4

Coping with Environmental Variation: Temperature and Water

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- *Case Study: Frozen Frogs*
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Case Study: Frozen Frogs

In the movie *2001*: *A Space Odyssey*, astronauts were put in a state of suspended animation.

Interest in this idea has resulted in *cryonics*—preservation of bodies by freezing, in hopes they can be brought back to life in the future.

Case Study: Frozen Frogs

Farfetched? Organisms such as frogs can survive winter in a completely frozen state.

Although frogs first evolved in tropical biomes, two species live in the Arctic tundra.

They overwinter in shallow burrows, in a semi-frozen state, with no heartbeat, no blood circulation, and no breathing.

Figure 4.1 A Frozen Frog

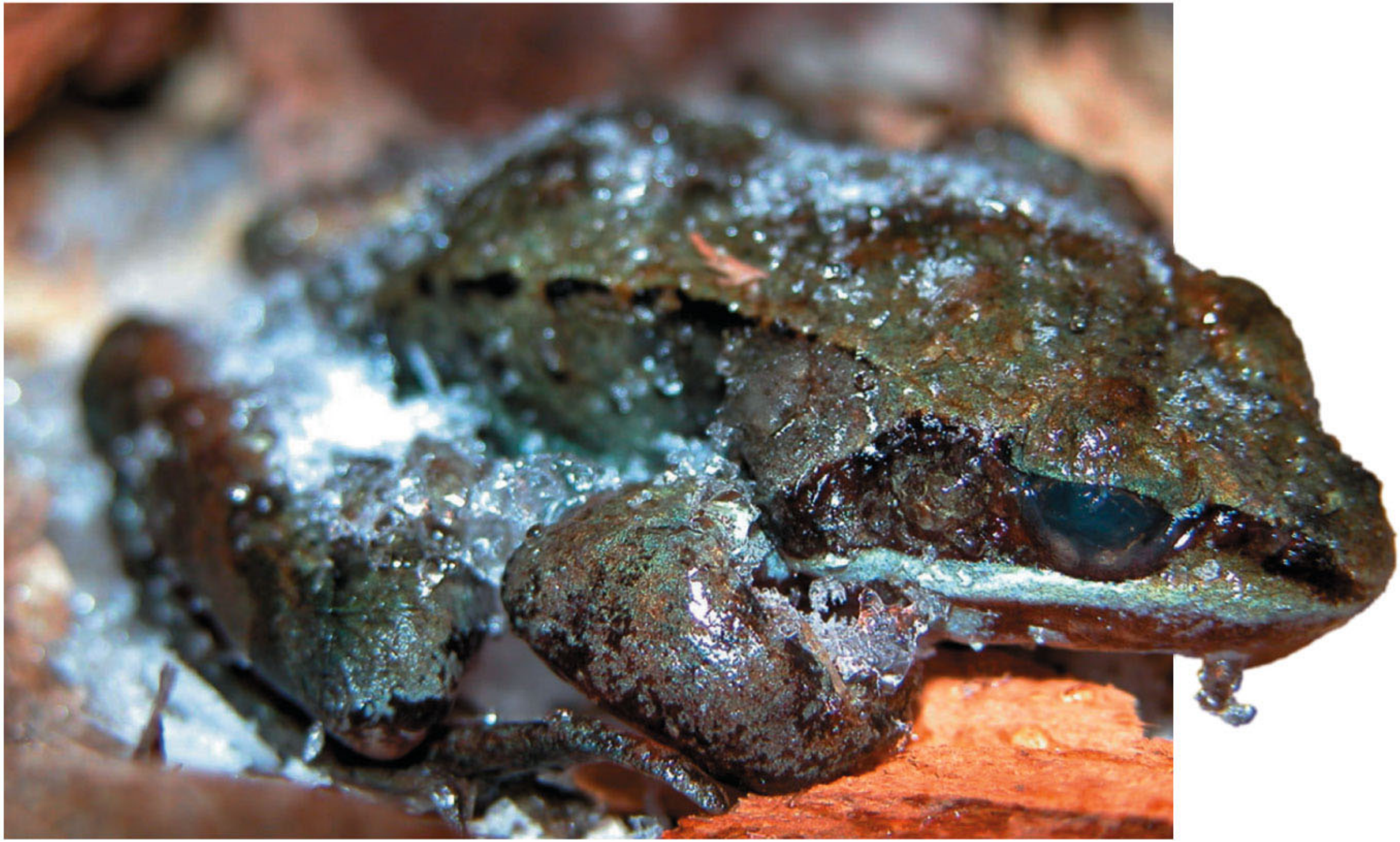
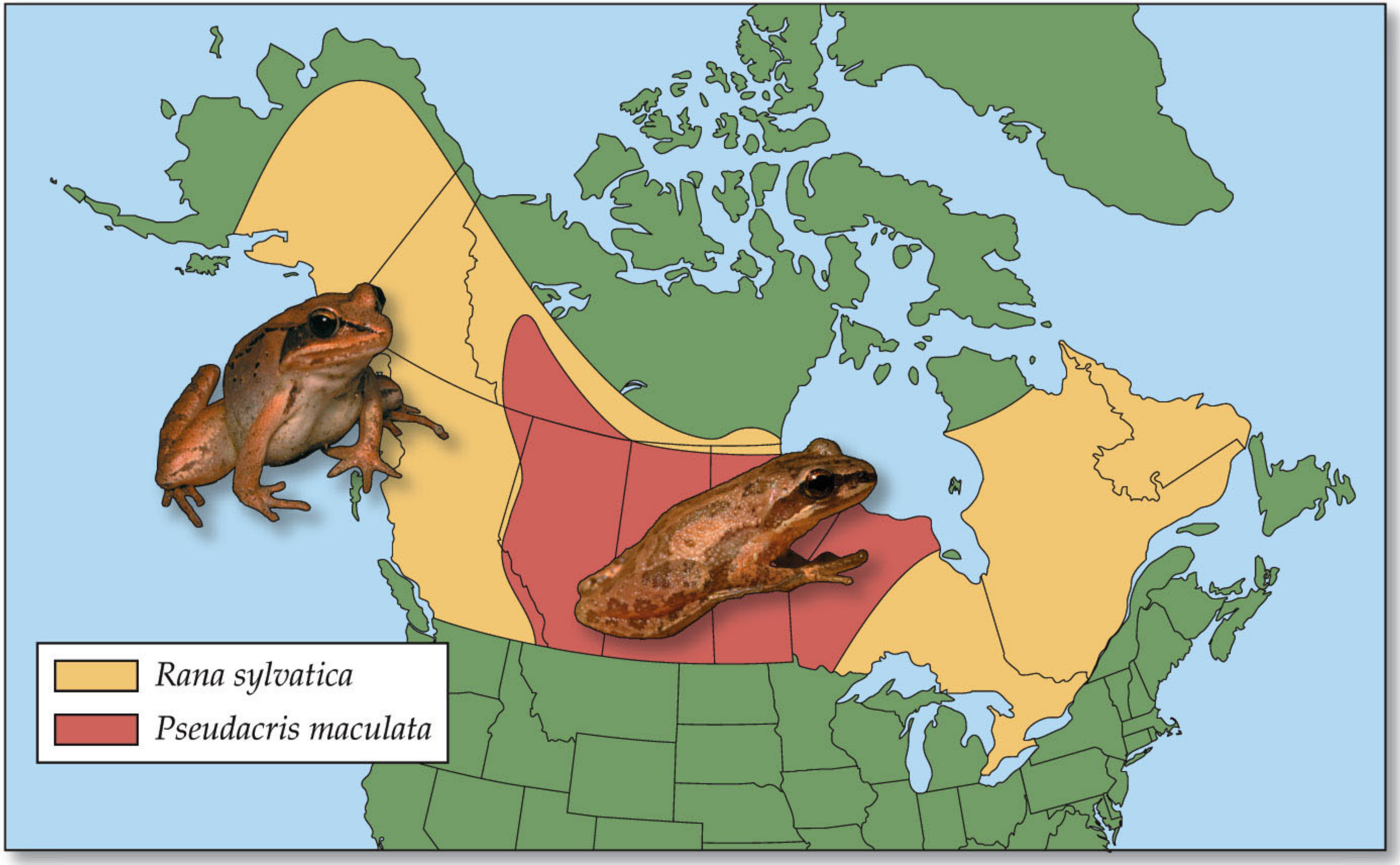


Figure 4.2 Northern Exposure



Case Study: Frozen Frogs

Few vertebrates can withstand freezing.

In most organisms, freezing results in tissue damage as ice crystals perforate cell membranes and organelles.

Organisms have two options for coping with environmental variation: **Tolerance** and **avoidance**.

Spruce trees in the boreal forest can not avoid temperature extremes, and so must be able to tolerate air temperatures that drop below –50°C in winter, and reach 30°C in summer.

Concept 4.1: Each species has a range of environmental tolerances that determines its potential geographic distribution.

A fundamental principle in ecology and biogeography is that geographic ranges of species are related to constraints imposed by the environment.

Response to Environmental Variation

The physical environment influences an organism’s success in two ways.

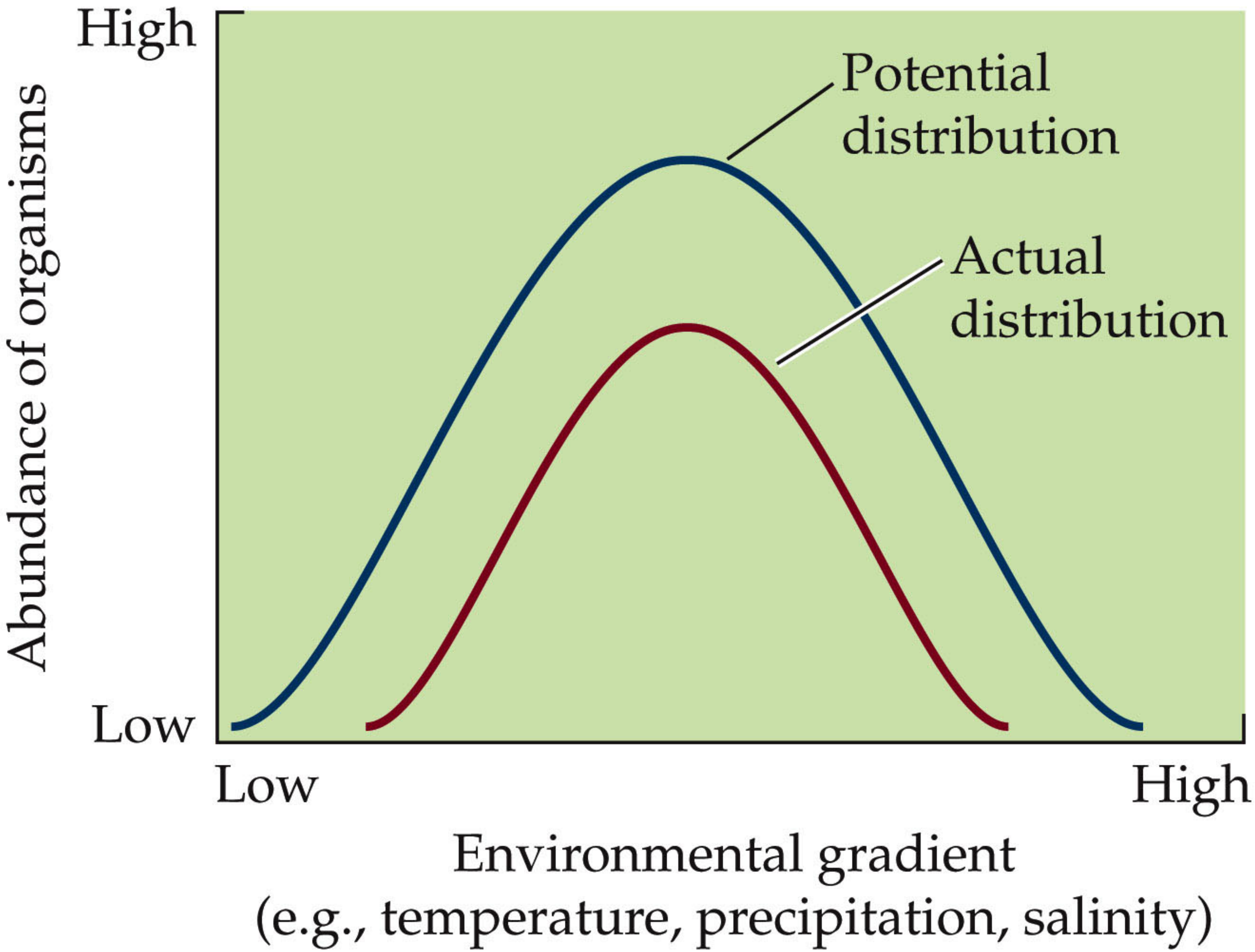
- Affects ability to obtain energy and resources, maintain metabolic functions, grow and reproduce.
- Extreme environmental conditions affect survival.

Response to Environmental Variation

Energy acquisition and environmental tolerance limits are not mutually exclusive: Energy supply influences an organism’s ability to tolerate environmental extremes.

The actual geographic distribution of a species is also related to other factors, such as disturbance and competition.

Figure 4.3 Abundance Varies across Environmental Gradients



ECOLOGY, Figure 4.3

Response to Environmental Variation

Because plants do not move, they are good indicators of the physical environment.

The range of aspens is related to climatic tolerance.

Aspen distribution can be predicted based on climate. Low temperatures and drought affect reproduction and survival.

Figure 4.4 Climate and Aspen Distribution (Part 1)

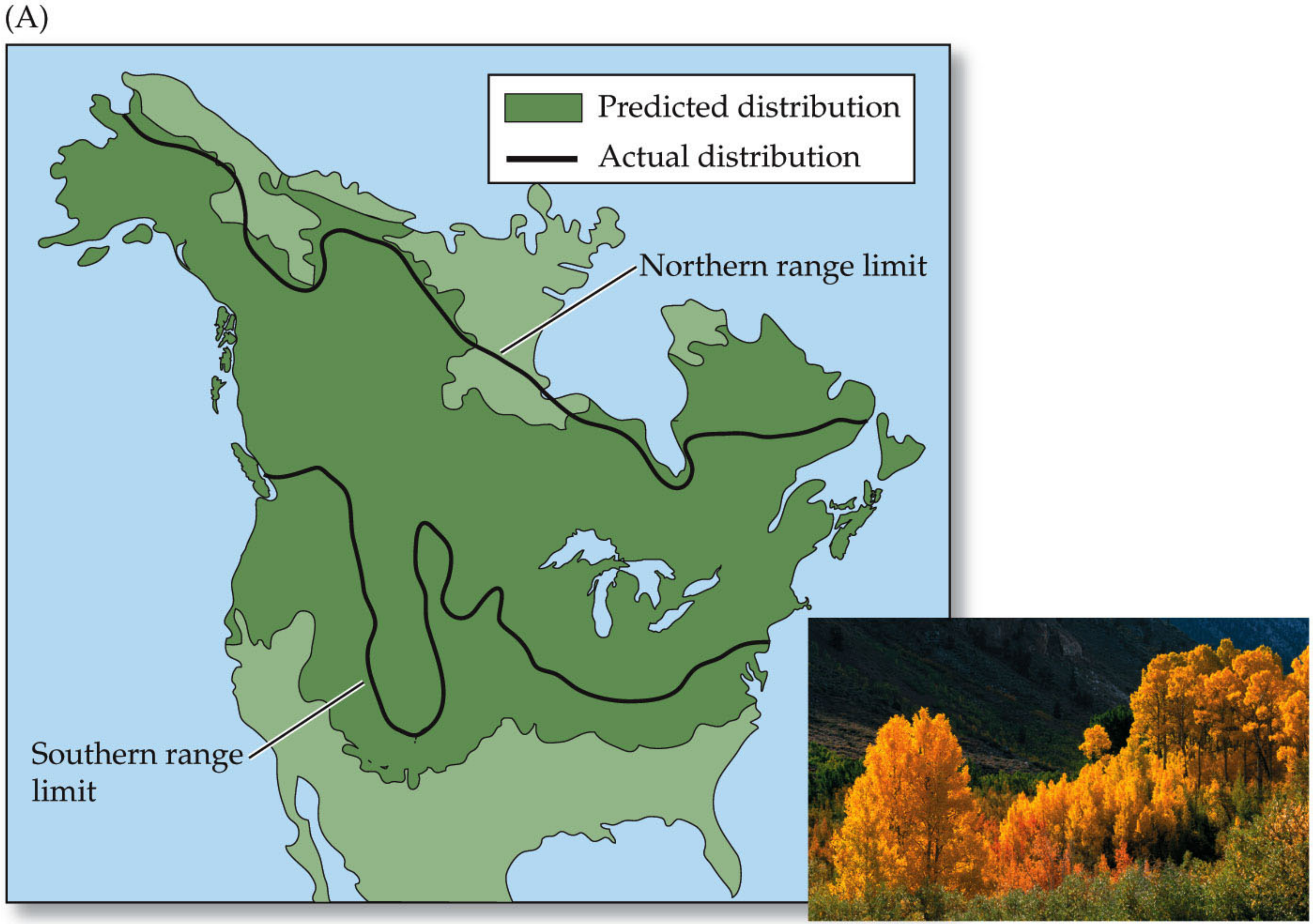
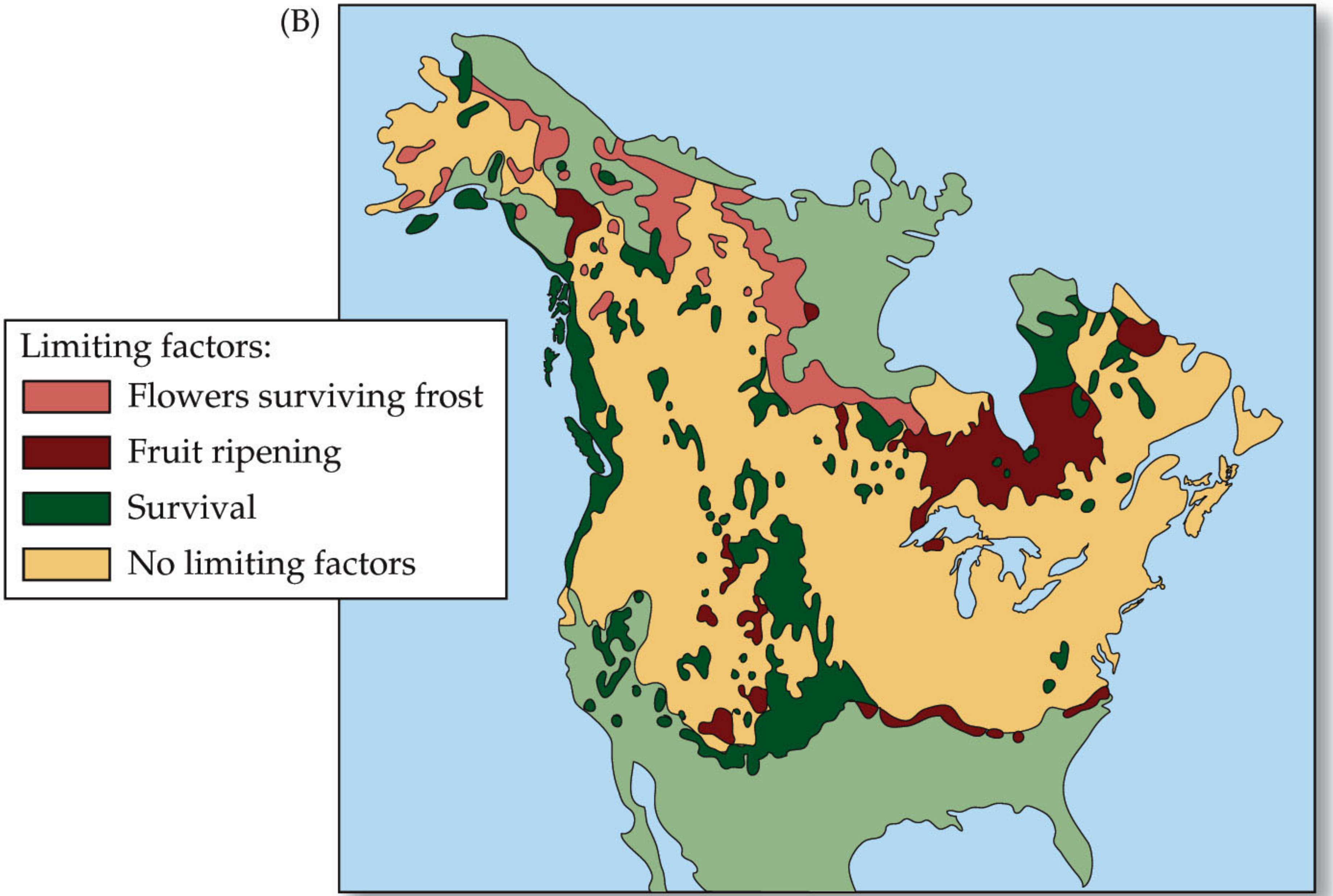


Figure 4.4 Climate and Aspen Distribution (Part 2)



Response to Environmental Variation

A species' *climate envelope* is the range of condition over which it occurs.

It is a useful tool for predicting its response to climate change.

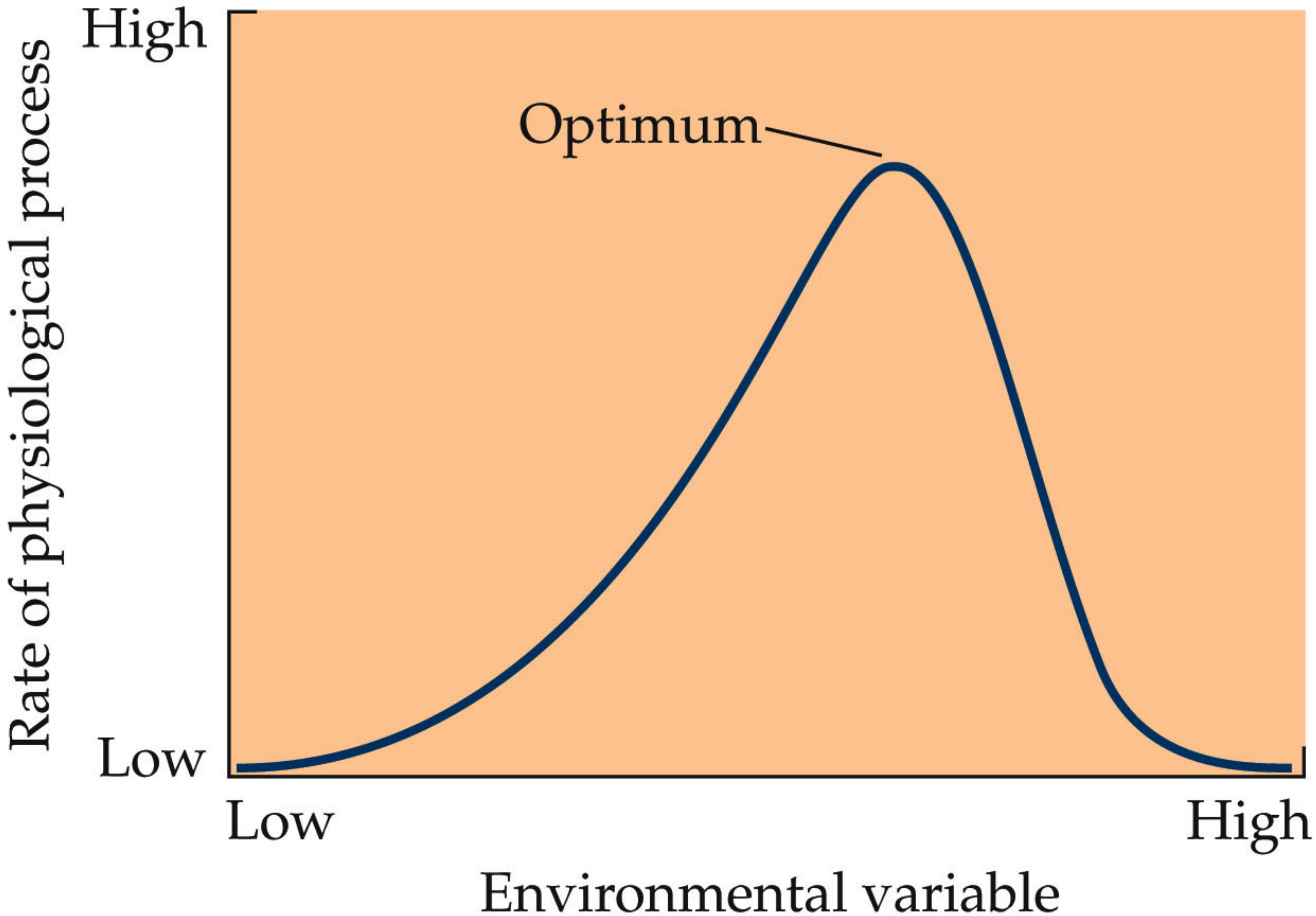
Response to Environmental Variation

Physiological processes have a set of optimal conditions for functioning.

Deviations from the optimum reduce the rate of the process.

Stress—environmental change results in decreased rates of important physiological processes, lowering the potential for survival, growth, or reproduction.

Figure 4.5 Environmental Control of Physiological Processes



ECOLOGY, Figure 4.5

Response to Environmental Variation

Example: At high altitudes, lower partial pressure of oxygen in the atmosphere results in *hypoxia*—not enough oxygen is delivered to your tissues.

Hypoxia causes “altitude sickness,” which is physiological stress.

Response to Environmental Variation

Many organisms can adjust to stress through behavior or physiology—called **acclimatization**.

It is usually a short-term, reversible process.

Acclimatization to high elevations involves higher breathing rates, greater production of red blood cells, and higher pulmonary blood pressure.

Response to Environmental Variation

Over time, natural selection can result in **adaptation** to environmental stress.

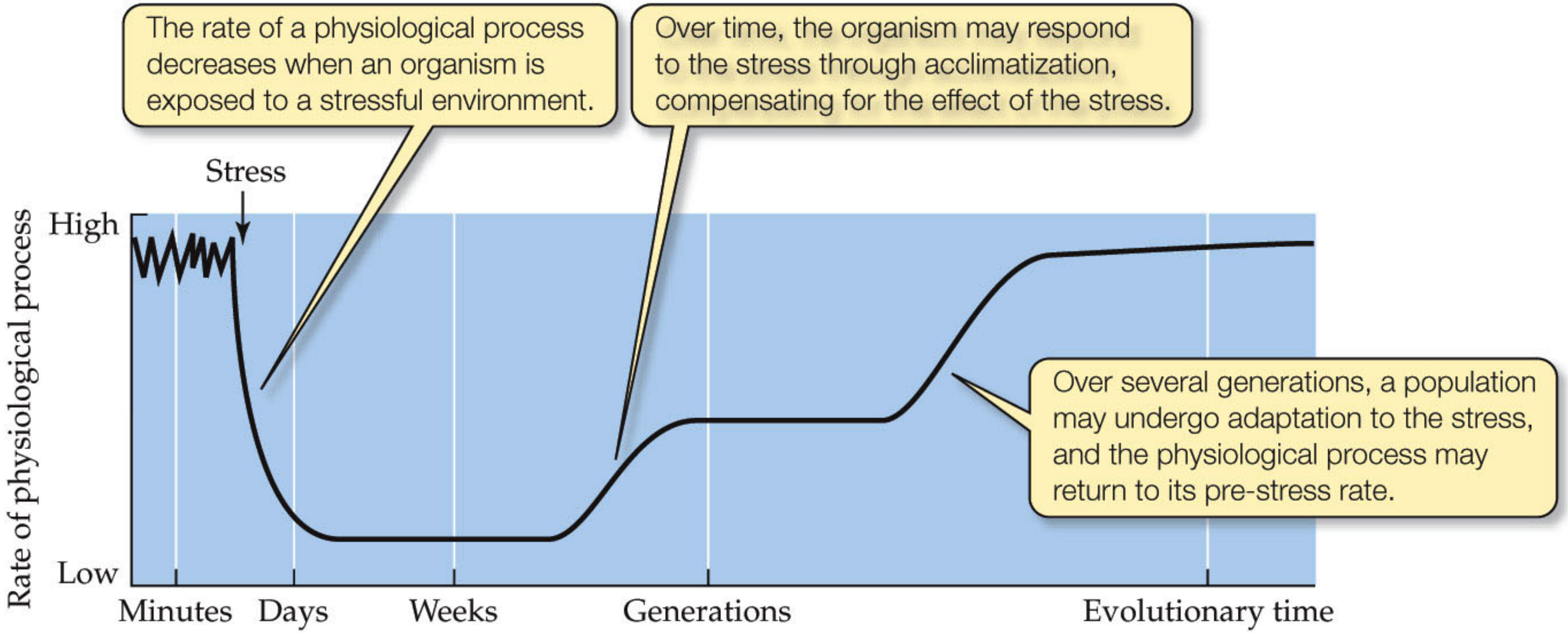
Individuals with traits that make them best able to cope with stress are favored.

Over time, these unique, genetically-based solutions become more frequent in the population.

Response to Environmental Variation

Adaptation is similar to acclimatization but it is the long-term, genetic response of a population to environmental stress that increases its survival and reproductive success.

Figure 4.6 Organismal Responses to Stress



Response to Environmental Variation

Populations with adaptations to unique environments are called **ecotypes**.

Ecotypes can eventually become separate species as populations diverge and eventually become reproductively isolated.

Response to Environmental Variation

An example of adaptation: Humans have lived in the Andes Mountains for 10,000 years.

When the Spanish first settled there in the sixteenth and seventeenth centuries, their birth rates were low for 2–3 generations, probably due to poor oxygen supply to developing fetuses.

Response to Environmental Variation

The indigenous Andean populations were adapted to the low-oxygen conditions by having higher red blood cell production and greater lung capacity.

Response to Environmental Variation

Adaptations can vary among populations.

Populations at high elevations in Tibet and Ethiopia have different adaptations.

Tibetans don’t have higher blood cell counts, but do have faster breathing rates.

Ethiopians don’t have higher cell counts, but have higher blood oxygen levels.

Response to Environmental Variation

Acclimatization and adaptation require investments of energy and resources, representing possible trade-offs with other functions that can also affect survival and reproduction.

Variation in Temperature

Concept 4.2: The temperature of organisms is determined by exchanges of energy with the external environment.

Environmental temperatures vary greatly throughout the biosphere.

Some habitats experience little variation, while others have large seasonal or daily variation.

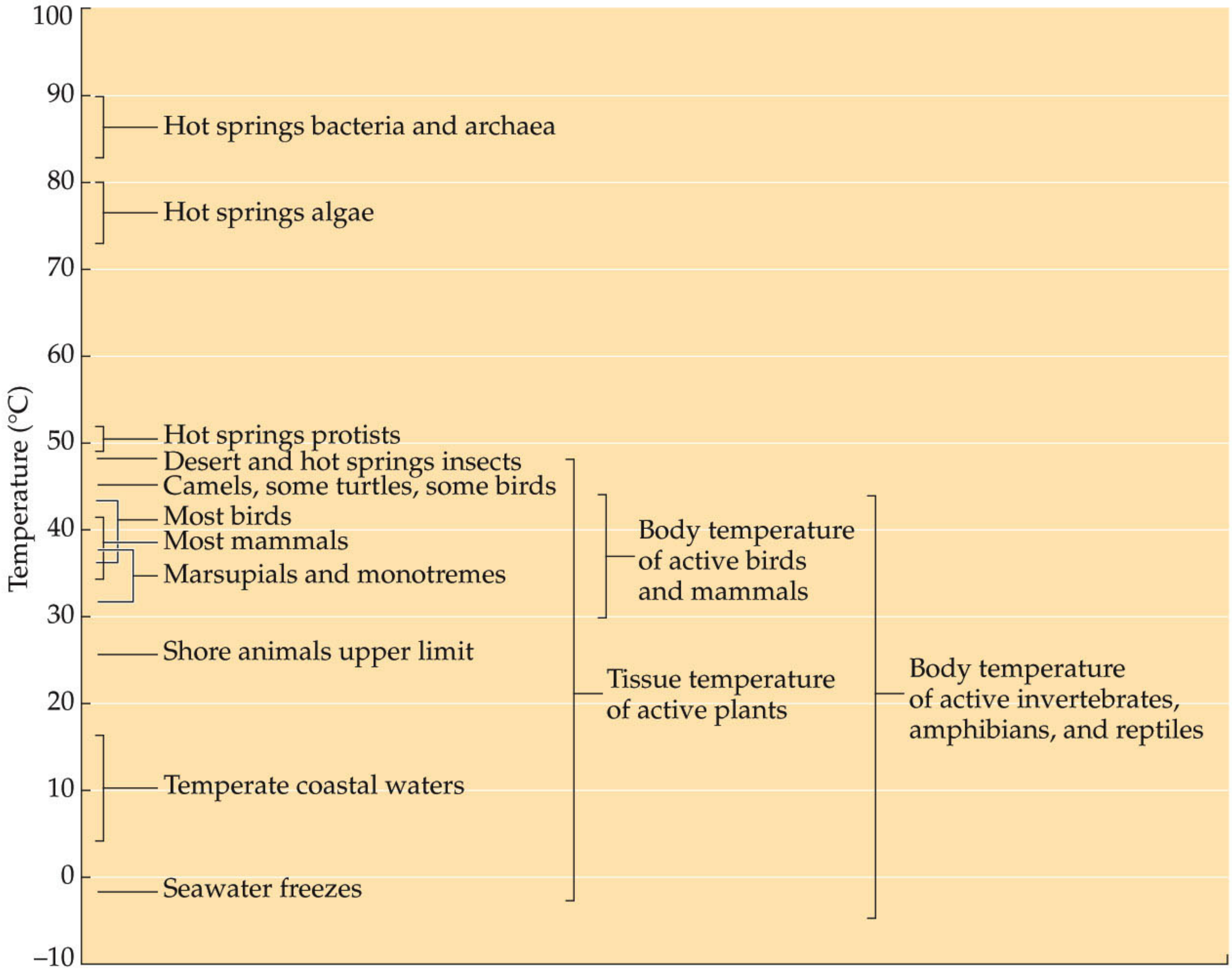
Variation in Temperature

Survival and functioning of organisms is strongly tied to their internal temperatures.

Some archaea and bacteria in hot springs can function at 90°C.

Lower limits are determined by temperature at which water freezes in cells (–2 to –5°C).

Figure 4.7 Temperature Ranges for Life on Earth



ECOLOGY, Figure 4.7

Variation in Temperature

Some organisms can survive periods of extreme heat or cold by entering a state of *dormancy*, in which little or no metabolic activity occurs.

Variation in Temperature

The temperature of an organism is related to the balance between gains and losses of energy to the external environment.

Organisms must either tolerate internal temperature change or modify it by some physiological, morphological, or behavioral means.

Variation in Temperature

Metabolic reactions are temperature-sensitive, due to the sensitivity of *enzymes*, which catalyze the reactions.

Enzymes are stable only within a narrow range of temperatures.

At high temperatures, enzymes become *denatured*, which destroys enzyme function.

Variation in Temperature

Bacteria in hot springs have enzymes that are stable up to 100°C.

Antarctic fish and crustaceans must have enzymes that function at –2ºC; and soil microbes are active at temperatures as low as –5ºC.

Variation in Temperature

Temperature also affects the properties of cell and organelle membranes, which are composed of two layers of lipid molecules.

At low temperatures, these lipids can solidify, embedded proteins can’t function, and the cells leak metabolites.

Variation in Temperature

The chemical composition of membrane lipid molecules affects temperature sensitivity.

Plants that thrive at low temperatures have higher proportions of unsaturated lipids (with double bonds) in their cell membranes.

Variation in Temperature

Temperature also affects water availability.

The rate at which terrestrial organisms lose water from their bodies is related to air temperature.

Variation in Temperature

The balance between inputs and outputs of energy determines whether the temperature of any object will increase or decrease.

Organisms can adjust their exchange of energy with the environment.

Many can change behaviors to avoid adverse temperatures; many also have varying degrees of tolerance.

Variation in Temperature

Energy exchange with the environment can be by:

Conduction—transfer of energy from warmer to cooler molecules.

Convection—heat energy is carried by moving water or air.

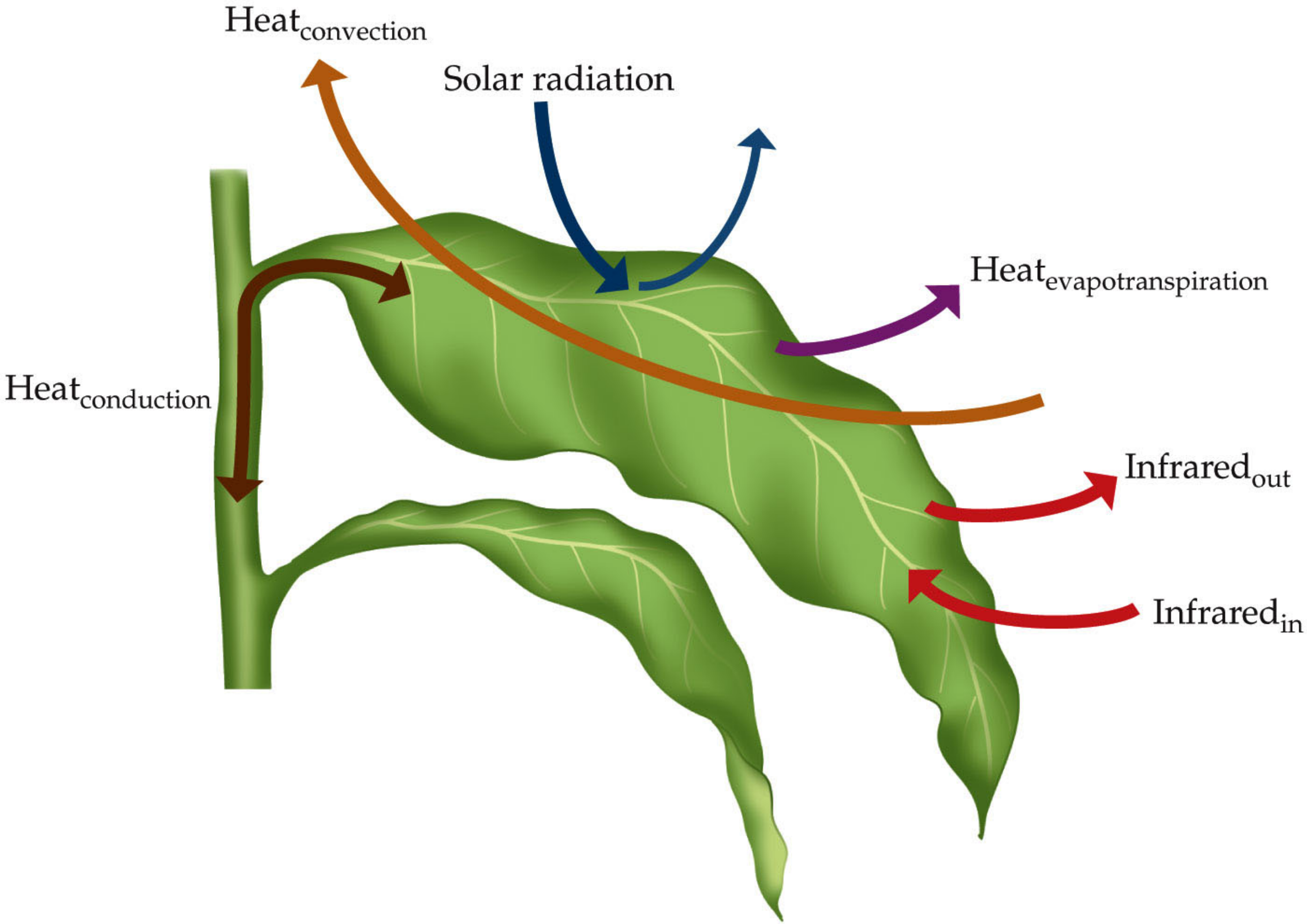
Latent heat transfer—water absorbs heat as it changes state from liquid to gas.

Variation in Temperature

For terrestrial plants, energy inputs include sunlight and longwave (infrared) radiation from surrounding objects.

Losses of energy include emission of infrared radiation to the environment, and through *evapotranspiration.*

Figure 4.8 Energy Exchange in Terrestrial Plants



ECOLOGY, Figure 4.8

Variation in Temperature

Temperature change in a plant can be expressed by the following equation.

$$\Delta H_{plant} = SR + IR_{in} - IR_{out} \pm H_{conv} \pm H_{cond} - H_{et}$$

SR = Solar radiation

IR = Infrared radiation

H_{conv} = Convective heat transfer

H_{cond} = Conductive heat transfer

H_{et} = Heat transfer by evapotranspiration

Variation in Temperature

If the plant is warmer than the surrounding air, H_{conv} and H_{cond} are negative.

If the total energy inputs exceed total outputs, then ΔH_{plant} is positive, and the plant's temperature is increasing.

If more heat is being lost than gained, then ΔH_{plant} is negative, and the plant's temperature is decreasing.

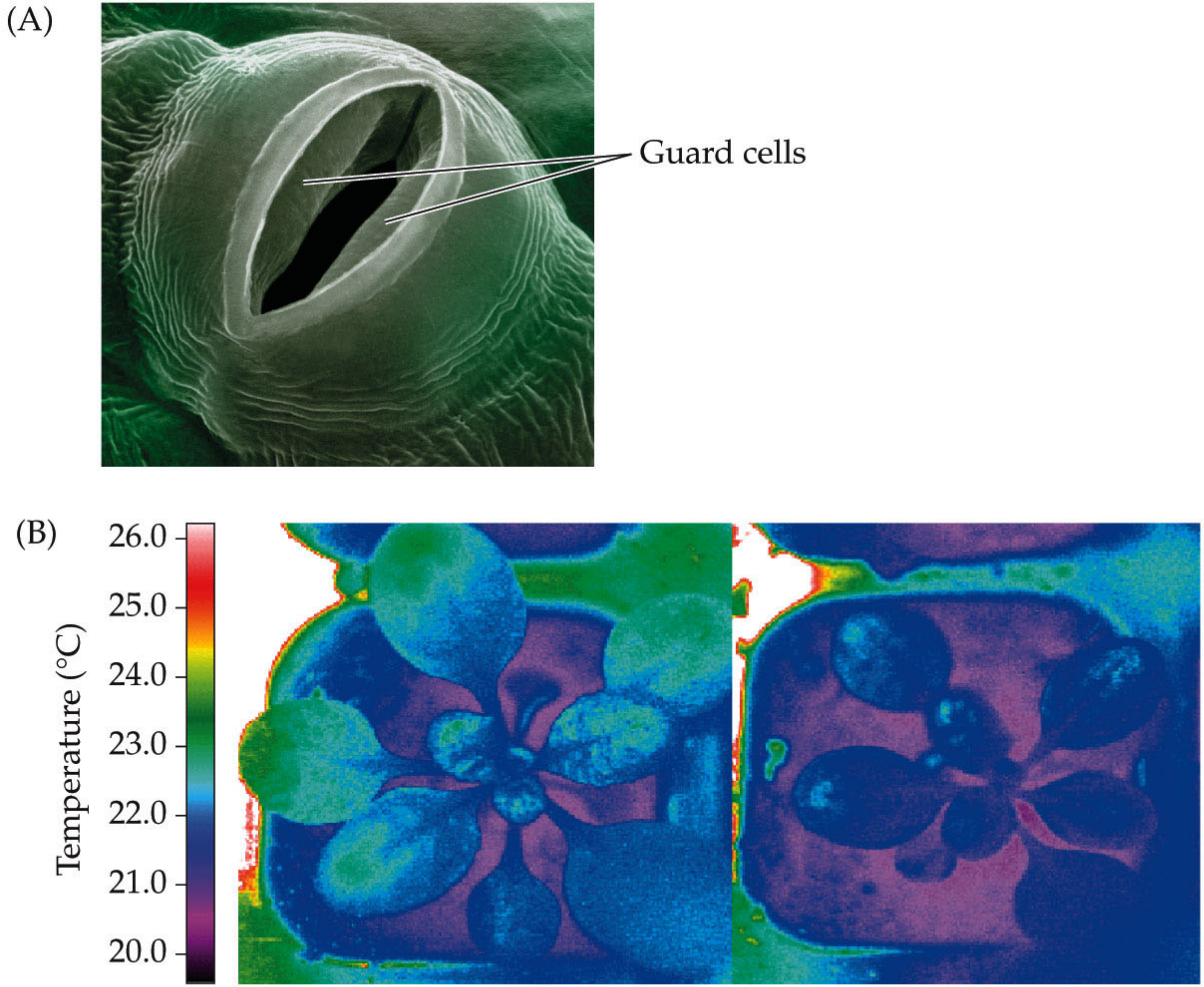
Variation in Temperature

Plants can adjust energy inputs and outputs.

Transpiration rates can be controlled by specialized *guard cells* surrounding a pore, called a **stomate**.

Variation in the size of the opening and number of stomates control the rate of transpiration and thus control leaf temperature.

Figure 4.9 Stomates Control Leaf Temperature by Controlling Transpiration



Variation in Temperature

If soil water is limited, transpirational cooling is not a good mechanism.

Some plants shed their leaves during dry seasons.

Other mechanisms include **pubescence**—hairs on leaf surfaces that reflect solar energy. But hairs also reduce conductive heat loss.

Variation in Temperature

Pubescence has been studied in *Encelia* (plants in the daisy family) (Ehleringer and Cook 1990).

Desert species with high pubescence were compared with non-pubescent species in moister, cooler environments.

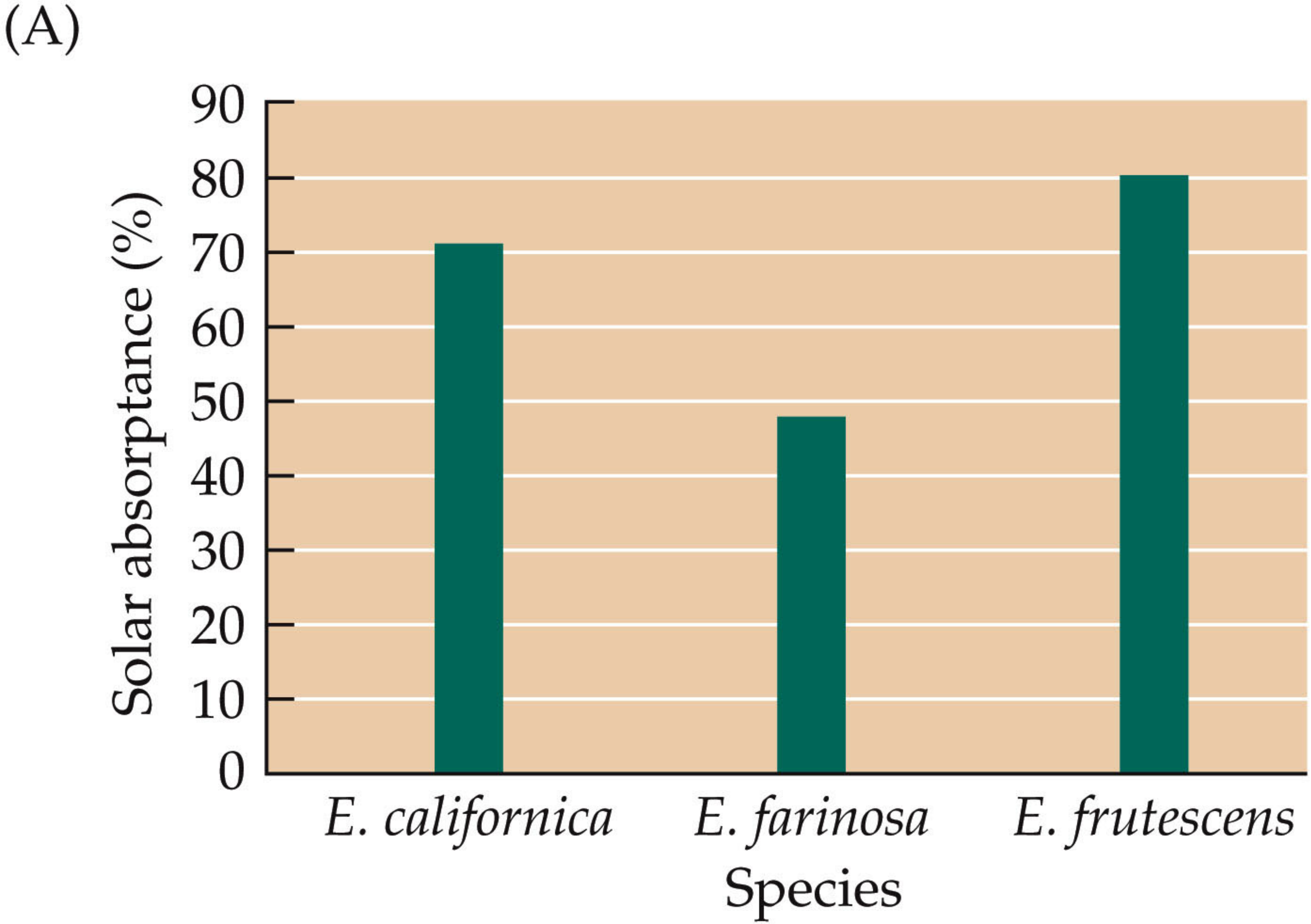
Plants of all species were grown in both locations.

Variation in Temperature

In the cool, moist location, the three *Encelia* species showed few differences in leaf temperature and stomatal opening.

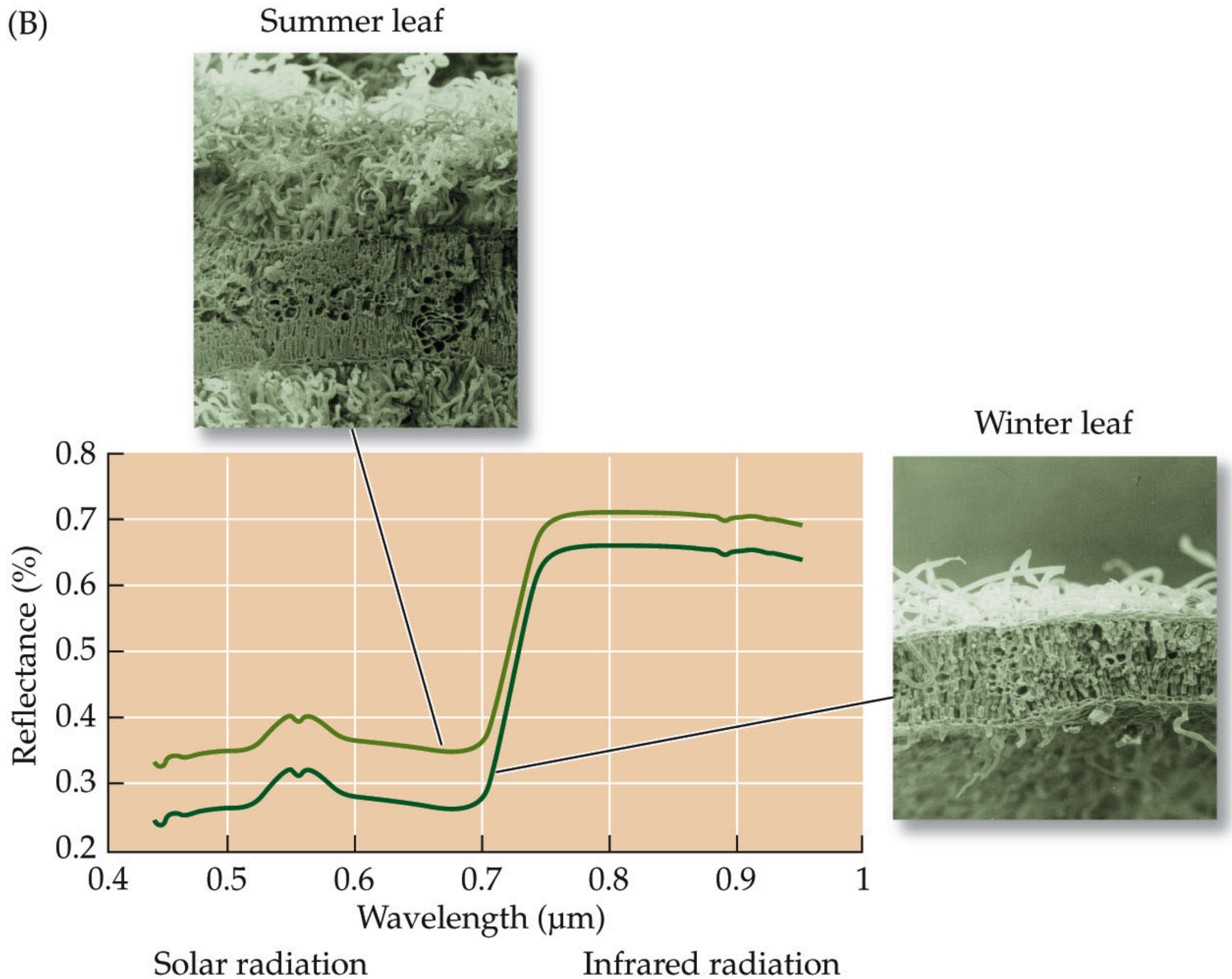
In the desert, the species with no hairs maintained leaf temperature by transpiration; the pubescent species leaves reflected about twice as much solar radiation.

Figure 4.10 Sunlight, Seasonal Changes, and Leaf Pubescence (Part 1)



ECOLOGY, Figure 4.10 (Part 1)

Figure 4.10 Sunlight, Seasonal Changes, and Leaf Pubescence (Part 2)



ECOLOGY, **Figure 4.10 (Part 2)**

Variation in Temperature

Natural selection has acted on populations (ecotypes) of *E. farinosa*.

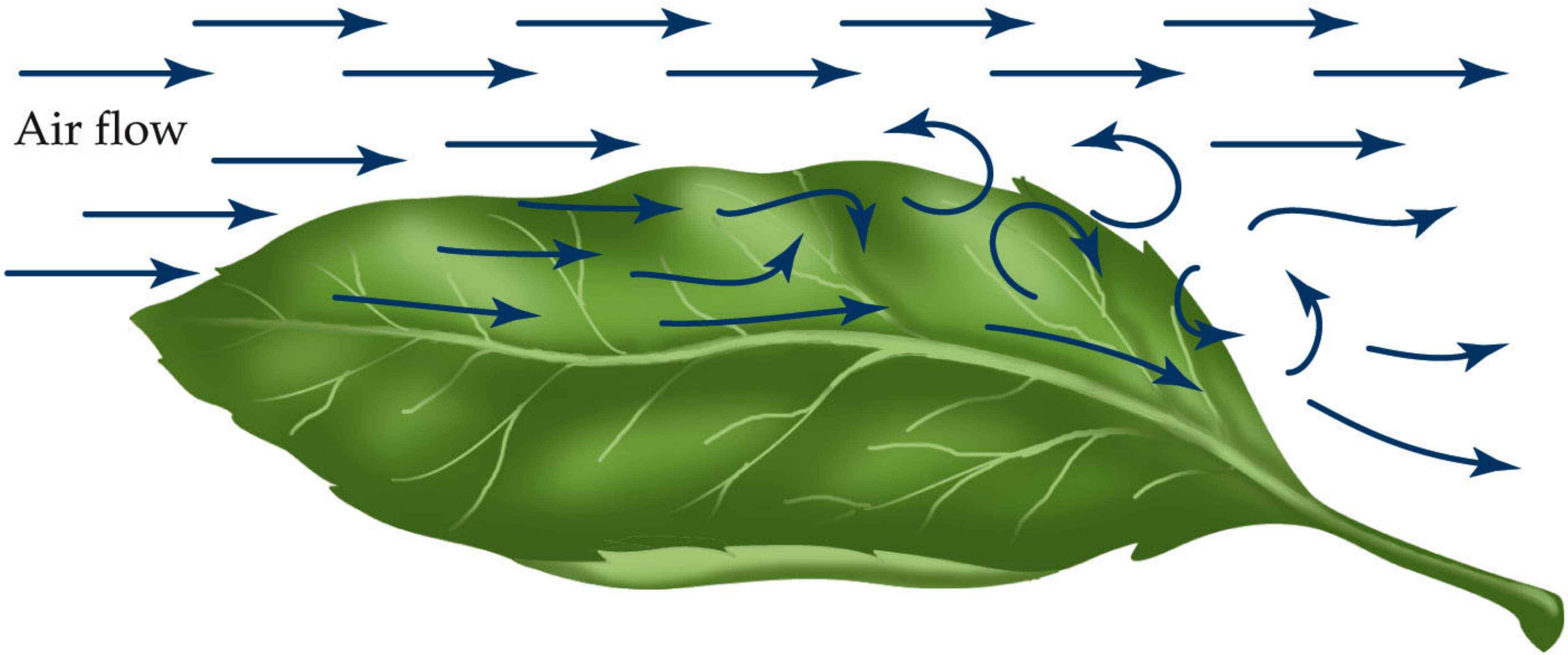
In drier environments, leaves had more pubescence, and absorbed less solar radiation than populations from moister environments (Sandquist and Ehleringer 2003).

Variation in Temperature

If air temperature is lower than leaf temperature, heat can be lost by convection, dependent on speed of air moving across the leaf surface.

Moving air encounters more resistance close to the surface of an object; the flow becomes more turbulent, forming eddies. The zone of turbulent flow is the **boundary layer**.

Figure 4.11 A Leaf Boundary Layer



Variation in Temperature

The boundary layer lowers convective heat loss.

The thickness of the boundary layer on a leaf is related to its size and its surface roughness.

Small, smooth leaves have thin boundary layers and lose heat more effectively than large or rough leaves.

Variation in Temperature

In alpine environments, convection is the main heat loss mechanism.

Most alpine plants hug the ground surface to avoid the high wind velocities.

Some have a layer of insulating hair to lower convective heat loss.

Figure 4.12 A Woolly Plant of the Himalayas

ECOLOGY, Figure 4.12

Variation in Temperature

Animals, especially birds and mammals, can generate heat internally.

The energy balance equation for animals is shown below.

$$\Delta H_{animal} = SR + IR_{in} - IR_{out} \pm H_{conv} \pm H_{cond} - H_{evap} + H_{met}$$

H_{evap} = Heat transfer by evaporation

H_{met} = Metabolic heat generation

Variation in Temperature

Evaporative heat loss in animals includes sweating in humans, panting in dogs and other animals, and licking of the body by some marsupials.

Variation in Temperature

Generating heat internally is an advantage: Animals can maintain relatively constant internal temperatures near the optimum for metabolic functions under a wide range of external temperatures.

Variation in Temperature

Ectotherms: Primarily regulate body temperature through energy exchange with the external environment.

Endotherms: Rely primarily on internal heat generation, mostly birds and mammals.

Variation in Temperature

Some other organisms that generate heat internally include bees, some fish, such as tuna, and even some plants.

Skunk cabbage warms its flowers using metabolically generated heat during the spring.

Figure 4.13 Internal Heat Generation as a Defense

(A) (B)

Variation in Temperature

Ectotherms generally have a higher tolerance for temperature variation than do endotherms.

In exchanging heat with the environment, the surface area-to-volume ratio of the body is a factor.

Variation in Temperature

Larger surface area allows greater heat exchange, but makes it harder to maintain internal temperature.

A smaller surface area relative to volume decreases the animal's ability to gain or lose heat.

Variation in Temperature

As body size increases, surface area-to-volume ratio decreases, and large ectotherms are thus improbable.

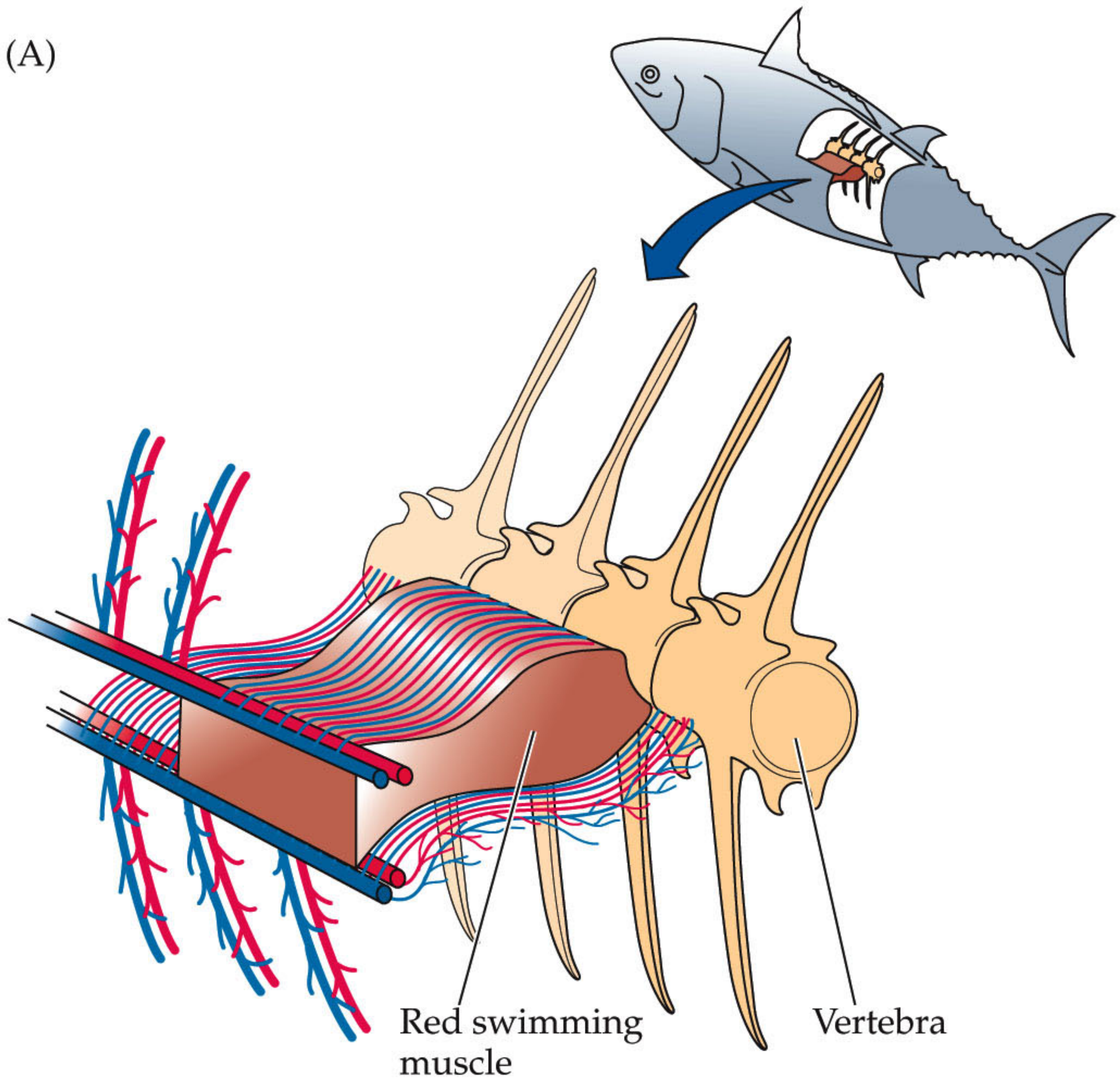
This had led to speculation that large dinosaurs may have had some degree of endothermy.

Variation in Temperature

Some large ectotherms can maintain body temperature above the environmental temperature.

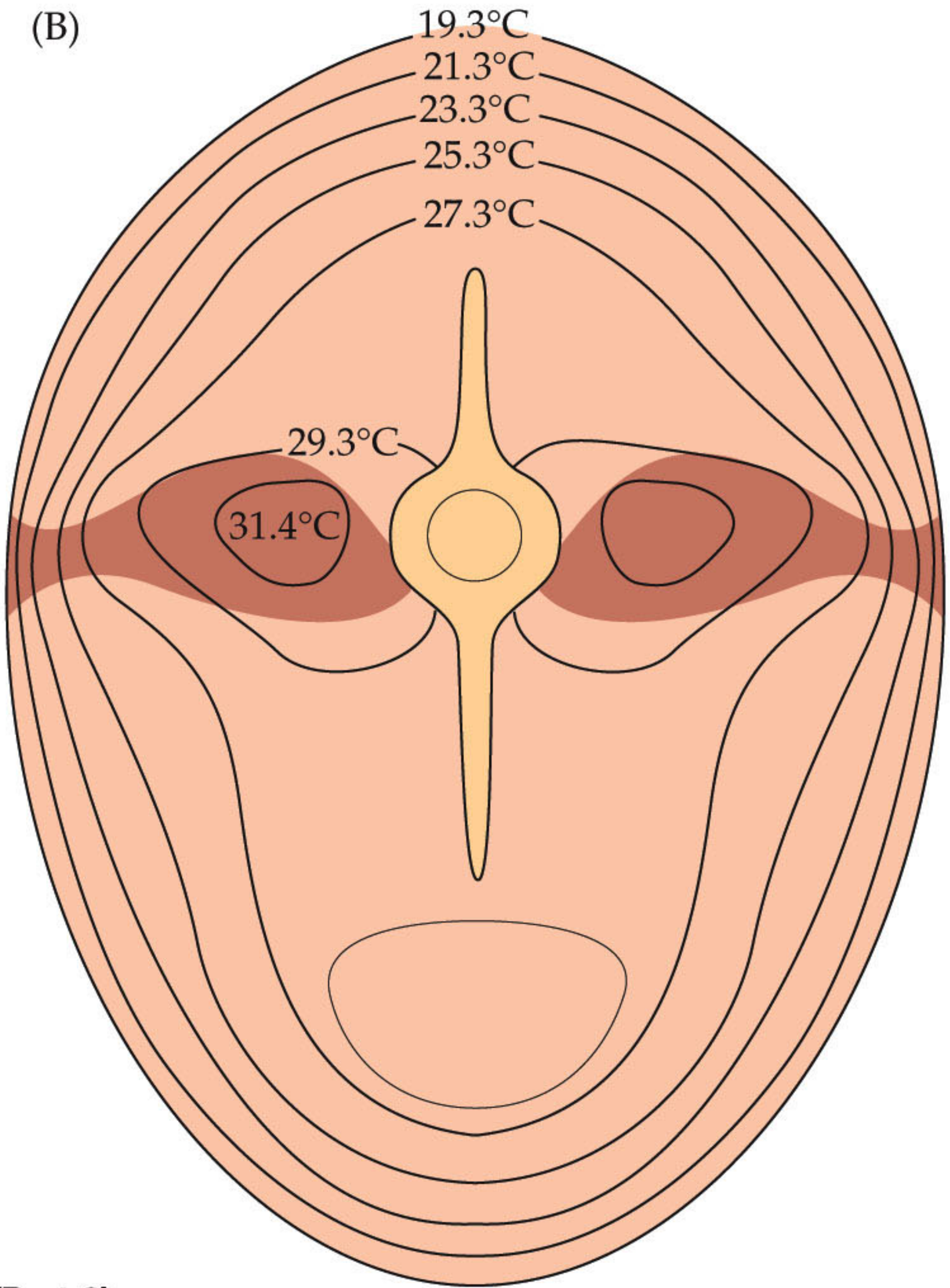
Skipjack tuna use muscle activity in conjunction with heat exchange between blood vessels to maintain a body temperature as much as 14°C warmer than the surrounding seawater.

Figure 4.14 Internal Heat Generation by Tuna (Part 1)



ECOLOGY, Figure 4.14 (Part 1)

Figure 4.14 Internal Heat Generation by Tuna (Part 2)



***ECOLOGY,* Figure 4.14 (Part 2)**

Variation in Temperature

Many terrestrial ectotherms can move to adjust temperature.

Many insects and reptiles bask in the sun to warm up after a cold night. Because this increases risk from predators, many are also camouflaged.

Figure 4.15 Mobile Animals Can Use Behavior to Adjust Their Body Temperature

***ECOLOGY*, Figure 4.15**

Variation in Temperature

Ectotherms in temperate and polar regions must avoid or tolerate freezing.

Avoidance behavior includes seasonal migration to lower latitudes or microsites that are above freezing (e.g., burrows in soil).

Variation in Temperature

Tolerance to freezing involves minimizing damage associated with ice formation in cells.

Some insects contain high concentrations of glycerol, a chemical lowers the freezing point of body fluids.

Vertebrates generally do not tolerate freezing temperatures.

Variation in Temperature

Endotherms can remain active at subfreezing temperatures.

The cost of being endothermic is a high demand for energy (food) to support metabolic heat production.

Variation in Temperature

Metabolic rate in endotherms is associated with the external temperature and rate of heat loss.

Rate of heat loss is related to body size due to surface area-to-volume ratio.

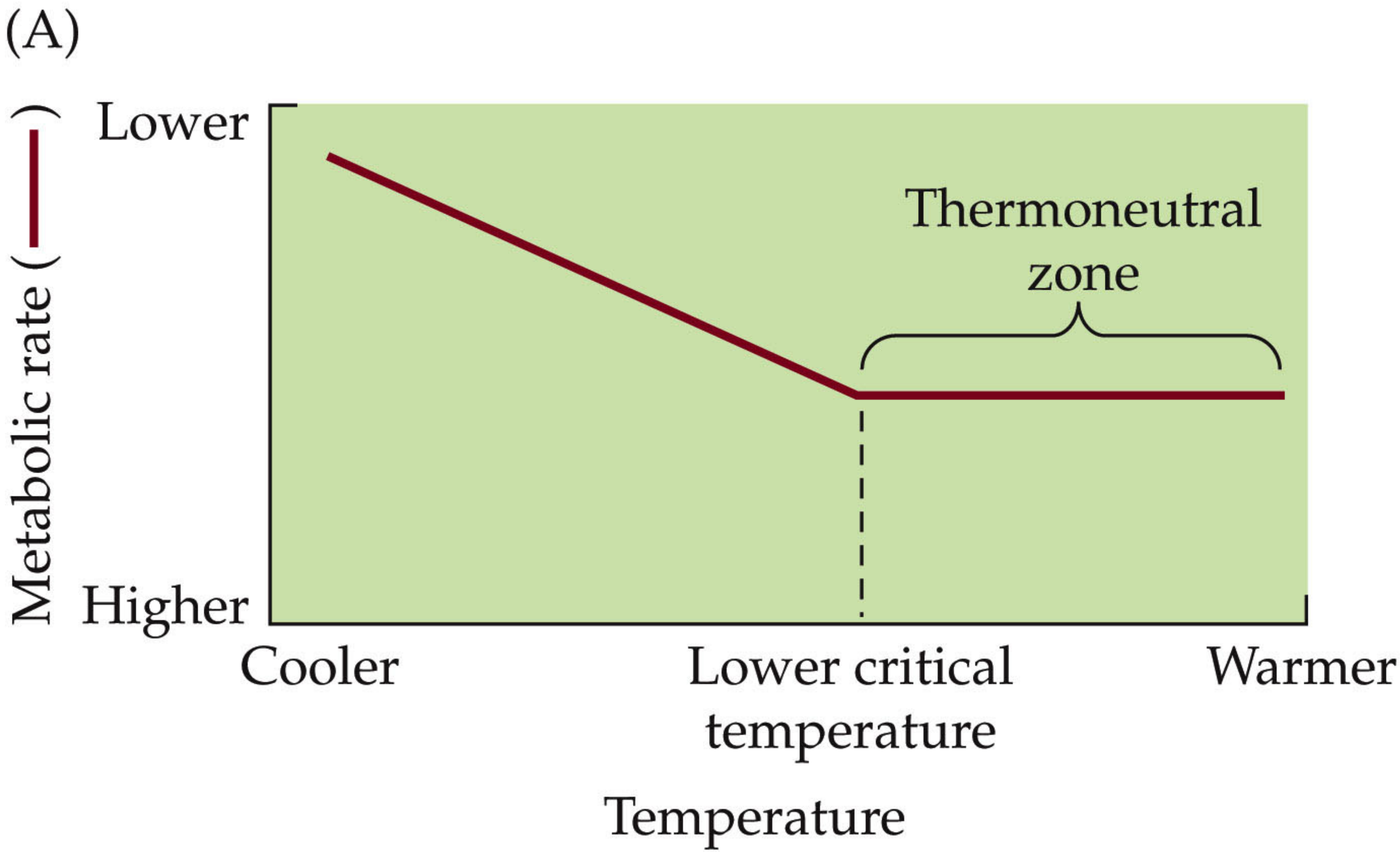
Small endotherms have higher metabolic rates, and require more energy and higher feeding rates than large endotherms.

Variation in Temperature

Thermoneutral zone—constant resting metabolic rate over a range of environmental temperatures.

Lower critical temperature—when heat loss is greater than metabolic production; body temperature drops and metabolic heat generation increases.

Figure 4.16 A Metabolic Rates in Endotherms Vary with Environmental Temperatures

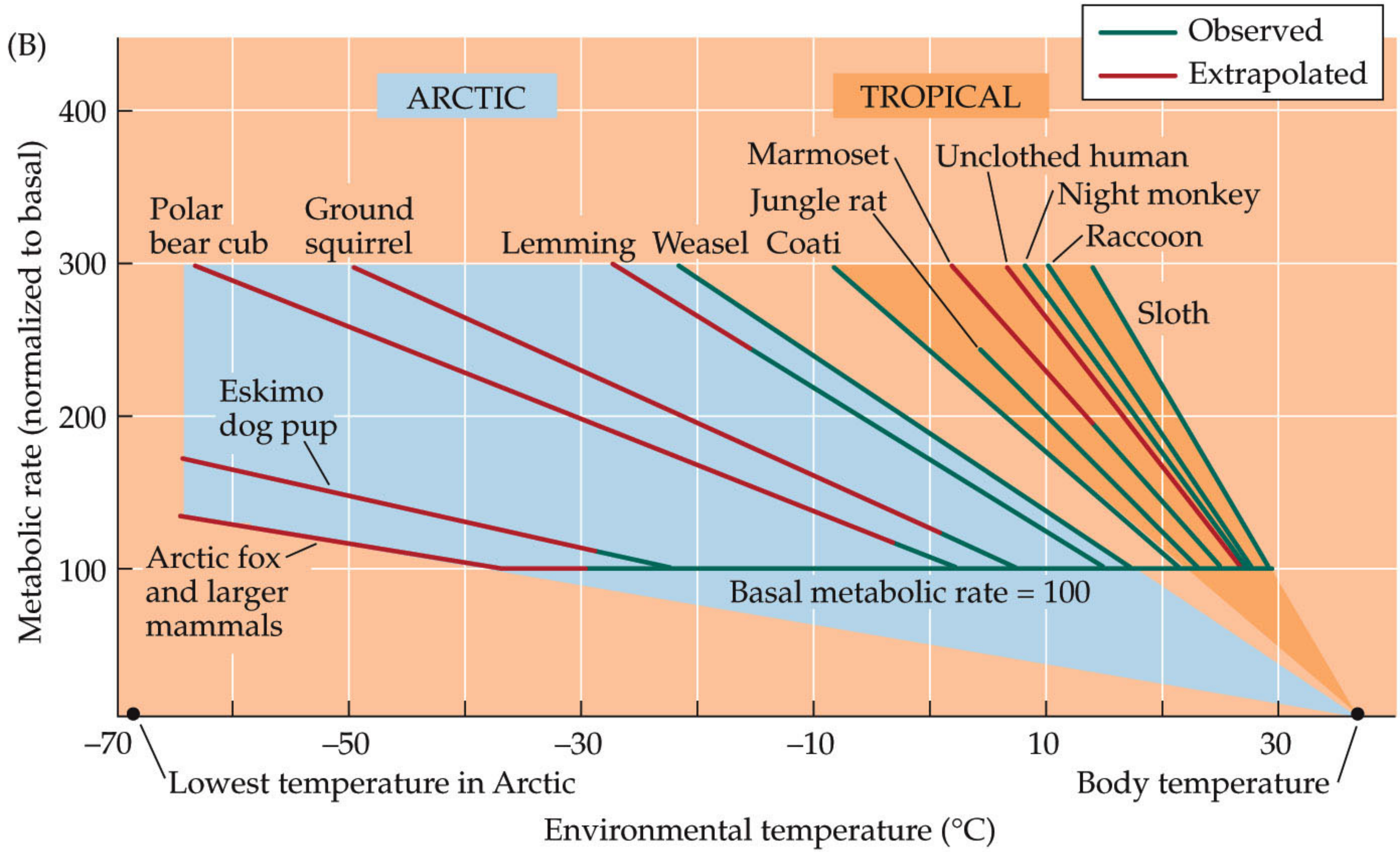


Variation in Temperature

Animals from the Arctic have lower critical temperatures than those of animals from tropical regions.

Note also that the rate of metabolic activity increases more rapidly below the lower critical temperature in tropical as compared to Arctic mammals.

Figure 4.16 B Metabolic Rates in Endotherms Vary with Environmental Temperatures



Variation in Temperature

Evolution of endothermy required insulation—feathers, fur, fat.

Insulation limits conductive and convective heat loss.

Fur and feathers provide a layer of still air adjacent to the skin.

Some animals grow thicker fur for winter.

Variation in Temperature

Small endotherms have high demand for metabolic energy below the lower critical temperature, low insulation values of their fur, and low capacity to store energy.

How can they survive in cold climates?

By altering the lower critical temperature by entering a state of dormancy known as **torpor**.

Variation in Temperature

In torpor, body temperature may drop as much as 20°C below normal, and metabolic rate can be 50%–90% lower than normal.

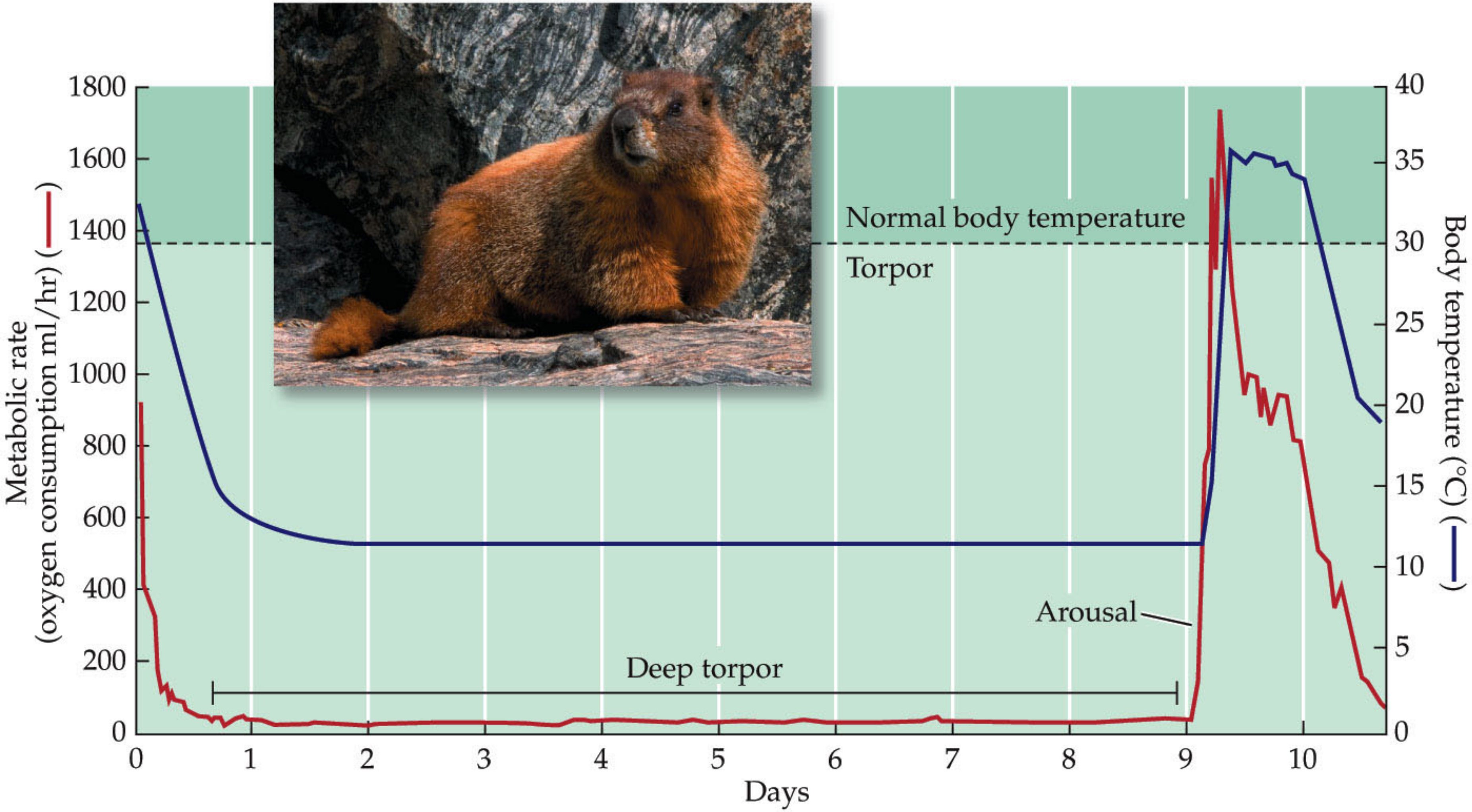
Energy reserves are needed to come out of torpor. The length of time an animal can remain in torpor is limited by its reserves of energy.

Variation in Temperature

Small endotherms may regularly undergo daily torpor to minimize energy needed during cold nights.

Long-term torpor is possible only for animals that have enough food and can store enough energy reserves, such as marmots.

Figure 4.17 Long-Term Torpor in Marmots



Concept 4.3: The water balance of organisms is determined by exchanges of water and solutes with the external environment.

Water is the medium in which all biochemical reactions necessary for life occur.

Water has unique properties that make it a universal solvent for biologically important solutes.

Variation in Water Availability

Maintaining optimal water content is a challenge for freshwater and terrestrial organisms.

Ocean waters maintain the water balance of marine organisms.

Terrestrial species lose water to a dry atmosphere.

Freshwater organisms lose solutes to and gain water from their environment.

Variation in Water Availability

Water flows along energy gradients.

- Gravity—water flows downhill. The associated energy is **gravitational potential**.

- Pressure—from an area of higher pressure, to lower. The associated energy is **pressure** (or *turgor*) **potential**.

Variation in Water Availability

- **Osmotic potential**—water flows from a region of high concentration (low solute concentration) to a region of low concentration (high solute concentration).
- **Matric potential**—energy associated with attractive forces on surfaces of large molecules inside cells or on surfaces of soil particles.

Variation in Water Availability

Water potential is the sum of all these energy components. It can be defined as:

$$\Psi = \Psi_o + \Psi_p + \Psi_m$$

Ψ_o = osmotic potential (negative value).
Ψ_p = pressure potential.
Ψ_m = matric potential (negative value).

Variation in Water Availability

Water always moves from a system of higher Ψ to lower Ψ, following the energy gradient.

Atmospheric water potential is related to relative humidity. If less than 98%, water potential is low relative to organisms. Terrestrial organisms must thus prevent water loss to the atmosphere.

Variation in Water Availability

Resistance—a force that impedes water movement along an energy gradient.

To resist water loss, terrestrial organisms have waxy cuticles (insects and plants) or animal skin.

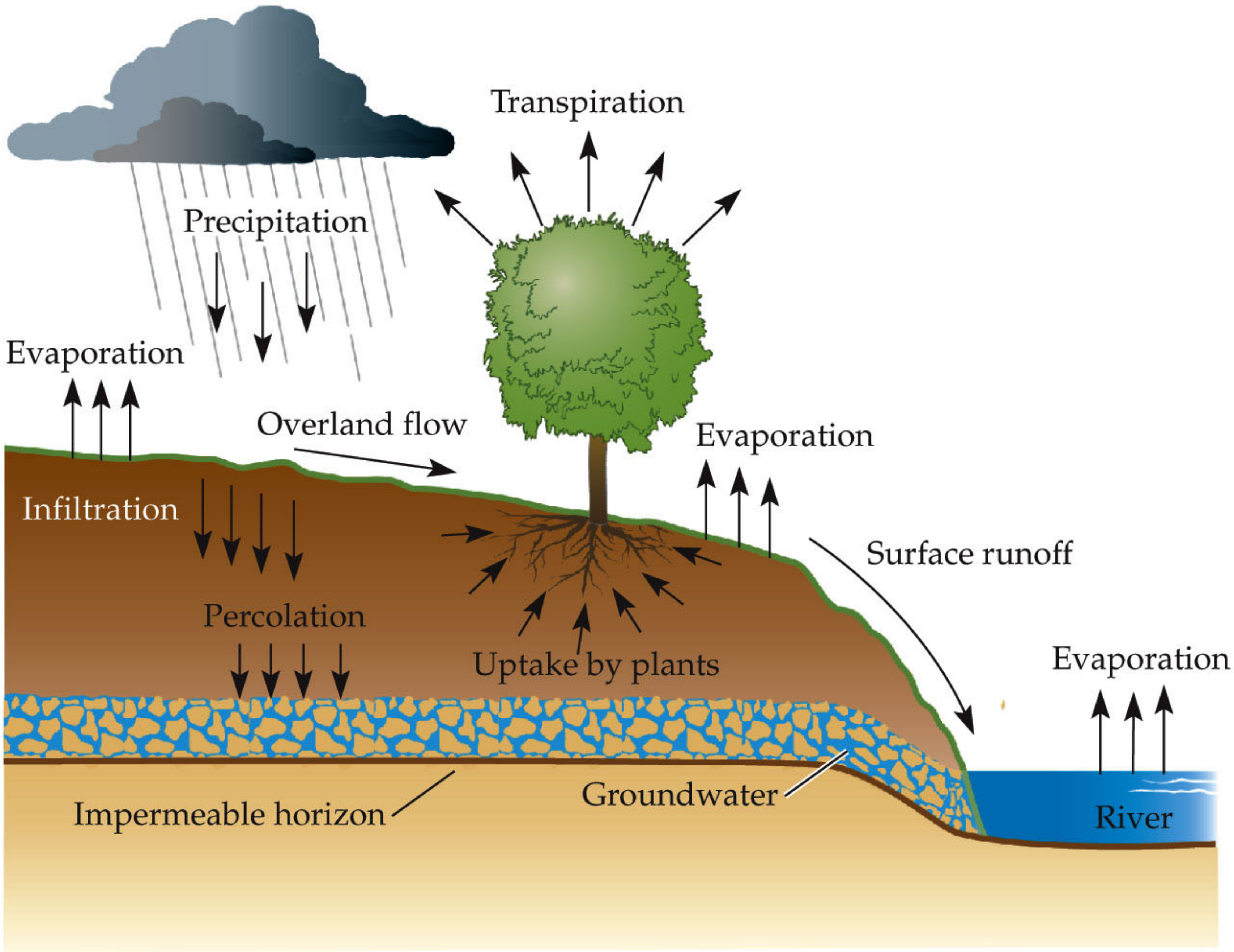
Variation in Water Availability

Terrestrial plants and soil microorganisms must take up water from the soil to replace water lost to the atmosphere.

Water potential of soils is mostly dependent on matric potential.

Amount of water in soil is determined by balance of inputs and outputs, soil texture, and topography.

Figure 4.18 What Determines the Availability of Water from the Soil?



ECOLOGY, Figure 4.18

Variation in Water Availability

Sandy soils store less water than fine-textured soils.

Fine soil particles also have a higher matric potential, and hold onto water more tightly.

Soils with mixed coarse and fine particles are generally most efficient in storing water and supplying it to organisms.

Variation in Water Availability

Water balance of single-celled aquatic organisms is mostly determined by osmotic potential.

In most aquatic environments, the osmotic potential doesn’t change much over time, except in tidal pools, estuaries, saline lakes, and soils.

Variation in Water Availability

In variable environments cells must alter their osmotic potential to maintain water balance—**osmotic adjustment**.

Solute concentration in a cell can be increased by synthesizing solutes, or by taking up inorganic salts.

Not all microorganisms can do this; some can adjust to extreme saline conditions.

Variation in Water Availability

Some microorganisms avoid dry conditions by forming resistant spores encased in protective coatings.

Some filamentous forms are tolerant of low water potential and live in dry habitats.

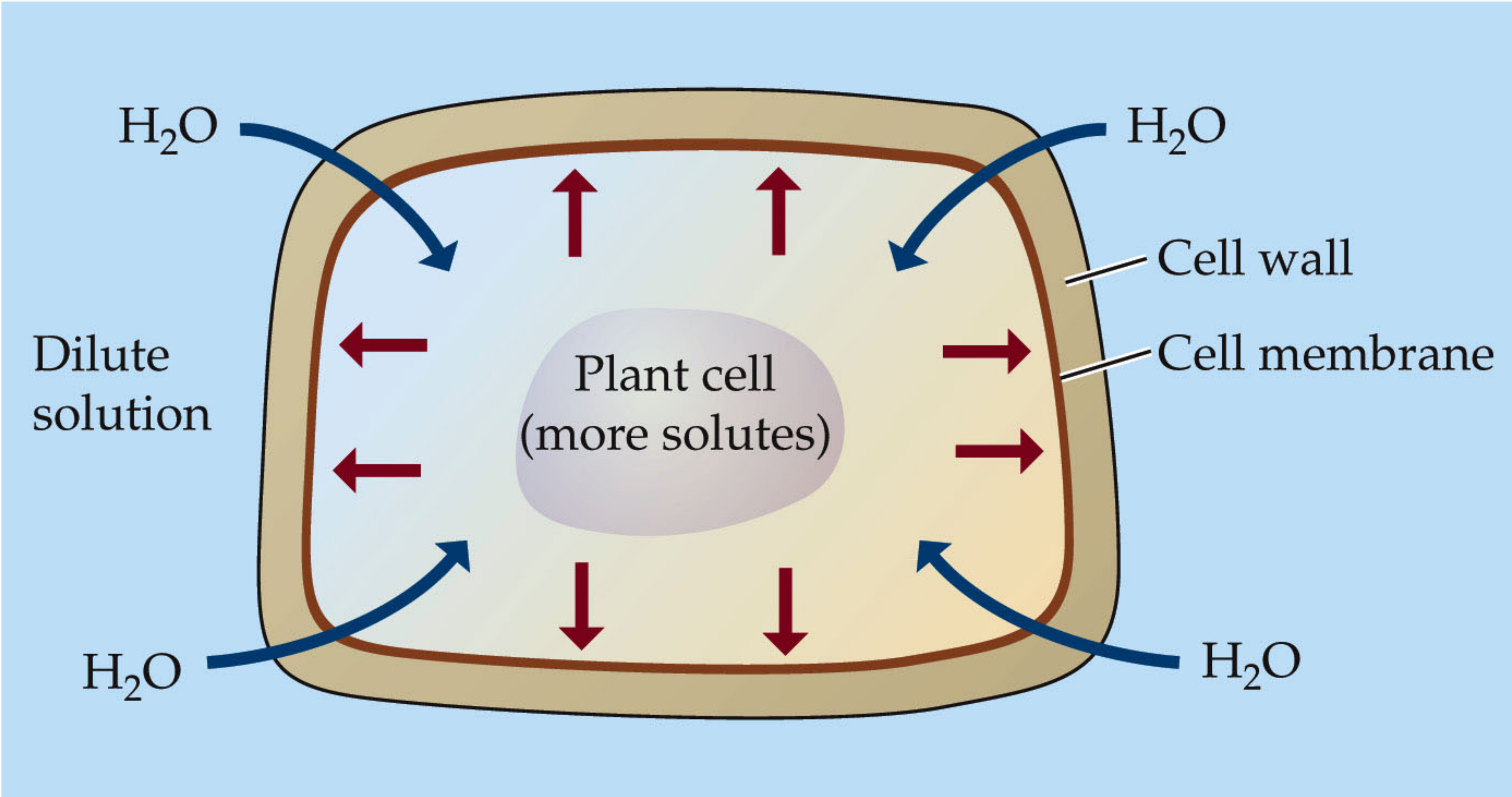
But most terrestrial microorganisms are found in moist soils.

Variation in Water Availability

Plants have rigid cell walls of cellulose, fungi have cell walls of chitin, and bacteria have cell walls of peptidoglycan.

Cell walls allow development of **turgor pressure**—when water moves into a cell, the expanding cell presses against the cell wall.

Figure 4.19 Turgor Pressure in Plant Cells



Variation in Water Availability

Turger pressure helps give form to plants, and is an important force for growth, promoting cell division.

When non-woody plants lose turgor pressure, they wilt. Wilting is an indication of water stress.

Variation in Water Availability

Plants must take up water from a source with higher water potential than their own cells.

In freshwater plants, solutes in the cells create the water potential gradient.

In marine plants and terrestrial plants in saline soils, cells make osmotic adjustments by synthesizing solutes or taking up inorganic salts.

Variation in Water Availability

Terrestrial plants take up water through their roots, and by beneficial fungi called *mycorrhizae*.

Older, thicker roots have a waxy cuticle that limits water uptake.

Mycorrhizae provide greater surface area for absorption of water and nutrients, and allow exploration for these resources. The fungi get energy from the plant.

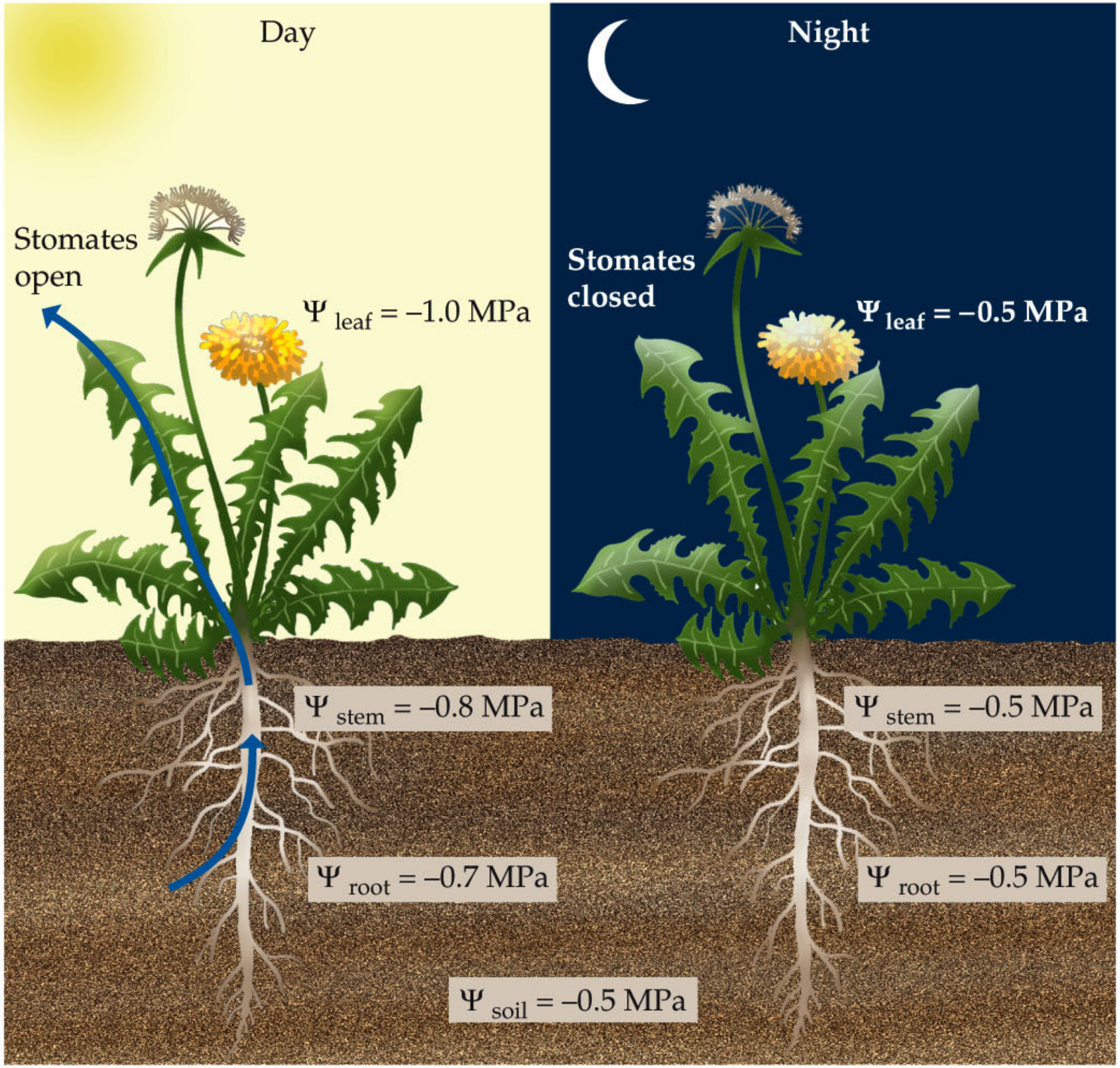
Variation in Water Availability

Plants lose water by transpiration when stomates are open for CO_2 uptake.

Inside the leaf humidity is 100%, so water potential inside the leaf is higher than the atmosphere.

Plants must replace this water. As the leaf loses water, water potential in the cell decreases relative to the xylem in the stem, so water moves from stem to leaf.

Figure 4.20 The Daily Cycle of Dehydration and Rehydration



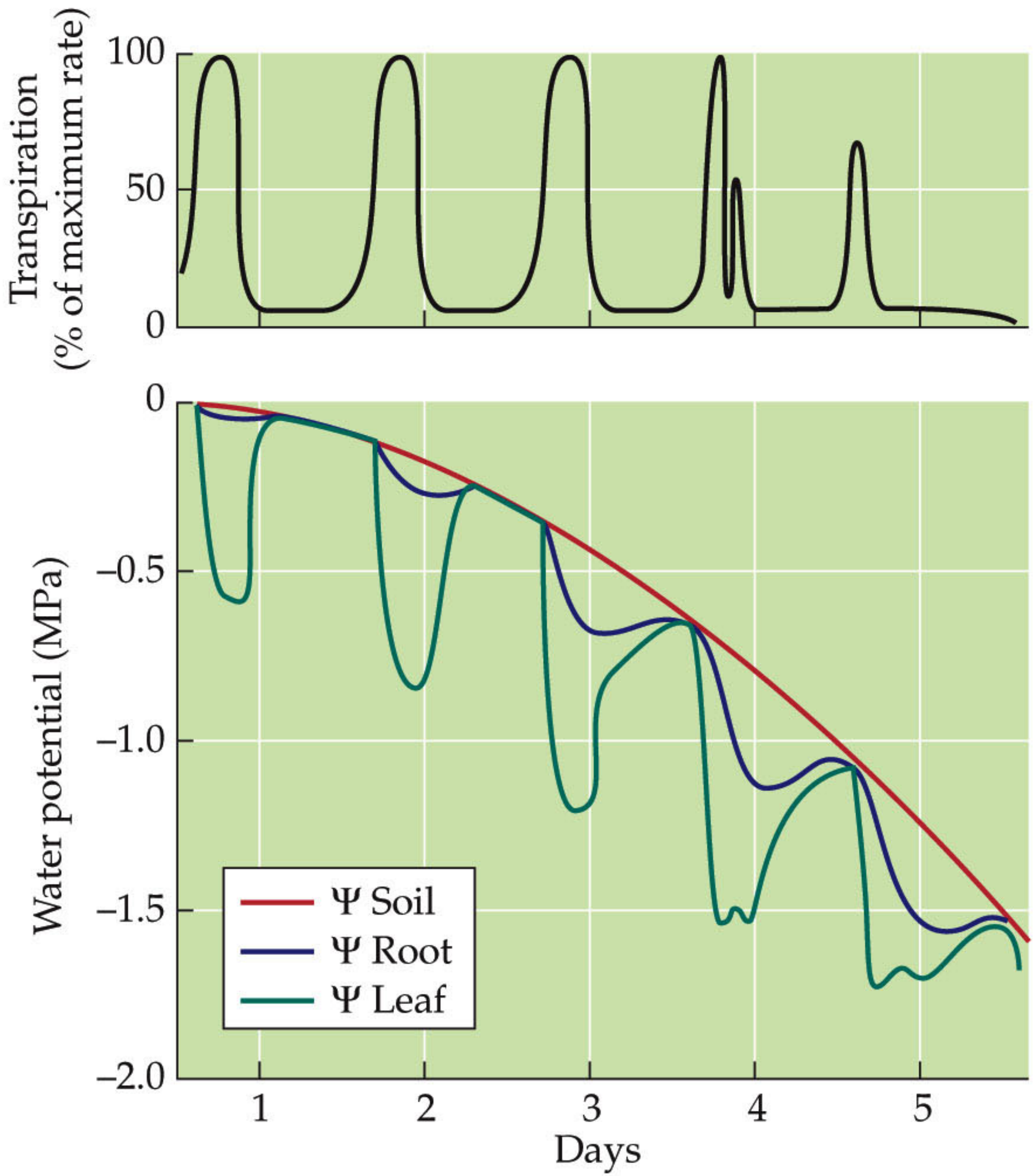
Variation in Water Availability

Root uptake lags behind transpiration rates during the day, so plant water content decreases.

At night the stomates close, and plant water increases until it reaches equilibrium with the soil water potential.

If lack of precipitation decreases soil water, water content and turgor pressure of plants will decrease.

Figure 4.21 Depletion of Soil Water



ECOLOGY, Figure 4.21

Variation in Water Availability

Plants restrict water losses from transpiration in several ways.

If turgor pressure is lost, the stomates close. This also impairs photosynthesis. Some plants send a hormonal signal (abscisic acid) that causes stomates to open less.

Some plants shed leaves in dry seasons.

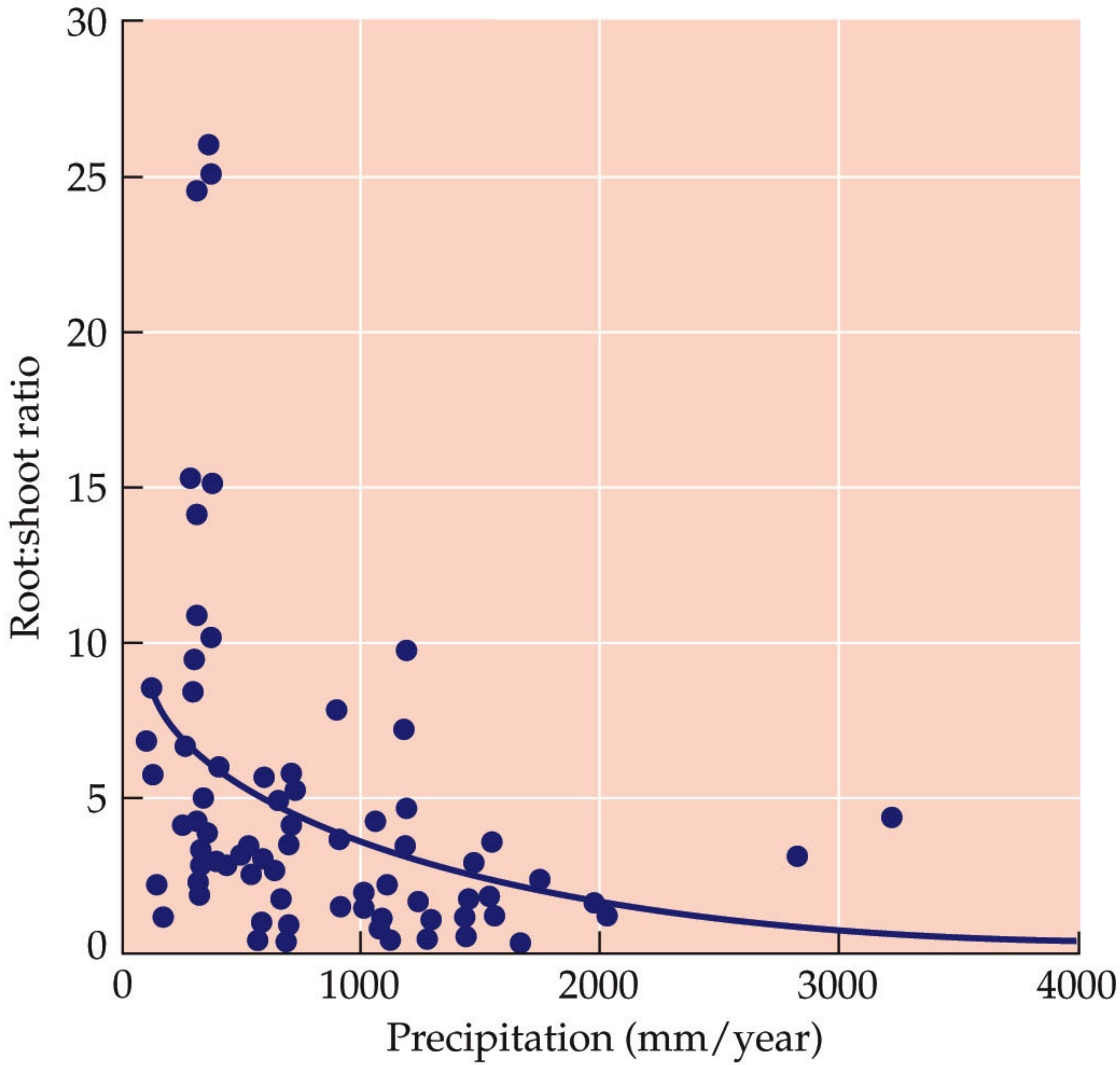
Variation in Water Availability

Plants in dry environments may also have thicker cuticles.

Higher ratio of root biomass to the rest of the plant enhances the rate of water supply.

Some plants can acclimatize by altering the growth of roots to match the availability of soil moisture and nutrients.

Figure 4.22 Allocation of Growth to Roots versus Shoots Is Associated with Precipitation Levels



ECOLOGY, Figure 4.22

In extremely dry conditions, the xylem can be under high tension (negative Ψ_p), which can pull air into the water column, called **cavitation**.

Cavitation can occur in woody plants in winter when water in the xylem freezes and bubbles form. Most plants have multiple xylem tubes. If cavitation occurs in many tubes, tissue death can result.

Variation in Water Availability

In wet soils, oxygen diffusion is limited. Waterlogged soils inhibit aerobic respiration in roots.

Moist soils can also promote growth of harmful fungi.

Root death can result, and ironically, plants can wilt in waterlogged soils.

Variation in Water Availability

Plants that are adapted to wet soils may have air channels in root tissues (*aerenchyma*) to alleviate oxygen stress.

Alternatively, they may have specialized roots (e.g., *pneumatophores*). Plants, such as mangroves, which grow vertically above the water or in waterlogged soil are an example.

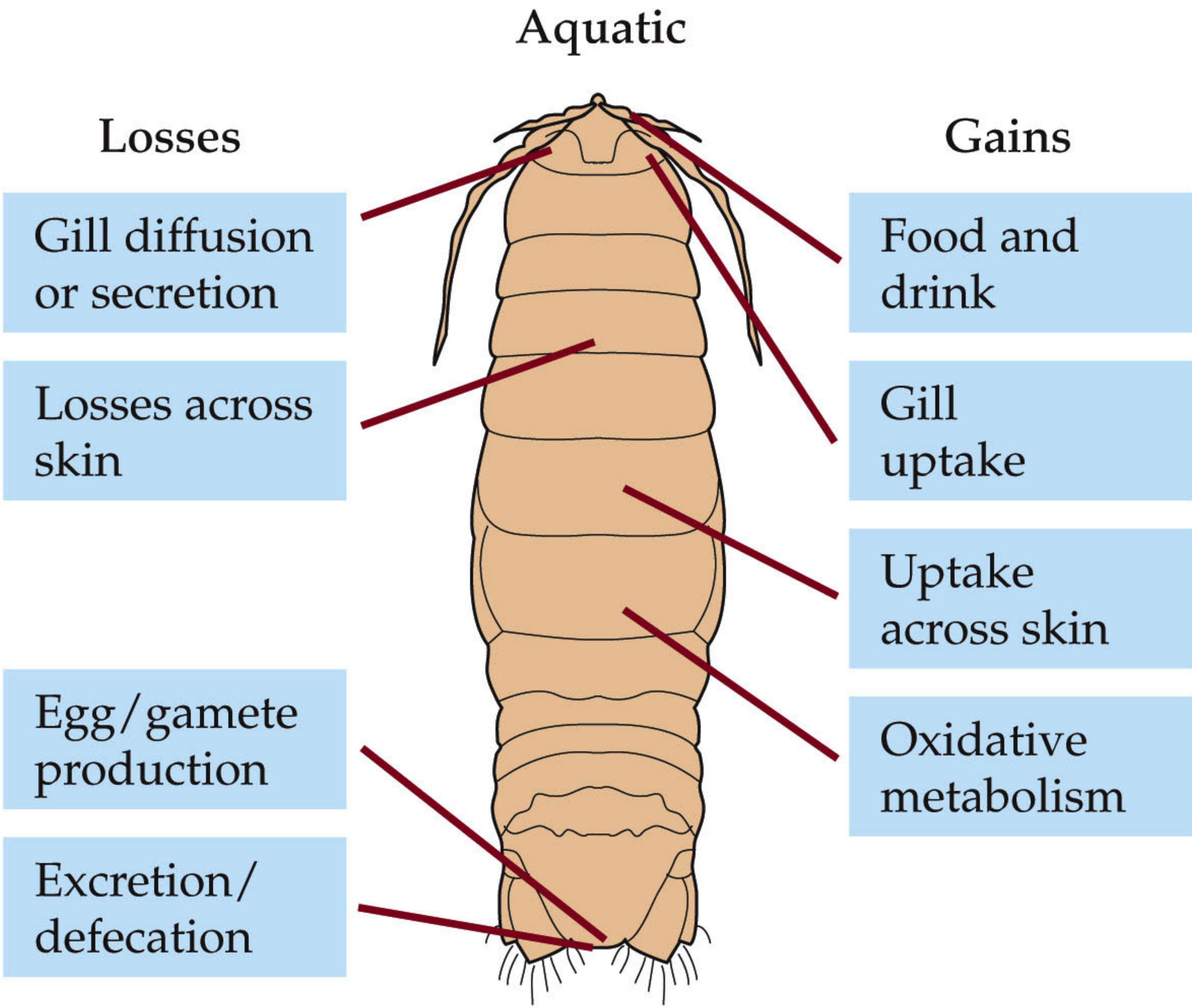
Variation in Water Availability

Water losses and gains in multicellular animals are more complex.

Many have organs for excretion and other functions—local areas of water and solute exchange, and gradients within the body can occur.

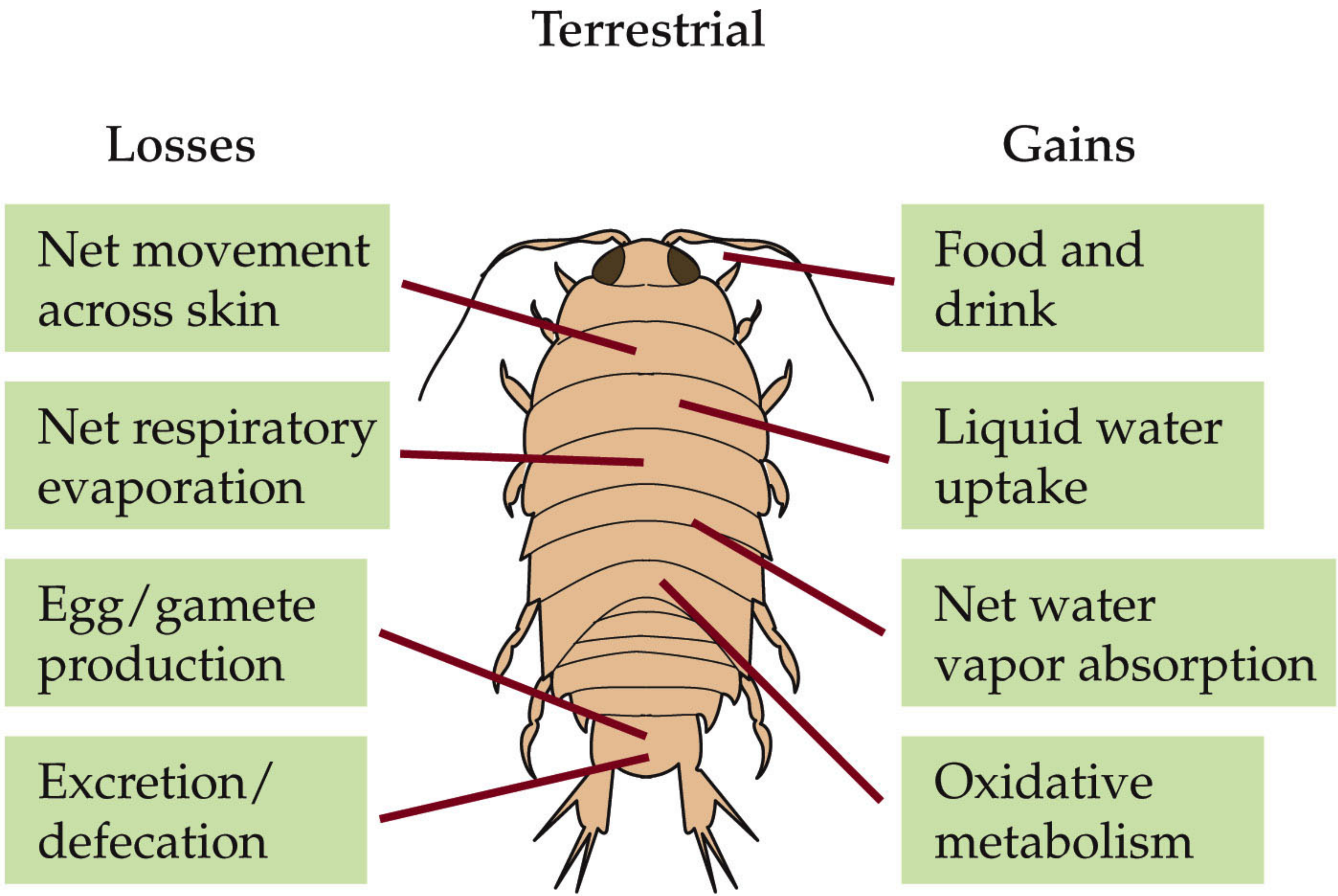
Most animals are mobile and can move to different environments to maintain water balance.

Figure 4.23 Gains and Losses of Water and Solutes in Aquatic and Terrestrial Animals (Part 1)



***ECOLOGY*, Figure 4.23 (Part 1)**

Figure 4.23 Gains and Losses of Water and Solutes in Aquatic and Terrestrial Animals (Part 2)



ECOLOGY, Figure 4.23 (Part 2)

Variation in Water Availability

For aquatic animals, the water can be:

Hyperosmotic—more saline than the animal's cells.

Hypoosmotic—less saline than the animal's cells.

Isoosmotic—have the same solute concentration as the animal's cells.

Marine animals tend to be isoosmotic to seawater.

Invertebrates capable of osmotic adjustment do so by exchanging solutes with the environment.

For example, jellyfish have Na^+ and Cl^- concentrations similar to seawater, but their SO_4^{2-} concentrations may be one-half to one-fourth that of seawater.

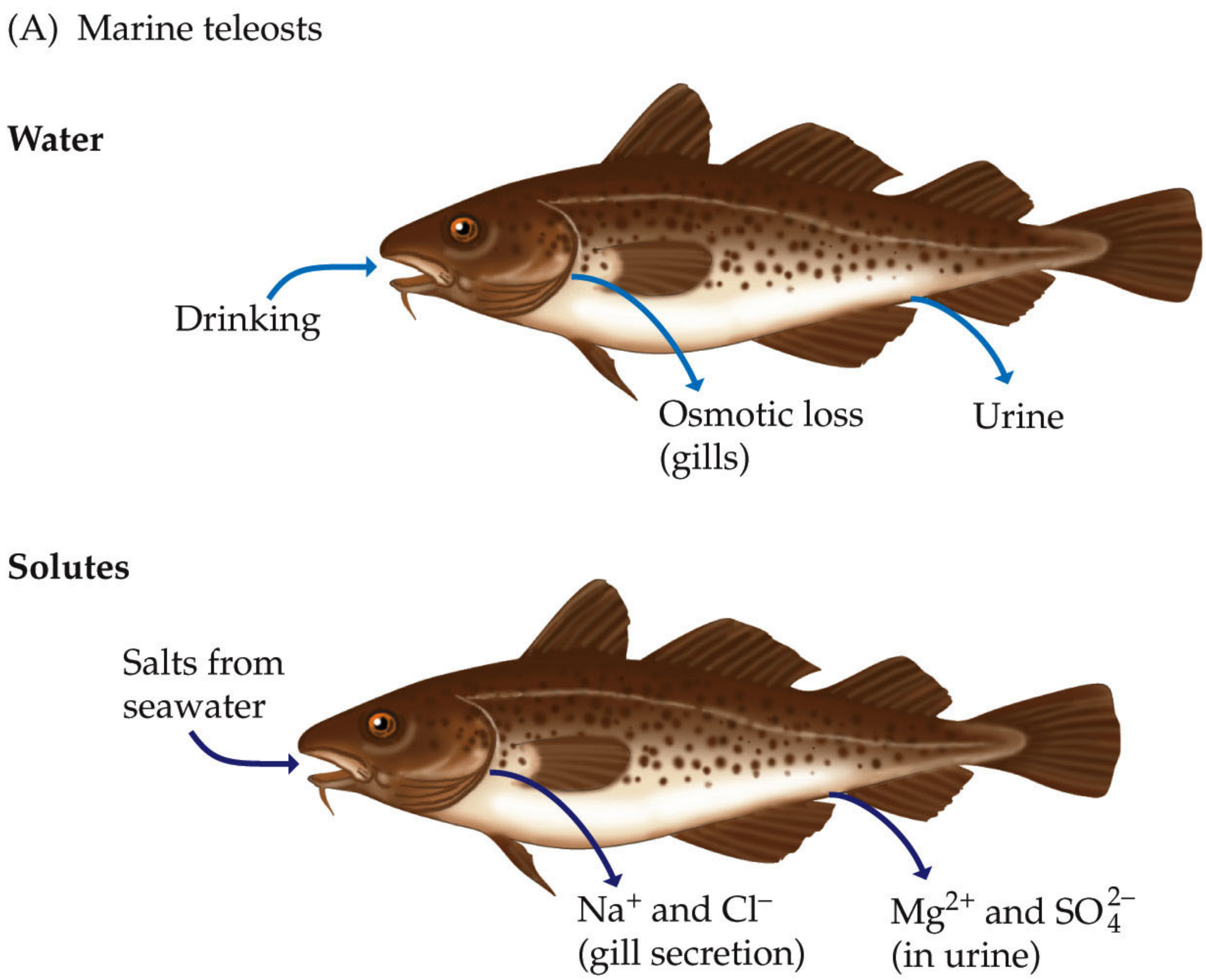
Variation in Water Availability

In marine cartilaginous fishes (e.g., sharks and rays) the blood is isoosmotic to seawater.

Marine bony fishes evolved in freshwater and their blood is hypoosmotic to seawater.

Fish exchange salts across the gills, and by eating and drinking.

Figure 4.24 A Water and Salt Balance in Marine and Freshwater Teleost Fishes



***ECOLOGY*, Figure 4.24 (Part 1)**

Variation in Water Availability

Salts that enter bony fishes must be continually excreted through urine or across the gills, against an osmotic gradient (requires energy). Water is replaced by drinking.

Marine mammals do not drink seawater, and produce urine that is hyperosmotic to seawater.

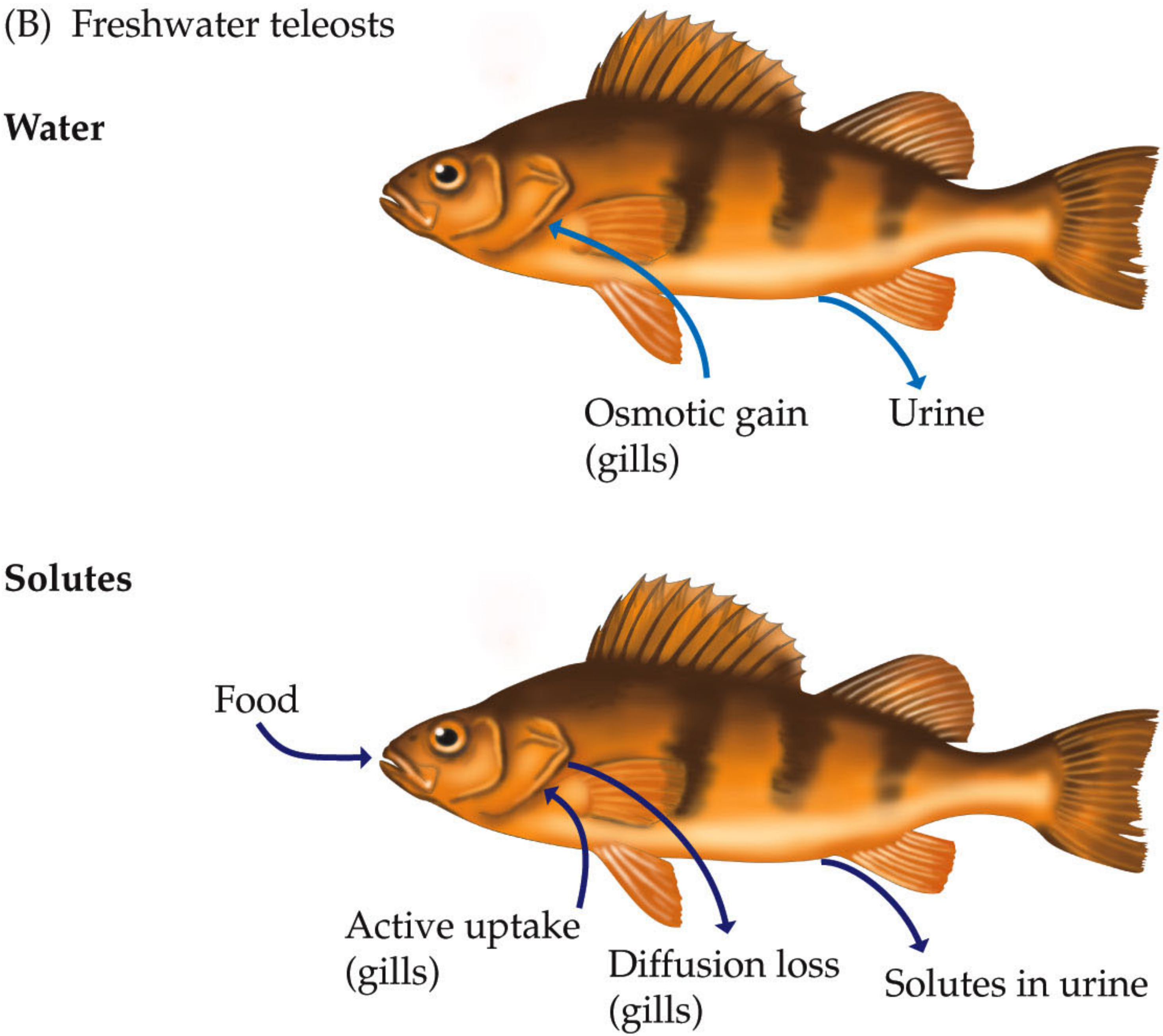
Variation in Water Availability

Freshwater animals are hyperosmotic to the water—they tend to gain water and lose salts from the skin or respiratory surfaces.

Solutes are taken up in food or across gills, against the osmotic gradient.

Excess water is excreted as dilute urine.

Figure 4.24 B Water and Salt Balance in Marine and Freshwater Teleost Fishes



ECOLOGY, Figure 4.24 (Part 2)

Variation in Water Availability

Terrestrial animals must exchange gases with a dry environment.

To minimize water loss, some live in moist environments, while some increase skin resistance.

Resistance to water loss limits amount of gas exchange possible.

Tolerance for water loss varies.

TABLE 4.1

Tolerances for Water Loss in Selected Animal Groups

Group	Weight loss (%)
INVERTEBRATES	
Mollusks	35–80
Crabs	15–18
Insects	25–75
VERTEBRATES	
Frogs	28–48
Small birds	4–8
Rodents	12–15
Human	10–12
Camel	30

Source: Willmer et al. 2005.

Note: Values are maximum percentages of body weight lost as water that can be tolerated, from a range of exemplary species in each group.

Variation in Water Availability

Amphibians rely primarily on a stable water supply to maintain water balance.

They can occur in a variety of habitats, even deserts, as long as there is a reliable water source—rains or pools.

Some gas exchange occurs through the skin; thus the skin is very thin, with low resistance to water loss.

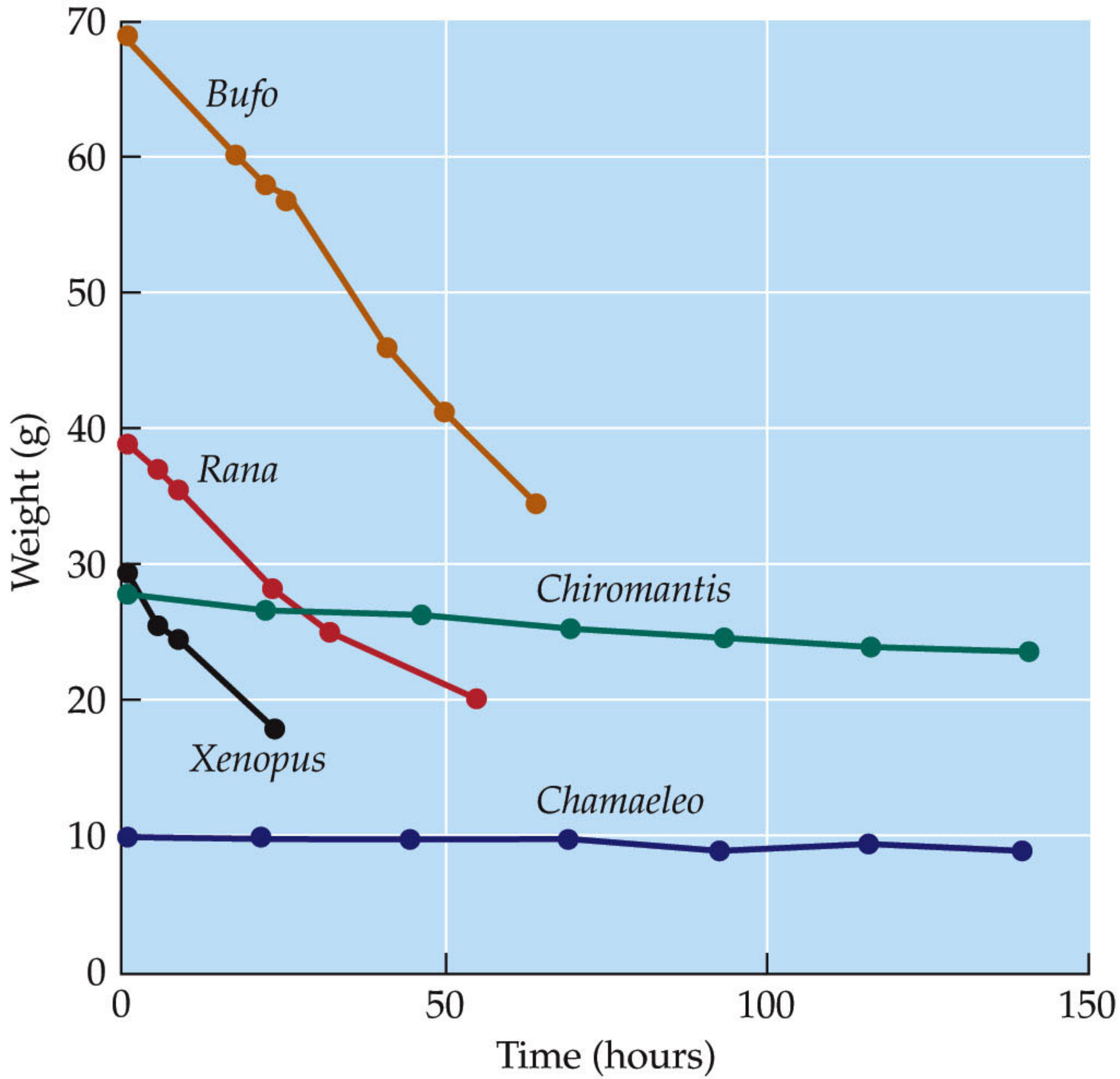
Variation in Water Availability

Some amphibians in dry environments have thicker skin.

To compensate for decreased gas exchange, they may have higher breathing rates.

Some form a “cocoon” of mucous secretions consisting of proteins and fats that lower their rates of water loss.

Figure 4.25 Resistance to Water Loss Varies among Frogs and Toads



ECOLOGY, Figure 4.25

Variation in Water Availability

Reptiles have been very successful in dry environments. They have thick skin with layers of dead cells, fatty coatings, and plates or scales.

Mammals and birds have similar skin, and fur or feathers to minimize water loss.

Variation in Water Availability

Desert invertebrates have the highest resistance to water loss.

The outer exoskeleton of chitin is covered by waxy hydrocarbons that are impervious to water.

TABLE 4.2

Resistance of External Cover (Skin, Cuticle) on Animals to Water Loss

Group	Resistance (seconds/centimeter)
Crabs (marine)	6–14
Fish	2–35
Frogs	3–100
Earthworms	9
Birds	50–158
Desert tortoises	120
Desert lizards	1,400
Desert scorpions, spiders	1,300–4,000

Source: Willmer et al. 2002.

Variation in Water Availability

The kangaroo rat uses a variety of adaptations to cope with an arid environment.

Water is obtained from dry seeds oxidatively—carbohydrates and fats are converted into CO_2 and water.

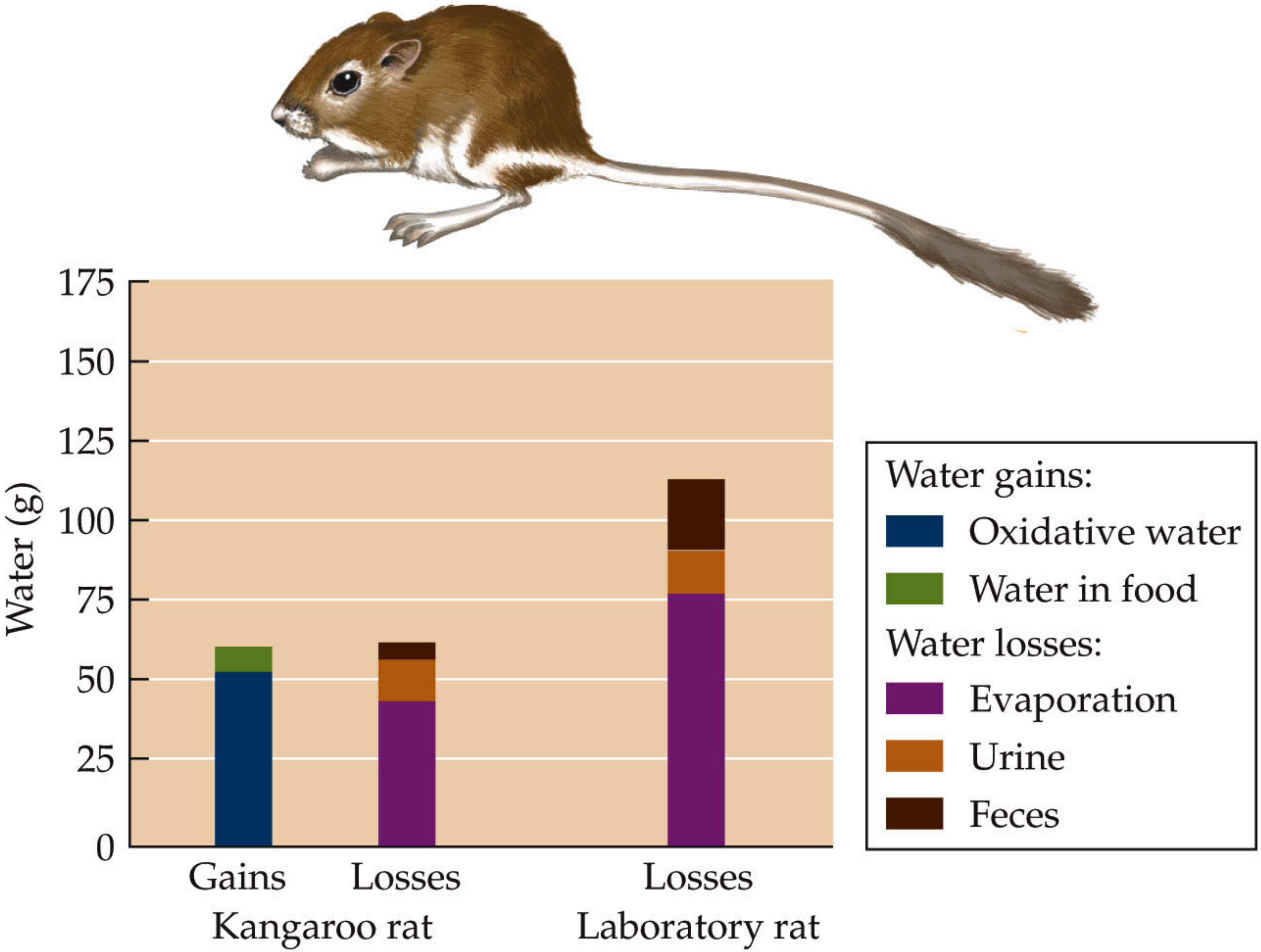
Food with more water is sometimes available (insects and plants).

Variation in Water Availability

Water loss is minimized by:

- Being active at night, staying in cooler burrows during day.
- Having thicker, oilier skin and fewer sweat glands than other rodents.
- Excreting very little water in urine and feces.

Figure 4.26 Water Balance in a Kangaroo Rat



ECOLOGY, Figure 4.26

Case Study Revisited: Frozen Frogs

Three problems must be overcome for an organism to withstand freezing:

- Water forms needle-like ice crystals that can pierce cell membranes.
- Oxygen supply to tissues is restricted due to lack of breathing and circulation.
- When ice forms, it pulls water from cells.

Case Study Revisited: Frozen Frogs

In animals that withstand freezing, the freezing water is limited to the space outside the cells.

Ice-nucleating proteins outside cells serve as sites of slow, controlled ice formation.

Additional solutes, such as glucose and glycerol inside cells lower the freezing point.

Case Study Revisited: Frozen Frogs

Winter burrows covered with layers of leaves and snow keep temperatures above –5°C (the lower limit for their survival).

Freezing occurs over several days to weeks, but thawing can be rapid.

Connections in Nature: Desiccation Tolerance, Body Size, and Rarity

Arid conditions are a more widespread challenge for organisms.

Some tolerate dry conditions by going into suspended animation. Many microorganisms do this, as do some multicellular organisms.

Figure 4.27 Desiccation-Tolerant Organisms

(A)

(B)

(C)

Connections in Nature: Desiccation Tolerance, Body Size, and Rarity

As cells dry out, the organisms synthesize sugars that form a glassy coating over the cellular constituents.

When moisture returns, metabolic functions are regained rapidly.

Why aren’t more organisms tolerant of drying?

Small organisms do not require structural reinforcement, such as a skeleton, which would restrict the necessary shrinking of the organism as it dehydrated.

Connections in Nature: Desiccation Tolerance, Body Size, and Rarity

Water loss must be slow enough to allow sugars to be synthesized, but not too slow.

Small organisms have surface area-to-volume ratios and thicknesses favorable for the water loss rates required.

Connections in Nature: Desiccation Tolerance, Body Size, and Rarity

Small size is often associated with slow growth rate and poor competitive ability under conditions of low resource availability.

Natural selection for desiccation tolerance may involve trade-offs with other ecological characteristics, such as competitive ability.