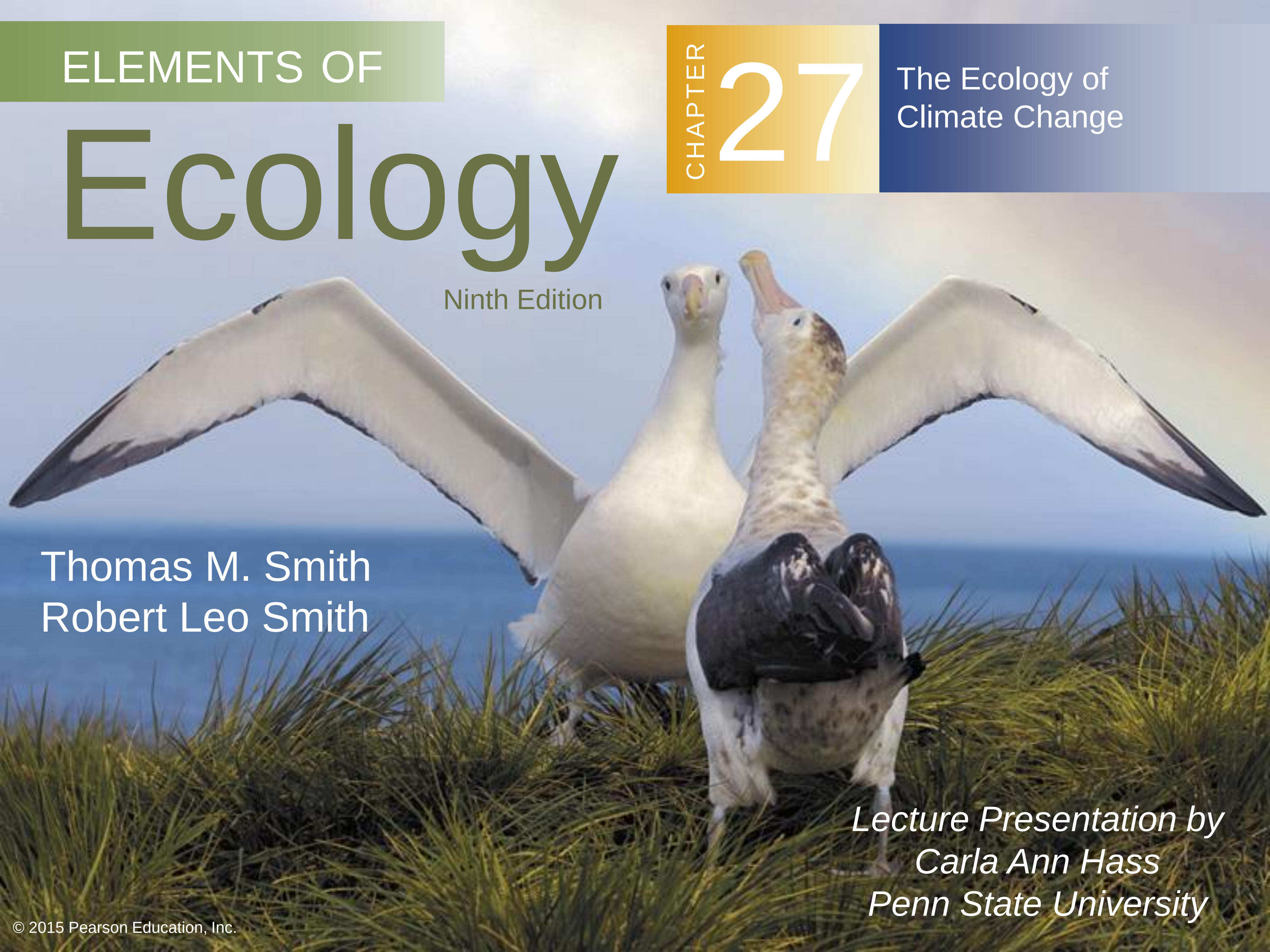

ELEMENTS OF

Ecology

Ninth Edition

CHAPTER 27

The Ecology of Climate Change

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Lecture Presentation by
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Chapter 27 The Ecology of Climate Change

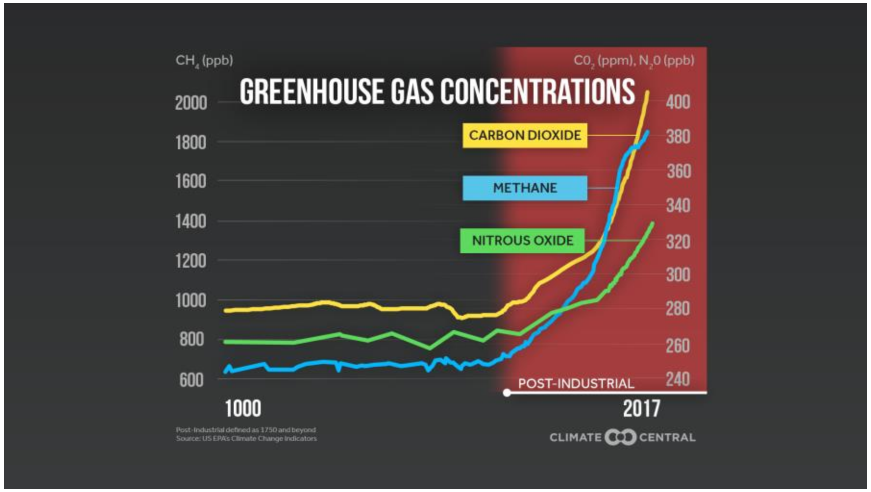
- What natural phenomena have caused climate change in the past?
- How are humans affecting the climate of the Earth today?

Chapter 27 The Ecology of Climate Change

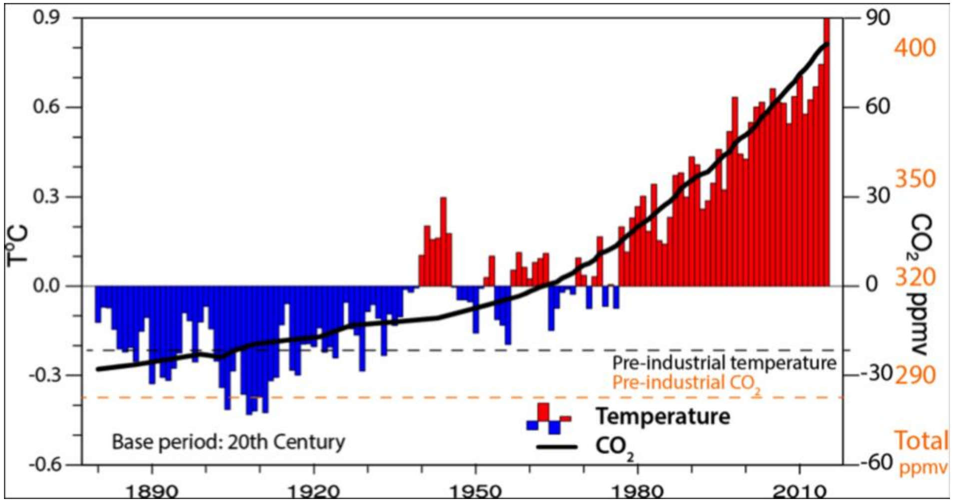
- Change is inherent in Earth's climate system so the term **global climate change** is redundant
- The amount of tilt in Earth's rotation affects the amount of sunlight striking the different parts of the globe and causes the seasons
  - Tilt of Earth's axis varies from 22.5° to 24° over a cycle of 41,000 years
  - This is responsible for the ice ages

Chapter 27 The Ecology of Climate Change

- Since the Industrial Revolution began, the burning of fossil fuels has led to an exponential increase in the concentration of carbon dioxide and other greenhouse gases in the atmosphere
- This has led to a general pattern of warming over the past century



Post-Industrial defined as 1750 and beyond
Source: US EPA's Climate Change Indicators

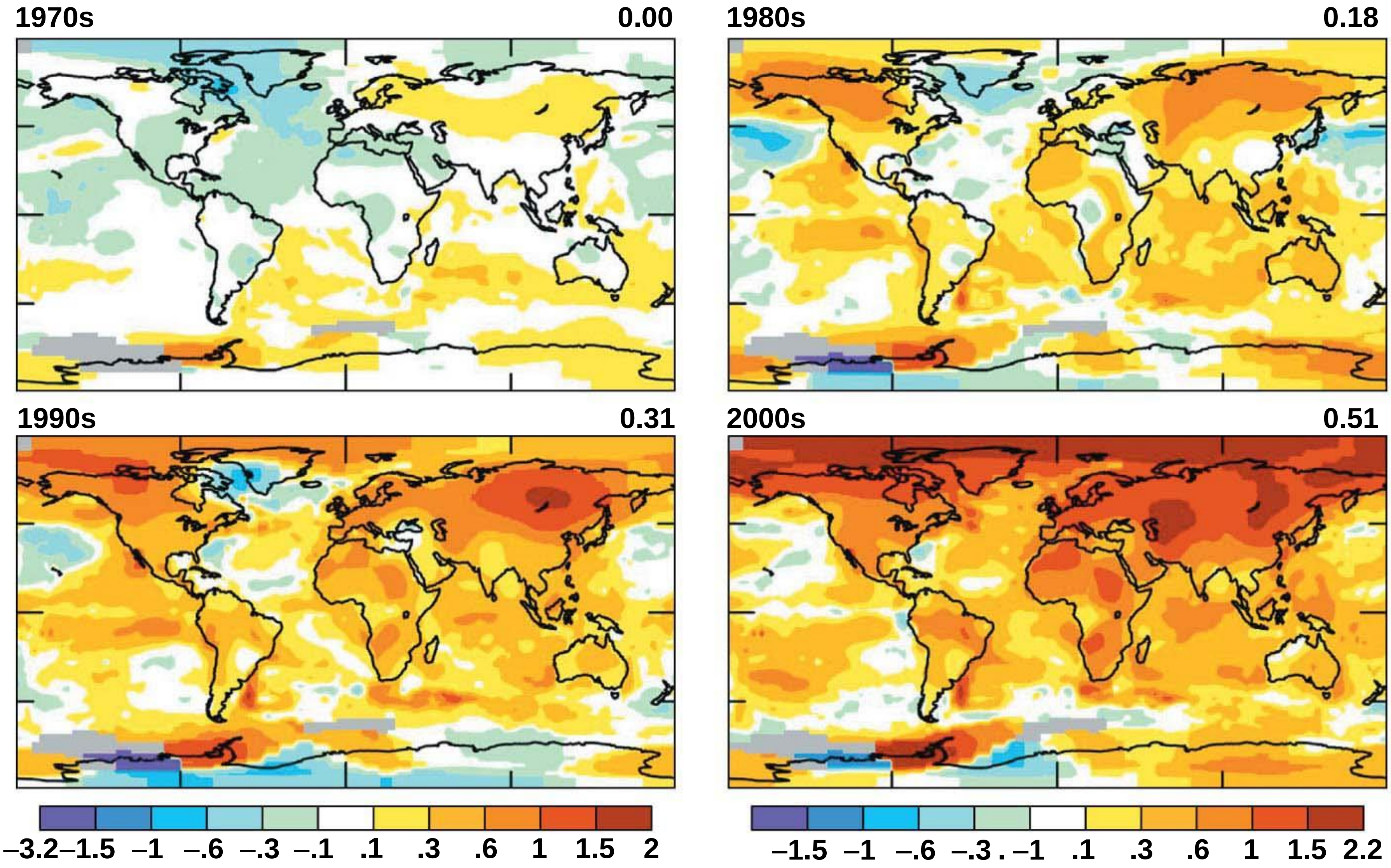


Section 27.1 Earth's Climate Has Warmed over the Past Century

- These temperature changes have not been equal across Earth's surface
  - regional changes have been very heterogeneous
  - the polar regions have warmed the most, especially the Arctic
- Throughout the seasons
  - the winter months show the greatest warming
  - diurnal temperature ranges have decreased
    - Minimum temperatures have risen twice as fast as maximum

Figure 27.1

Decadal Surface Temperature Anomalies (°C)



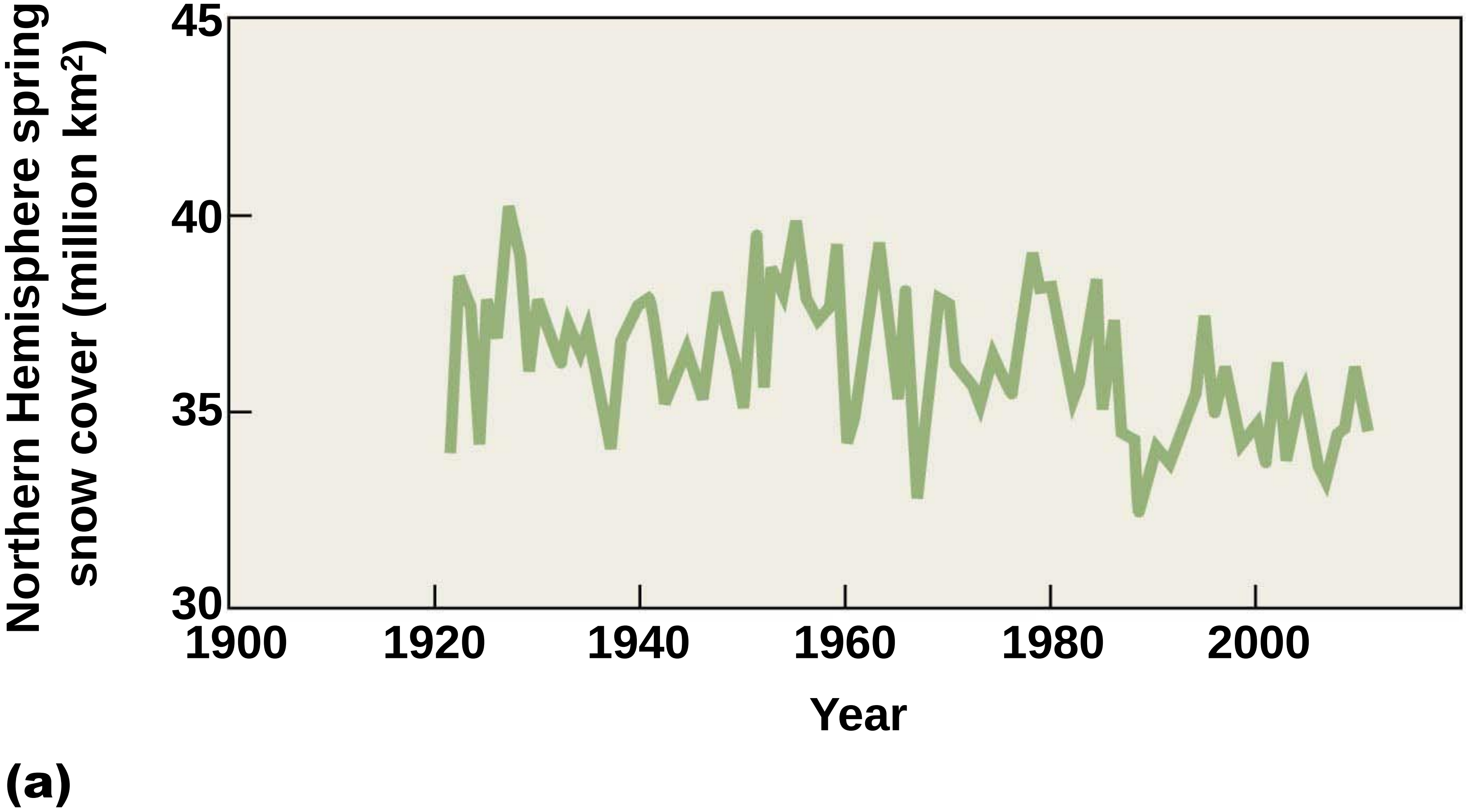
Decadal changes (°C) in mean annual surface temperatures for the period of 1970 to 2010. Changes (anomalies) were calculated as the difference between the current year mean surface temperature and the average surface temperature for the base period of 1951 to 1980 (a period over which temperatures were relatively stable; see Figure 2.26). The value reported in the upper right corner of each map is the global average temperature change for that decade. (From Hansen et al. 2010.)

Section 27.1 Earth's Climate Has Warmed over the Past Century

- Features of the global climate system have been influenced by changes in Earth's surface energy balance, affecting terrestrial and aquatic ecosystems
  - There has been a 10 percent decrease in snow cover/ice extent since the late 1960s

Figure 27.2a

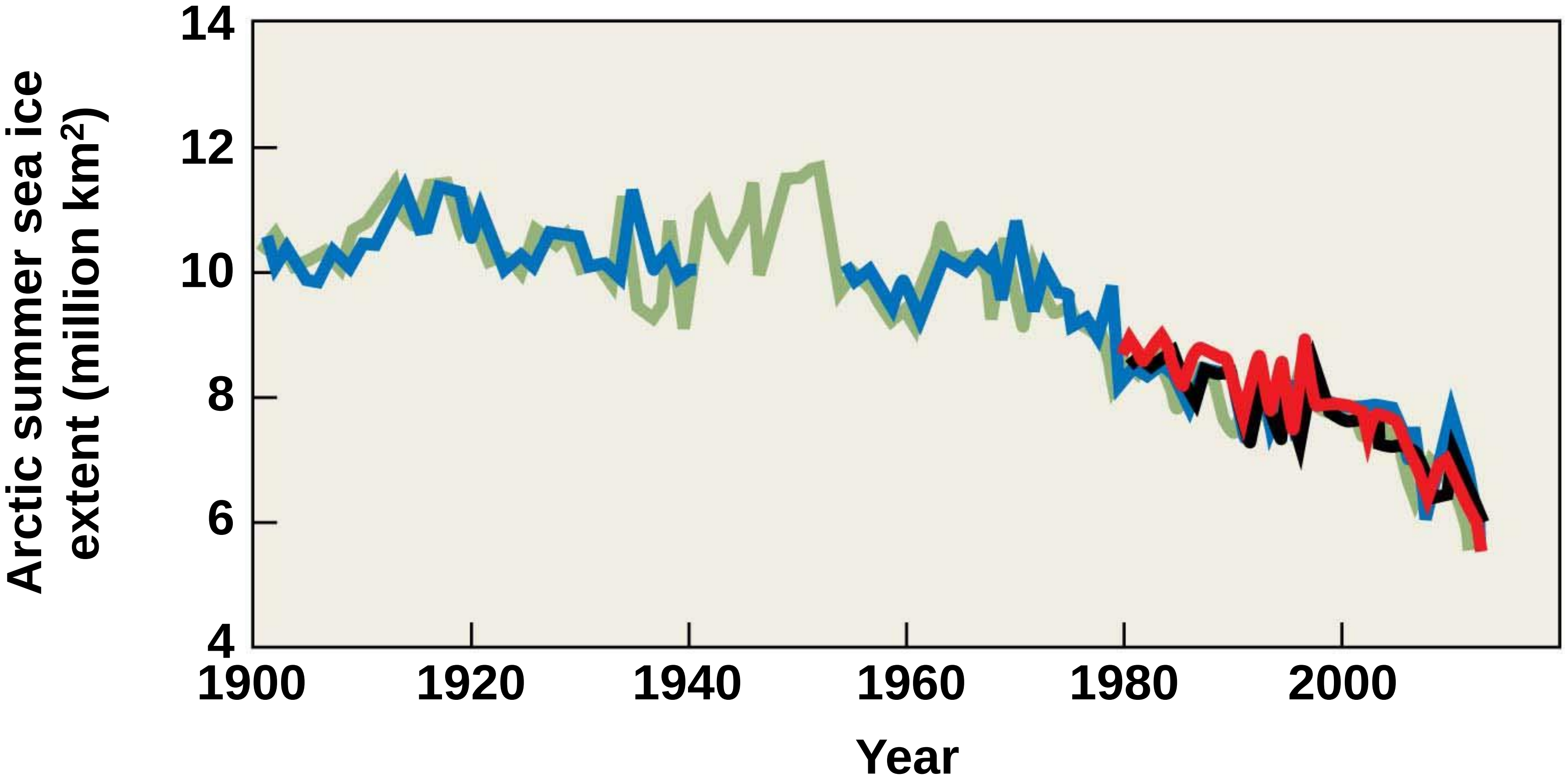
Changes in (a) Northern Hemisphere spring snow cover, (b) Arctic summer sea ice extent, (c) global average heat content of upper ocean waters, and (d) global average sea level over the past century.
(From Intergovernmental Panel on Climate Change 2013.)



Section 27.1 Earth's Climate Has Warmed over the Past Century

- The average global ocean temperature has increased to a depth of at least 3000 feet
  - The ocean has absorbed > 80 percent of the added heat

Figure 27.2b

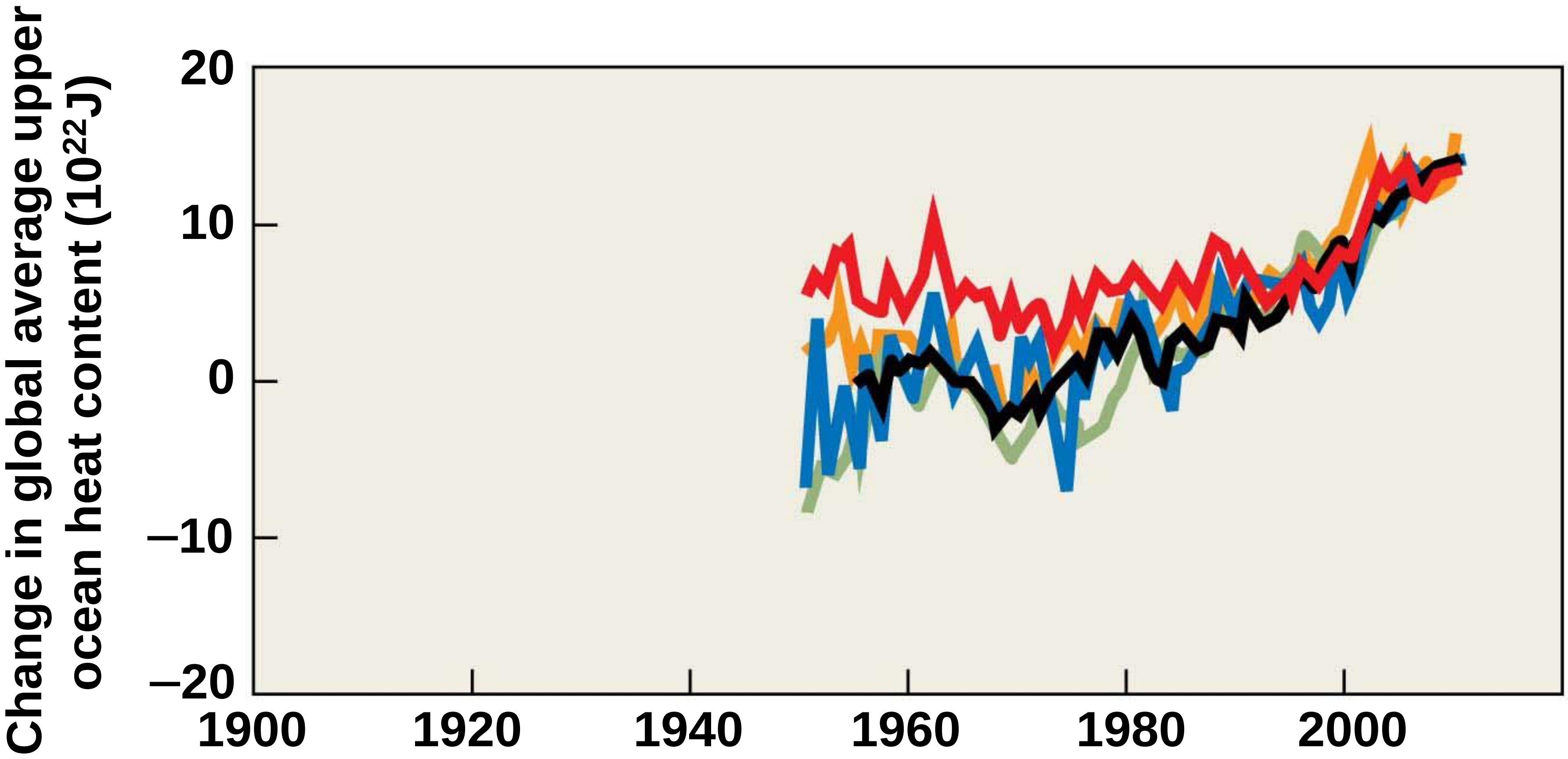


(b)

Section 27.1 Earth's Climate Has Warmed over the Past Century

- The warming of the ocean surface has been largest over the Arctic Ocean

Figure 27.2c

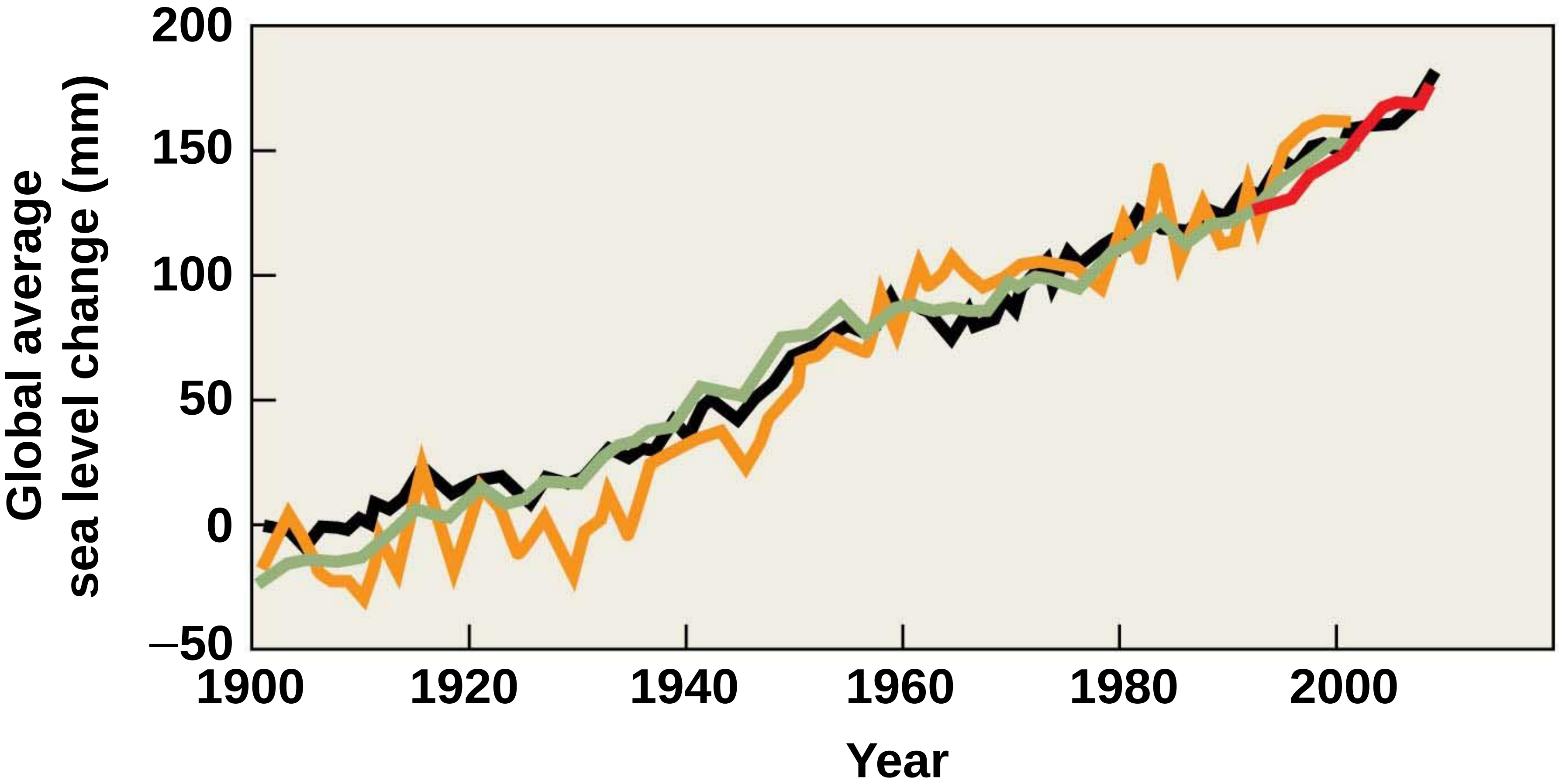


(c)

Section 27.1 Earth’s Climate Has Warmed over the Past Century

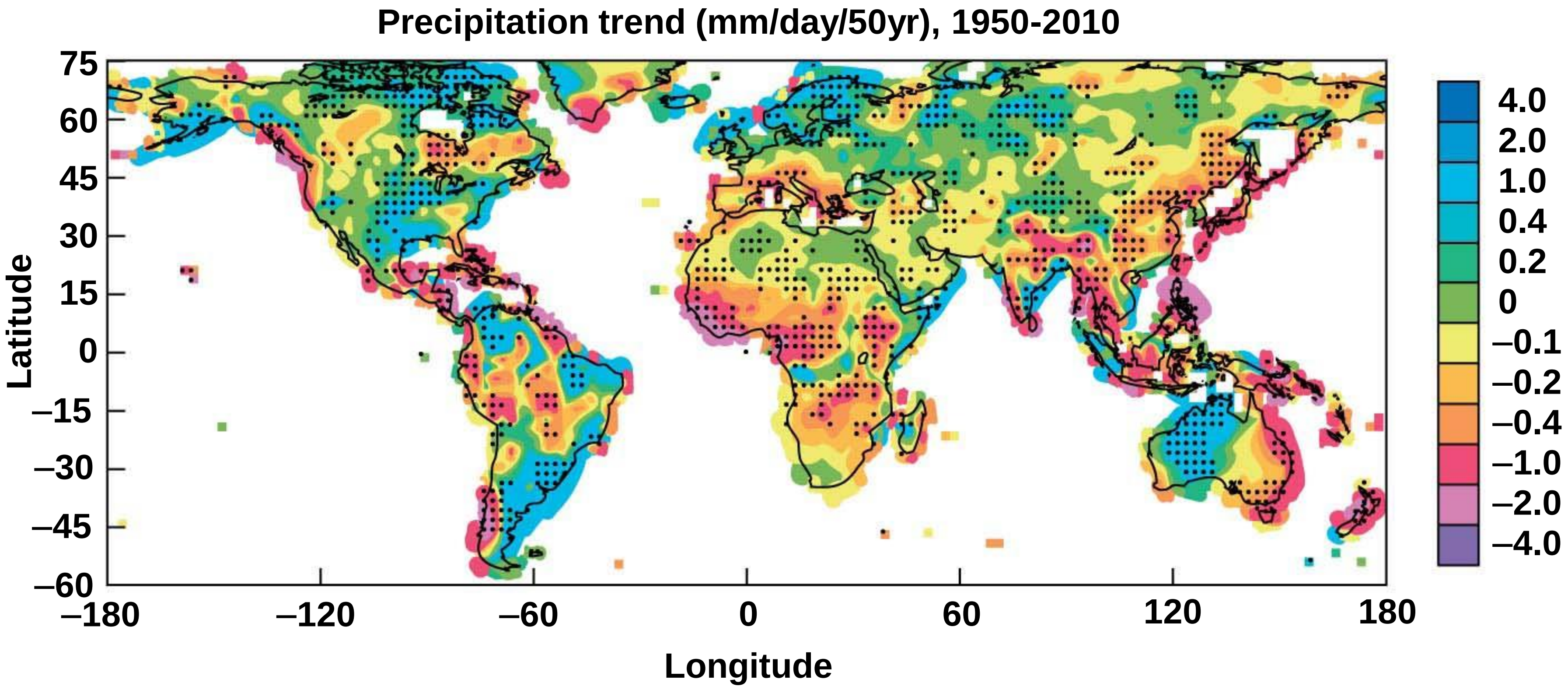
- Warming causes seawater to expand, raising the sea level

Figure 27.2d



(d)

Figure 27.3


Precipitation trend (mm/day/50yr), 1950-2010
Latitude
75
60
45
30
15
0
–15
–30
–45
–60
Longitude
–180
–120
–60
0
60
120
180
4.0
2.0
1.0
0.4
0.2
0
–0.1
–0.2
–0.4
–1.0
–2.0
–4.0

Section 27.2 Climate Change Has a Direct Influence on the Physiology and Development of Organisms

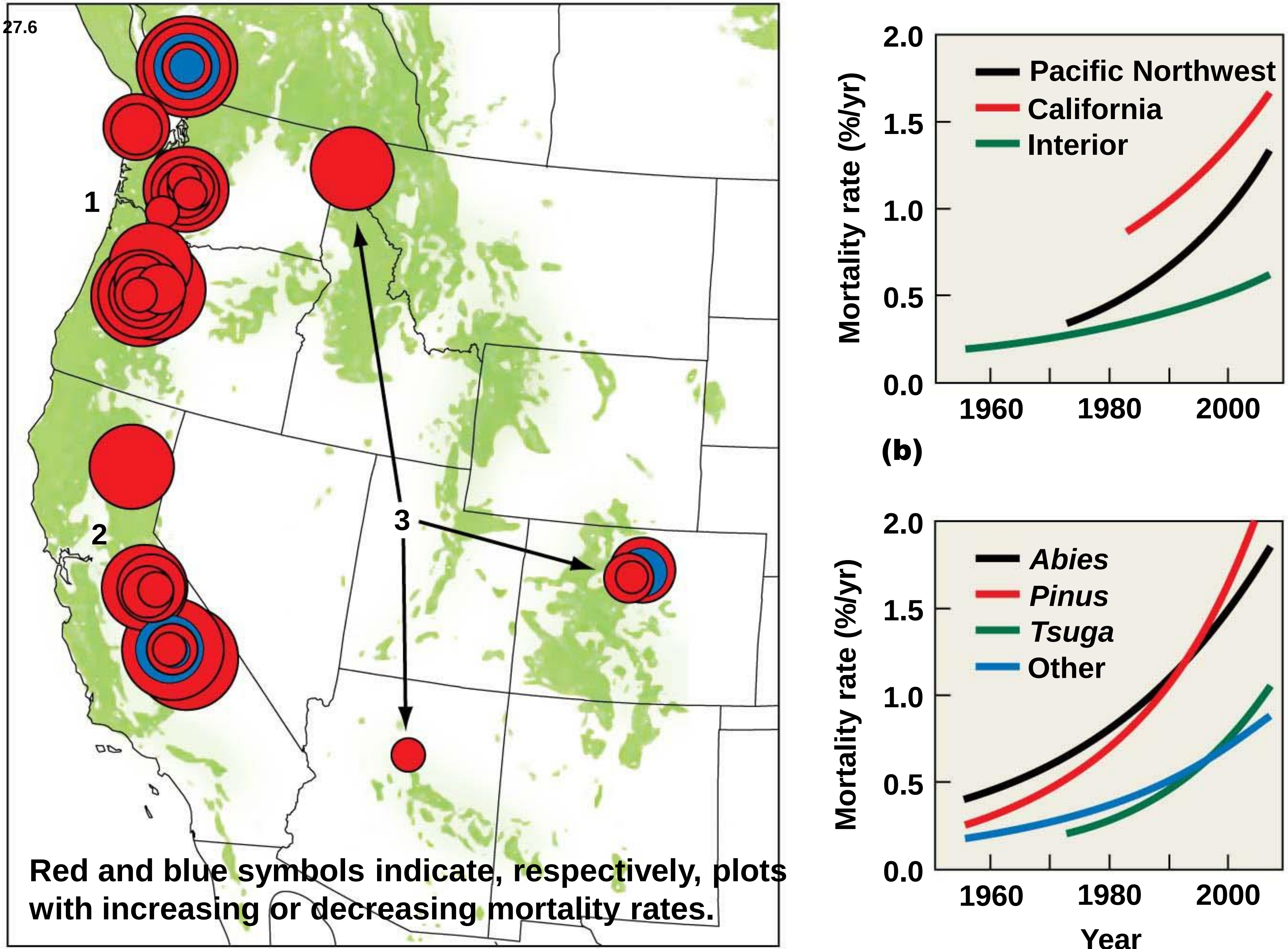
- Investigating impacts of recent climate change on terrestrial plant species is more complicated
- Response of plants to changes in both temperature and precipitation is influenced by atmospheric CO_2 levels
  - Temperature and CO_2 levels have risen in parallel
- Regional changes in climate also can be modified by edaphic and microhabitat conditions
- Given these complicating factors, some general, regional trends have been reported

Section 27.2 Climate Change Has a Direct Influence on the Physiology and Development of Organisms

- An increase in growth rates over the past century has been shown through tree ring analysis of trees in mesic areas of eastern North America
  - correlated to an increase in the length of the growing season (first and last frost)
- In western North America, increasing droughts associated with warming have increased tree mortality

(a) Locations of the 76 forest plots in the western USA and southwestern British Columbia. Red and blue symbols indicate, respectively, plots with increasing or decreasing mortality rates. Symbol size corresponds to annual fractional change in mortality rate (smallest symbol, < 0.025 per year; largest symbol, > 0.100 per year; the three intermediate symbol sizes are scaled in increments of 0.025 per year). Numerals indicate groups of plots used in analyses by region: (1) Pacific Northwest, (2) California, and (3) interior. Forest cover is shown in green. Average trends in tree mortality rates are shown by (b) region and (c) tree genus (Aibes, fir; Pinus, pine; Tsuga, hemlock).(From van Mantgem et al. 2009.)

Figure 27.6



Red and blue symbols indicate, respectively, plots with increasing or decreasing mortality rates.

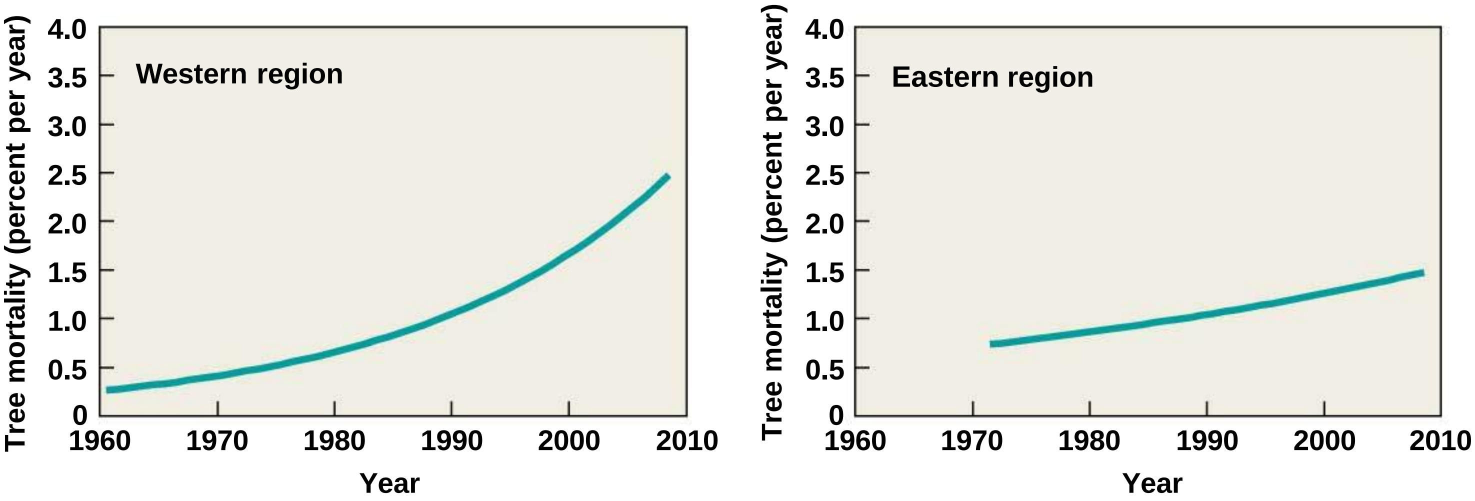
Section 27.2 Climate Change Has a Direct Influence on the Physiology and Development of Organisms

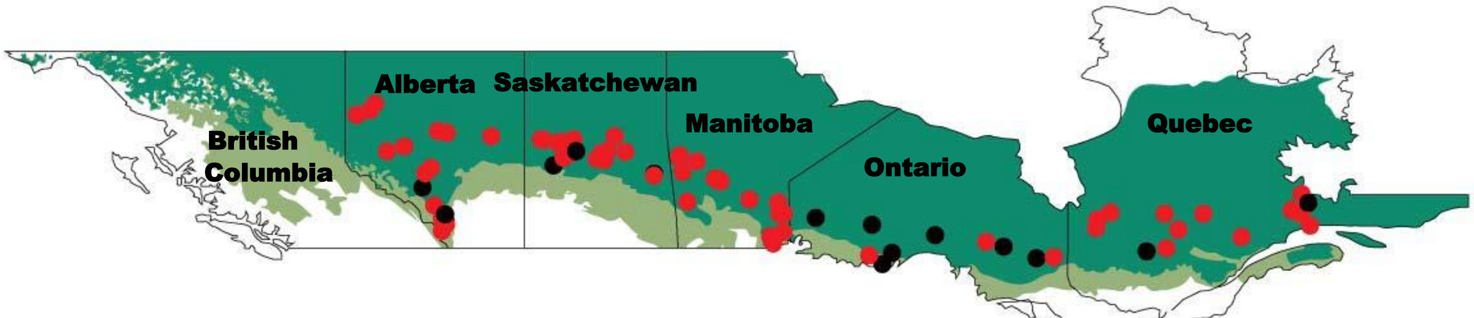
- In tropical rain forests of Costa Rica, there was a decrease in the growth rate of six rain forest tree species
  - Associated with increasing minimum daily temperature (temperature at night) over 16 years
  - This was the result of higher rates of respiration
- A similar trend was seen for a dominant grass (C_4) in the shortgrass prairies of the Great Plains
  - Daily minimum temperatures have increased at about twice the rate of daily maximum temperatures over the last 50 years

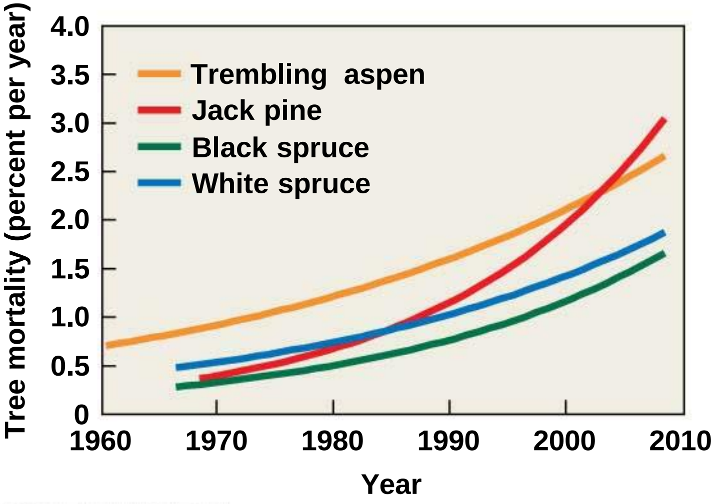
Section 27.2 Climate Change Has a Direct Influence on the Physiology and Development of Organisms

- Mixed results from studies of the response of tree growth to recent climate change in the Arctic
- Some studies have shown localized increases in tree growth rates over the past 50 years of warming
- Most showed declines in growth rates and increases in mortality as a result of a rise in warming-related water stress
- Sites from the entire boreal forest region of Canada was studied from 1963 to 2008 (96 sample plots)
  - Tree mortality rates increased, greater in the west than the east

Figure 27.7







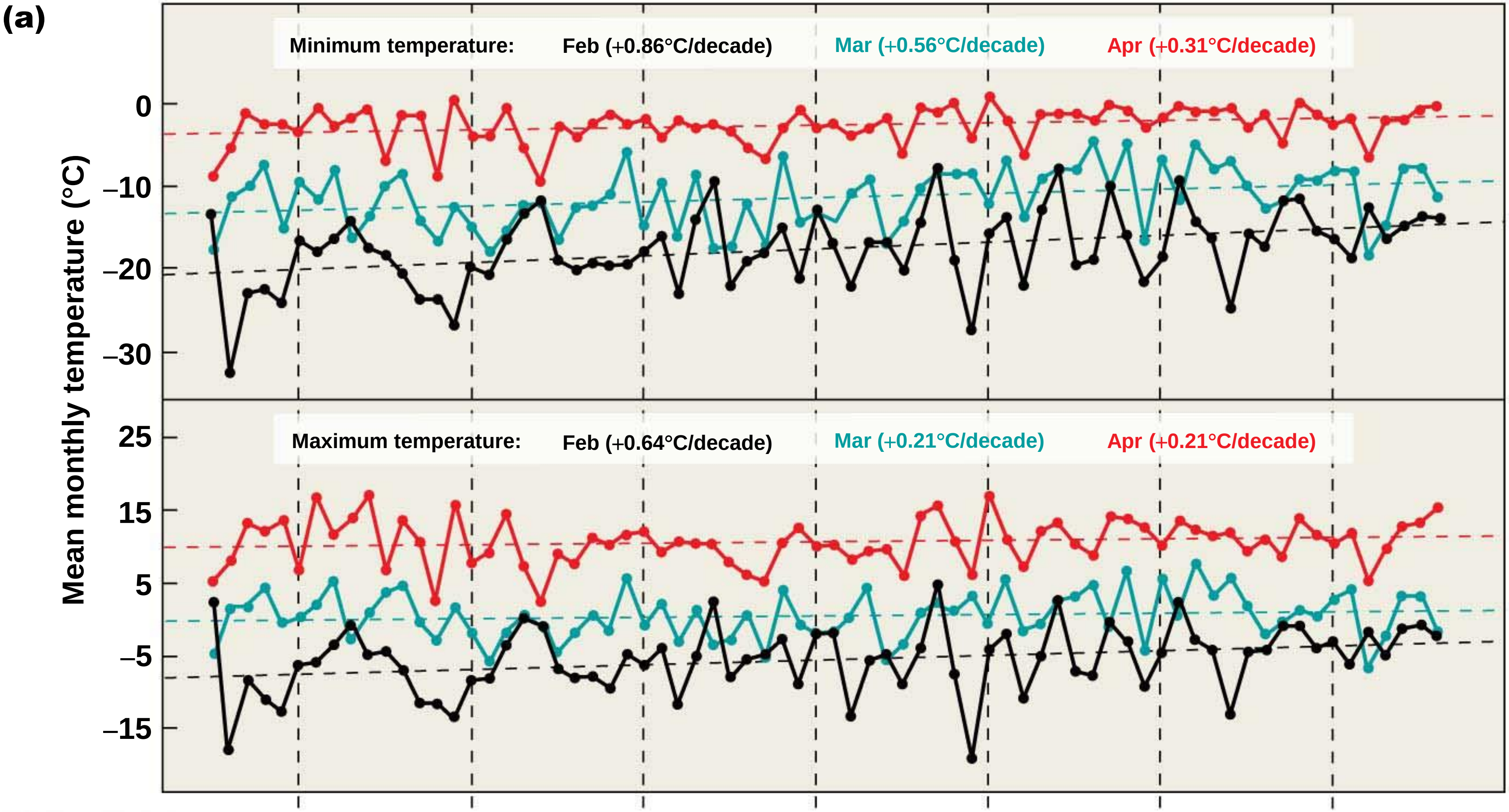
Locations of the 96 forest permanent sampling plots in Canada's boreal forests. The black and red points represent plots with decreasing and increasing mortality rates, respectively.

The background colors of green and light green represent, respectively, Canada's boreal and hemiboreal (transition between boreal and northern temperate) regions.

Average trends in tree mortality rates are shown for the Eastern and Western Regions of Canada and for the major tree species.

Figure 27.10a

Temperature trends for the central Alberta, Canada study area for (a) the change in the mean monthly minimum temperature and the change in the mean monthly maximum temperature. (b) Corresponding trends in observations of first bloom for seven plant species in the study area species.

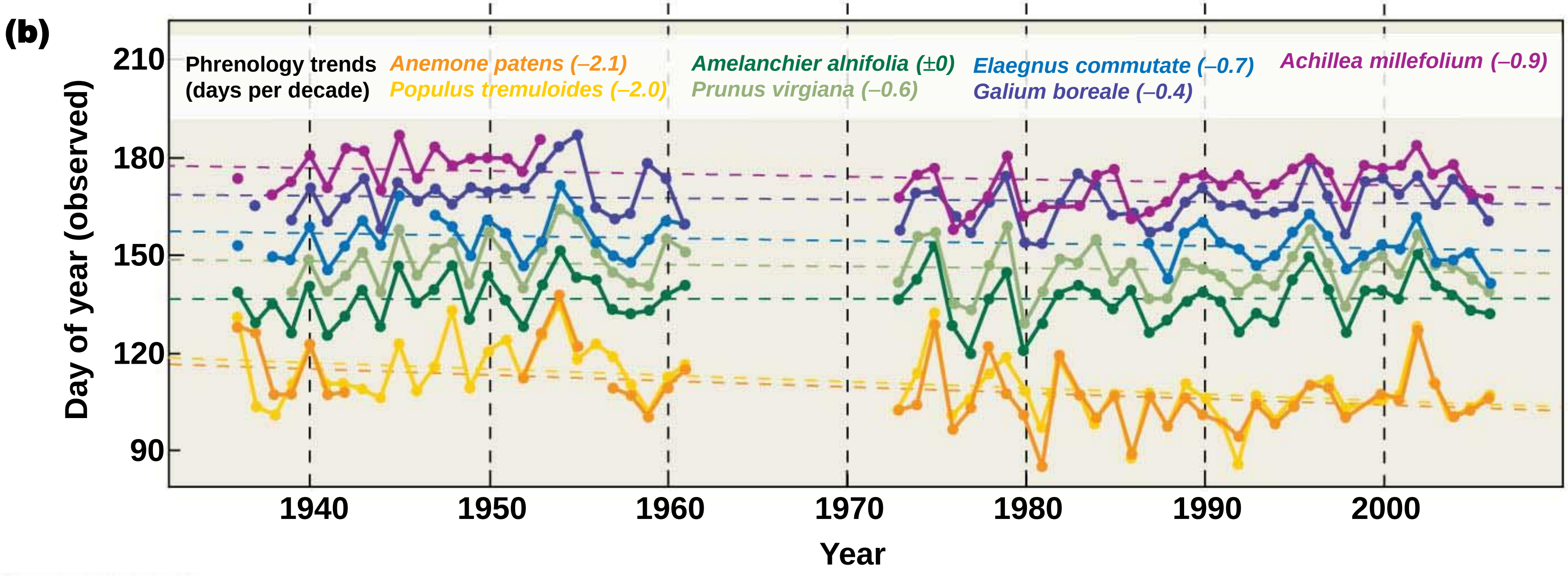


Section 27.3 Recent Climate Warming Has Altered the Phenology of Plant and Animal Species

- Extensive data sets are available for plant populations, particularly in northern latitudes
- Study on climate trends and flowering times for seven plant species in Alberta, Canada
- During the 71 years of the study, there has been substantial warming

Figure 27.10b

Temperature trends for the central Alberta, Canada study area for (a) the change in the mean monthly minimum temperature and the change in the mean monthly maximum temperature. (b) Corresponding trends in observations of first bloom for seven plant species in the study area species.

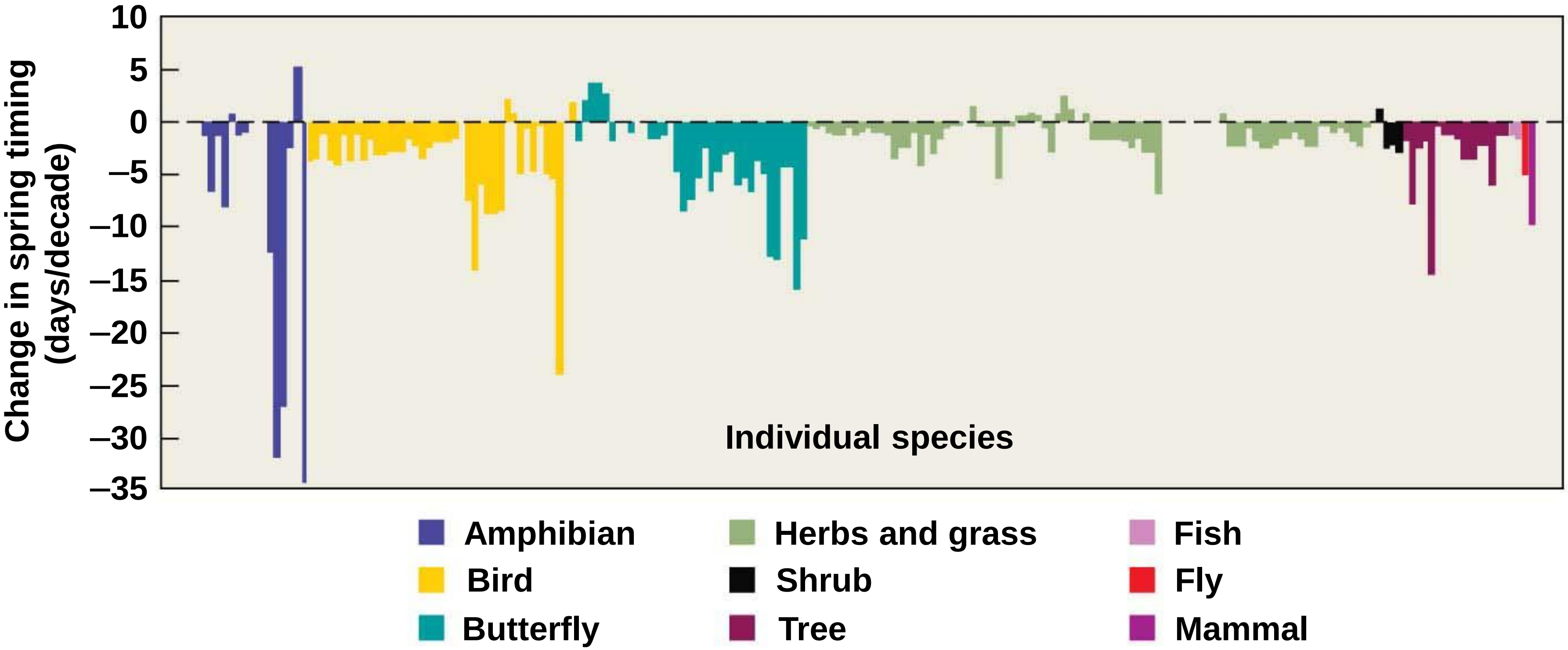


Section 27.3 Recent Climate Warming Has Altered the Phenology of Plant and Animal Species

- Flowering dates for the early blooming species advanced an average of two weeks over this time
- The late-flowering species advanced between zero and six days

Figure 27.11

Summary of results from published studies that have examined the phenological responses of 203 different plant and animal species to recent changes in climate. Observed changes in the timing of spring events are expressed in days per decade for individual species grouped by taxonomy or functional type for the combined data set. Each bar represents a separate, independent species. Negative values indicate advancement (earlier phenology through time), whereas positive values indicate delay (later phenology through time). Note that most species experience an advance in the timing of spring activities.



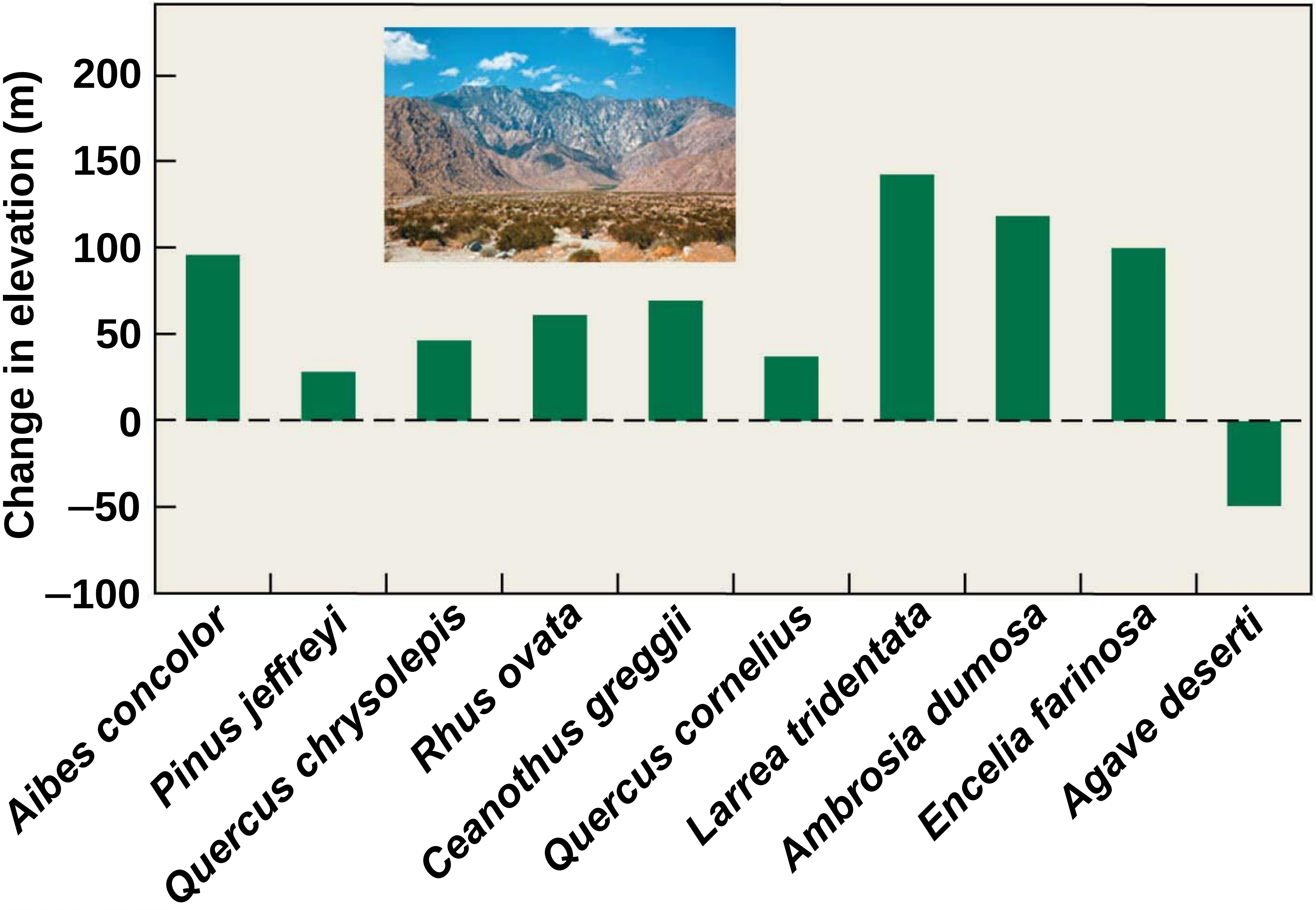
Section 27.3 Recent Climate Warming Has Altered the Phenology of Plant and Animal Species

- Review of published studies for 203 plant and animal species in the Northern Hemisphere
    - Overall, shifts are larger at higher latitudes
- Amphibians had a greater shift toward early breeding times than other taxonomic groups
    - more than twice as fast as trees, birds, butterflies
- Butterfly emergence or migratory arrival advanced three times faster than the first herbaceous plant flowering
    - could impact insect-plant interactions

Section 27.4 Changes in Climate Have Shifted the Geographic Distribution of Species

- As the climate warms, the minimum temperatures should shift toward higher latitudes and elevations
- If dispersal and other factors allow, species should track the shifting climate, shifting their distribution poleward in latitude and upward in elevation
- Do the experimental data support this expectation?

Figure 27.15 Change in elevational range (meters) of the 10 most widely distributed plant species along the Deep Canyon transect in Southern California's Santa Rosa Mountains between 1997 and 2007. Positive values represent a movement of the species' range up the mountain range (increase in elevation), whereas a negative value represents a contraction of the species' range. (Data from Kelly and Goulden 2008.)



Section 27.4 Changes in Climate Have Shifted the Geographic Distribution of Species

- Numerous studies have shown shifts of plant elevational boundaries in mountain areas
- Surveys of plant cover in 1977 for an elevation gradient in southern California compared with those done in 2006–2007
- Over the 30-year period,
  - the climate warmed, with a 0.4°C increase in mean temperature
  - precipitation variability increased
  - amount of snow decreased

Section 27.4 Changes in Climate Have Shifted the Geographic Distribution of Species

- The average elevation of the dominant plant species increased by 65 m; all species except one showed a distribution shift up the mountain range

Section 27.4 Changes in Climate Have Shifted the Geographic Distribution of Species

- Observations of shifts in plant species' distributions in response to recent climate change are more limited
- Study using large-scale forest inventory data examined the distributional changes for seedlings and trees of 92 species in the eastern United States
  - compared changes in species distributions from 1999 to 2009 with patterns of temperature and precipitation change in the 20th century

Section 27.4 Changes in Climate Have Shifted the Geographic Distribution of Species

- Results suggest that 54 of the 92 species showed a pattern consistent with range contraction, rather than expansion, at both the northern and southern boundaries
  - 19 species had a pattern consistent with northern shift
  - 25 species had a pattern consistent with southern shift
  - Only 4 species showed expansion at both range limits
- No consistent evidence that shifts in these populations are greatest in areas where climate has changed the most

Section 27.4 Changes in Climate Have Shifted the Geographic Distribution of Species

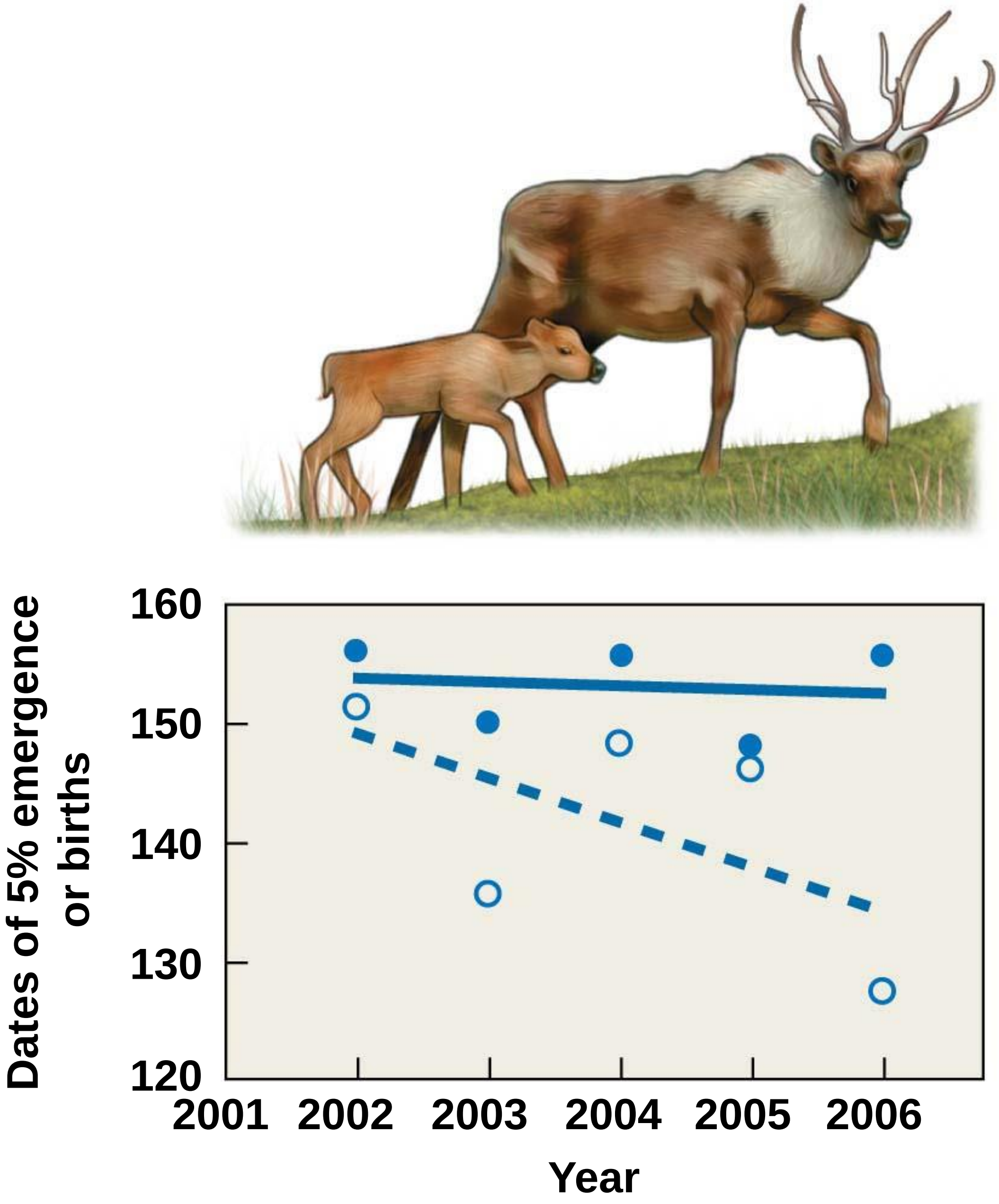
- In the Arctic, a number of studies have shown a northern expansion in the abundance and extent of shrub species into tundra areas
- Study (1942 to 2002) shows the cover of alder, willow and dwarf birch has been increasing
    - most obvious on hill slopes and valley bottoms
- Studies in Canada, Scandinavia, and parts of Russia have reported similar findings
- A vegetation transition as a result of recent climate warming appears to be taking place in the Arctic

Section 27.5 Recent Climate Change Has Altered Species Interactions

- Climate change can influence interactions among species within existing communities through its different effects on different species
- Often interactions are modified because species show different phenological responses to changes in important climate variables
- Reproduction is timed to correspond to resource availability
  - For herbivores, this is the plant growing season
  - If plant phenology changes, will it affect herbivores?

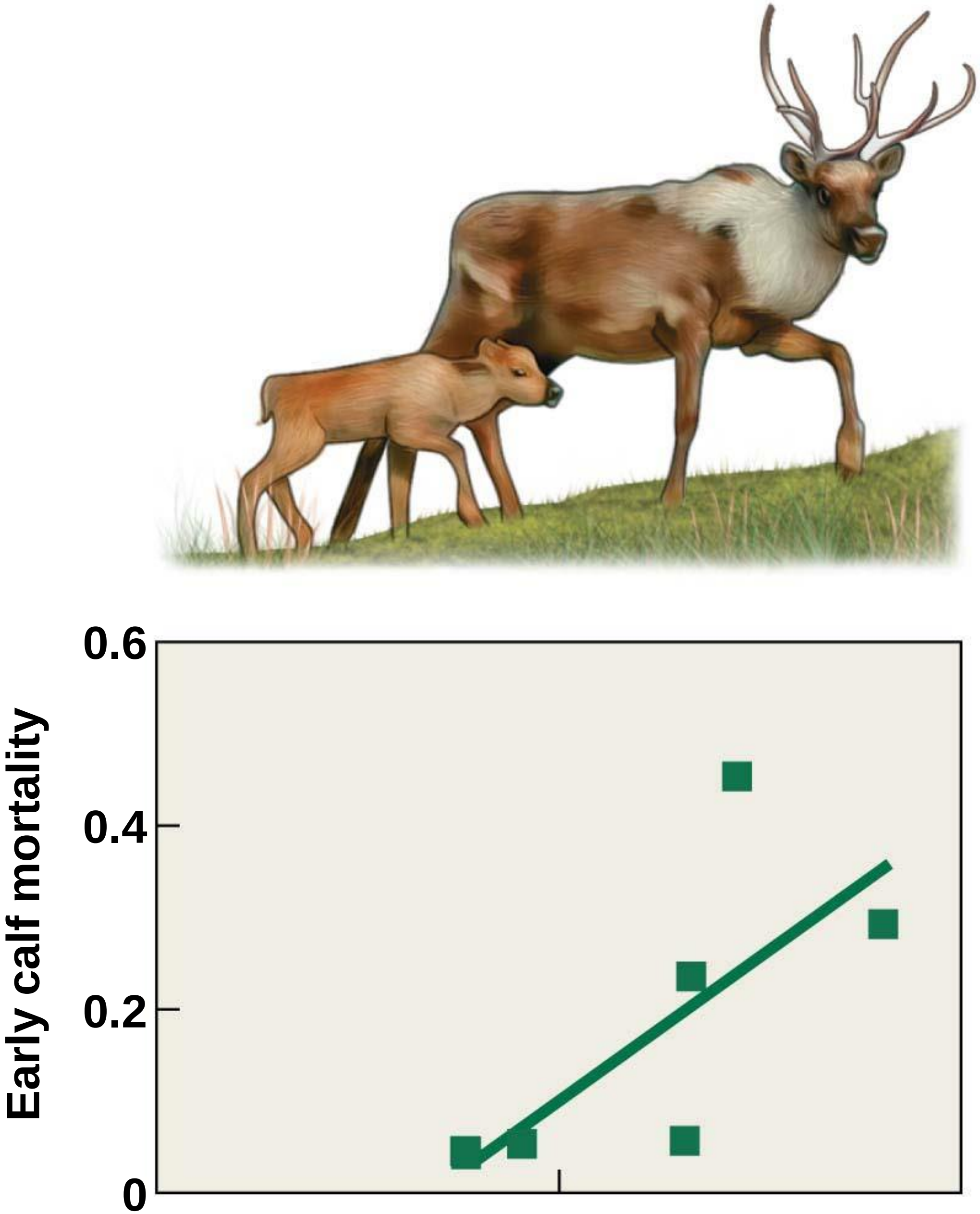
Figure 27.16a

(a) Dates (in day of year) of emergence of 5 percent of forage species (open circles, dashed line) and of 5 percent of caribou births (filled circles, solid line) at the study site in Kangerlussuaq, West Greenland, during the period of continuous annual data collection from 2002 to 2006. Relation between the magnitude of trophic mismatch between caribou calving and plant phenology (as shown in (a)) and (b) early calf mortality, and (c) calf production. Calf production is estimated as the final proportion of calves observed each year. The index of the degree of trophic mismatch each year is based on the percentage of forage species emergent on the date at which 50 percent of caribou births have occurred. This index quantifies the temporal state of the forage resource midway through the season of caribou births.
(From Post and Forchhammer 2008.)

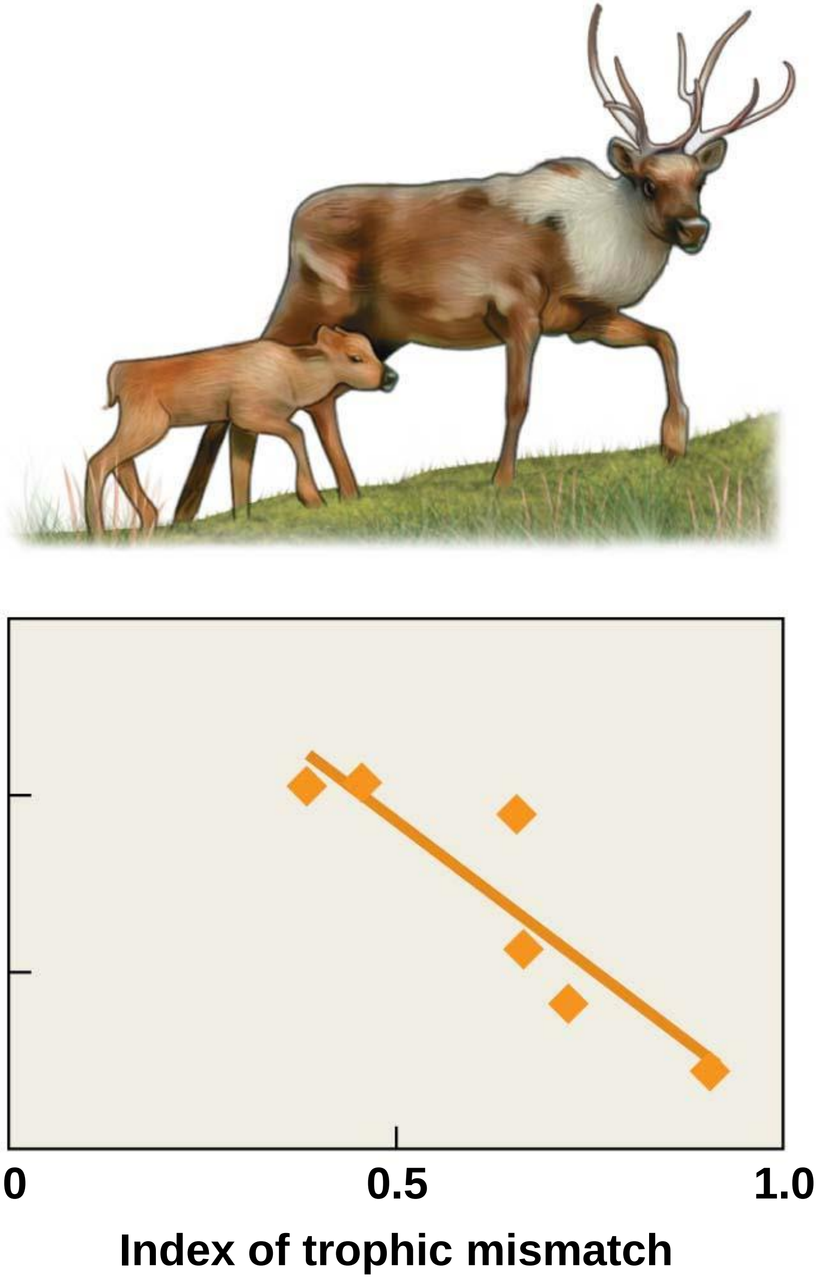


(a)

Figure 27.16b



(b)



(c)

Section 27.5 Recent Climate Change Has Altered Species Interactions

- Study conducted over six summers in western Greenland
- Monitored caribou calving season and plant phenology (timing and progression of emergence)
  - Successful caribou reproduction depends on synchrony of calving with resource abundance
  - In the far north, plant nutrient content and digestibility peak soon after emergence and then decline rapidly

Section 27.5 Recent Climate Change Has Altered Species Interactions

- Onset of plant growing season (based on plant species emergence) advanced by 14.8 days (open circles)
- Onset of calving advanced by 1.28 days (filled circles)
- This results in a rapidly developing mismatch between caribou reproduction and food supply

Section 27.5 Recent Climate Change Has Altered Species Interactions

- There is a difference in the environmental cues that trigger each event
- Caribou are cued by changes in day length
  - same from year to year
- The growing season of the plants is correlated with mean spring temperature
  - increased by 4.6°C during the study

Section 27.5 Recent Climate Change Has Altered Species Interactions

- The rate of calf mortality increased as the degree of mismatch increased
- The annual calf production decreased as the degree of mismatch increased

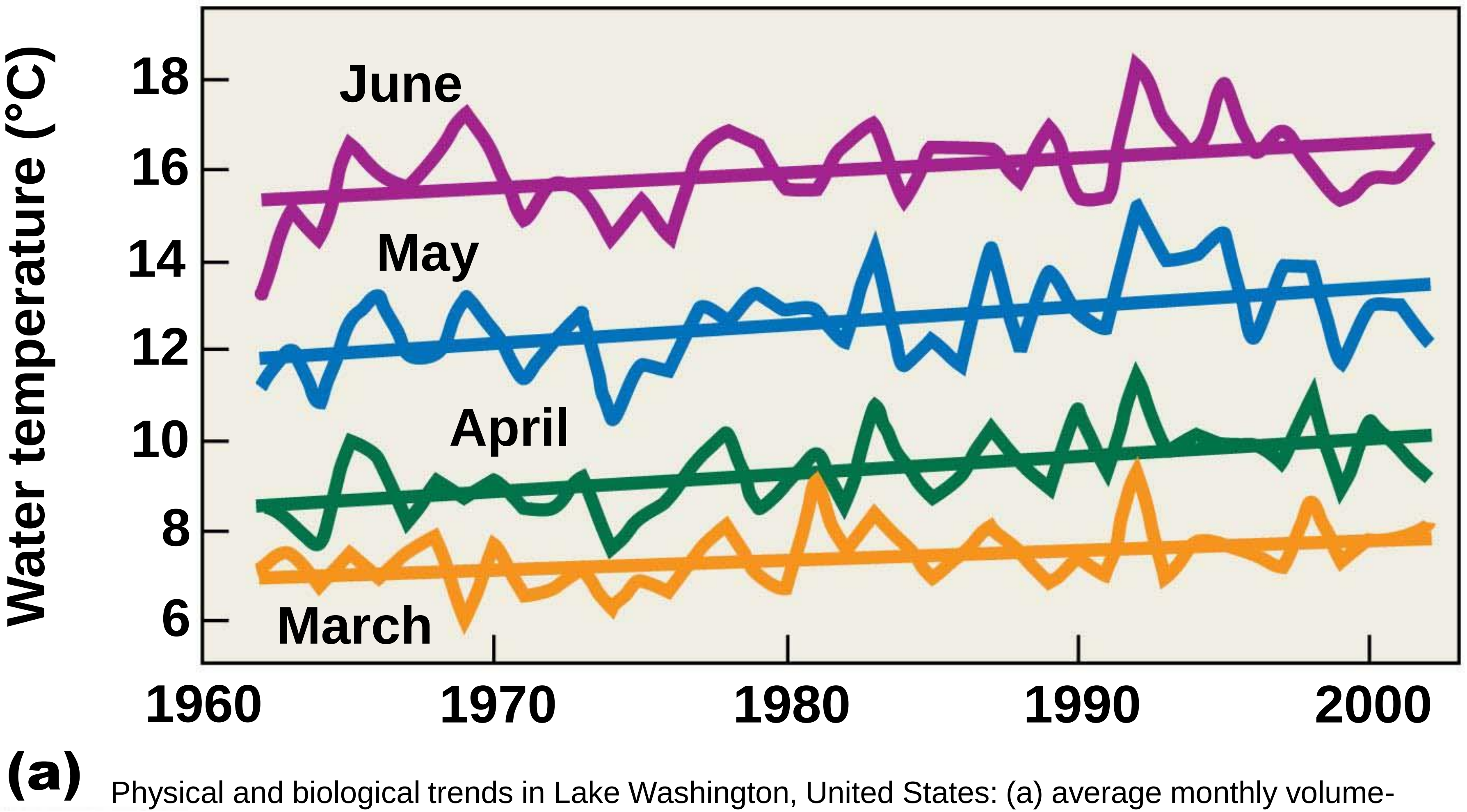
Section 27.5 Recent Climate Change Has Altered Species Interactions

- Changes in phenology of phytoplankton and zooplankton populations in Lake Washington between 1962 and 2002 in response to warming
  - Spring (March to June) water temperatures showed significant warming trends
  - The upper 10-m water layer increased in temperature an average of 1.4°C over 40 years

In response to this warming, the spring phytoplankton bloom has advanced by 27 days over those 40 years

Figure 27.17a

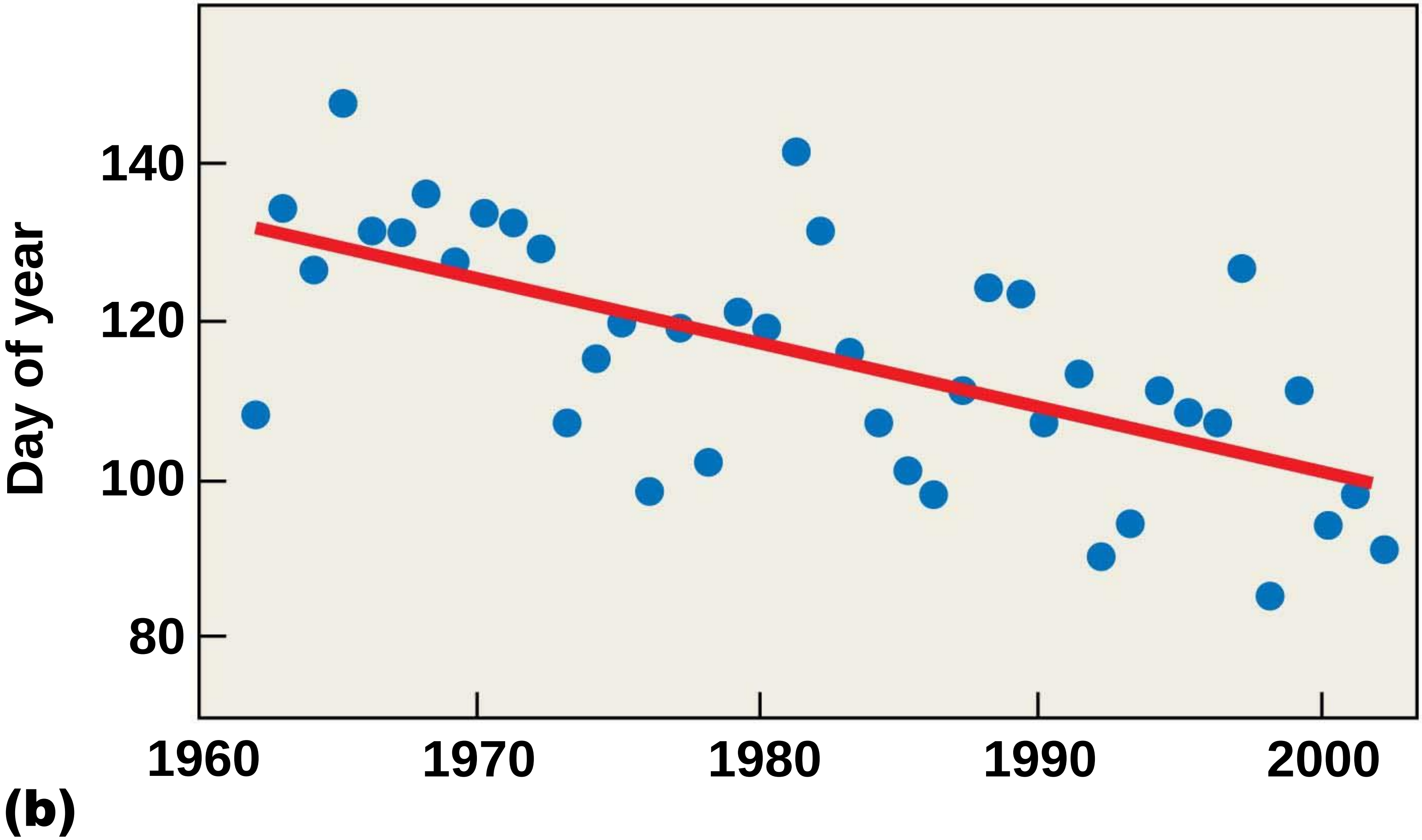
(a) average monthly volume-weighted temperature of the upper 10-m water layer during spring (March through June),



Physical and biological trends in Lake Washington, United States: (a) average monthly volume-weighted temperature of the upper 10-m water layer during spring (March through June), (b) timing of diatom bloom, (c) timing of diatom bloom (solid line) relative to annual timing of Daphnia peaks (circles, dashed line). (d) Relation of Daphnia densities in May to the mismatch (in days) between the timing of diatom bloom and Daphnia peak for the period of 1977–2002.
(Adapted from Winder and Schindler 2004.)

Figure 27.17b

(b) timing of diatom bloom

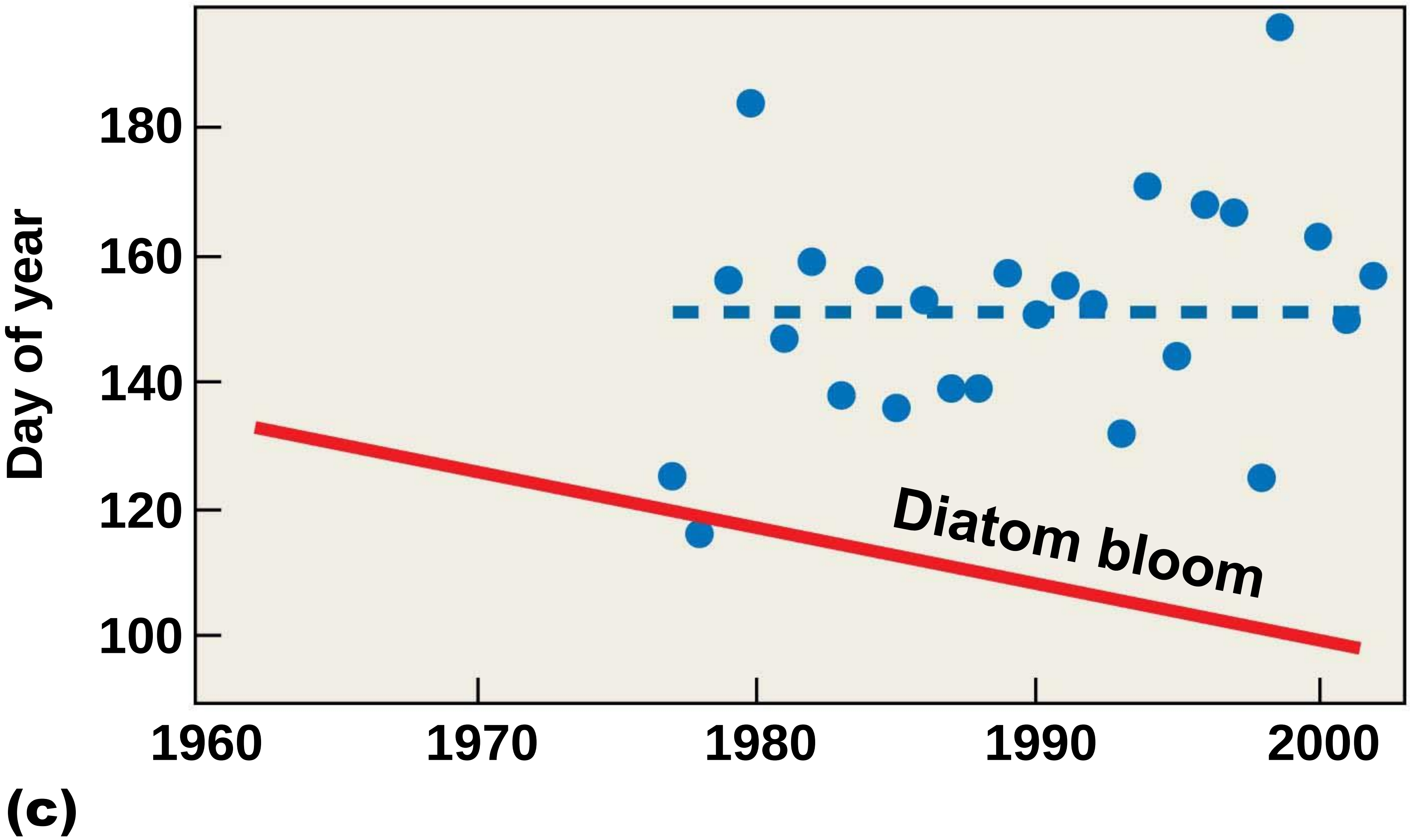


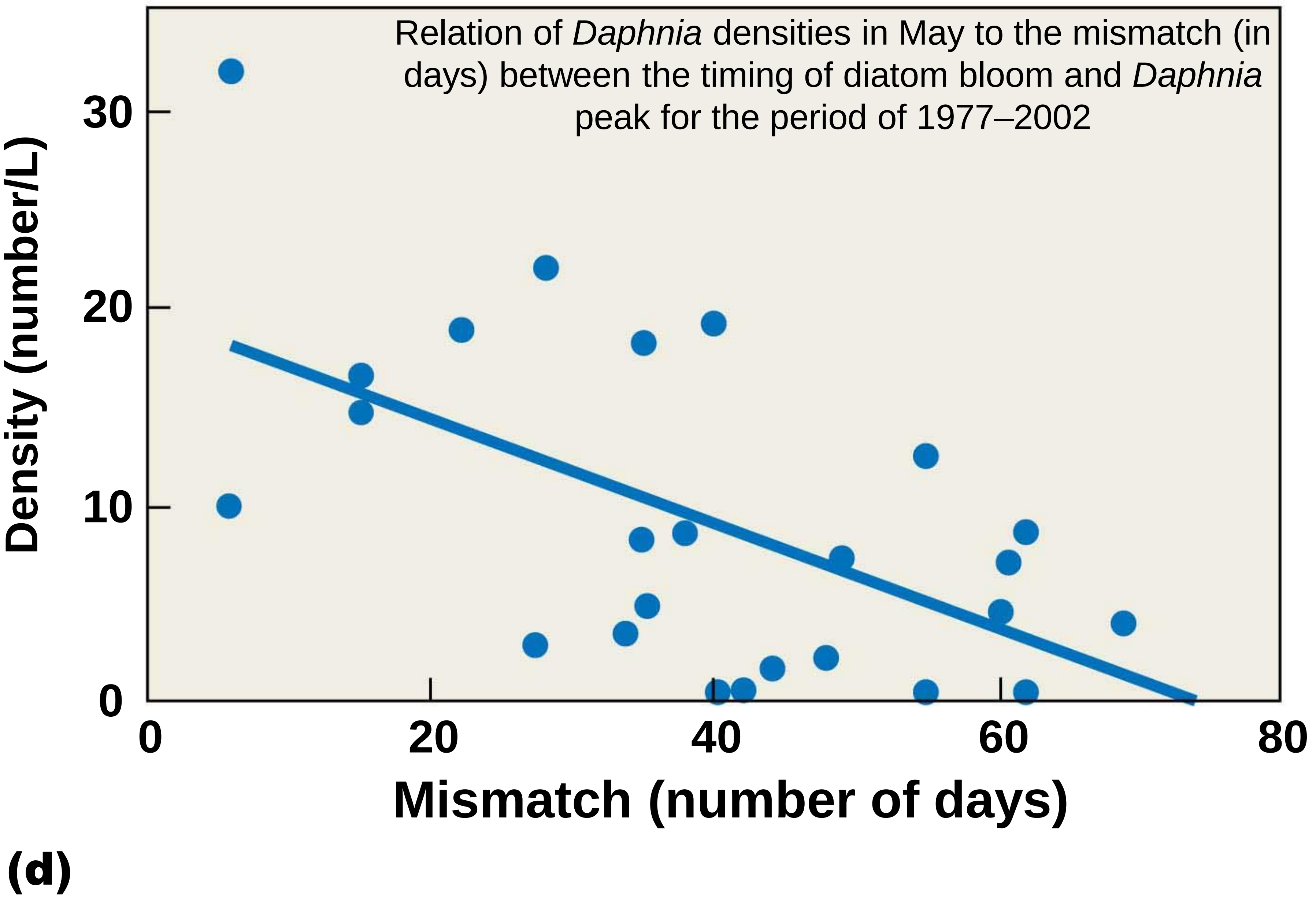
Section 27.5 Recent Climate Change Has Altered Species Interactions

- *Keratella* (herbivorous rotifer) has also shown a large advance in peak densities (21 days) – red line
- In contrast, the peak densities of *Daphnia* (another herbivore) showed no advance, increasing the trophic mismatch, and *Daphnia* densities have declined – blue line

Figure 27.17c

(c) timing of diatom bloom (solid line) relative to annual timing of *Daphnia* peaks (circles, dashed line).




Relation of *Daphnia* densities in May to the mismatch (in days) between the timing of diatom bloom and *Daphnia* peak for the period of 1977–2002

Section 27.5 Recent Climate Change Has Altered Species Interactions

- Changes in climate can increase the fitness of one species at the expense of another
- Mountain pine beetle (native to western North America) attacks most trees in the genus *Pinus*
  - can erupt into epidemics
- Over the past ten years, these epidemics have been larger than previously recorded
- What role has climate change played?

Section 27.5 Recent Climate Change Has Altered Species Interactions

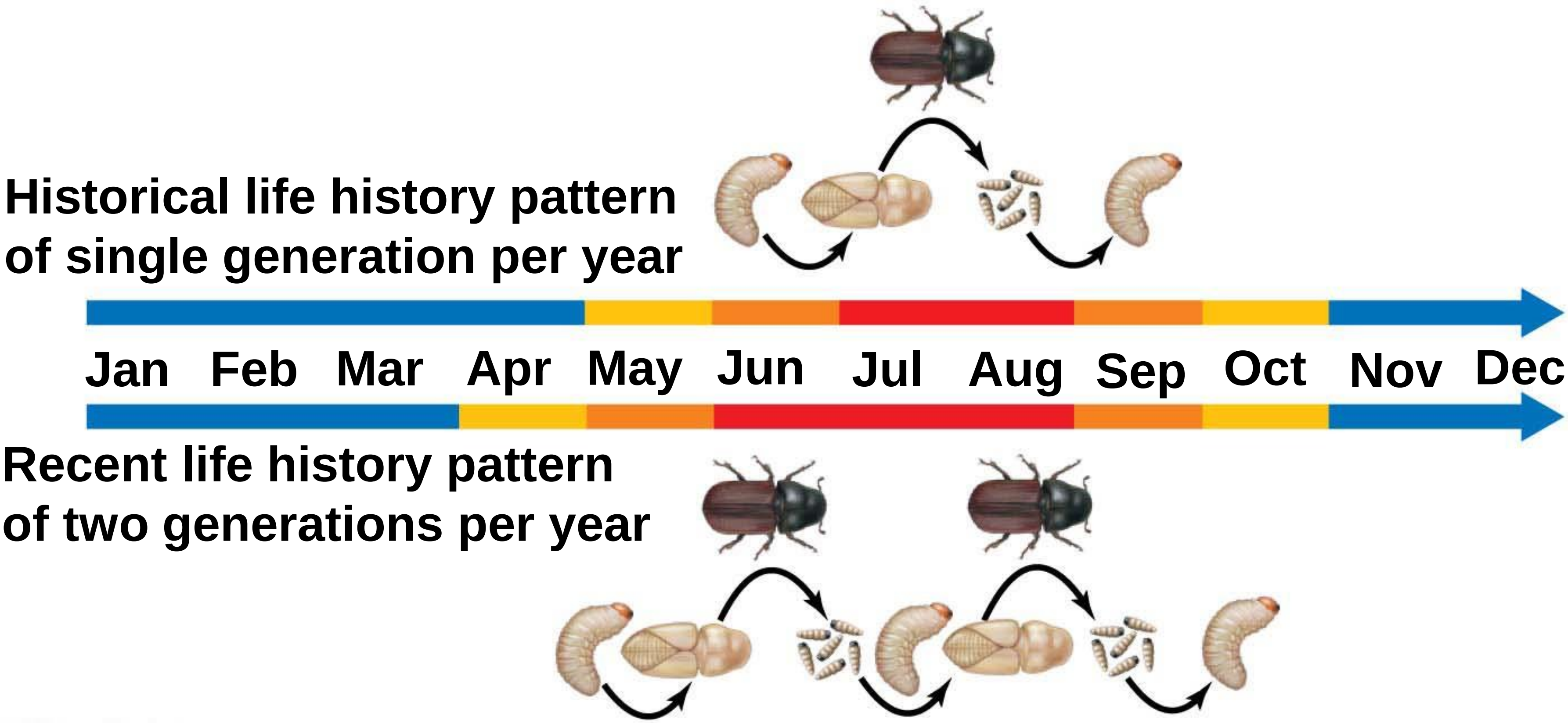
- Region has experienced
  - increased temperatures
  - increased frequency of drought
- This has decreased tree health and increased susceptibility to beetles
- Regional warming has led to range expansion of the beetle, especially at higher elevations
- Warming has also affected the beetle’s life history
  - The beetle flight season (flying to attack new trees) starts one month earlier and lasts twice as long

Section 27.5 Recent Climate Change Has Altered Species Interactions

- As a result, some beetle populations have two generations in a year instead of one

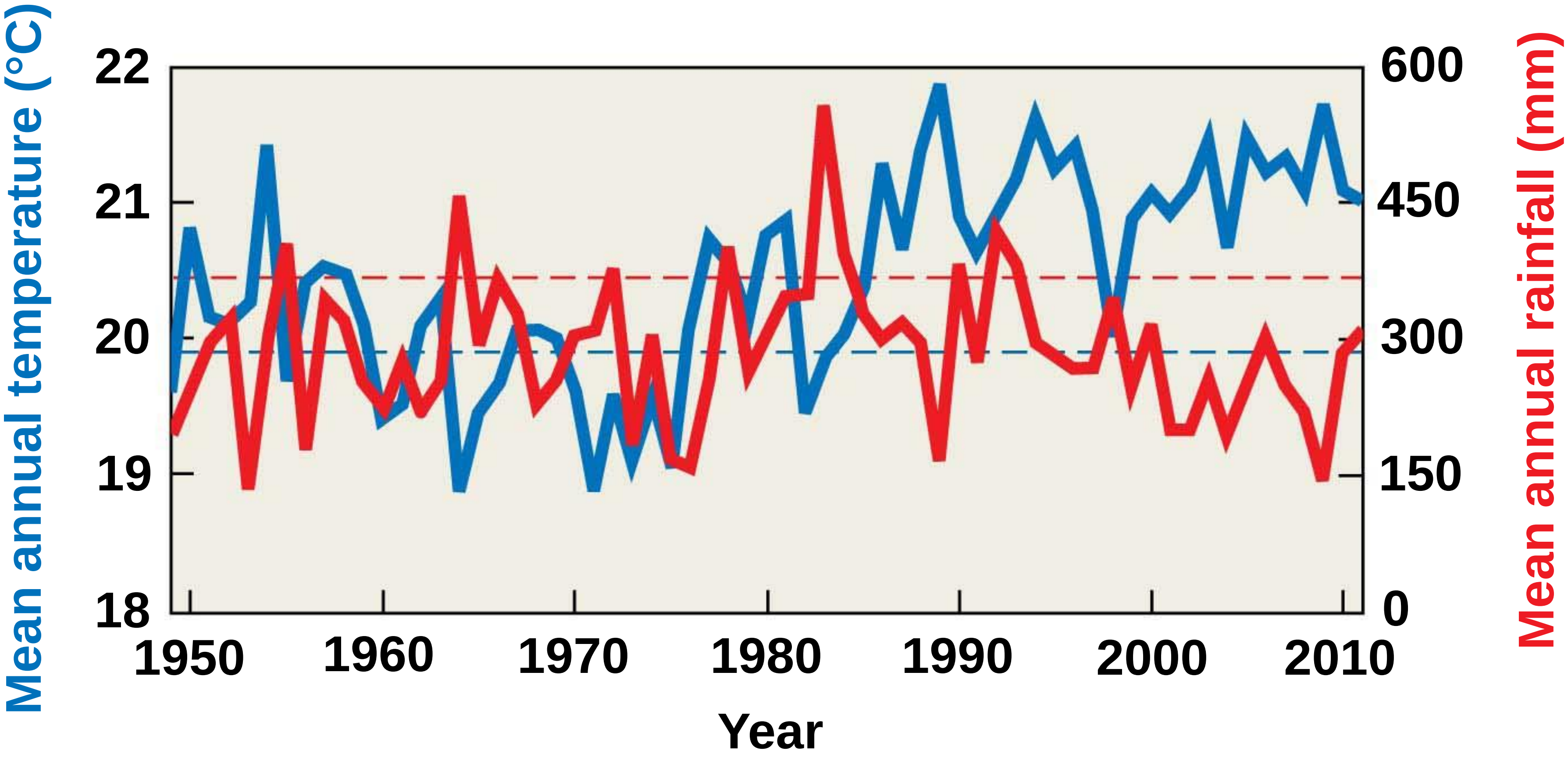
Figure 27.18

The historical mountain pine beetle life cycle of a single generation per year and the recently observed life cycle of two generations per year. Calendar arrow colors represent corresponding monthly temperature regimes: blue for < 0°C, yellow for 0–4.99°C, orange for 5–9.99°C, and red for 10°C and higher



Section 27.6 Community Structure and Regional Patterns of Diversity Have Responded to Recent Climate Change

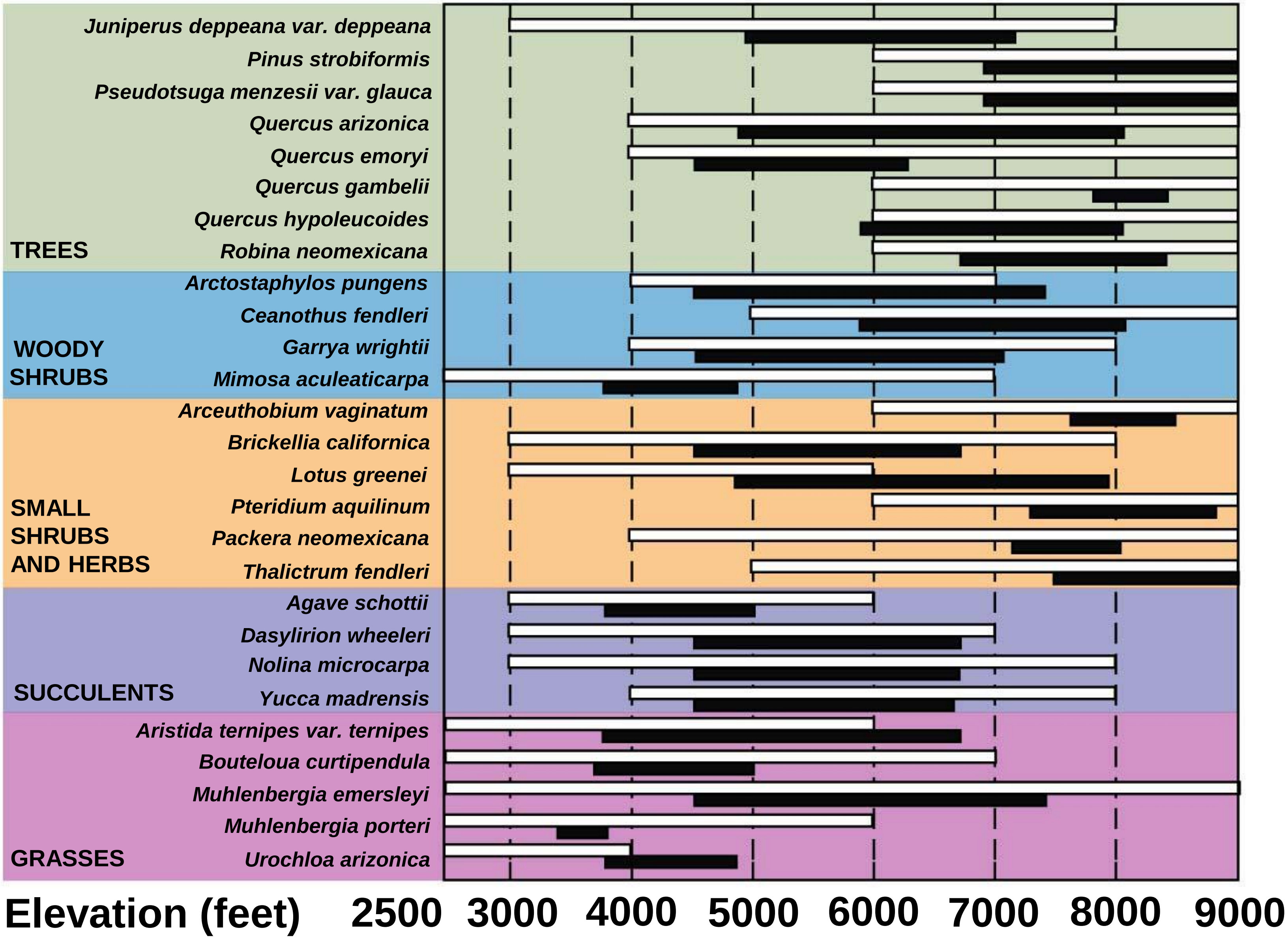
- Changes in climate that shift species ranges and lead to change in species interactions can cause shifts in species composition and diversity
- Examination of the impact of climate warming on plant communities **in the Santa Catalina Mountains – comparison with data from 1963**
- During that time
    - the mean annual rainfall has decreased
    - the mean annual temperature has increased by 0.25°C per decade between 1949 and 2011



(a)

a) Mean annual air temperature and rainfall for region of Tucson, Arizona, for the period from 1949 to 2011 (Data from United States National Weather Service).

b) Summary of elevation range of the 27 most common upland montane plants along the original elevational transect in the Santa Catalina Mountains (area of Tucson, AZ) reported by Whittaker and Niering in 1964. White bars are 1963 elevational range data from Whittaker and Niering study, whereas the black bars represent 2011 elevation data from the current study.



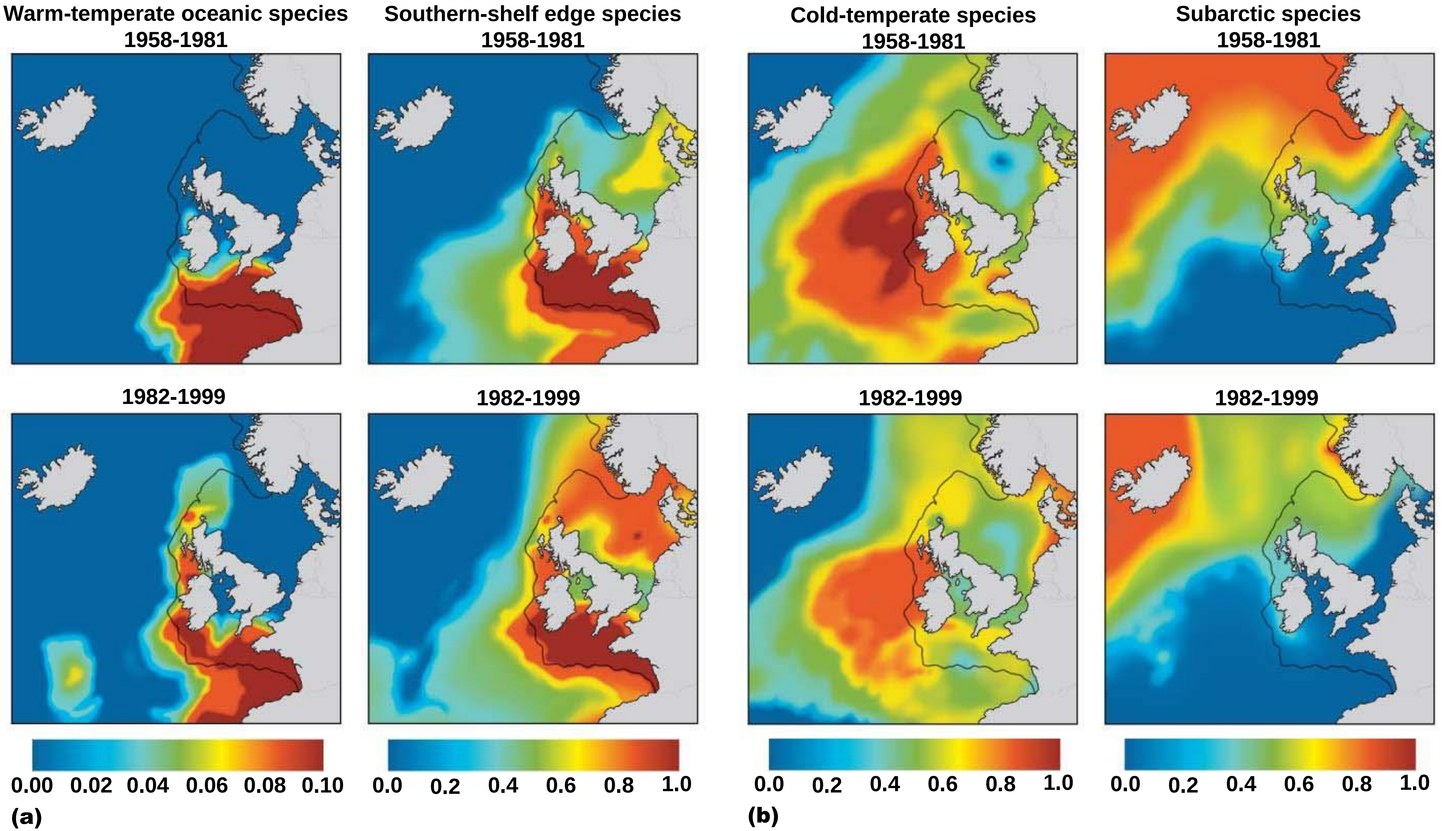
(b)

27.19b (a) Mean annual air temperature and rainfall for region of Tucson, Arizona, for the period from 1949 to 2011 (Data from United States National Weather Service). (b) Summary of elevation range of the 27 most common upland montane plants along the original elevational transect in the Santa Catalina Mountains (area of Tucson, AZ) reported by Whittaker and Niering in 1964. White bars are 1963 elevational range data from Whittaker and Niering study, whereas the black bars represent 2011 elevation data from the current study.(Brusca et al. 2013.)

Section 27.6 Community Structure and Regional Patterns of Diversity Have Responded to Recent Climate Change

- Resampled the original elevation transect
- Focused on the 27 most abundant species
  - The range of 75 percent of the species has shifted significantly upslope – more than 300 m for some
  - Other species grow in a narrower elevation range
- The species compositions of the plant communities along the elevation gradient have changed significantly in 50 years as the result of independent shifting of the elevation ranges of individual species

Figure 27.20



Observed northerly shift of zooplankton assemblages (functional categories of species) in the Northeast Atlantic over two periods (1958–1981 and 1982–1999). See text for description of species assemblages. There has been (a) a northerly shift of approximately 1000 km for warmer-water species during the past 40 years, whereas colder-water species (b) have contracted their range. Scale is the mean number of species per assemblage, which provides an index of abundance. For example, in a given region, a decrease in the number of warm-temperate species, associated with an increase in the number of cold-temperate and subarctic species, would suggest a community shift from a warm to a colder environment species.
(From Beaugrand et al. 2001 as presented by Hayes et al. 2005.)

Section 27.6 Community Structure and Regional Patterns of Diversity Have Responded to Recent Climate Change

- These types of geographical shifts may have serious consequences for North Sea fisheries
- If they continue, could lead to changes in fish abundance
- Stocks of northern species, such as cod, could decline or even collapse

Section 27.7 Climate Change Has Impacted Ecosystem Processes

- What are important ecosystem processes?
- How does climate change impact ecosystem processes?

Section 27.7 Climate Change Has Impacted Ecosystem Processes

- Net primary productivity and decomposition are two key ecosystem processes
  - These control energy and nutrients in the ecosystem
- Climate has a direct influence on both processes
- Site-based studies of local ecosystems can be difficult to interpret because there are multiple factors influencing these ecosystems
  - soils, topography, carbon dioxide concentration
- Current studies used data from satellites

Section 27.7 Climate Change Has Impacted Ecosystem Processes

- Terrestrial NPP can be estimated from satellite-based measures of absorbed photosynthetically active radiation (APAR) over large land areas
  - can examine temporal and spatial changes
- Study estimated global patterns of terrestrial NPP from 1982 to 1999
- Global changes in climate have eased climatic constraints on plant growth and NPP increased 6 percent over the 18-year study
  - largest increase in tropical ecosystems

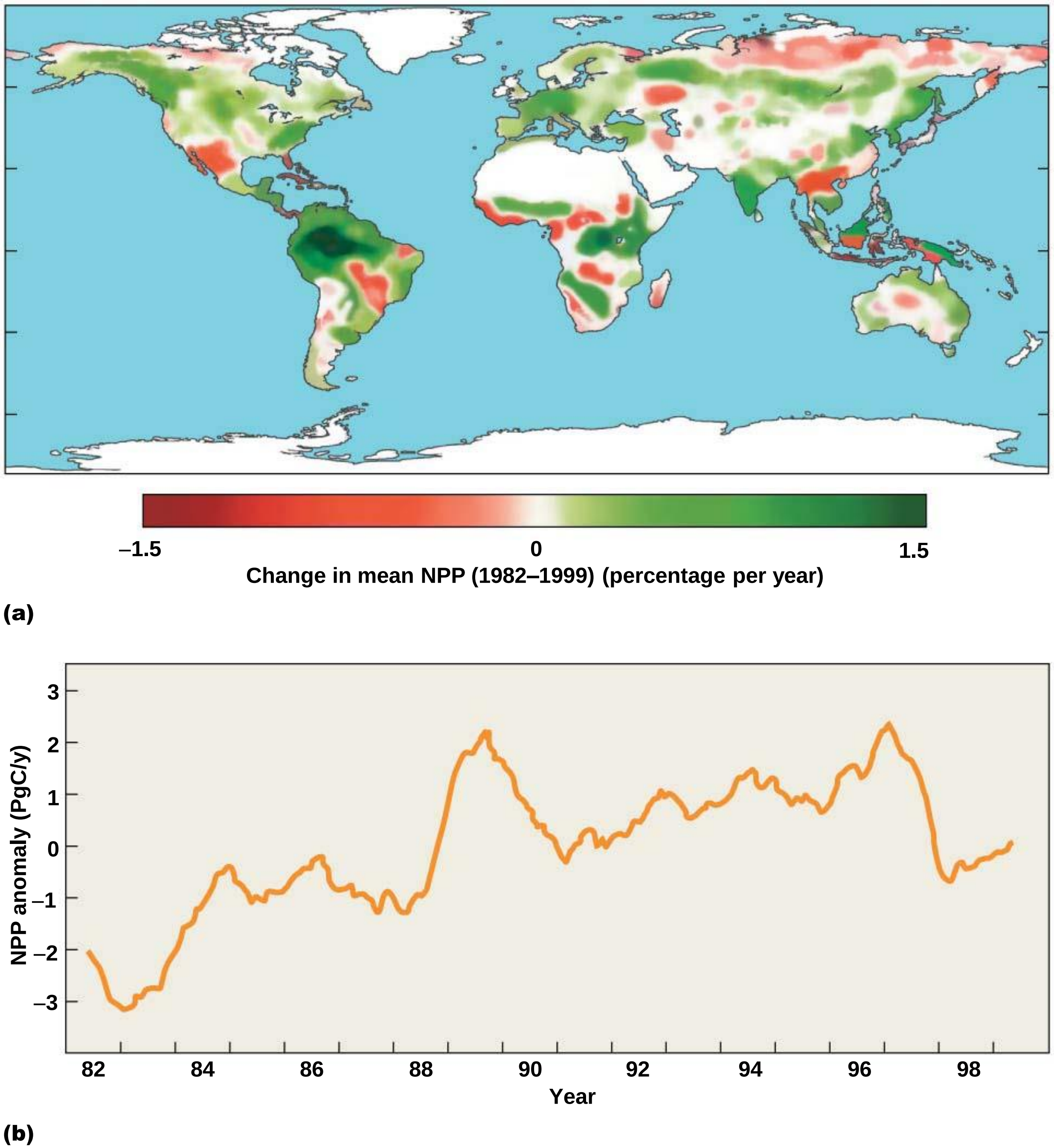
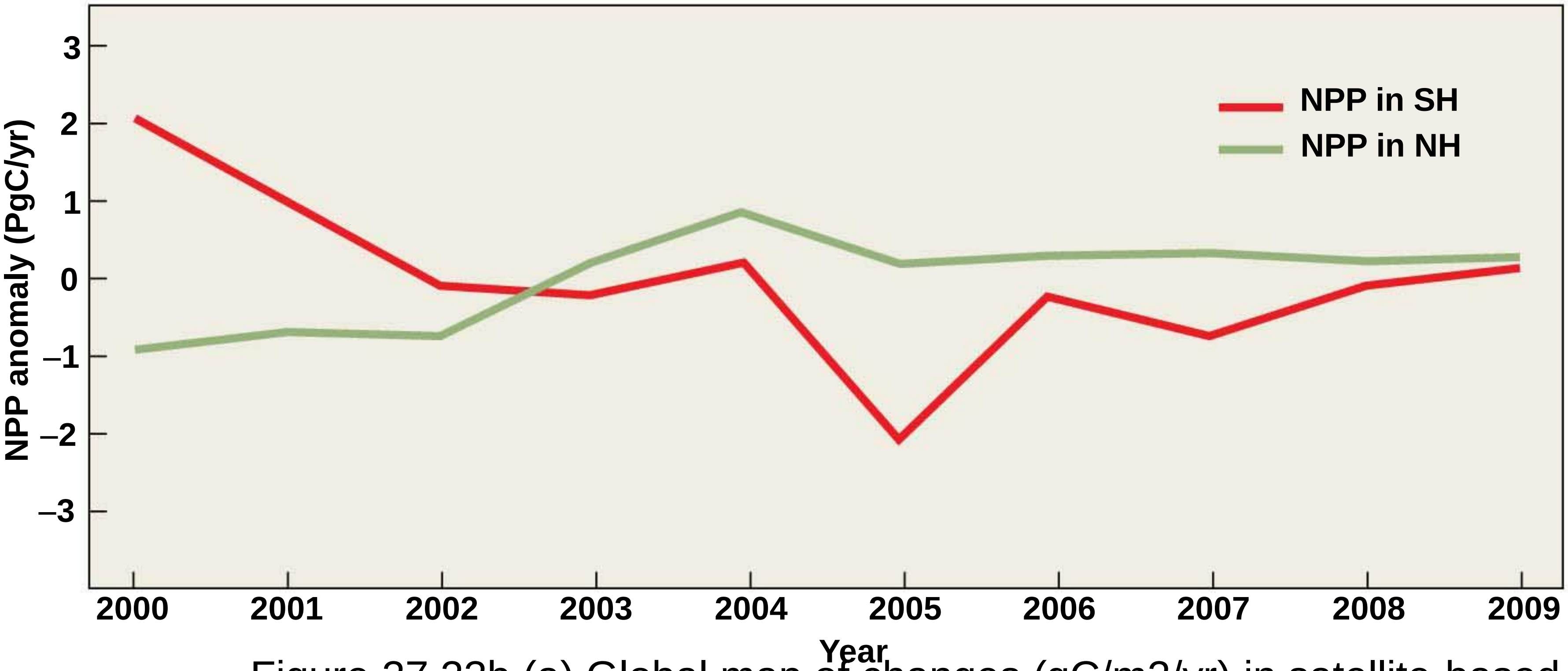


Figure 27.22 (a) Global map of changes (percent per year) in satellite-based estimates of net primary productivity (NPP) over the period from 1982 to 1999. (b) Interannual variation in global NPP from 1982 to 1999. NPP anomaly represents the difference between yearly annual NPP and the average value of NPP over the study period (mean = 54.5 PgC per year). (Adapted from Nemani et al. 2003.)

Figure 27.23b

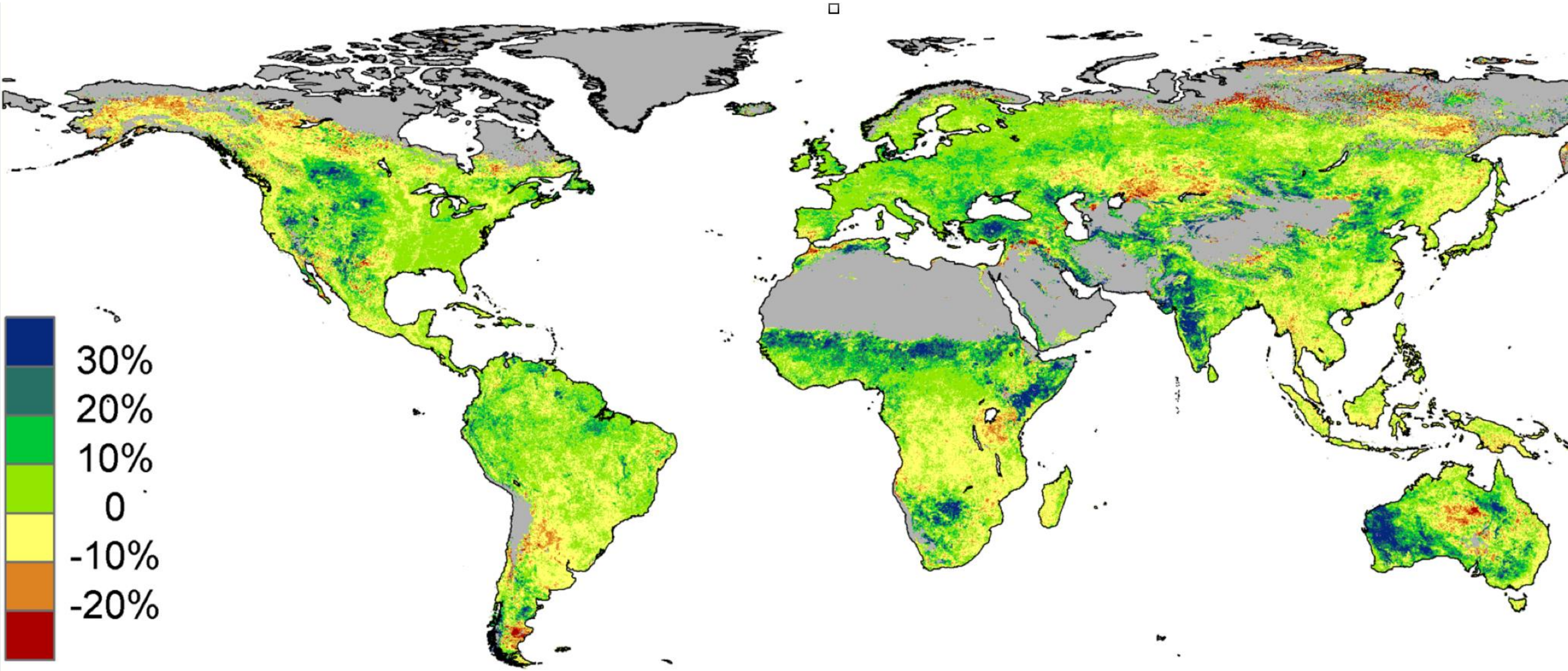


(b)

Figure 27.23b (a) Global map of changes (gC/m2/yr) in satellite-based estimates of net primary productivity (NPP) from 2000 through 2009. (b) Interannual variation in total NPP over the Northern and Southern Hemispheres. NPP anomaly represents the difference between yearly annual NPP and the average value of NPP over the study period (mean = 53.5 PgC per year).

(Adapted from Zhao and Running 2010.)

CO$_2$ is greening the Earth?



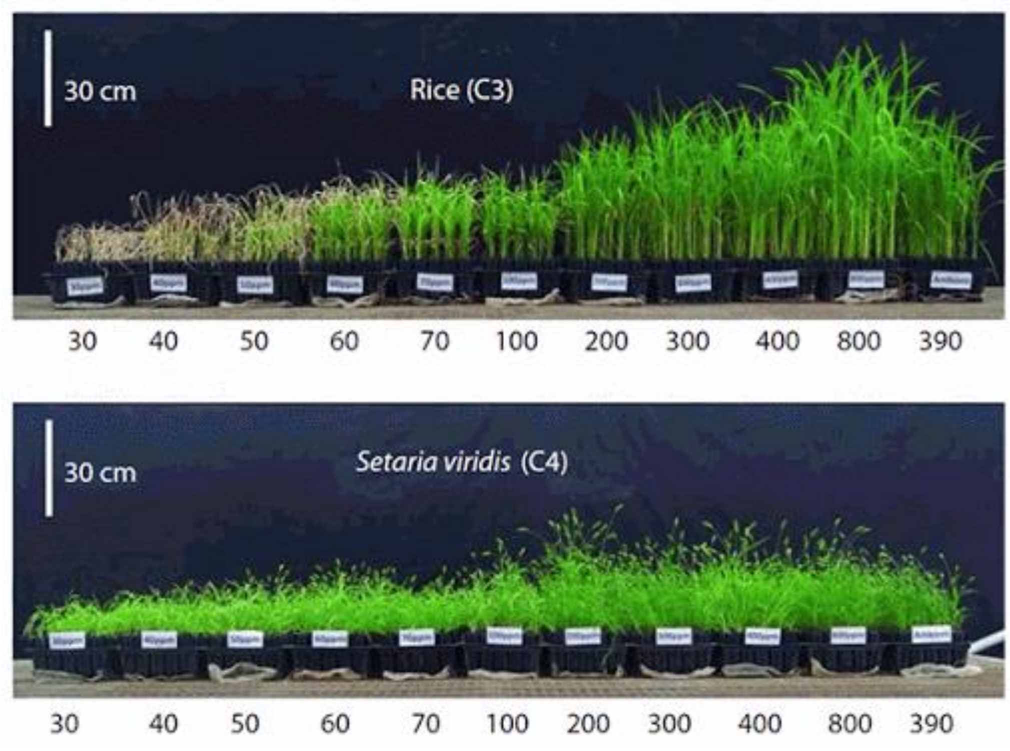
Map 2

1982 through 2010.

Global Greening From High And Rising CO2

http://russgeorge.net/2014/06/28/global-greening/

CO_2 is greening the Earth?



Section 27.7 Climate Change Has Impacted Ecosystem Processes

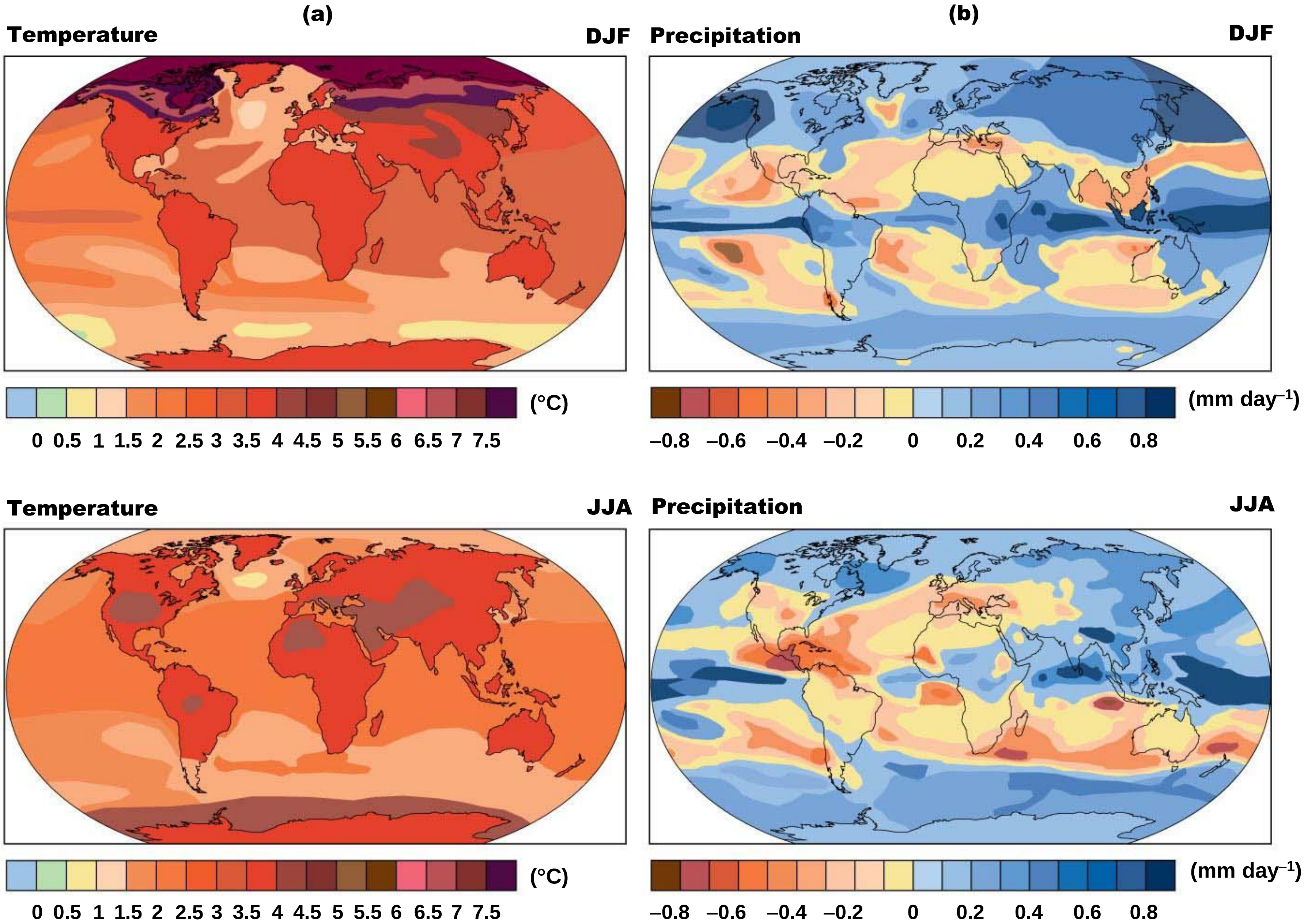
- A more recent analysis used the same methods but extended the analysis to cover 2002 to 2009
- The decade between 2000 and 2009 is the warmest recorded since instrumental measurements started
- Results suggest a reduction in NPP of 0.55 petagrams of carbon as a result of regional drying that would constrain plant growth

Section 27.7 Climate Change Has Impacted Ecosystem Processes

- Spatial patterns of NPP over the past decade have not been globally consistent
- NPP has increased over large areas in the Northern Hemisphere
  - 65 percent of vegetated land area had an increase
- NPP has generally decreased in the Southern Hemisphere
  - 70 percent of vegetated land area had a decrease
  - Higher temperatures lead to increased evaporation and reduced water availability

Section 27.8 Continued Increases in Atmospheric Concentrations of Greenhouse Gases Is Predicted to Cause Future Climate Change

- The preindustrial level of atmospheric carbon dioxide was 280 parts per million (ppm)
  - The level will double sometime this century
  - Current level (January 2014) is 398 ppm
- Carbon dioxide is not the only greenhouse gas; other significant components include:
  - methane (CH_4)
  - chlorofluorocarbons (CFCs)
  - hydrogenated chlorofluorocarbons (HCFCs)
  - nitrous oxide (N_2O)



Mean changes in (a) surface air temperature (°C), and (b) precipitation (mm per day) for Northern Hemisphere winter (DJF—December, January, and February, top) and summer (JJA—June, July, and August, bottom) under a scenario of rising atmospheric concentrations of greenhouse gases developed by the Intergovernmental Panel on Climate Change. Results represent an average of the patterns predicted by the various global circulation models used in the fourth assessment. Changes are for the period 2080 to 2099 relative to 1980 to 1999. Note that most of the warming is predicted to occur in the more northern latitudes and during the winter months. (Intergovernmental Panel on Climate Change 2007.)

Section 27.8 Continued Increases in Atmospheric Concentrations of Greenhouse Gases Is Predicted to Cause Future Climate Change

- Greenhouse gases in the atmosphere warm Earth's surface
  - What effect will doubling the concentration of carbon dioxide in the atmosphere have on global climate systems?
- **General circulation models** (**GCMs**) are complex computer models of Earth's climate system
- Give insight into the influence of increasing carbon dioxide concentration on large-scale patterns of global climate

Section 27.8 Continued Increases in Atmospheric Concentrations of Greenhouse Gases Is Predicted to Cause Future Climate Change

- There are some consistent patterns in the predictions from these GCMs
  - an increase in average global temperature
    - Intergovernmental Panel on Climate Change report (2013) suggests a global average surface temperature increase of 1.1 to 6.4°C by 2100
  - an increase in global precipitation
- These changes would not be evenly distributed
  - greatest warming during winter months and in northern latitudes

Section 27.8 Continued Increases in Atmospheric Concentrations of Greenhouse Gases Is Predicted to Cause Future Climate Change

- Popular use of the term greenhouse effect is synonymous with global warming, but the models predict more than just hotter days
- Increasing climate variation is predicted
  - more storms and hurricanes
  - greater snowfall
  - increased variability in rainfall
- The predictions that rising concentrations of greenhouse gases will significantly affect global climate in the future are consistent

Section 27.9 A Variety of Approaches Are Being Used to Predict the Response of Ecological Systems to Future Climate Change

- There are two major sources of uncertainty in predicting the response of ecological systems to future climate change
  - the limitations in our understanding of processes that control the current distribution and abundance of species
  - the uncertainly associated with the specific predictions of how the climate in a given region will change in response to increasing greenhouse gases
- Following are examples of methods being used

Section 27.9 A Variety of Approaches Are Being Used to Predict the Response of Ecological Systems to Future Climate Change

- Research is being conducted at all levels of organization, from individual to global scale
- The studies fall into two categories:
    - examining the response of ecological systems to experimental warming and the associated environmental factors
    - using models of ecological systems to evaluate the response to future climate scenarios

Section 27.9 A Variety of Approaches Are Being Used to Predict the Response of Ecological Systems to Future Climate Change

- A number of experimental studies in various environments (tropical to polar) show that communities and ecosystems respond strongly to warming
  - Most studies have been done at a single location for a short period of time
- Comparison among studies is difficult because of the diverse techniques used to produce warming experimentally

Section 27.9 A Variety of Approaches Are Being Used to Predict the Response of Ecological Systems to Future Climate Change

- International Tundra Experiment (ITEX) is a coordinated international effort using standardized methods
- Network of Arctic and alpine research sites throughout the world
    - Experimental and observational studies use standardized protocols to measure responses of tundra plants and plant communities to increases in temperature
    - Investigators from 13 countries working at 11 sites

Figure 27.25

(a)

(b)

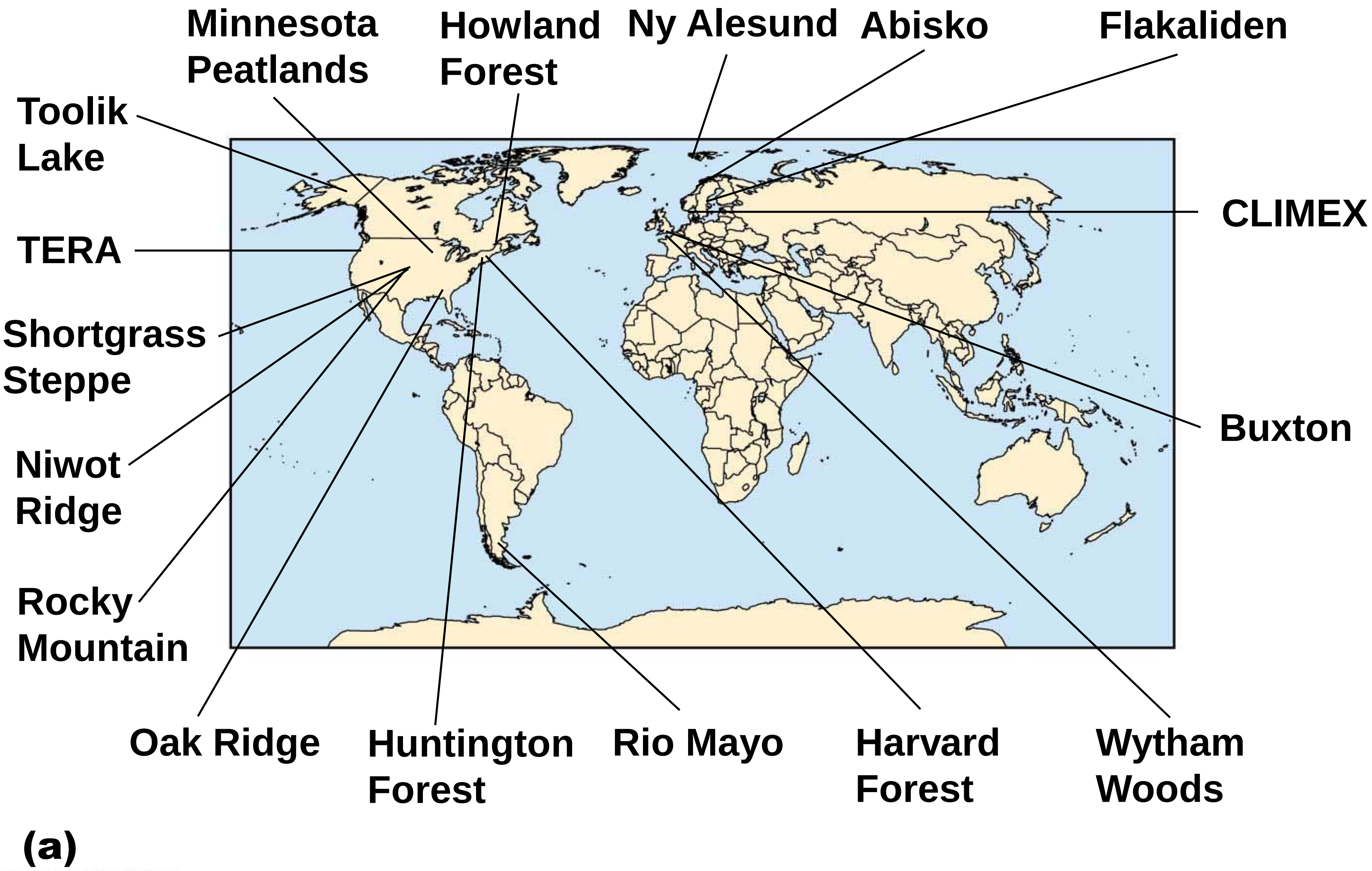
Section 27.9 A Variety of Approaches Are Being Used to Predict the Response of Ecological Systems to Future Climate Change

- These studies used passive warming treatments
- Increased plant-level air temperature by 1–3°C
  - This is in the range of observed and predicted tundra region warming
- Responses were rapid, detected in whole plant communities after two growing seasons
  - increased height and cover of deciduous shrubs and graminoids
  - decreased cover of mosses and lichens
  - decreased species richness and evenness

Section 27.9 A Variety of Approaches Are Being Used to Predict the Response of Ecological Systems to Future Climate Change

- Network of Ecosystem Warming Studies is another coordinated international effort to study the response of ecosystems to climate warming
  - Experiments focus on the response of soil respiration, net nitrogen mineralization, and aboveground NPP
- There are 32 research sites in four broadly defined biomes
  - high (latitude or altitude) tundra, low tundra, grassland, forest

Figure 27.26a

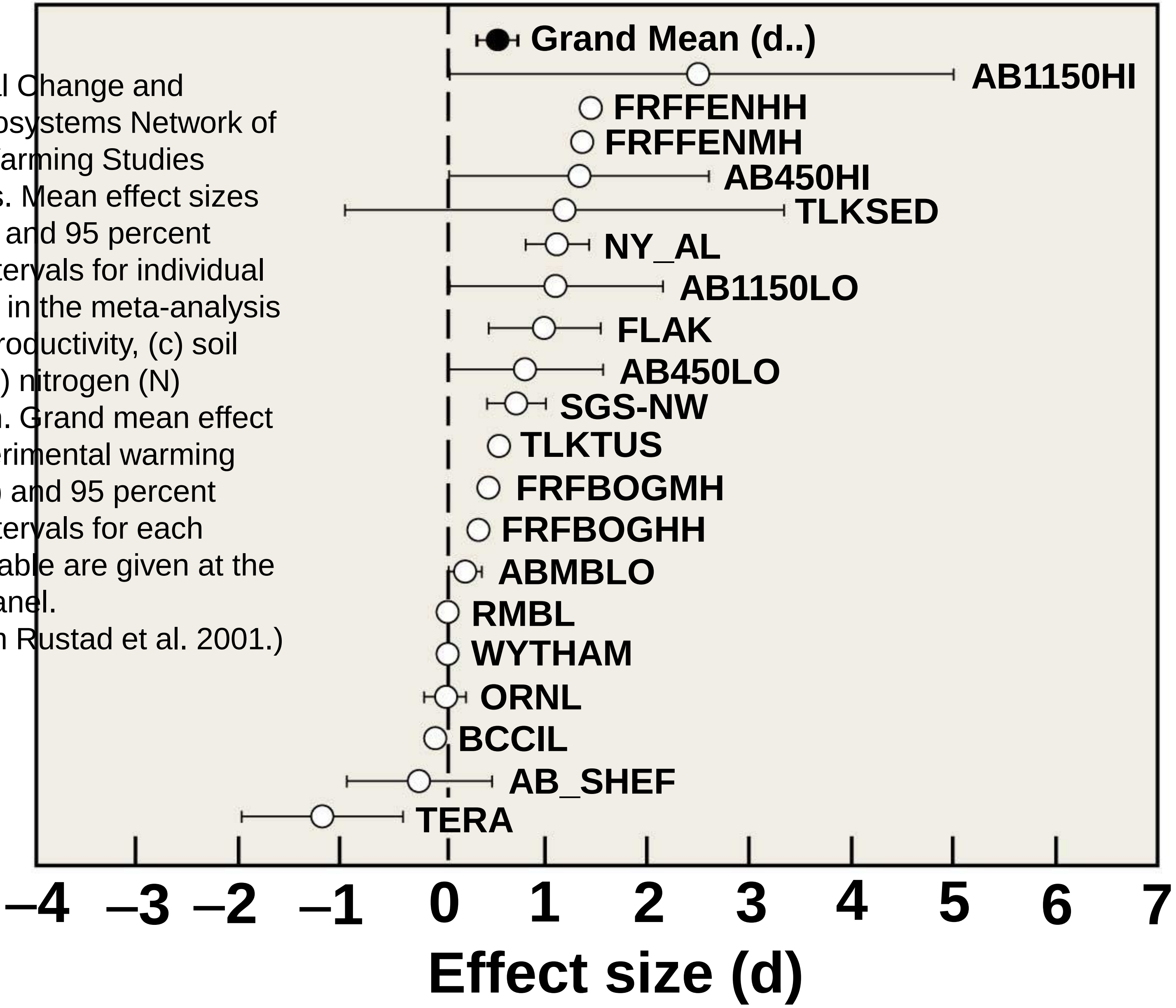


Section 27.9 A Variety of Approaches Are Being Used to Predict the Response of Ecological Systems to Future Climate Change

- Results show considerable variation in response to warming
- Across all sites, experimental warming (0.3 to 6.0°C) for 2 to 9 years duration
- Increases were seen in
  - soil respiration rates, by 20 percent
    - larger in forested ecosystems
  - Net nitrogen mineralization rates, by 46 percent
  - NPP, by 19 percent
    - larger in low tundra ecosystems

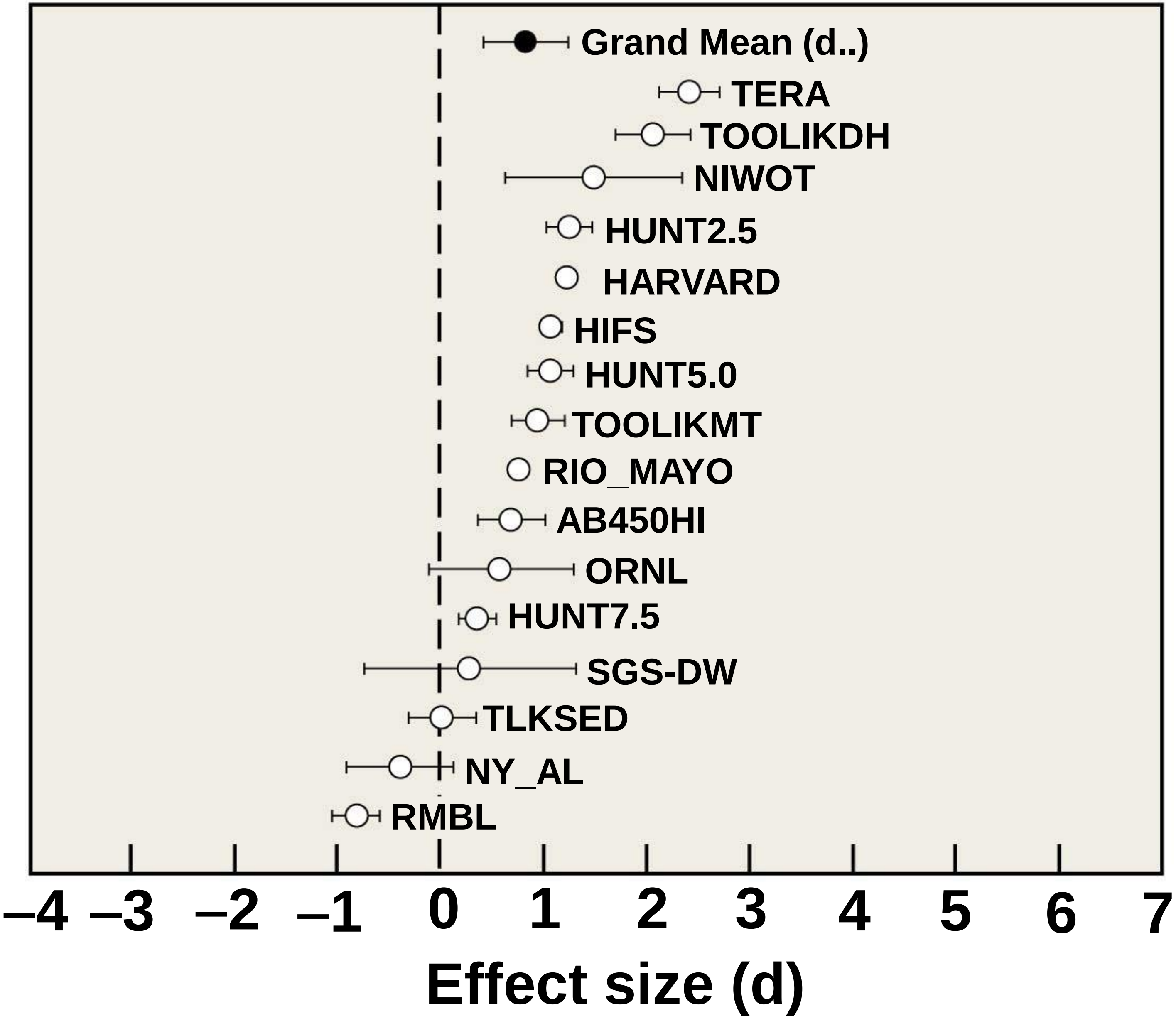
Figure 27.26b

(a) The Global Change and Terrestrial Ecosystems Network of Ecosystem Warming Studies research sites. Mean effect sizes (open circles) and 95 percent confidence intervals for individual sites included in the meta-analysis for (b) plant productivity, (c) soil respiration, (d) nitrogen (N) mineralization. Grand mean effect sizes for experimental warming (closed circle) and 95 percent confidence intervals for each response variable are given at the top of each panel.
(Adapted from Rustad et al. 2001.)



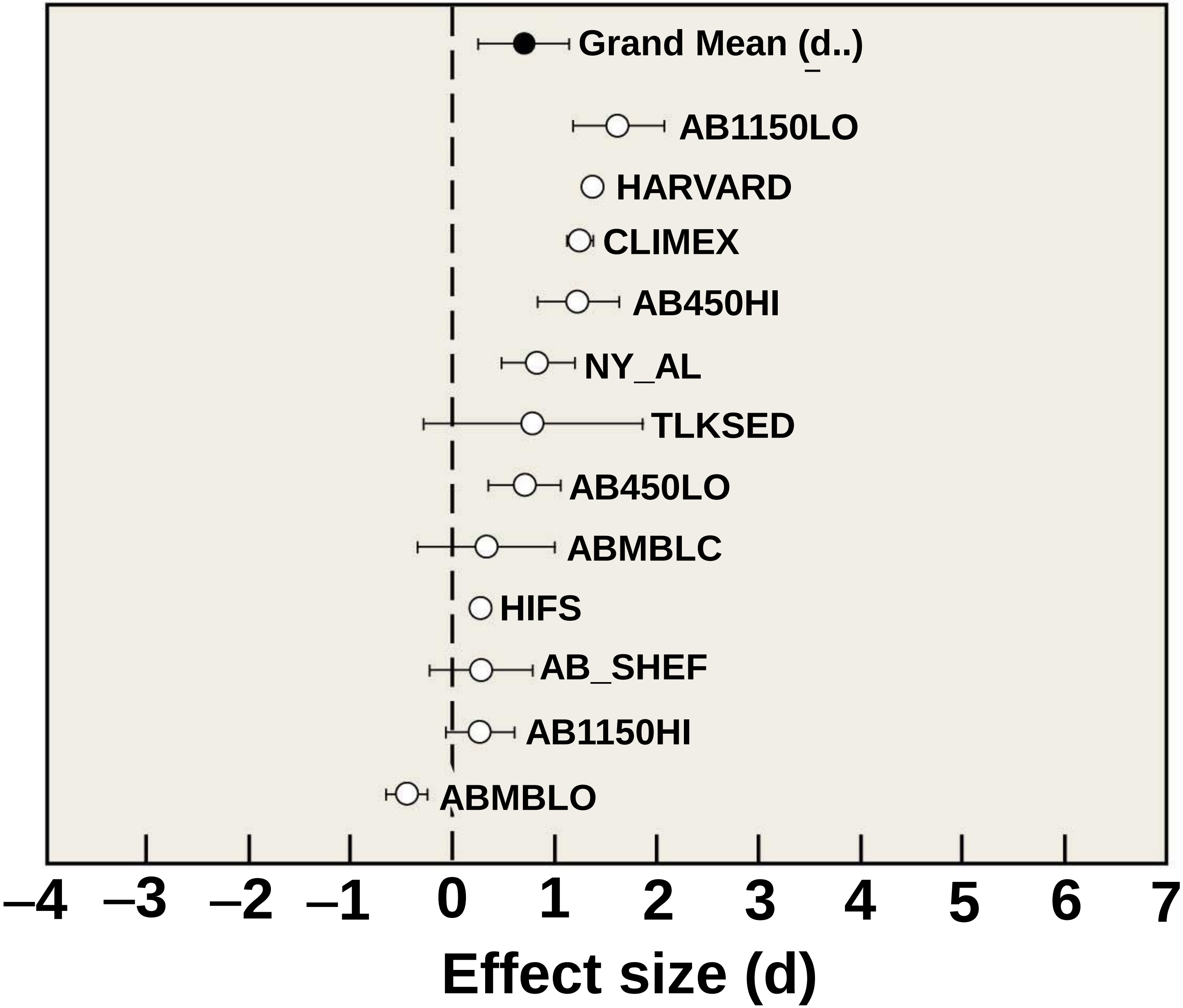
(b) Plant productivity

Figure 27.26c



(c) Soil respiration

Figure 27.26d



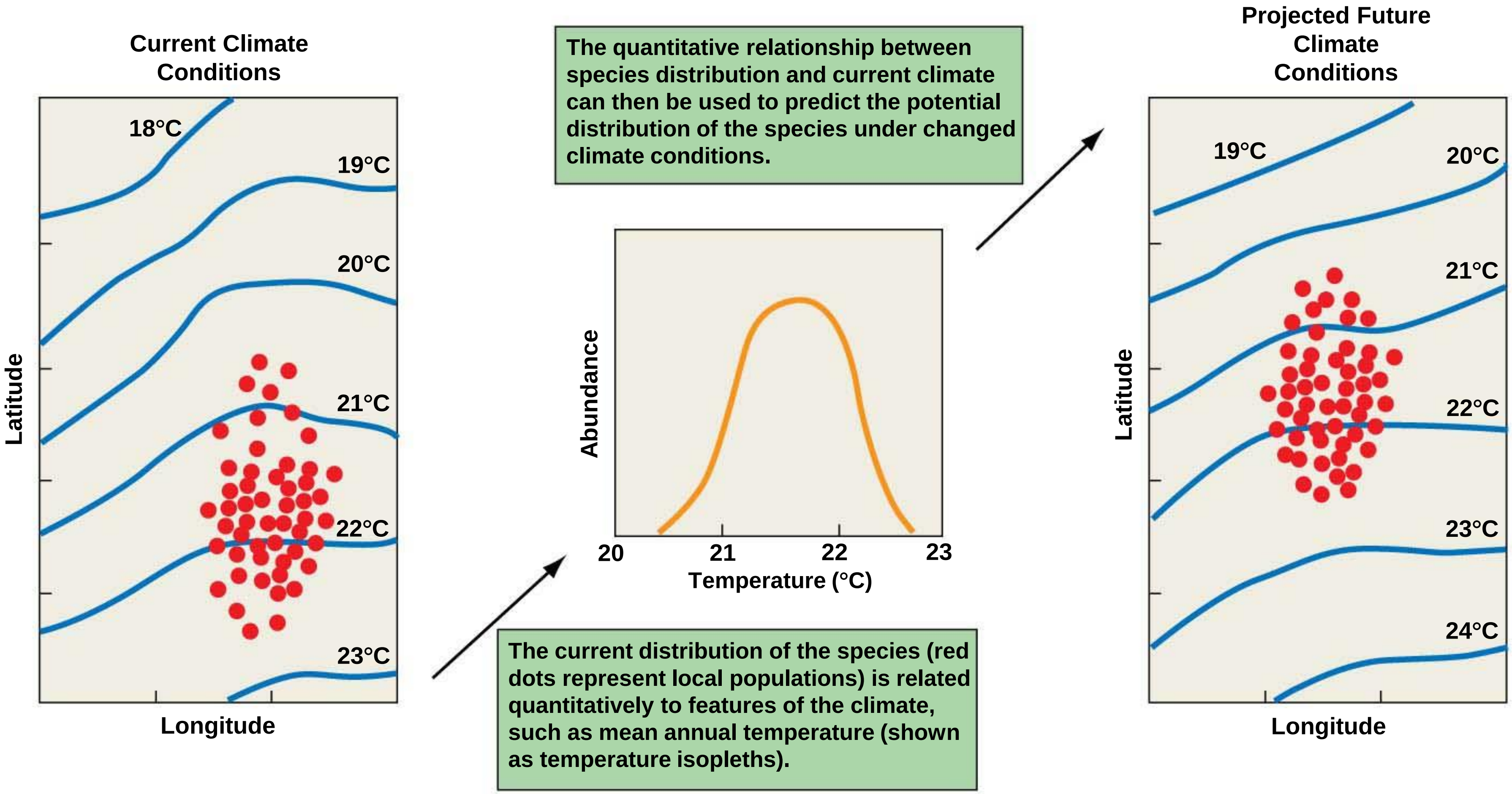
(d) N mineralization

Section 27.9 A Variety of Approaches Are Being Used to Predict the Response of Ecological Systems to Future Climate Change

- The **bioclimatic envelope model** is one of the most widely applied modeling approaches to investigate the response of an individual species to climate change
- Relates features of climate and edaphic factors to geographic patterns of species occurrence

Figure 27.27

Figure 27.27 General procedure used in the development of a bioclimatic envelope model.



The quantitative relationship between species distribution and current climate can then be used to predict the potential distribution of the species under changed climate conditions.

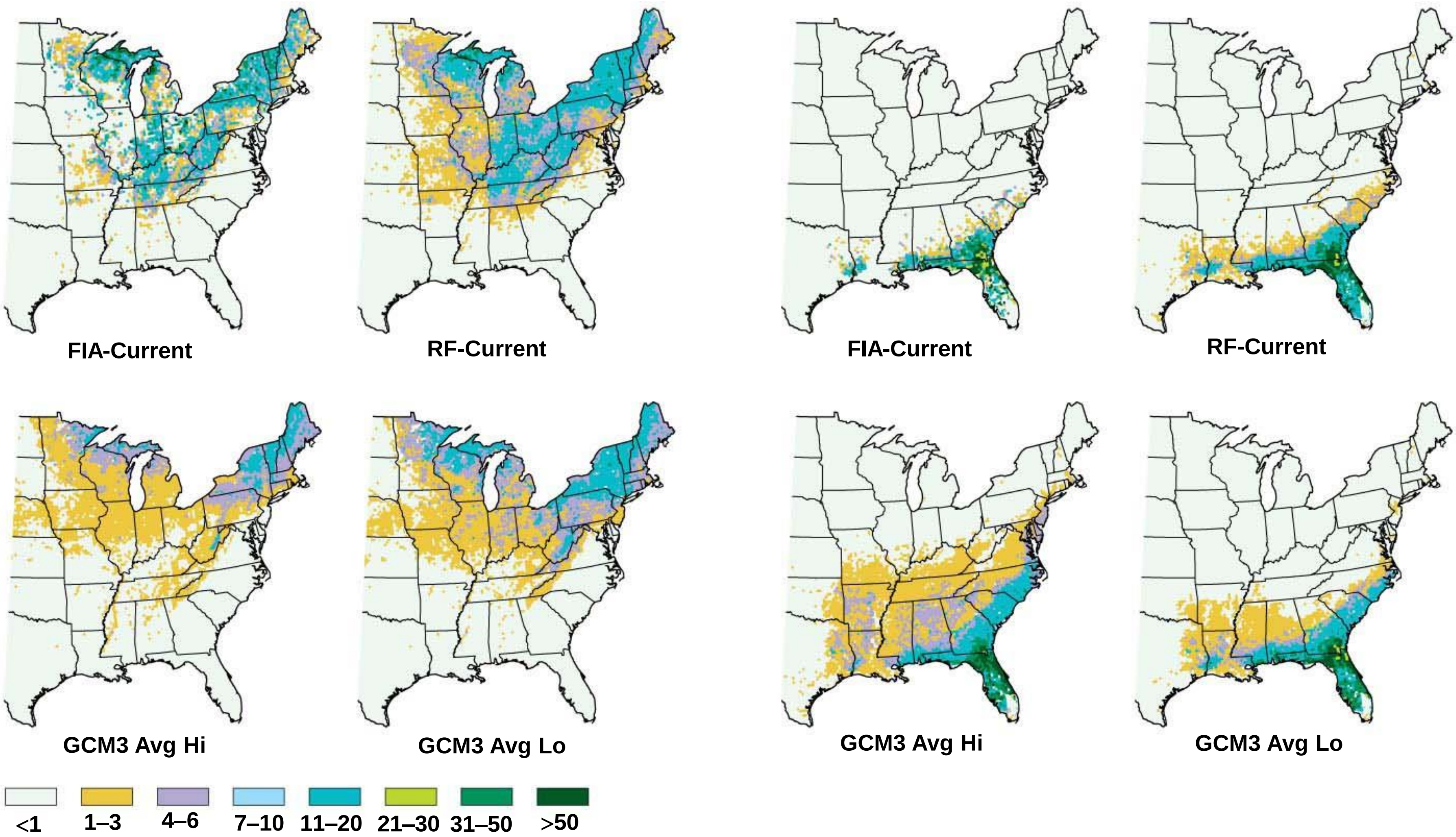
The current distribution of the species (red dots represent local populations) is related quantitatively to features of the climate, such as mean annual temperature (shown as temperature isopleths).

Section 27.9 A Variety of Approaches Are Being Used to Predict the Response of Ecological Systems to Future Climate Change

- Establishes a quantitative relationship between climate and the current geographic distribution
- This relationship can be used to map the possible geographic range of the species under different climate change scenarios
- Investigation of the effect of climate change on 134 tree species in the eastern United States with 36 environmental variables
  - Climate change could have large impacts on suitable habitat for these tree species

Figure 27.28

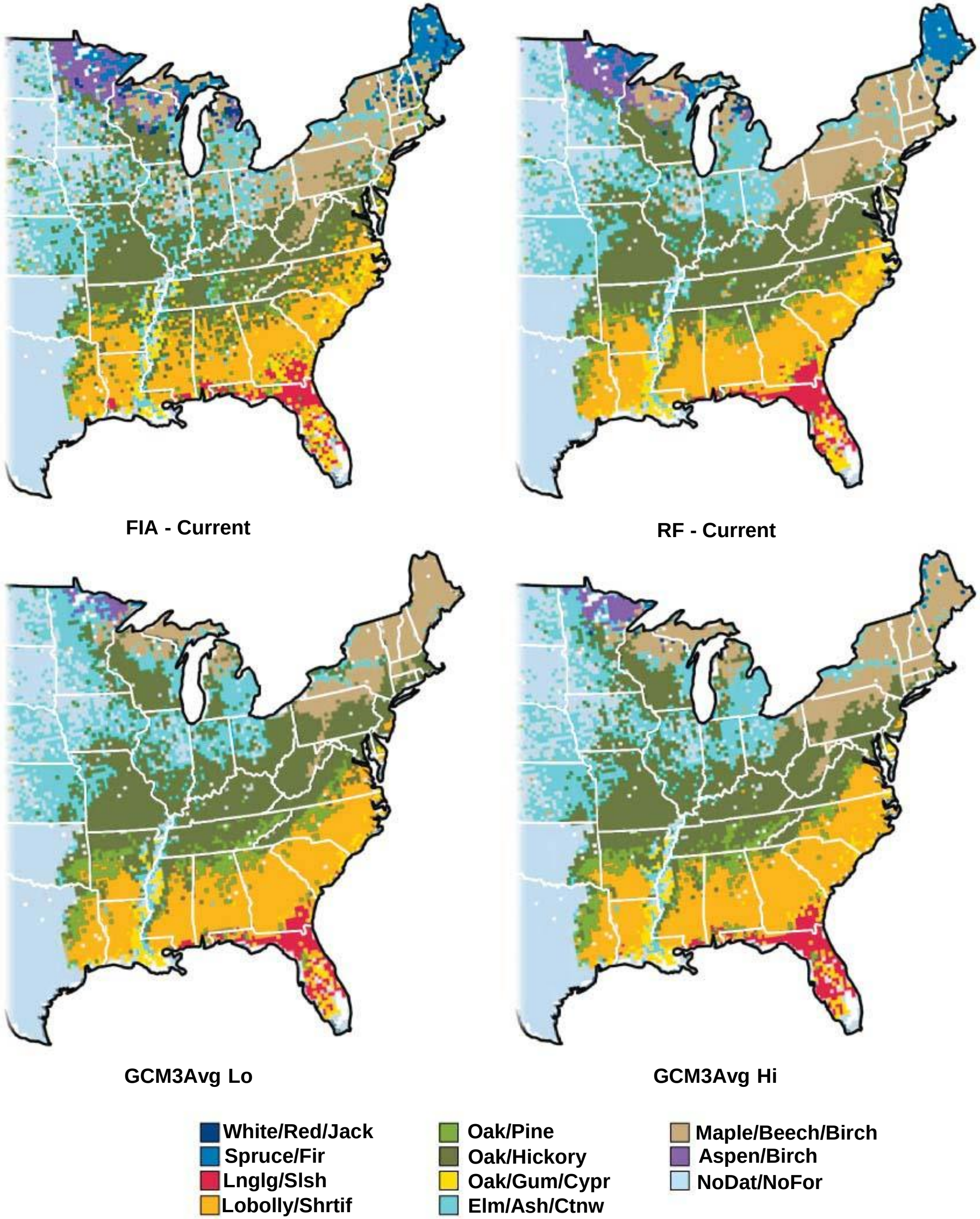
Maps of current and future potential distributions for (a) sugar maple (*Acer saccharum*) and (b) slash pine (*Pinus elliottii*). Maps include the United States Forest Service-Forest Inventory Analysis (FIA) estimate of current distribution and abundance, the modeled current map (RF-Current), and climate change scenarios based on the average of three general circulation models (GCM) using high future emissions estimates (GCM3 Avg Hi), and low future emissions estimates (GCM3 Avg Lo).



(a) Sugar maple (*Acer saccharum*)

(b) Slash pine (*Pinus elliottii*)

Figure 27.29



FIA - Current

RF - Current

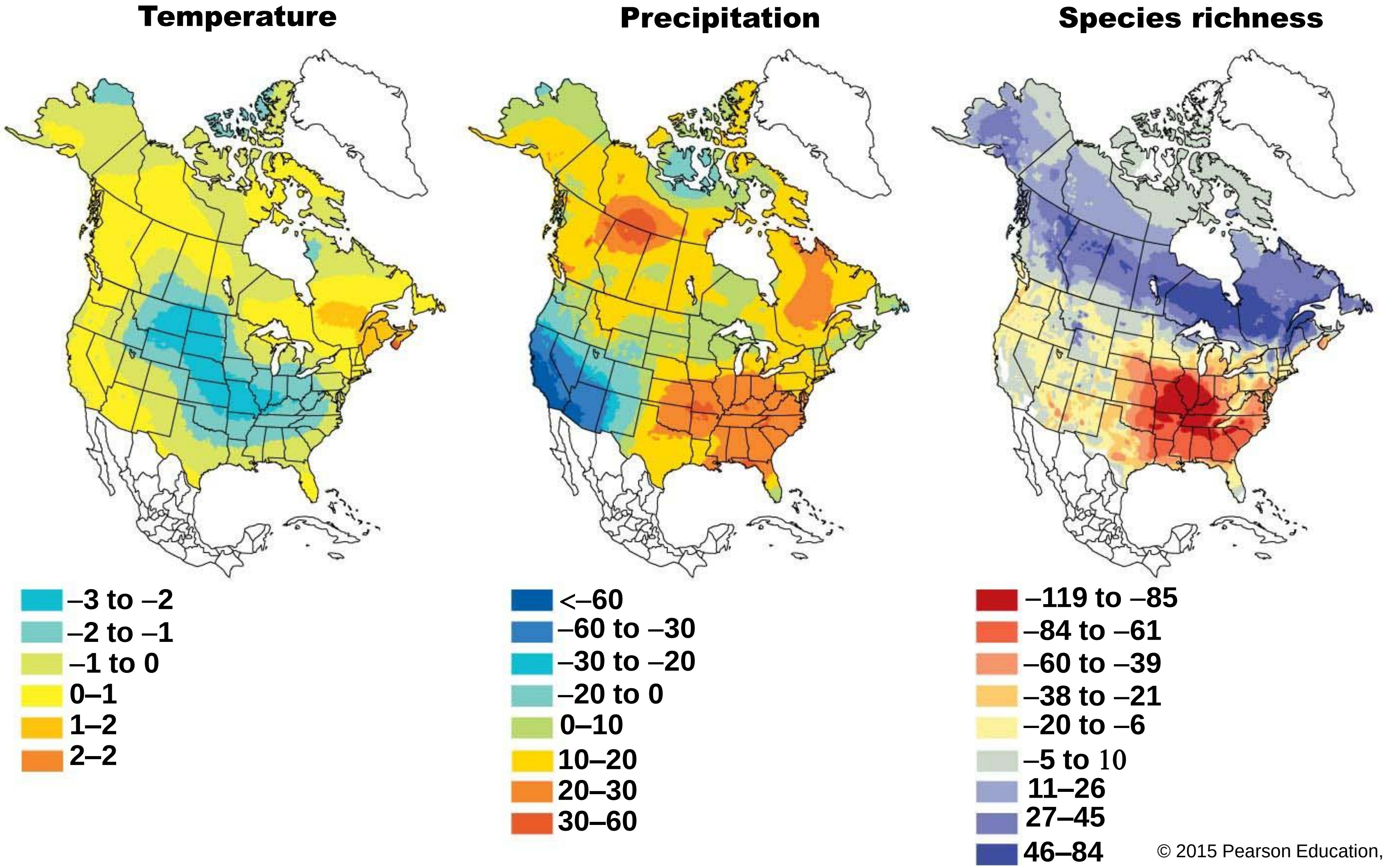
GCM3Avg Lo

GCM3Avg Hi

Maps of current and future potential distributions for United States Department of Agriculture Forest Service forest types. Maps include the United States Forest Service-Forest Inventory Analysis (FIA) estimate of current distribution and abundance, the modeled current map (RF-Current), and climate change scenarios based on the average of three general circulation models (GCM) using high future emissions estimates (GCM3 Avg Hi) and low future emissions estimates (GCM3 Avg Lo).

Figure 27.30

Projected changes in climate and tree species richness for North America under future climate change scenario of CGCM2 (Canadian Center for Climate Change Modeling and Analysis, Canada: CCCMA). Differences between current (1971–2000) and future (2071–2100) mean annual temperature (°C), annual precipitation (expressed as a percentage of current values), and tree species richness.



Section 27.10 Predicting Future Climate Change Requires an Understanding of the Interactions between the Biosphere and the Other Components of Earth's System

- In order to predict the fate of future carbon dioxide emissions, how rising carbon dioxide and associated climate change will influence carbon exchange between the atmosphere and terrestrial ecosystems needs to be determined
  - If NPP increases and there is a net removal of carbon dioxide – negative feedback
  - If NPP decreases (or decomposition increases) and there is a net addition of carbon dioxide – positive feedback