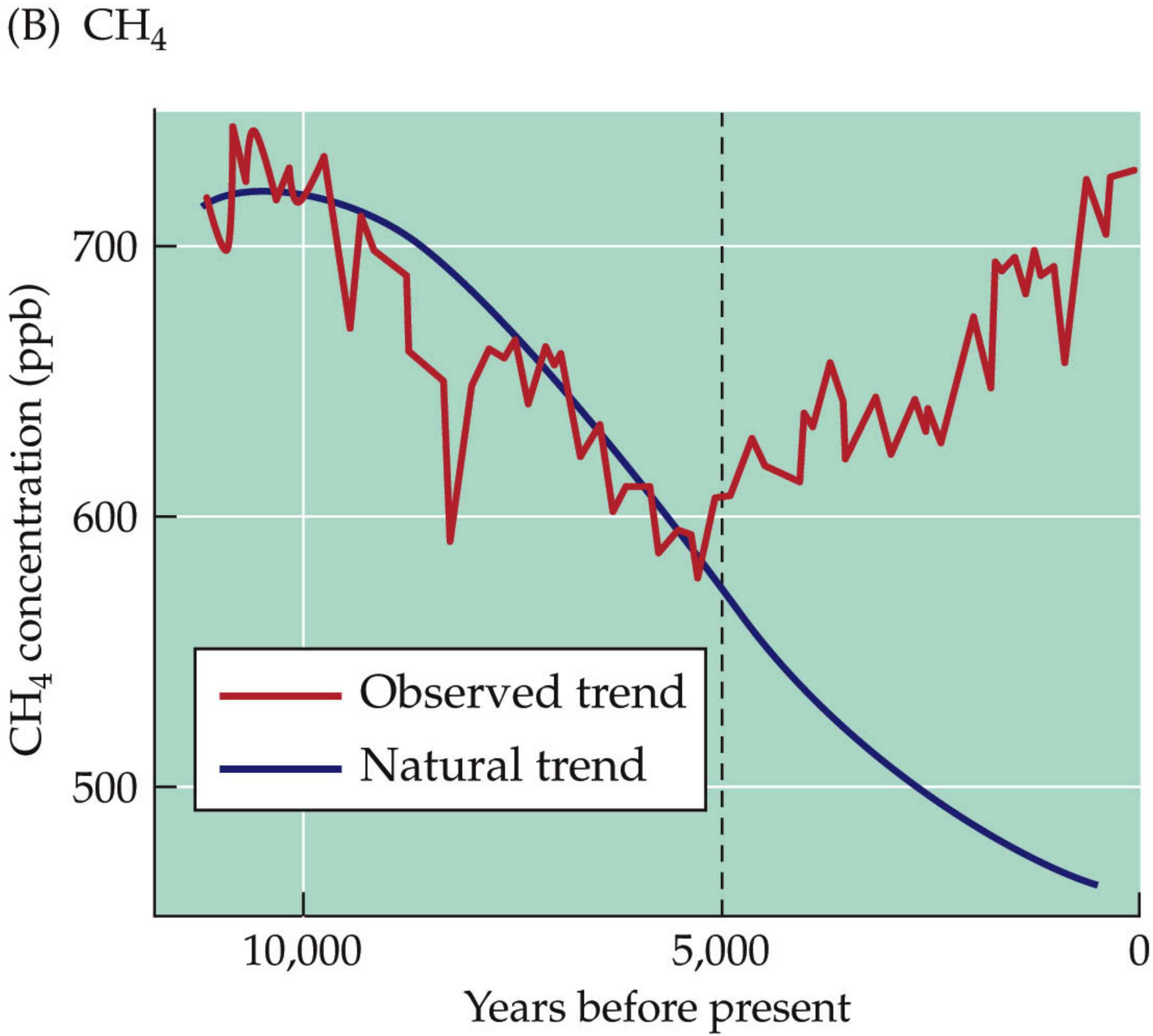


Figure 24.13 A Delayed Ice Age? (Part 2)



ECOLOGY, **Figure 24.13 (Part 2)**

Ruddiman suggested that increases in atmospheric CO_2 and CH_4 concentrations associated with agriculture prevented Earth from entering a new glacial cycle about 8,000 years ago.

The IPCC's models project an increase in average global temperature of 1.8°C–4.0°C over the 21st century.

The range reflects uncertainties about future emission rates and behavior of the climate system.

Future rates of emissions are in part dependent on economic development scenarios.

Aerosols also contribute to the uncertainty.

Aerosols, which reflect solar radiation, have a cooling effect. Volcanic eruptions can add large amounts of aerosols to the atmosphere.

Some aerosols have been increasing (e.g., dust); others have decreased (e.g., SO_4^{2-}, due to decreasing SO_2 emissions).

Water may play contrasting roles: Clouds can have a cooling effect, but water vapor, which may increase due to greater evapotranspiration, may increase greenhouse warming.

Box 24.1 Models, Volcanoes, and Climate Change

Despite uncertainties, climate models have provided reasonably accurate predictions, giving us some confidence in their forecasts.

Hansen et al. (1992) used models to predict that a volcanic eruption in the Philippines would cool Earth's average temperature by 0.5°C over a 15-month period.

Box 24.1 Models, Volcanoes, and Climate Change

Mount Pinatubo erupted in June of 1991, one of the largest eruptions of the 20th century.

17 million tons of SO_2 was ejected into the stratosphere. SO_2 reacts with water to form aerosols of sulfuric acid.

These aerosols can persist for several years in the stratosphere, and be spread around the globe.

Box 24.1, Figure A Eruption of Mount Pinatubo, 1991

ECOLOGY, Box 24.1, Figure A

Box 24.1 Models, Volcanoes, and Climate Change

Hansen's predictions were nearly perfect. Average global temperature dropped 0.5°C over 15 months, then gradually rose again, reaching previous levels by 1995.

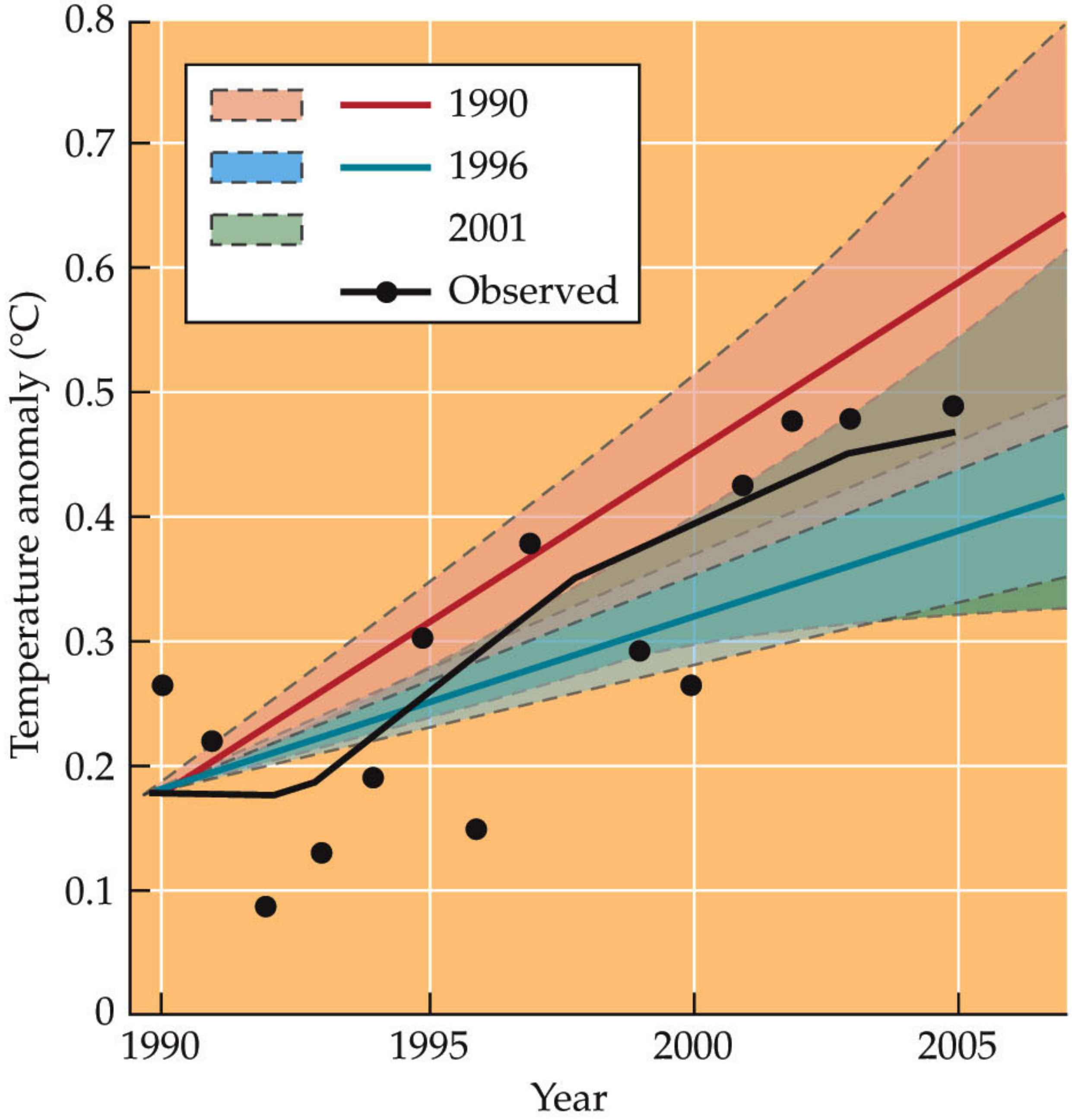
Box 24.1 Models, Volcanoes, and Climate Change

In their fourth report, the IPCC compared model predictions made in the first 3 reports with observed changes in climate.

Prediction of mean annual global temperature increase for the period 1990 to 2005 was 0.1°C–0.3°C per decade.

These were very close to the temperatures actually recorded—an increase of 0.2°C per decade.

Box 24.1, Figure B Can Climate Models Forecast Climate Change?



ECOLOGY, Box 24.1, Figure B

What does a 1.8°C–4.0°C change in temperature mean for biological communities?

This can be compared with elevational climatic variation on a mountain.

The median value (2.9°C) would correspond to a 500 m shift in elevation.

In the Rocky Mountains, this would correspond to a shift from subalpine forest (spruce and fir) to montane forest (Ponderosa pine).

Temperature change predictions for the 21st century would result in an elevational shift in vegetation zones of 200–860 m.

Similar predictions for latitudinal climatic shifts suggest movement of biological communities of 500–1,000 km toward the poles.

But there are many factors involved in determining species distributions. It is unlikely that the same assemblages of organisms will form the communities of the future.

Paleoecological records indicate that novel communities may emerge with climate change.

Overpeck et al. (1992) used pollen records to reconstruct large-scale vegetation change since the most recent glacial maximum in eastern North America (18,000 years ago).

Community types have made latitudinal shifts as the climate warmed.

Also, community types without modern analogs types existed under climatic regimes that were unique and no longer present.

Figure 24.14 Past Vegetation Change (Part 1)

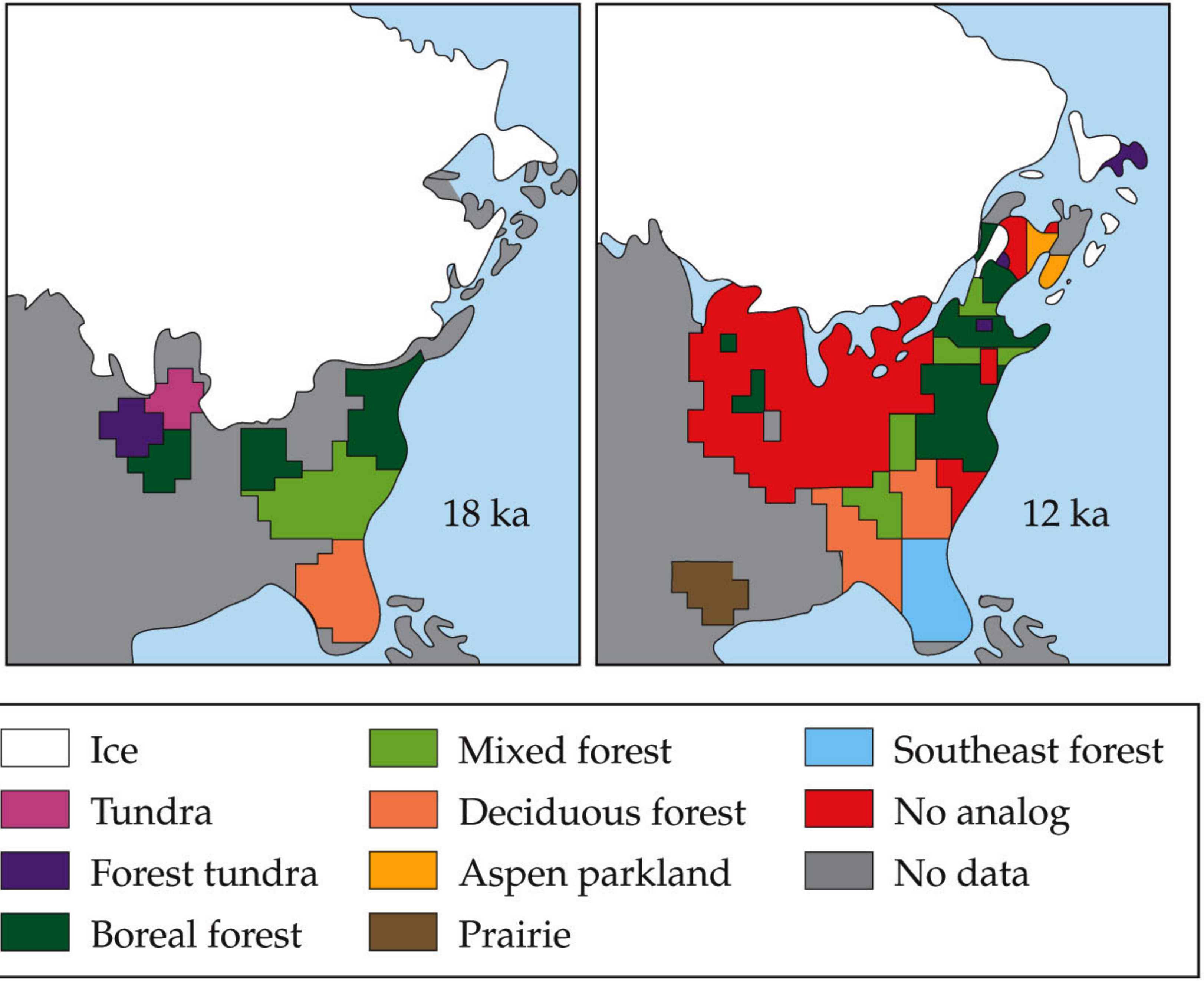
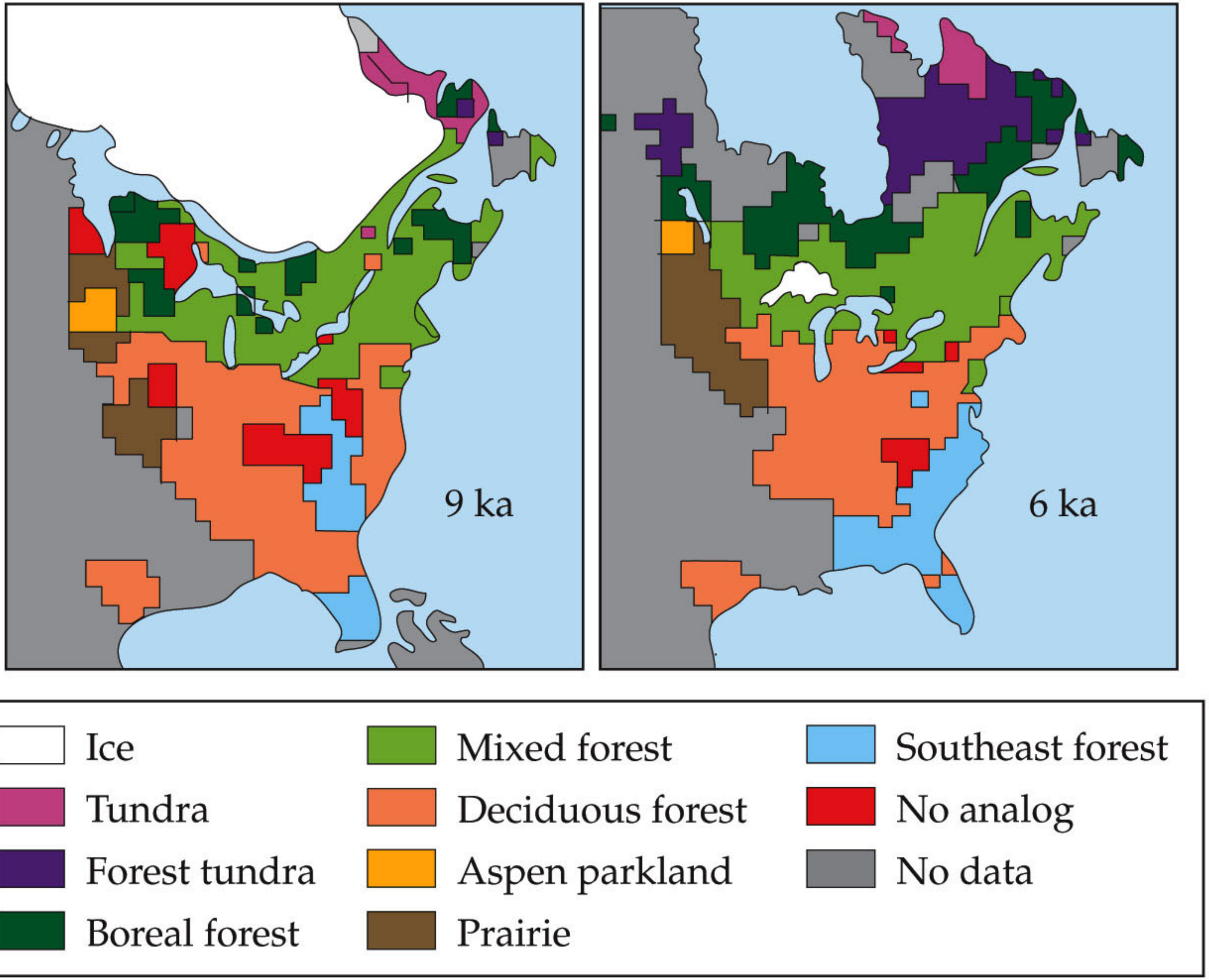
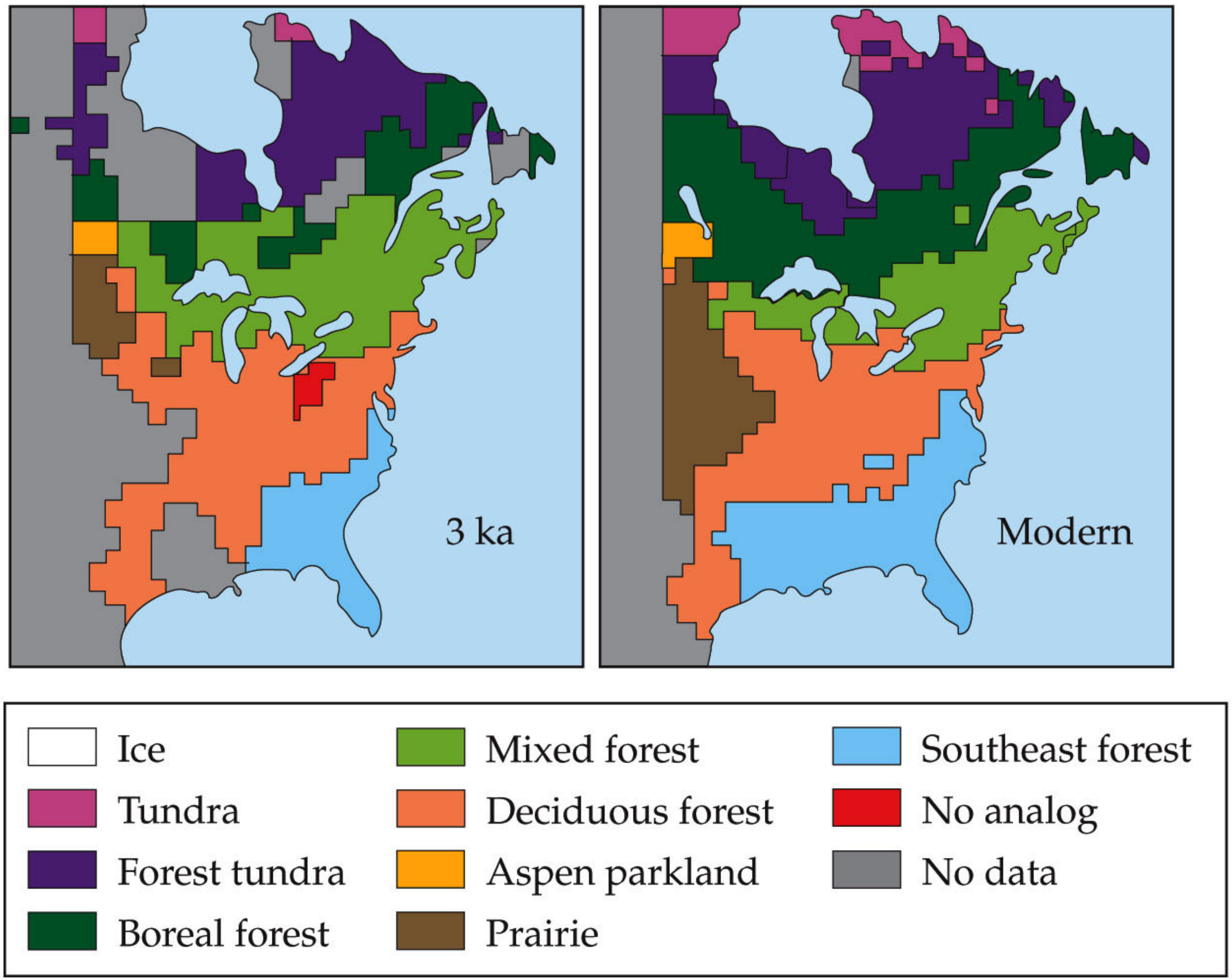


Figure 24.14 Past Vegetation Change (Part 2)



ECOLOGY, Figure 24.14 (Part 2)



ECOLOGY, Figure 24.14 (Part 3)

Because climate change will be rapid, it is likely that evolutionary responses will not be possible for most plants and animals.

Dispersal may be the only way to avoid extinction.

Dispersal barriers and habitat fragmentation will be important constraints.

Plant dispersal rates are, on average, much slower than the predicted rate of climate change.

Ruderal (weedy) herbaceous plants can disperse and establish quickly. Shrubs and trees have much slower dispersal rates.

Climate change will also affect ecosystem functions, such as net primary production (NPP), decomposition, nutrient cycling and retention.

Variation in NPP is related to water and nutrient availability and vegetation type, all of which may be affected by climate change.

The effects of climate on NPP will not be uniform—it may increase in some ecosystems and decrease in others.

Effects may be greatest in mid- to high-latitude terrestrial ecosystems, where low temperatures limit rates of nutrient cycling and soils have large pools of nutrients. Climate change may lead to increases in NPP in some temperate and boreal forest ecosystems.

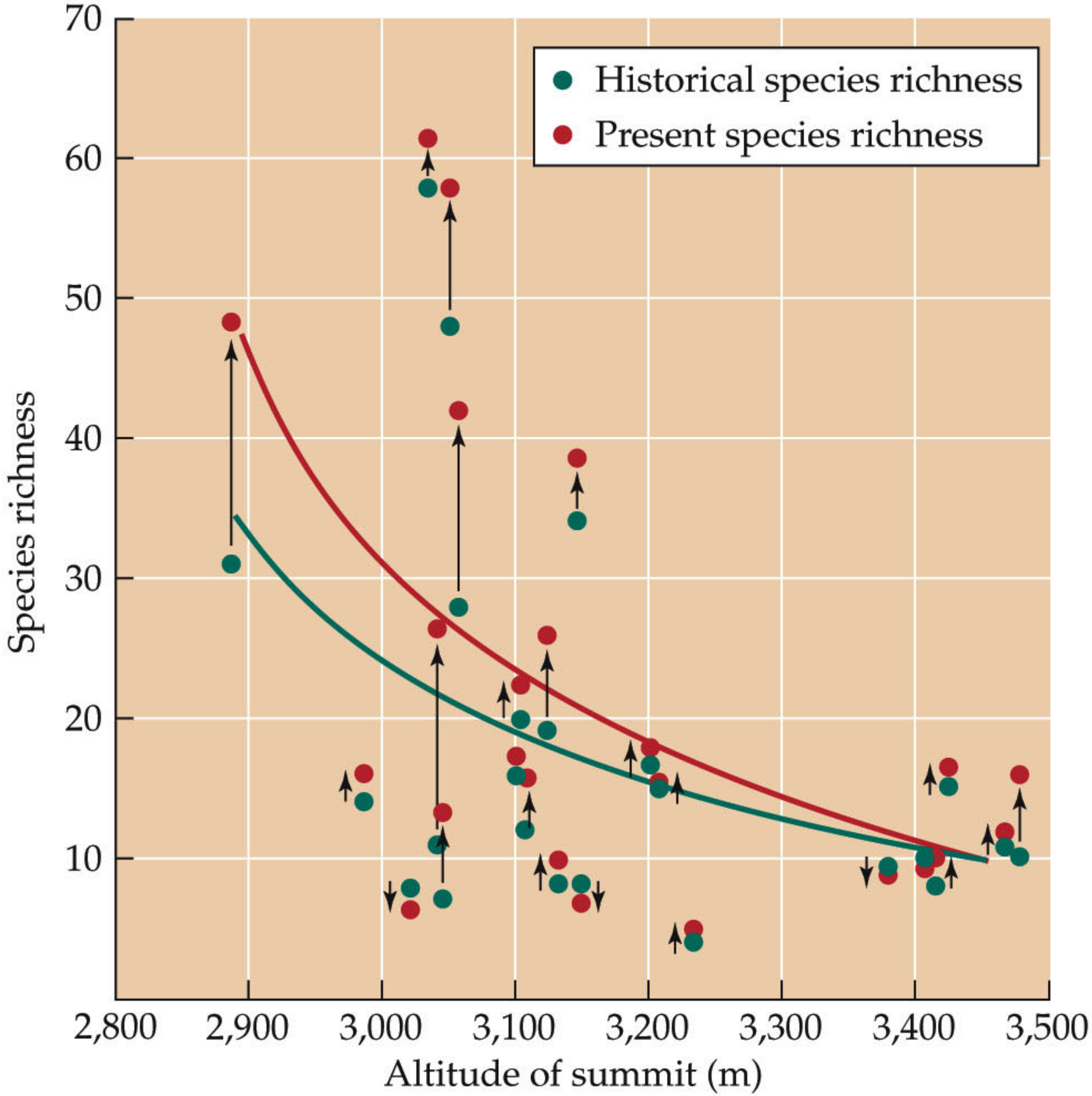
Organisms have already begun to respond to climate change (e.g., earlier migration of birds and earlier spring greening of vegetation).

Geographic ranges of some species have shifted.

Plant ranges in the European Alps were compared with historical records (Grabherr et al. 1994).

A consistent trend of upward movement of species from lower elevations onto the summits was reported.

Figure 24.15 Plants Are Moving Up the Alps (Part 1)



***ECOLOGY,* Figure 24.15 (Part 1)**

Figure 24.15 Plants Are Moving Up the Alps (Part 2)

Global Climate Change

63% of European nonmigratory butterfly species have shifted their ranges northward, while only 3% shifted their ranges southward (Parmesan and Yohe 2003).

Changes in community composition, as well as local extinctions, may also be indicators of climate change.

Warm water temperatures can kill the algal symbionts of corals, resulting in bleaching of coral reefs.

Several worldwide bleaching events have occurred in association with warmer-than-average sea surface temperatures.

Marine foraminiferans are also sensitive to temperature.

Foraminiferan shells from benthic sediments can be identified, and changes in species composition tracked over time.

Because the environmental tolerances of different species are known, changes in the abundances of species provide a means of reconstructing marine environments of the past.

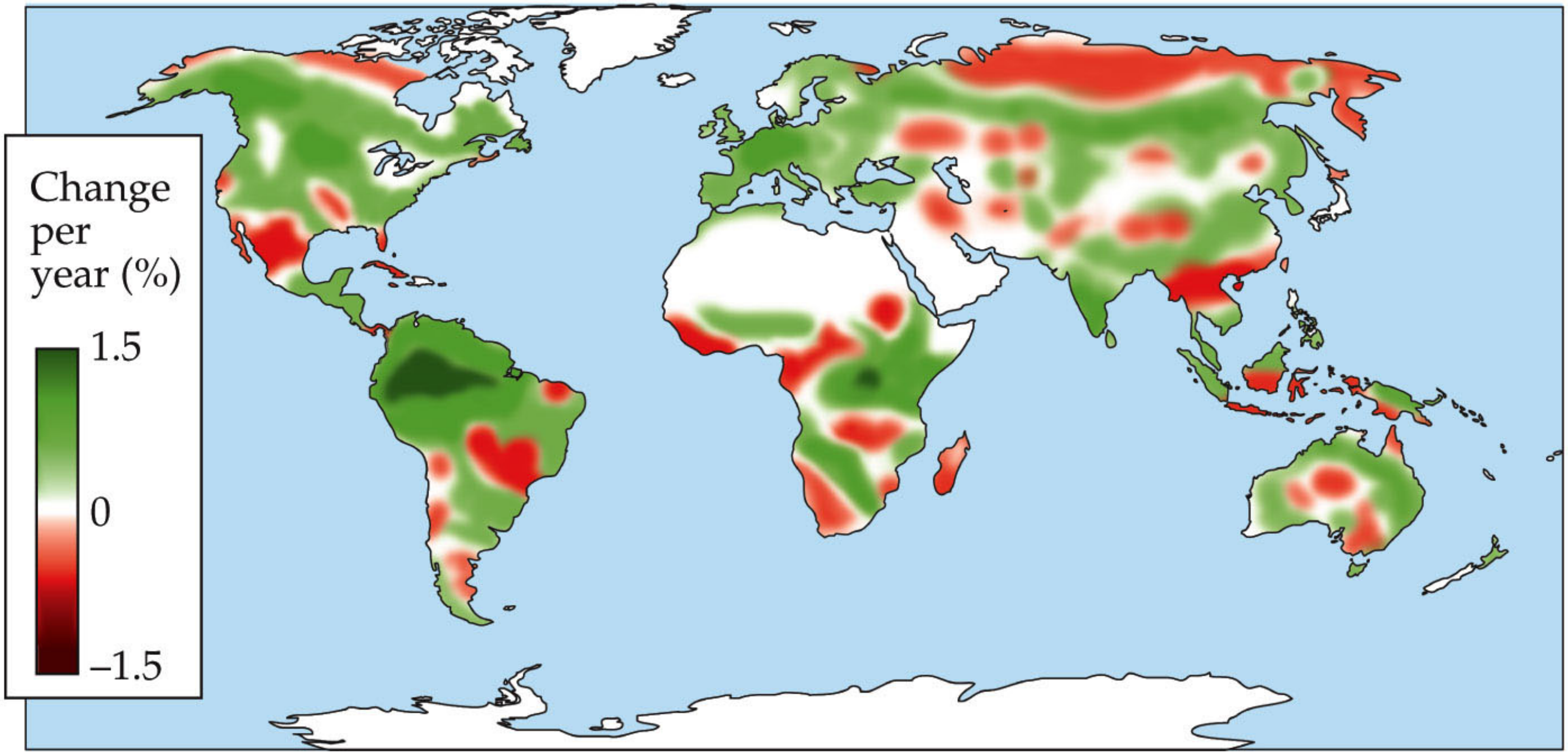
After the mid-1970s, an increase in tropical and subtropical foraminiferan species, and decrease in temperate and polar species, occurred in the eastern North Pacific Ocean, indicating a warming of ocean waters there.

Global patterns of NPP have also changed.

During an 18-year period (1982–1999), global NPP increased 6%, or 0.3% per year (Nemani et al. 2003).

Tropical ecosystems had the largest increase in NPP, associated with increased solar radiation due to less cloud cover during the study period.

Figure 24.16 Changes in Terrestrial NPP



There was a notable decrease in NPP in northern latitudes.

Other research indicated that some areas of the Arctic switched from a net uptake of CO_2 (acting as a *sink*) to a net export of CO_2 (acting as a *source*).

In boreal and arctic ecosystems, cold temperatures reduce decomposition rates, and C builds up in the soils.

20th century warming has increased the rate of CO_2 loss from Arctic soils, such that losses now exceed gains from NPP.

Warming may act as a positive feedback to climate change by enhancing the losses of CO_2 and CH_4.

Acid and Nitrogen Deposition

Concept 24.3: Anthropogenic emissions of sulfur and nitrogen cause acid deposition, alter soil chemistry, and affect the health of ecosystems.

Since the Industrial Revolution, air pollution has mainly been associated with urban industrial centers, power plants, and oil and gas refineries.

Acid and Nitrogen Deposition

These stationary source have regional effects.

But increasing emissions from cars, taller smokestacks, and widespread industrial development have increased the spatial extent of air pollution.

Fossil fuel burning, agriculture, and urban development have influenced fluxes of N and S to the atmosphere.

Acid and Nitrogen Deposition

Emissions of N and S have resulted in two related environmental issues: Acid precipitation and N deposition.

Sites affected by these problems now include national parks and wilderness areas.

Figure 24.17 Air Quality Monitoring in Grand Canyon National Park

Acid and Nitrogen Deposition

The effects of acid precipitation were recognized in the mid 19th century in England. Legislation was enacted in 1863 to reduce acidic emissions.

During the 1960s, awareness of the widespread effects of acid rain, including in pristine areas, increased. Damage to forests and aquatic ecosystems became well-known.

Sulfuric acid (H_2SO_4) originates from SO_2, and nitric acid (HNO_3) from NO_x.

These acids can fall to Earth with precipitation (wet deposition) or with dust or aerosols (dry deposition).

Natural precipitation has a pH of 5.0 to 5.6, because CO_2 and water form carbonic acid. Acid precipitation has a pH range from 5.0 to 2.0.

During winter, acidic compounds accumulate in snow. In the spring, melt water leaches the acids out of the snow.

This *acid pulse* has the potential to be toxic to sensitive organisms.

Acid and Nitrogen Deposition

The vulnerability of organisms to acid precipitation depends on the **acid neutralizing capacity** of their ecosystem.

It is associated with base cations, including Ca^{2+}, Mg^{2+}, and K^{+}. Soils from parent rock such as limestone have high levels of these cations, thus a high acid neutralizing capacity.

Acid and Nitrogen Deposition

As H^+ percolates through soil, it replaces Ca^{2+},Mg^{2+}, and K^+ at cation exchange sites on the surfaces of clay particles.

These cations can then leach out of the root zone, and then the soil becomes acidic.

Acid and Nitrogen Deposition

Large-scale mortality of trees in European forests during the 1970s and 1980s was associated with acid precipitation, Ca and Mg deficiencies, and other stresses.

Figure 24.18 Air Pollution Has Damaged European Forests

ECOLOGY, **Figure 24.18**

Aluminum (Al^{3+}) can also be released into the soil from cation exchange sites.

Al is toxic to plants, soil invertebrates, and aquatic organisms, including fish.

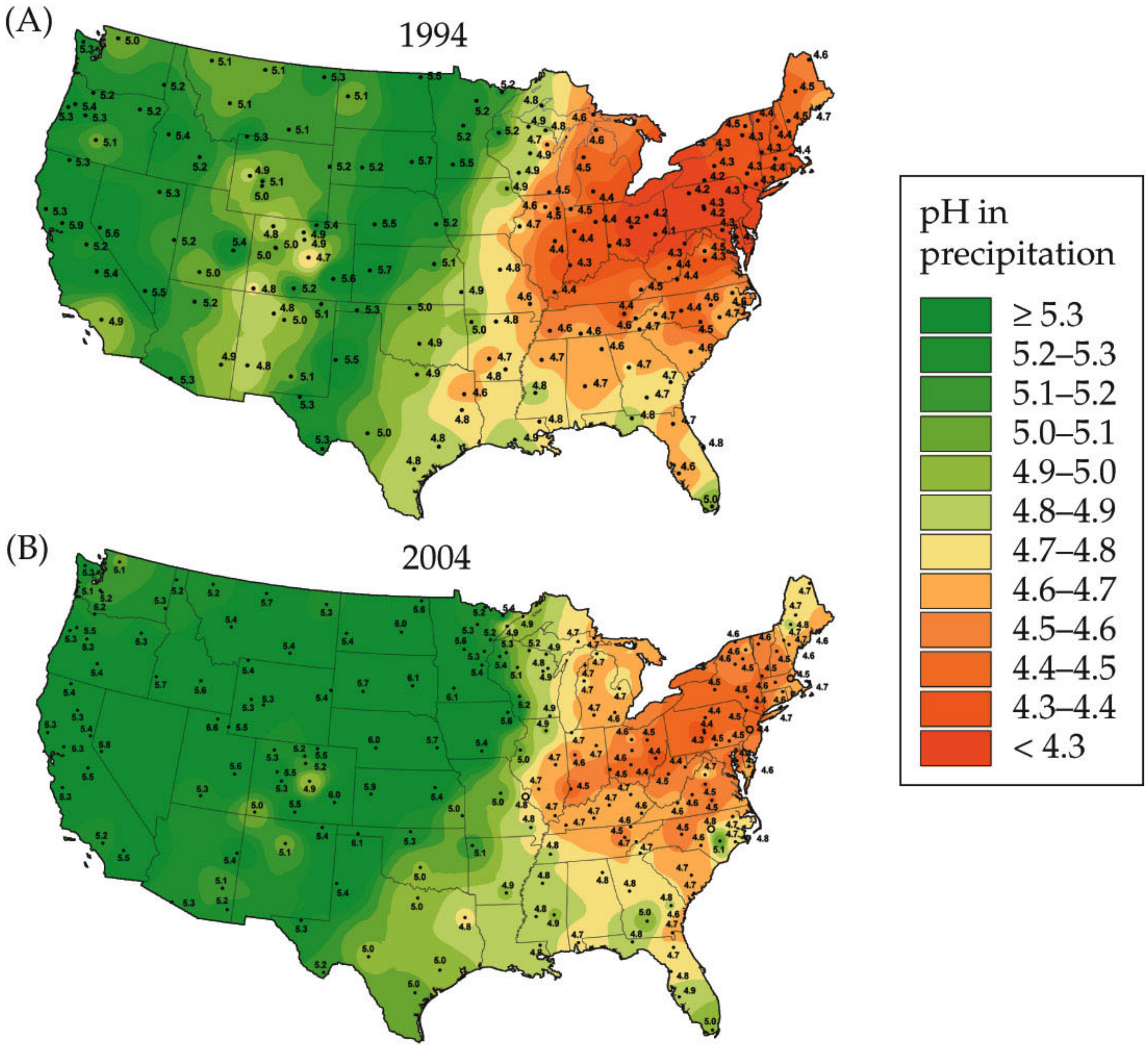
The combination of increasingly acid precipitation and increasing aluminum in runoff has been linked to fish die-offs in in northern Europe and eastern North America.

Acid and Nitrogen Deposition

Restrictions on emissions of S in North America and Europe have resulted in significant reductions in the acidity of precipitation, and forests are beginning to recover.

Acid precipitation remains a problem in some countries with rapid industrial development, such as China and India.

Figure 24.19 Decreases in Acid Precipitation



ECOLOGY, Figure 24.19

Anthropogenic emissions of N compounds have greatly altered global N cycles.

Reactive N (unlike N_2) can participate in chemical reactions and are biologically reactive.

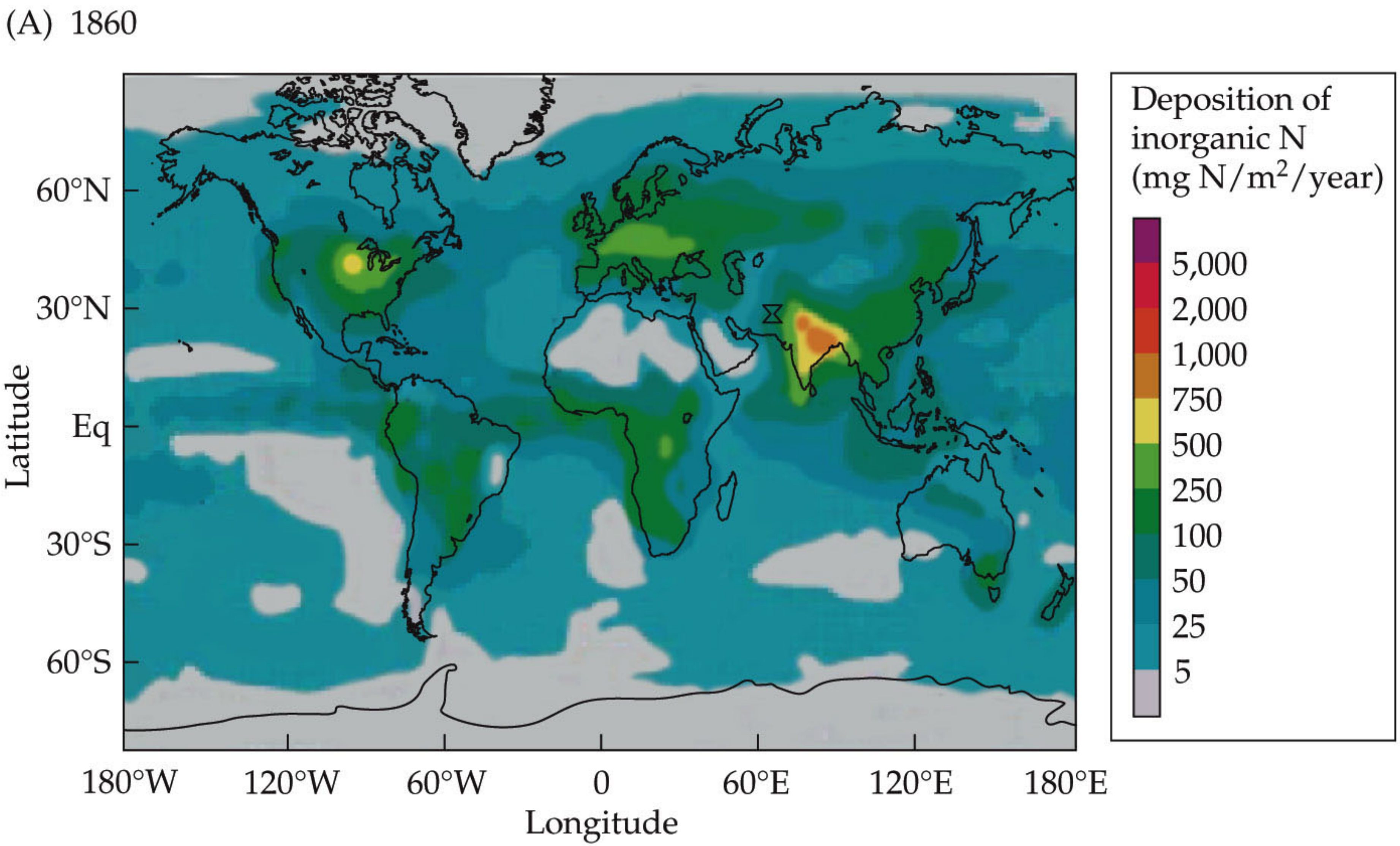
Reactive N can come back to Earth as wet and dry deposition.

Acid and Nitrogen Deposition

Globally, reactive N emission and deposition has increased 3-fold since 1860, and is expected to continue to increase.

While this increases supply of N for biological activity, it comes with a cost.

Figure 24.20 Historic and Projected Changes in Nitrogen Deposition (Part 1)



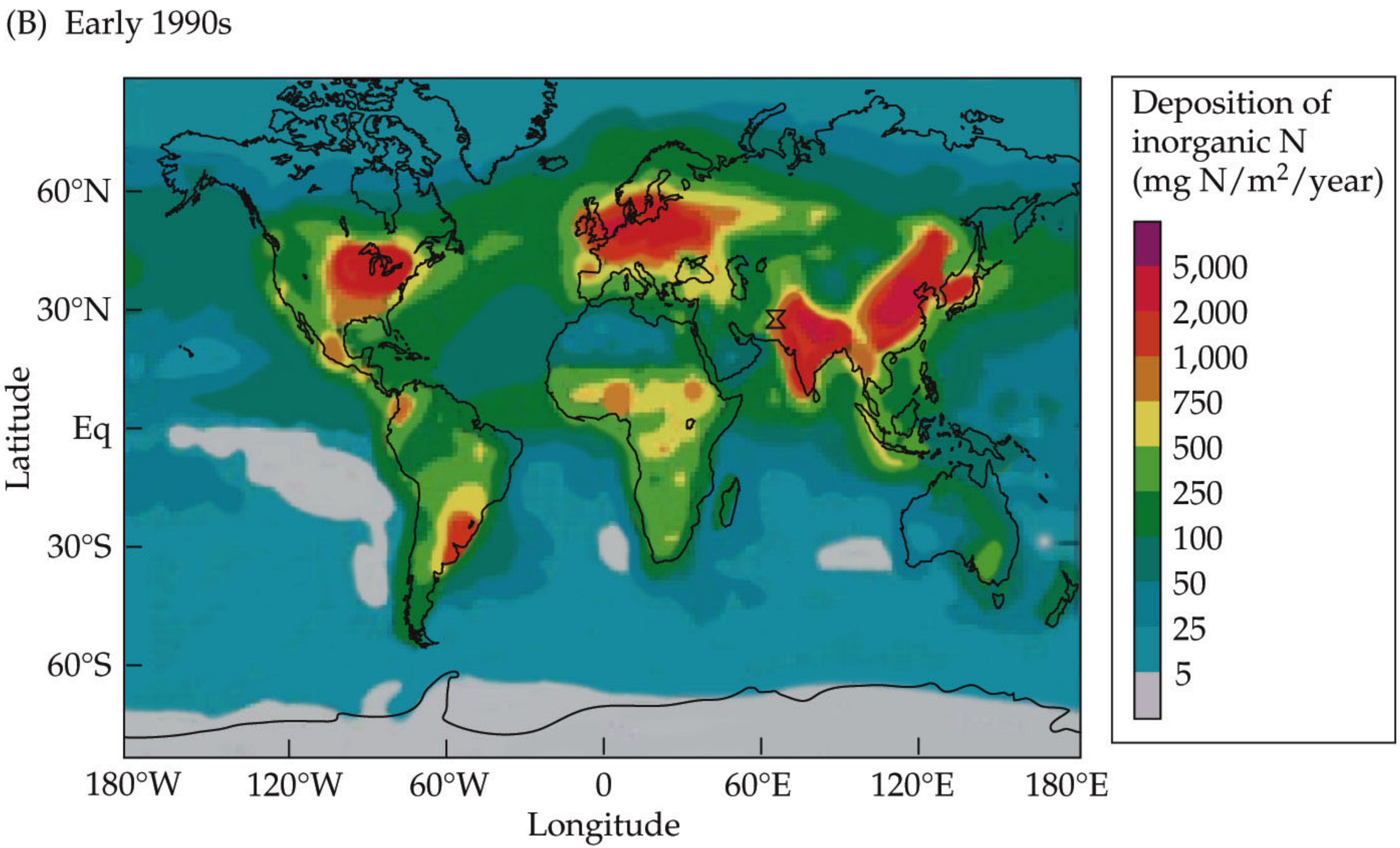
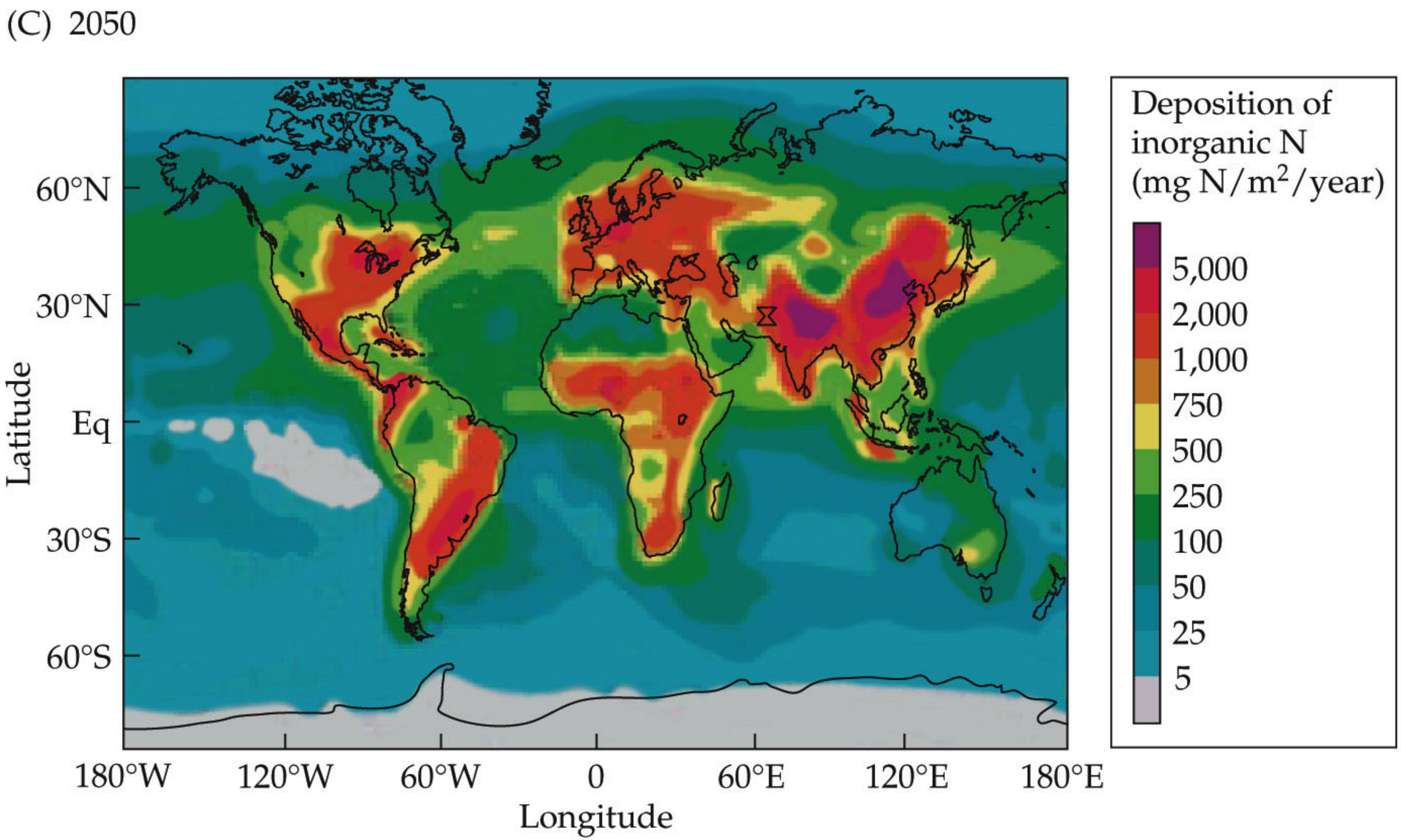

(B) Early 1990s
60°N
30°N
Eq
30°S
60°S
Latitude
180°W
120°W
60°W
0
60°E
120°E
180°E
Longitude
Deposition of inorganic N (mg N/m²/year)
5,000
2,000
1,000
750
500
250
100
50
25
5

Figure 24.20 Historic and Projected Changes in Nitrogen Deposition (Part 3)



Acid and Nitrogen Deposition

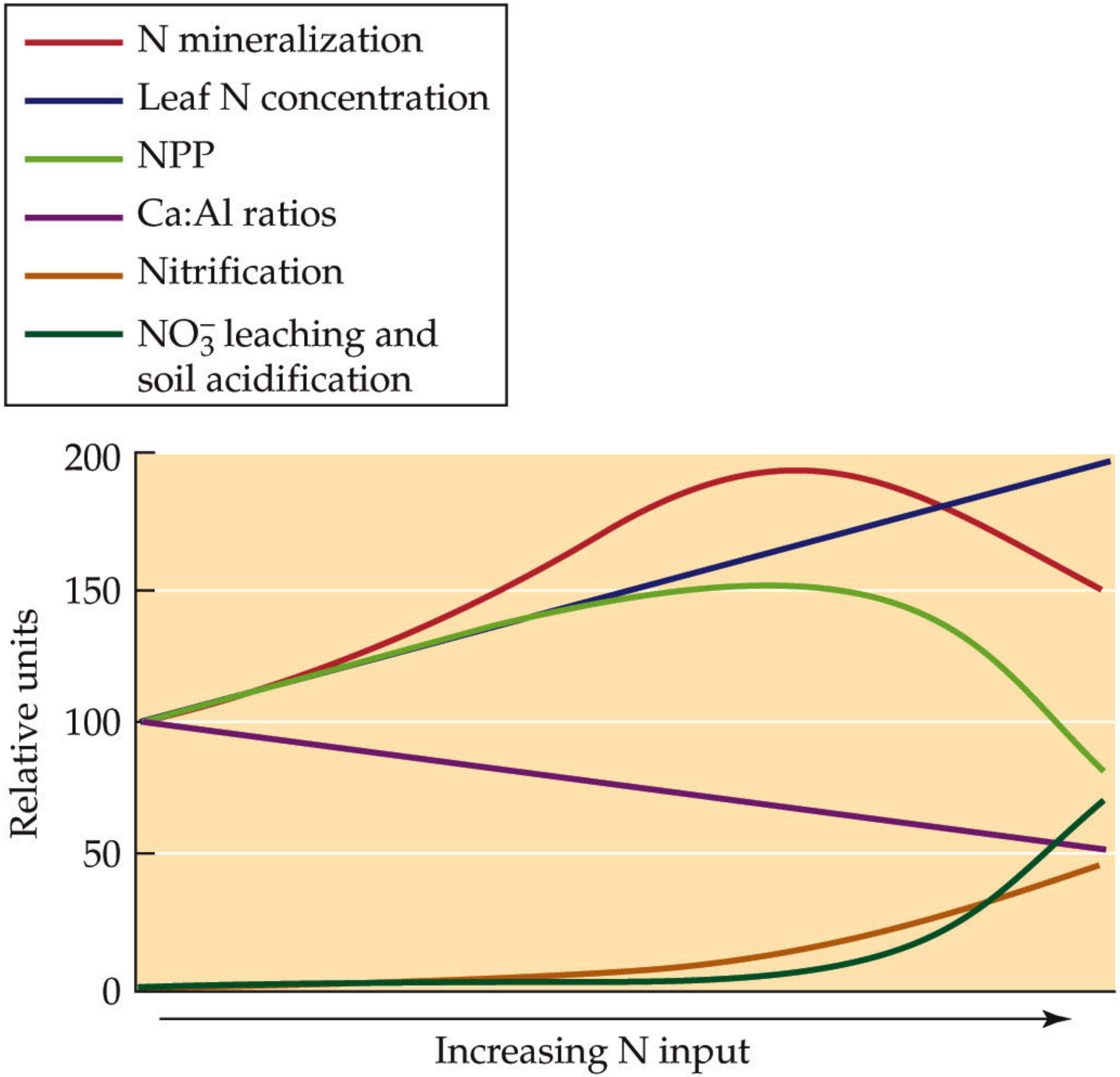
Primary production has increased in some ecosystems as a result of increased N deposition.

It may be partly responsible for a greater uptake of atmospheric CO_2 by terrestrial ecosystems.

But N deposition is associated with environmental degradation, loss of diversity, and acidification.

N deposition may exceed the capacity of plants and microbes to take it up —"nitrogen saturation."

Figure 24.21 Effects of Nitrogen Saturation



Other problems with N deposition:

- Higher levels of NH_4^+ and NO_3^- in soils lead to higher rates of microbial processes (nitrification and denitrification) that release N_2O, a potent greenhouse gas.

Acid and Nitrogen Deposition

- NO_3^- is easily leached from soils and can move into groundwater and aquatic ecosystems.
- When NO_3^- moves through the soil, it carries cations (K^+, Ca^{2+}, Mg^{2+}) with it. As in acid precipitation, losses of these cations can lead to nutrient deficiencies and eventually to acidification of soils.

Acid and Nitrogen Deposition

- N export to marine ecosystems can contribute to eutrophication and oxygen depletion.

Anoxic conditions over large areas are called “dead zones.”

Acid and Nitrogen Deposition

- In nutrient-poor environments, many plants have adaptations that lower their nutrient requirements, which lowers their capacity to take up excess N.

Faster-growing species may then outcompete them, resulting in loss of biodiversity and alteration of community composition.

In Holland, species-rich heath communities adapted to low-nutrient conditions have been replaced by species-poor grassland communities as a result of very high rates of N deposition.

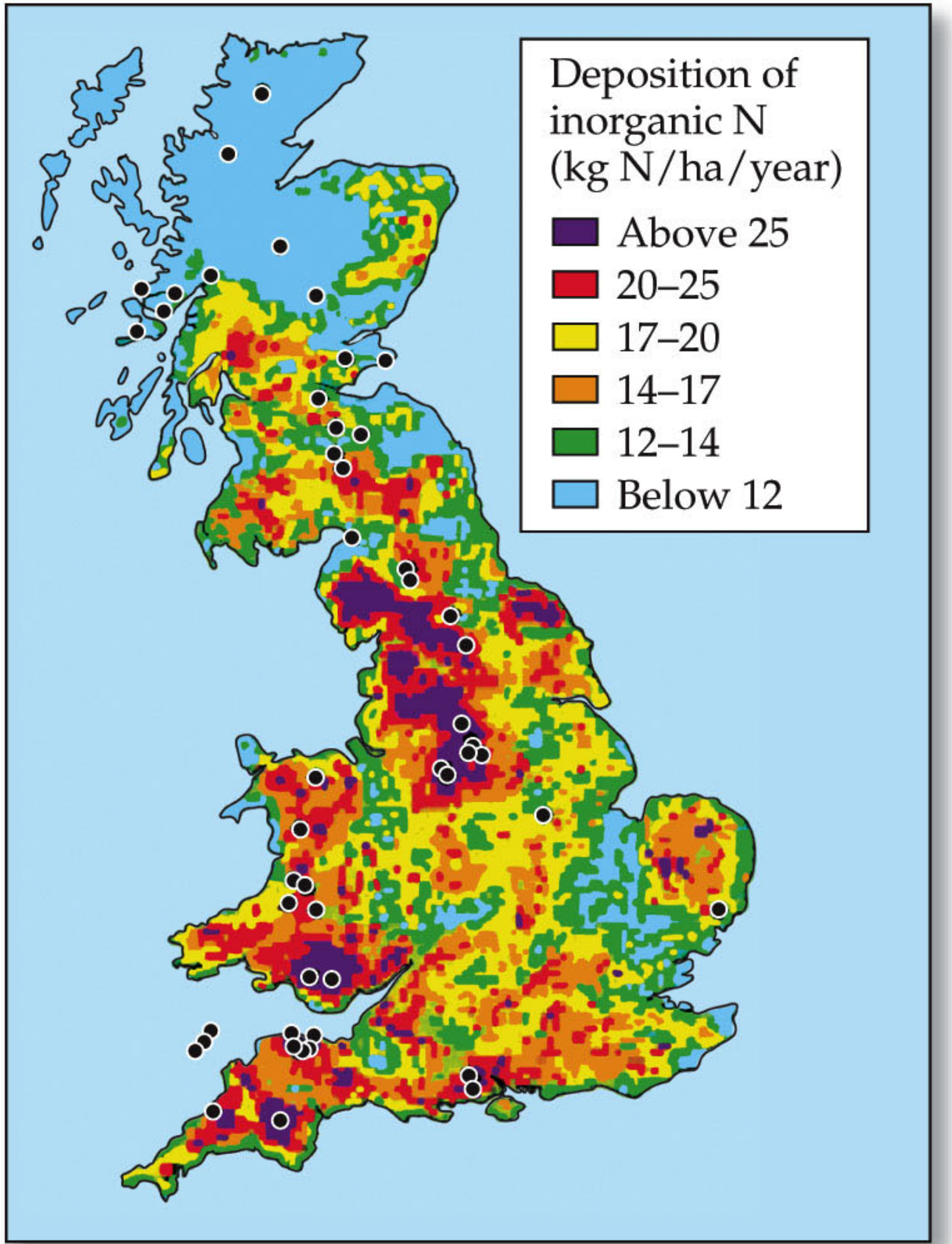
Acid and Nitrogen Deposition

A survey of grassland communities in Great Britain looked at a range of N deposition rates (Stevens et al. 2004).

Environmental variables included soil chemical factors, physical environment variables, grazing intensity, and the presence or absence of grazing enclosures.

Figure 24.22 A Nitrogen Deposition Lowers Species Diversity

(A)

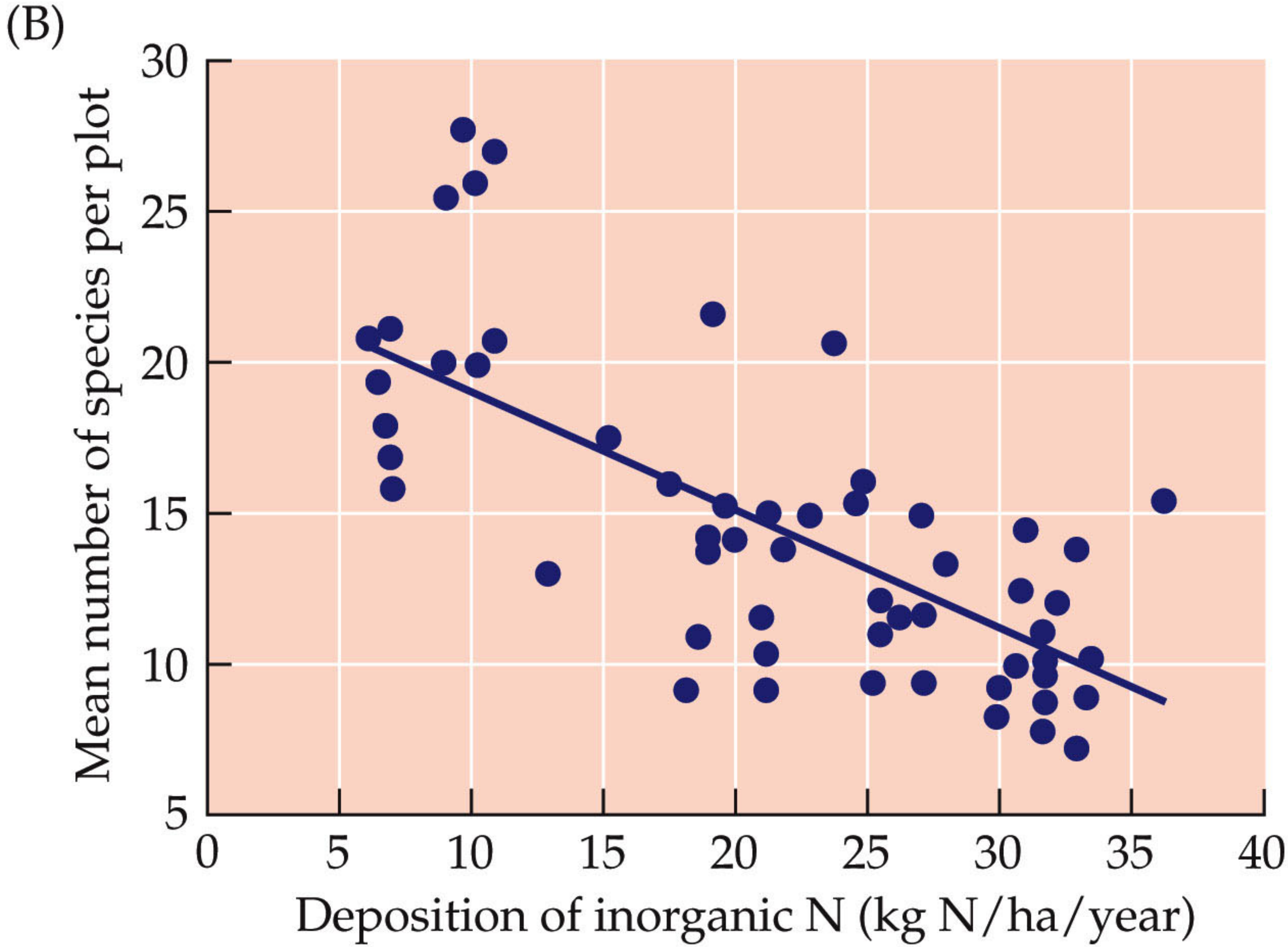


ECOLOGY, Figure 24.22 (Part 1)

Of the 20 factors that may have influenced species richness among the study sites, the amount of N deposition explained the greatest amount of variation.

Higher N inputs were associated with lower species richness.

Figure 24.22 B Nitrogen Deposition Lowers Species Diversity



ECOLOGY, Figure 24.22 (Part 2)

Acid and Nitrogen Deposition

Many experimental studies have also shown that adding N to experimental plots decreased species richness, often resulting in the loss of rare species.

Atmospheric Ozone

Concept 24.4: Losses of ozone in the stratosphere and increases in ozone in the troposphere each pose risks to organisms.

In the upper atmosphere (stratosphere), ozone provides a shield that protects Earth from harmful radiation.

In the lower atmosphere (troposphere), ozone can harm organisms.

Atmospheric Ozone

When photosynthesis evolved 2.3 billion years ago, oxygen began to accumulate in the atmosphere.

This facilitated the evolution of greater physiological and biological diversity, including the appearance of aerobic respiration.

Atmospheric Ozone

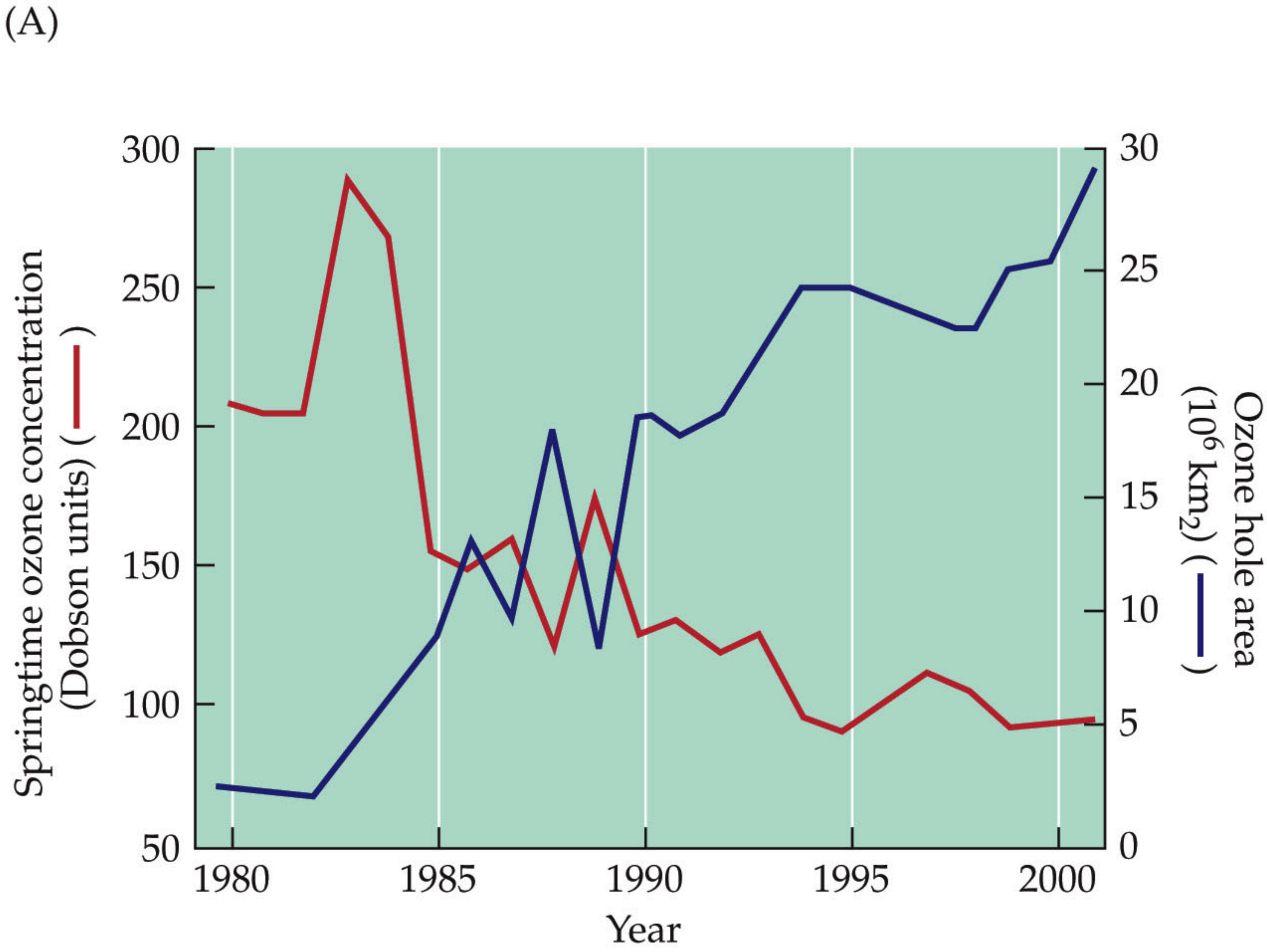
It also led to the formation of the ozone layer. Ozone (O_3) acts as a shield protecting Earth's surface from high-energy ultraviolet-B (UVB) radiation.

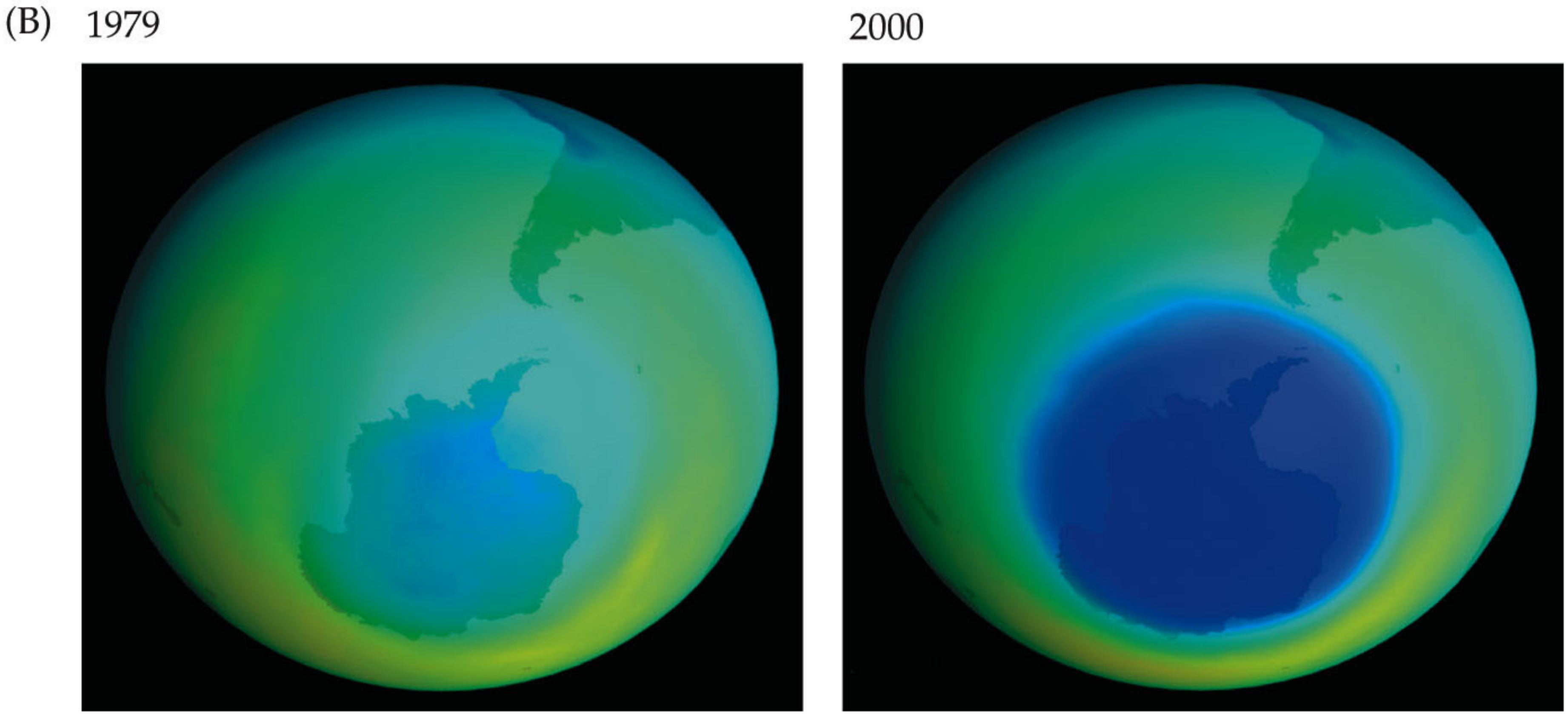
UVB radiation causes damage to DNA and photosynthetic pigments, impairment of immune responses, and cancerous skin tumors in animals.

Stratospheric ozone concentrations decrease in spring in polar regions.

In 1980, British scientists measured an unusually large decrease in springtime ozone over Antarctica. The trend has continued since then, and the spatial extent of the phenomenon, called the **ozone hole**, has increased.

Figure 24.23 The Antarctic Ozone Hole (Part 1)




(B) 1979
2000

Atmospheric Ozone

An ozone hole is not really a hole, but an area with low ozone concentrations.

In the Arctic, the decreases have not been as great (the **Arctic ozone dent**).

Molina and Rowland (1974) predicted a decrease in stratospheric ozone, due to manmade organic compounds called chlorofluorocarbons (CFCs), which can destroy ozone molecules.

CFCs were developed in the 1930s as refrigerants and as propellants in spray cans of hair spray, paint, deodorants, etc.

Atmospheric Ozone

In the stratosphere, CFCs react with other compounds to produce reactive chlorine molecules that destroy ozone.

A single free chlorine atom has the potential to destroy 10^5 ozone molecules.

Atmospheric Ozone

Increases in UVB radiation at Earth's surface coincide with decreasing concentrations of stratospheric ozone.

UVB radiation has increased as much as 130% in the Antarctic spring.

UVB in the Northern Hemisphere has increased by 22% at mid-latitudes during the spring.

Increases in UVB radiation at Earth's surface coincide with a higher incidence of skin cancer in humans (10 times higher than in the 1950s).

UVB radiation influenced evolution of skin pigmentation in humans. The skin pigment melanin was selected for in populations at low latitudes where ozone levels are naturally lowest.

As humans migrated to colder climates with less sunlight, melanin limited production of vitamin D, and so it was selected against.

Now lighter-skinned humans migrate back to regions of high sun, low ozone, and suffer increased risk of skin cancer.

In Australia, nearly 30% of the population is diagnosed with some form of skin cancer.

Increasing UVB radiation also has ecological effects. Larval amphibians are particularly susceptible.

Sensitivity to UVB varies among species within a community, so changes in community composition are likely to result from increased UVB radiation.

Several international conferences on ozone destruction took place in the 1980s.

The Montreal Protocol, an international agreement calling for reduction and eventual end to production and use of CFCs and other ozone-degrading chemicals, was developed.

The Montreal Protocol has been signed by more than 150 countries, and went into effect in 1989.

Concentrations of most CFCs have decreased, or remained the same.

Recovery of the ozone layer is expected to take decades due to the long life of CFCs, and slow mixing of the troposphere and stratosphere.

Figure 24.24 Progress against the Ozone Killers (Part 1)

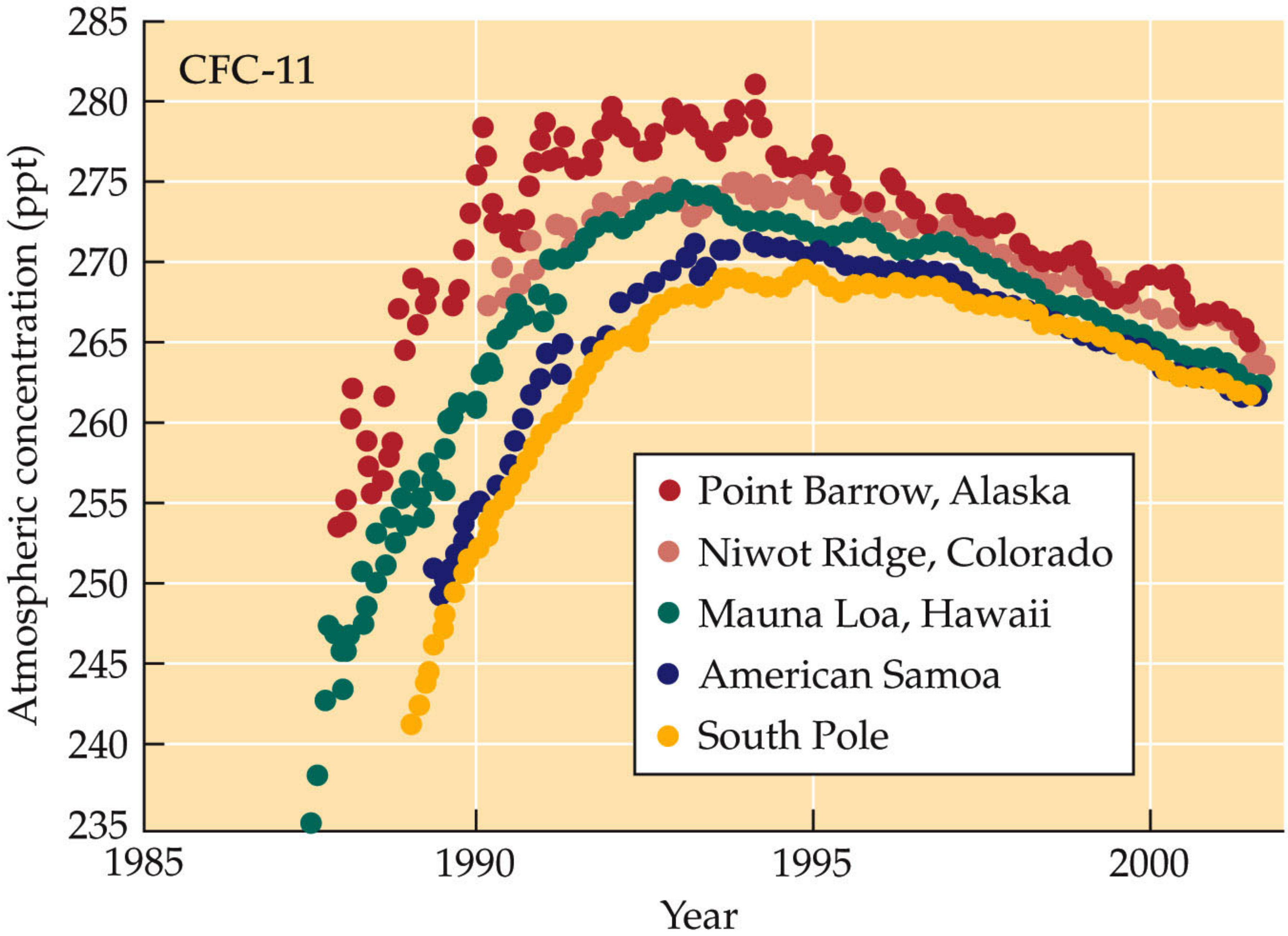


Figure 24.24 Progress against the Ozone Killers (Part 2)

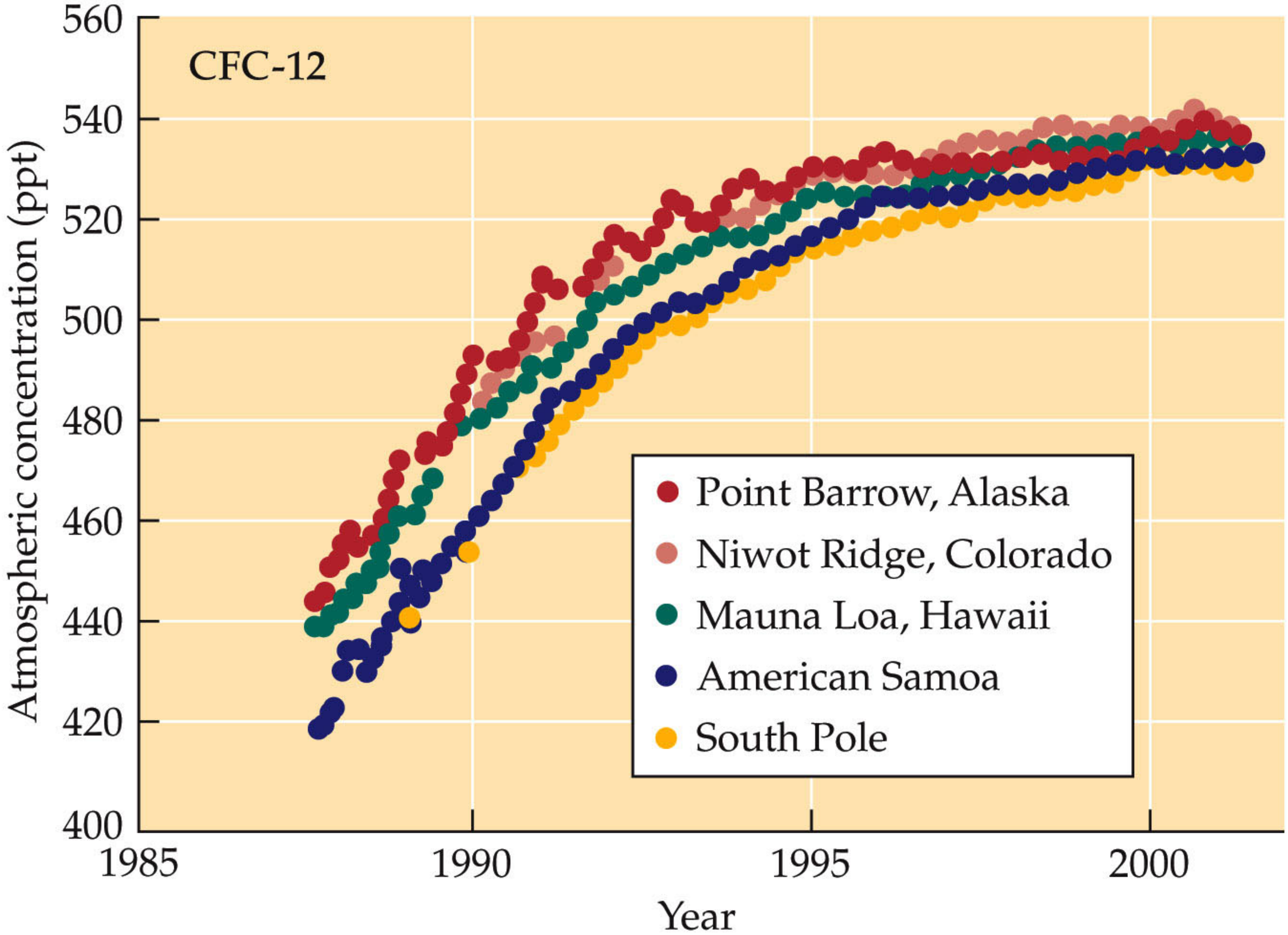


Figure 24.24 Progress against the Ozone Killers (Part 3)

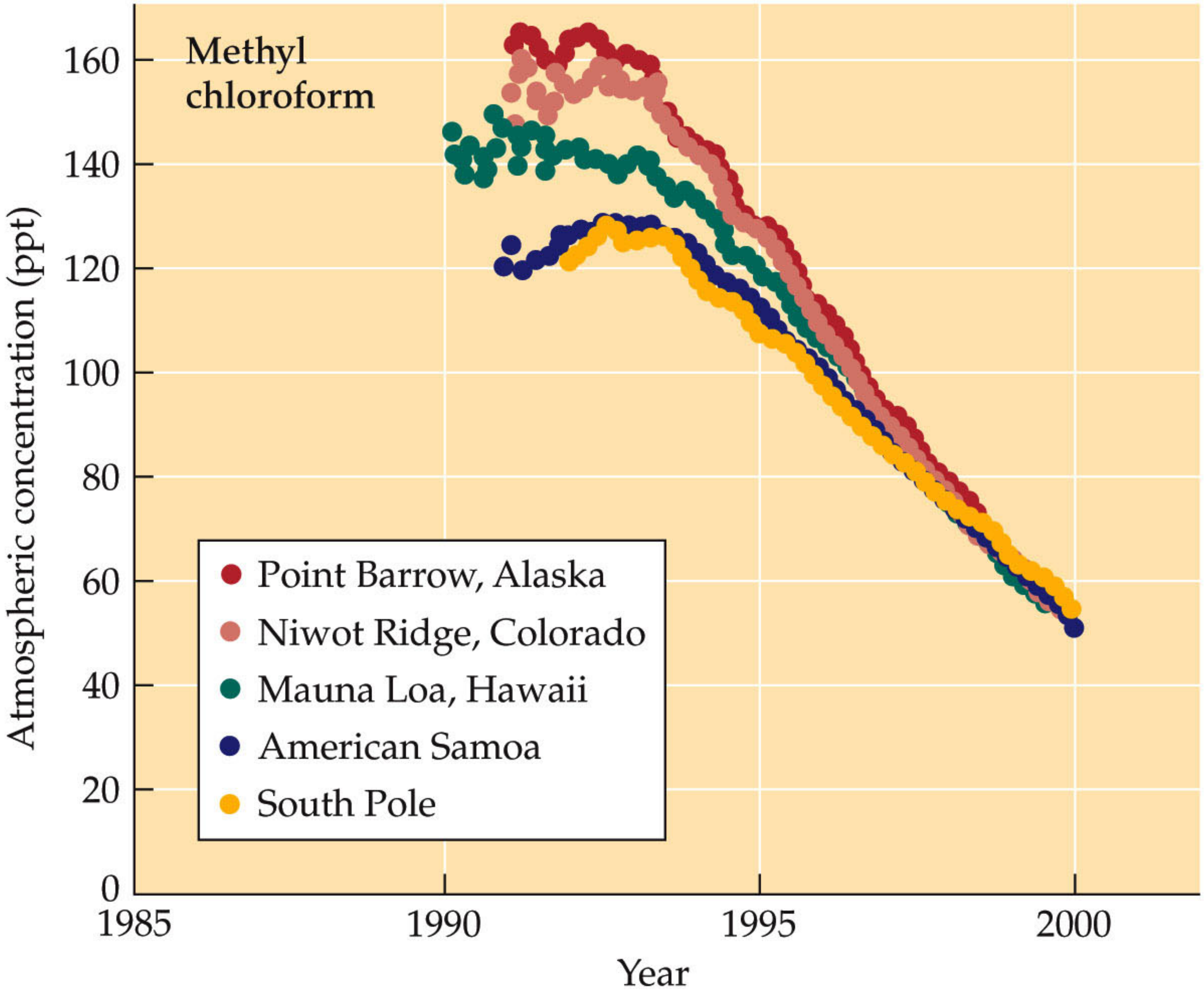
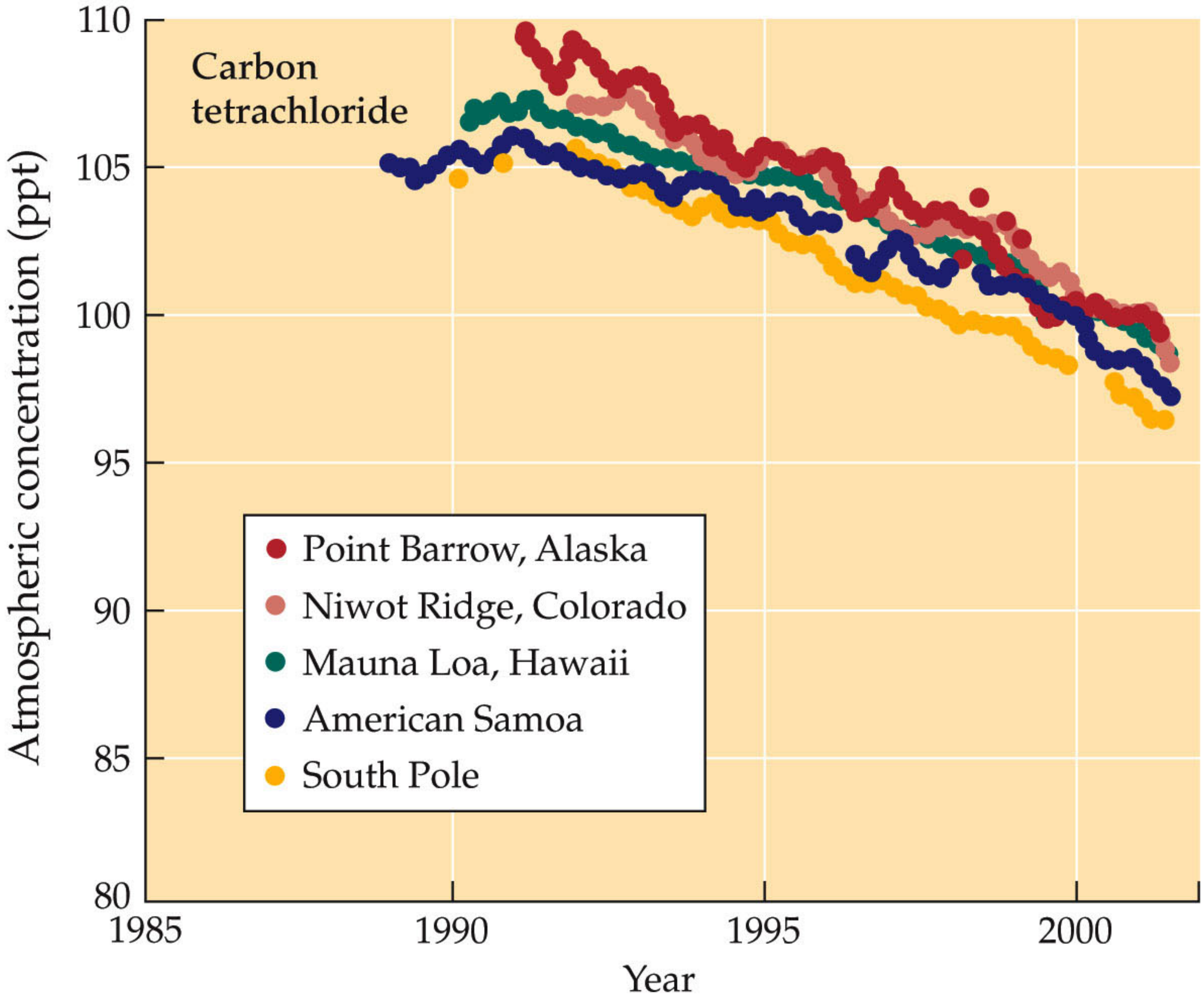


Figure 24.24 Progress against the Ozone Killers (Part 4)



Ozone in the troposphere is generated by a series of reactions involving sunlight, NO_x, and volatile organic compounds such as hydrocarbons, carbon monoxide, and methane.

Anthropogenic emissions of ozone precursor molecules have greatly increased production of ozone.

Atmospheric Ozone

Ozone is a strong oxidant—the oxygen reacts easily with other compounds.

Ozone causes respiratory damage and is an eye irritant.

Increased rate of childhood asthma has been linked to ozone.

Ozone damages plant membranes, and decreases photosynthetic rate and growth.

Atmospheric Ozone

Decreases in crop yields have been associated with exposure to ozone.

Symptoms of ozone pollution have long been noted in plants near urban areas. Recently, they have begun to show up in plants in national parks and wilderness.

Ozone also acts as a greenhouse gas. But it has a short life span in the atmosphere relative to other greenhouse gases. Its affect on climate change is hard to evaluate.

Controlling ozone has focused on lowering emissions of NO_x and volatile organic compounds, which has been relatively successful in developed countries.

Case Study Revisited: Dust in the Wind and the Decline of Coral

Atmospheric dust deposition has contributed to the widespread nature of coral reef decline (Garrison et al. 2003)

Fungal spores can be carried on dust particles. Dust samples from the atmosphere contain viable spores of some of the coral-disease fungi, including *Aspergillus.*

Case Study Revisited: Dust in the Wind and the Decline of Coral

Aspergillus causes the initial infection in the disease aspergillosis, which is followed by secondary infections by other marine fungi that do not normally attack healthy corals.

Case Study Revisited: Dust in the Wind and the Decline of Coral

The dust itself is a source of nutrients for marine biota.

Nutrient enrichment significantly increases the severity of coral diseases.

Deposition of iron can trigger more coral diseases by enhancing the growth of pathogenic sulfide-oxidizing bacteria.

Case Study Revisited: Dust in the Wind and the Decline of Coral

Pollutants such as pesticides and volatile chemicals are adsorbed onto the surfaces of dust particles.

This may also contribute to the decline in coral health.

Case Study Revisited: Dust in the Wind and the Decline of Coral

The origin of atmospheric dust is determined by measuring particle size and chemistry, particularly the ratios of certain key elements, which indicate the parent material.

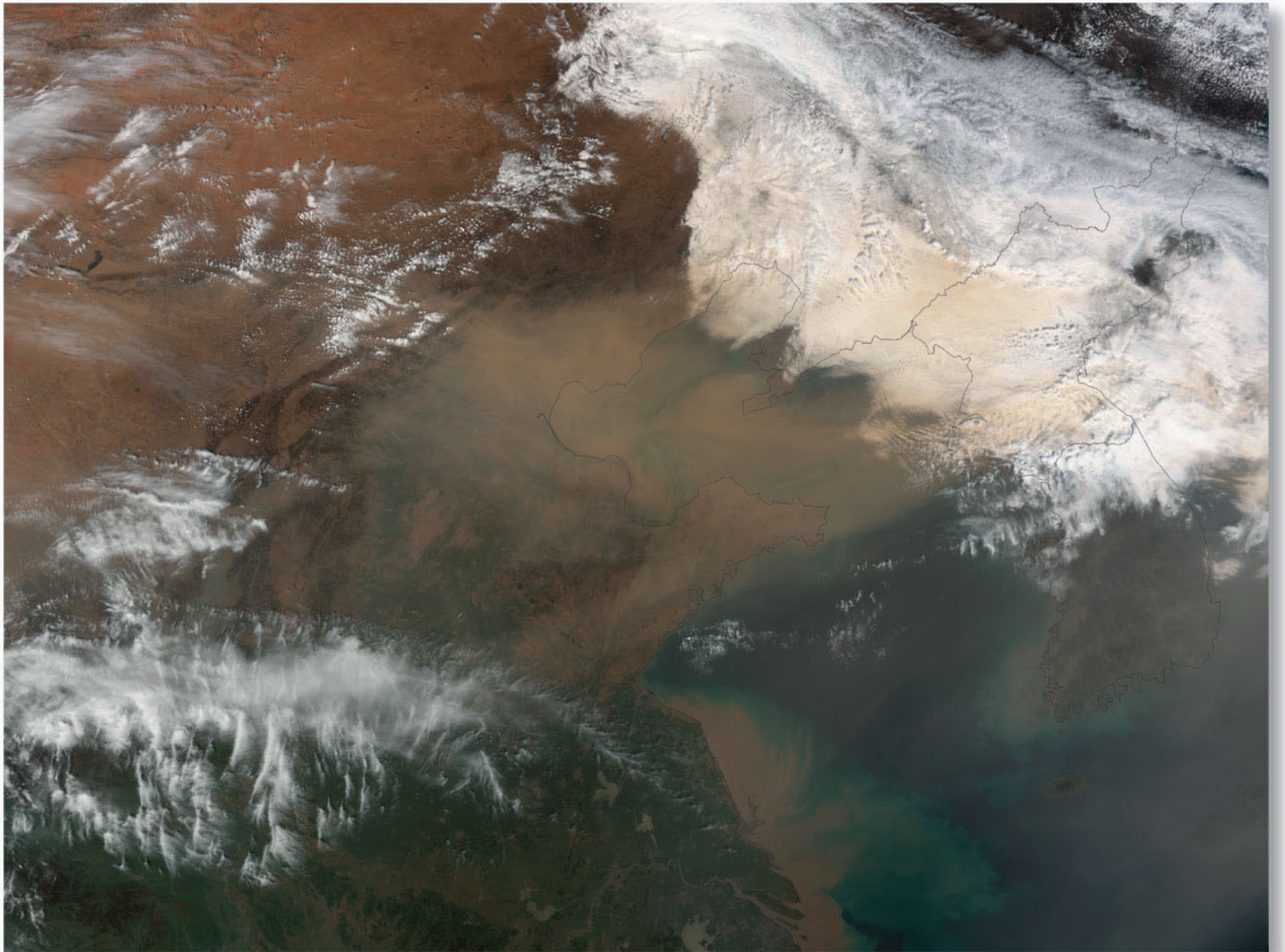
Another approach tracks the movements of air masses using weather maps, called *back-trajectory analysis*.

Case Study Revisited: Dust in the Wind and the Decline of Coral

Visible remote sensing data from satellites can also track the movement of dust storms.

Figure 24.25 A Global Dust Storms

(A)



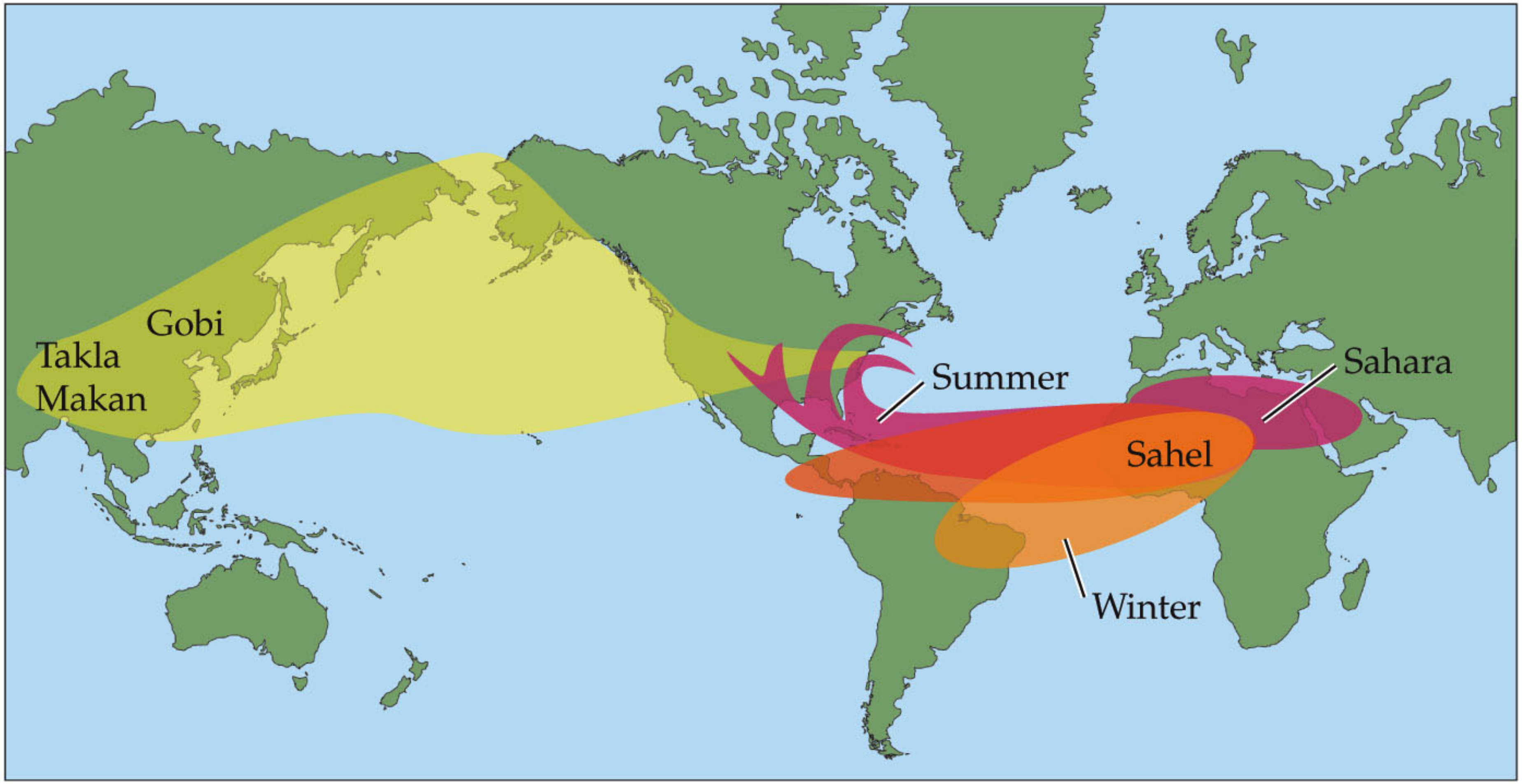
ECOLOGY, Figure 24.25 (Part 1)

Case Study Revisited: Dust in the Wind and the Decline of Coral

Results from these techniques show that dust deposited in the tropical Atlantic, Indian, and Pacific oceans has two main sources:

- The Sahara and Sahel regions of North Africa.
- The Gobi and Takla Makan deserts of Asia.

(B)



Case Study Revisited: Dust in the Wind and the Decline of Coral

These regions have undergone recent **desertification**, which involves loss of plant cover and acceleration of soil erosion.

A major cause of desertification is agricultural development in marginal sites, which has increased in these regions since the 1970s.

Case Study Revisited: Dust in the Wind and the Decline of Coral

The pattern of desertification, and subsequent dust in the atmosphere, is therefore consistent with the timing of coral reef decline.

Connections in Nature: A Historical Perspective on Dust and Ecology

Accelerating rates of desertification have resulted in dust deposition across the globe.

The effects of dust deposition on ecological processes is largely unknown.

Dust deposition of nutrients can have impacts on primary production and the global carbon cycle. Iron in dust may be important for ocean productivity.

Dust storms have also occurred in the past. During glacial periods, large amounts of loess (rock ground to fine powder by glaciers) have been transported across the globe.

Coral reefs are one of the most ancient ecosystems on Earth, probably first appearing in the Cambrian period, 500 million years ago.

Connections in Nature: A Historical Perspective on Dust and Ecology

Over the course of Earth's history, coral reefs have grown and shrunk.

The role of dust in this is uncertain. Past variation in reef extent may have been due to water temperature and sea level changes related to climate change.

The potential for dust to negatively affect coral reefs exemplifies the importance of global phenomena that influence local ecological patterns and processes.

Global ecology will continue to grow as we realize the importance of global biogeochemical cycles in local ecological phenomena, and the role of humans in intensifying their effects.