

# 13

## *Parasitism*



## 13 Parasitism

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## Case Study: Enslaver Parasites

Figure 13.1 Driven to Suicide



Hairworm

Some parasites can alter the behavior of their host in order to complete their life cycles.

## Case Study: Enslaver Parasites

The hairworm life cycle begins when the cricket drinks water that contains a hairworm larva.

The larva enters the cricket's body and feeds on its tissues, growing into an adult that fills the cricket's body cavity.

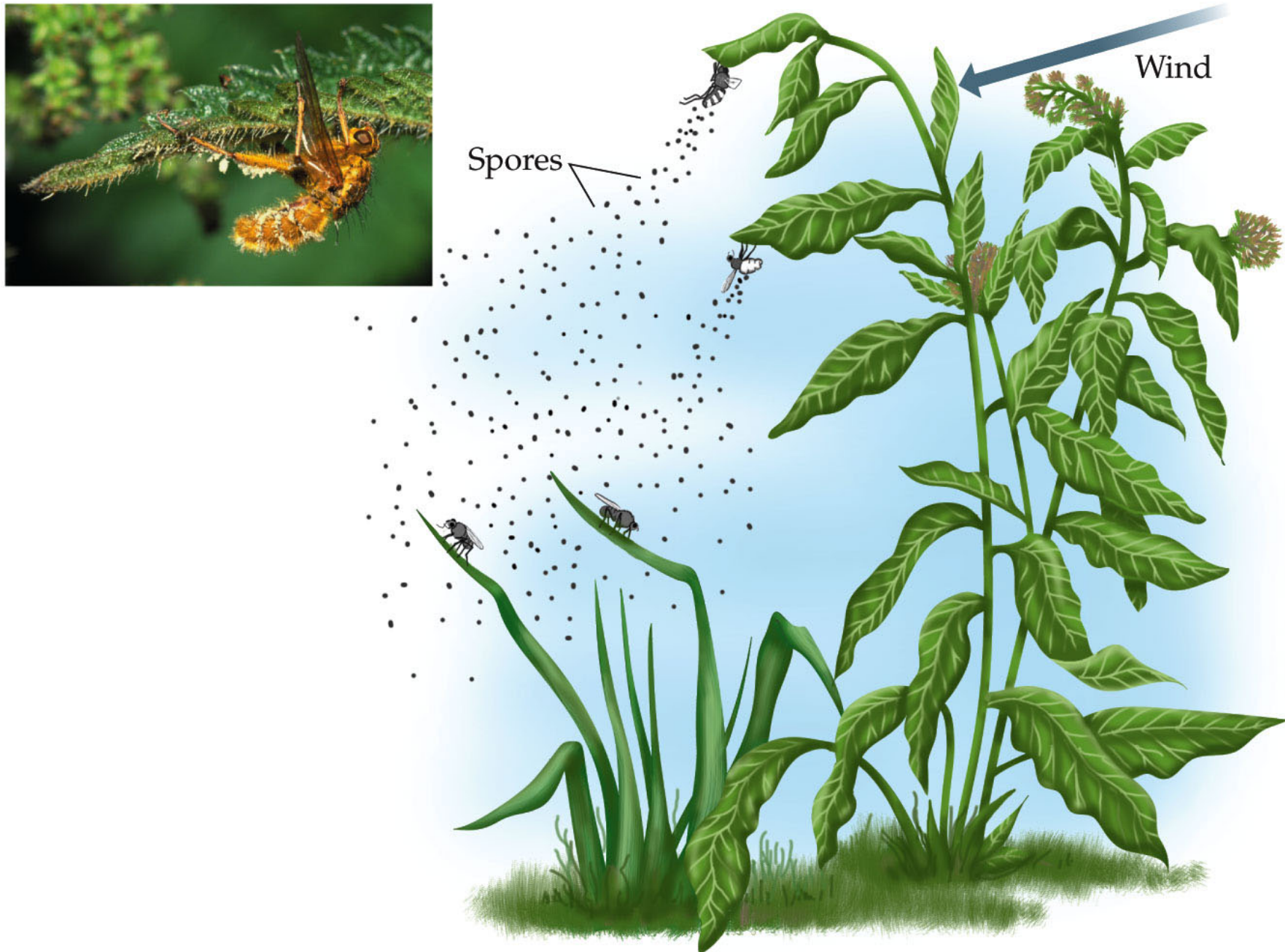
The cricket then jumps into water and drowns, the hairworm emerges and mates, to start the life cycle again.

## Case Study: Enslaver Parasites

Many other parasites “enslave” their hosts.

Some fungi alter the perching behavior of their fly hosts so that their spores can be dispersed more easily.

Figure 13.2 Enslaved by a Fungus





## Case Study: Enslaver Parasites

Rats infected with the protozoan parasite *Toxoplasma gondii* do not avoid cats, and in some cases are actually attracted to cats.

This increases the chance that the parasite will be transmitted to the next host in its complex life cycle—a cat.

## Case Study: Enslaver Parasites

The parasitoid wasp *Hymenoepimecis argyraphaga* manipulates its host, the orb-weaving spider *Plesiometa argyra*, to spin a special “cocoon web.”

The wasp larva then kills the spider and eats it, and spins a cocoon that is suspended from the special web. This arrangement keeps the cocoon from being washed away by rains.

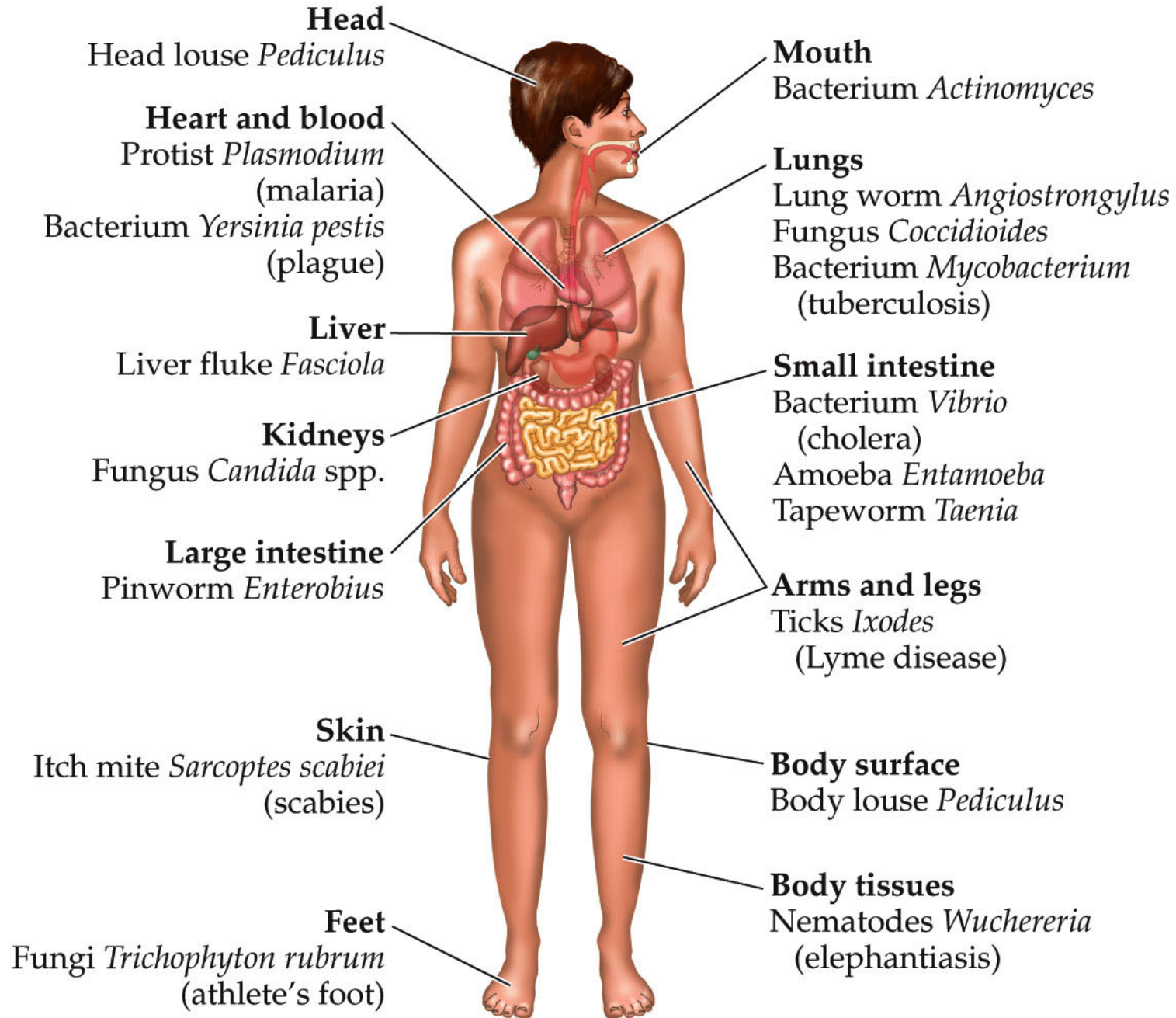


**Symbionts** are organisms that live in or on other organisms.

More than half of the millions of species that live on Earth are symbionts.

Our own bodies can be a home to many other species.

Figure 13.3 The Human Body as Habitat



## Introduction

Some symbionts are mutualists, but the majority are parasites.

A **parasite** consumes the tissues or body fluids of the organism on which it lives, its **host**.

**Pathogens** are parasites that cause diseases.

## Introduction

As a group, parasites typically harm, but do not immediately kill, the organisms they eat (unlike predators).

The degree of harm to the host varies widely.

Compare: The fungus that causes athlete's foot, and *Yersinia pestis*, the bacterium that causes the plague, which can be lethal.

## Parasite Natural History

**Concept 13.1: Parasites, which constitute roughly 50% of the species on Earth, typically feed on only one or a few host species.**

**Macroparasites** are large, such as arthropods and worms.

**Microparasites** are microscopic, such as bacteria.

## Parasite Natural History

Most parasites feed on only one or a few individual host organisms.

Defined broadly, parasites include herbivores such as aphids or nematodes, that feed on one or a few host plants.

Parasitoids, whose larvae feed on a single host, almost always kill it.

## Parasite Natural History

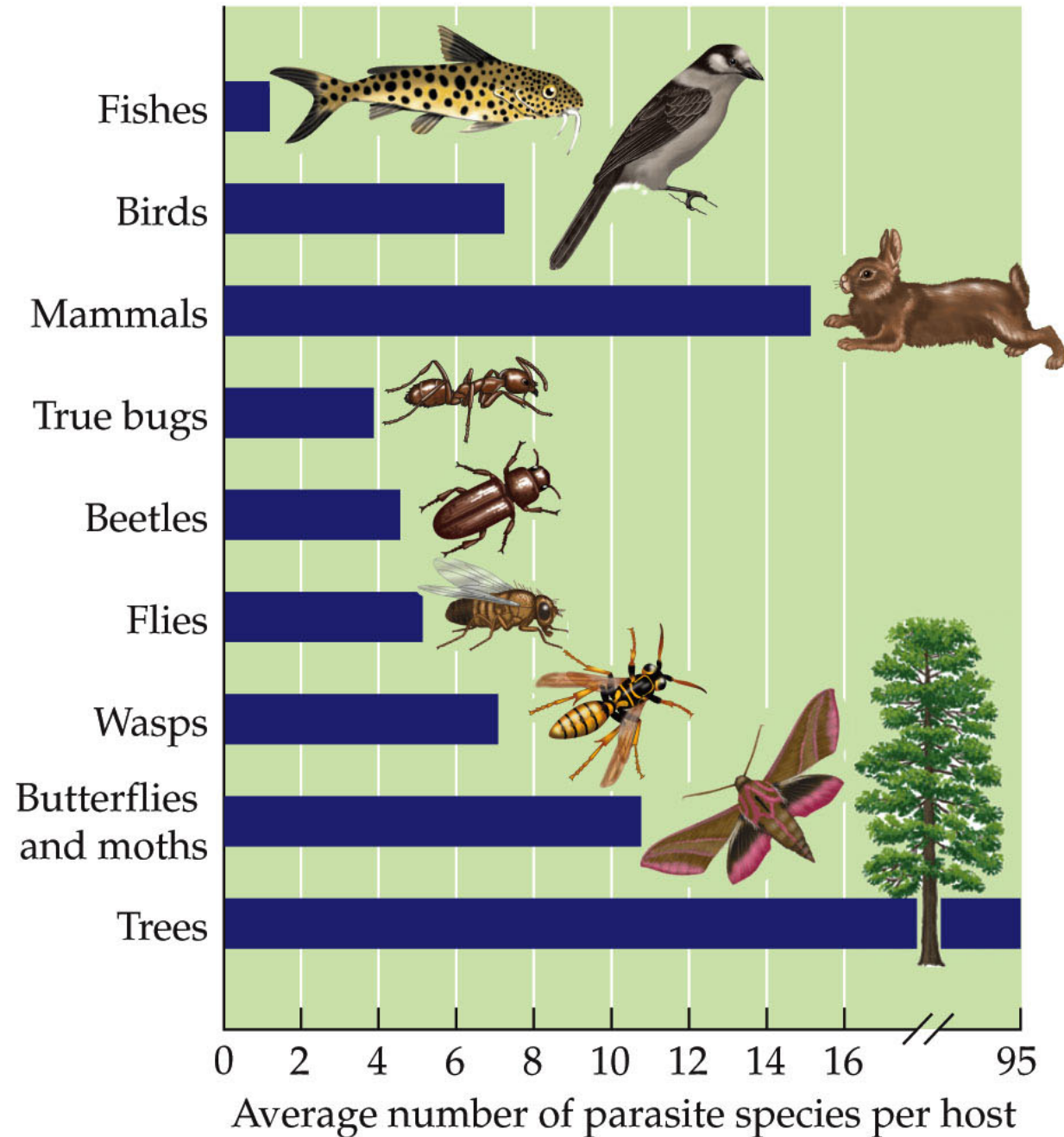
Most species are attacked by more than one kind of parasite; even parasites have parasites.

Many are closely adapted to particular host species.

This specialization helps explain why there are so many species of parasites—many host species have at least one parasite that eats only them.



Figure 13.4 Many Species Are Host to More Than One Parasite Species



**Ectoparasites** live on the outer body surface of the host.

They include plant parasites such as dodder. Dodder obtains water and food from the host plant via specialized roots called *haustoria*.

Mistletoes are hemiparasitic—they get water and nutrients from the host but can also photosynthesize.

## Figure 13.5 Ectoparasites

(A)



(B)



## Parasite Natural History

Many fungal and animal parasites are ectoparasites.

More than 5,000 species of fungi attack important crop and horticultural plants. Mildews, rusts, and smuts grow on the surface of the host plant and extend their hyphae (fungal filaments) into the plant to extract nutrients from its tissues.

## Parasite Natural History

Plants are also attacked by animals:  
Aphids, whiteflies, scale insects,  
nematodes, beetles, and juvenile  
cicadas.

These animals can be thought of as both  
herbivores and parasites (especially if  
they remain on one plant their entire  
life).

## Parasite Natural History

Animals also have many ectoparasites.

Examples: Athlete's foot fungus, fleas, mites, lice, and ticks.

Some of these parasites also transmit disease organisms.

**Endoparasites** live within the host, in the alimentary canal, or within cells or tissues.

Many disease organisms are endoparasites.

The alimentary canal is excellent habitat for many parasites. Many do not eat host tissue, but rob the host of nutrients.

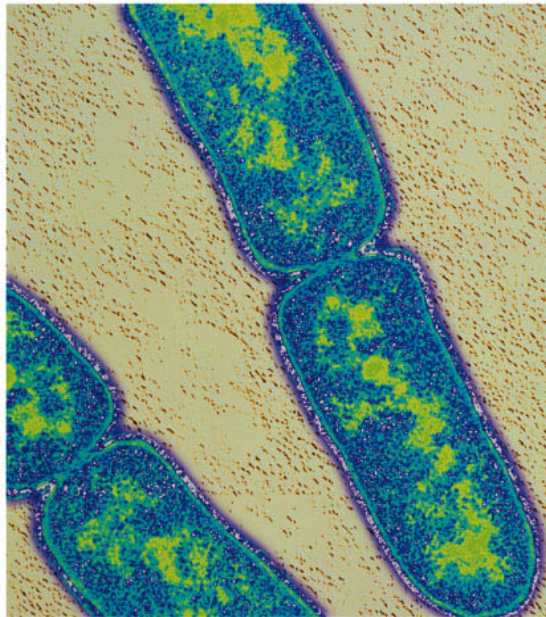


## Figure 13.6 Endoparasites

(A)



(B)



(C)



## Parasite Natural History

Tapeworms have a scolex, a structure with suckers and hooks to attach to the host's intestinal wall.

Once it is attached, the tapeworm absorbs food that the host has already digested.

Human tapeworms can grow up to 10–20 m and block the intestines and cause nutritional deficiencies.

## Parasite Natural History

Plants also have endoparasites, including pathogens.

Bacterial pathogens cause soft rot in various plant parts; fungi can rot various plant parts from the inside out.

Some bacteria invade vascular tissues, disrupt the flow of water and nutrients, causing wilting and often death.

## Parasite Natural History

There are advantages and disadvantages to both lifestyles.

Ectoparasites can disperse more easily.

Endoparasites have evolved various mechanisms for dispersal, including complex life cycles and enslaver parasites.

Some parasites of the alimentary canal are dispersed in feces.

**TABLE 13.1****Advantages and Disadvantages of Living In or On the Host**

	<b>Ectoparasitism</b>	<b>Endoparasitism</b>
Advantages	Ease of dispersal Safe from host's immune system	Ease of feeding Protected from external environment Safer from enemies
Disadvantages	Vulnerability to natural enemies Exposure to external environment Feeding more difficult	Vulnerability to host's immune system Dispersal difficult

## Parasite Natural History

Ectoparasites can be exposed to predators, parasites, and parasitoids.

Example: Aphids are eaten by many birds and insects, and also attacked by parasites and parasitoids.

## Parasite Natural History

Endoparasites are relatively well protected from the external environment, and have relatively easy access to food.

But they can also be attacked by the host's immune system.



## Defense and Counterdefense

**Concept 13.2: Hosts have adaptations for defending themselves against parasites, and parasites have adaptations for overcoming host defenses.**

Host organisms have many kinds of defense mechanisms.

Protective outer coverings include skin and exoskeletons. Many parasites that do gain entry are killed by the host's immune system.

## Defense and Counterdefense

Vertebrate immune systems have specialized “memory cells” that allow hosts to recognize microparasites it has been exposed to in the past.

Other immune system cells engulf and destroy parasites or mark them with chemicals that target them for later destruction.

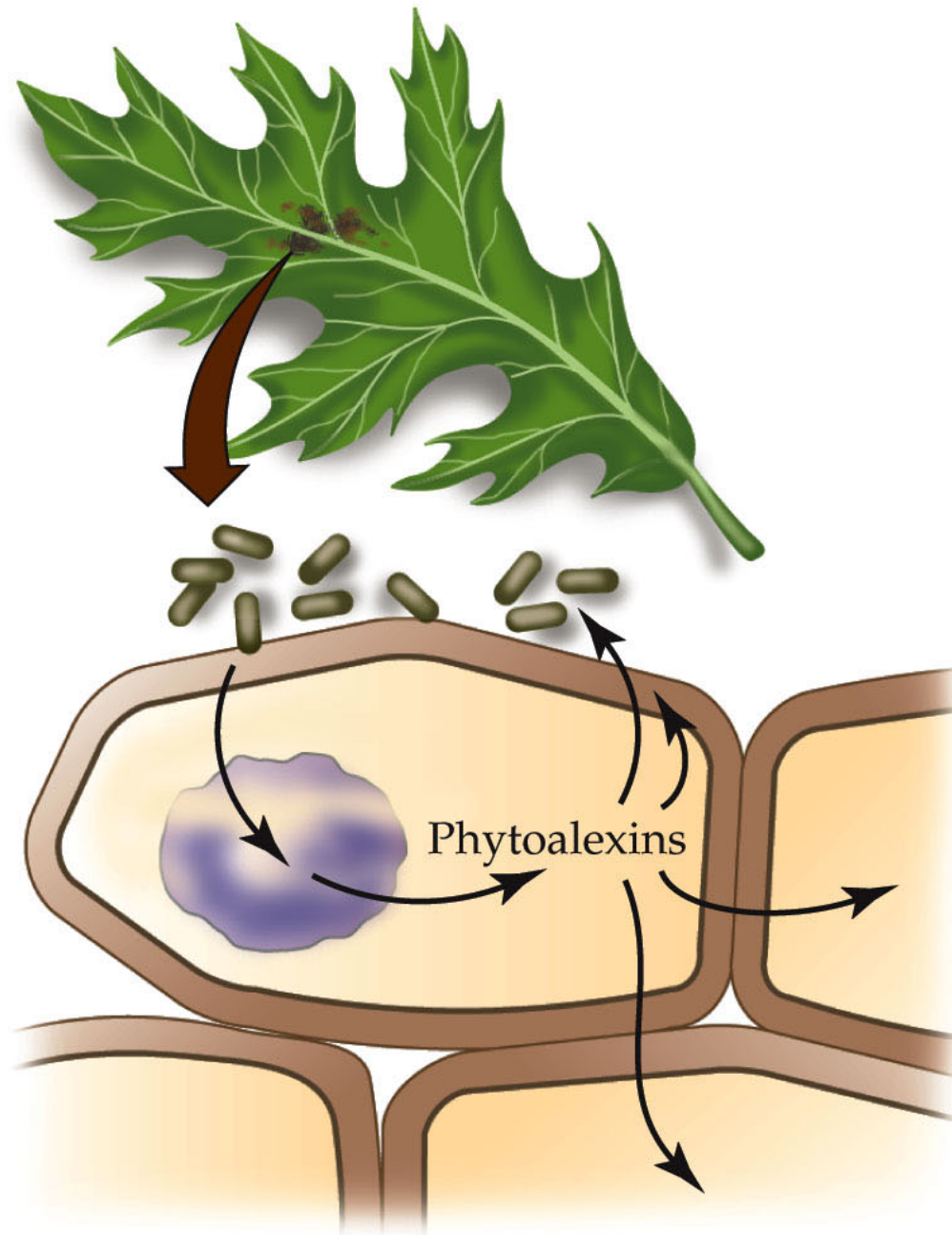
## Defense and Counterdefense

Plants also have defense systems.

Plants have resistance genes, as well as nonspecific immune responses.

Antimicrobial compounds attack the cell walls of bacteria, other compounds are toxic to fungi.

Figure 13.7 Nonspecific Plant Defenses



## Defense and Counterdefense

Some plant cells produce chemical signals that “warn” nearby cells of imminent attack.

Still other chemicals stimulate the deposition of lignin, a hard substance that provides a barricade against the invader’s spread.

## Defense and Counterdefense

Hosts can also regulate biochemistry to deter parasites.

Example: Bacterial and fungal endoparasites require iron for growth. Vertebrate hosts have a protein called transferrin that removes iron from blood serum and stores it in intracellular compartments.

But some parasites can steal iron from the transferrin.

## Defense and Counterdefense

Plants have many chemical weapons called secondary compounds.

Some animals eat specific plants to treat or prevent parasite infections.

Example: Woolly bear caterpillars switch from their usual food plants to poison hemlock when parasitic flies lay eggs on their bodies.



## Defense and Counterdefense

Chimpanzees infected with nematodes specifically seek out and eat a bitter plant that contains compounds that kill or paralyze the nematodes and can also deter many other parasites (Huffman 1997).

Figure 13.8 Using Plants to Fight Parasites



## Defense and Counterdefense

In some bird, mammal, and fish species, females select mates based on traits that indicate that a male has effective defenses.

A group of proteins known as the major histocompatibility complex (MHC) is a key part of vertebrate immune systems.

The more MHC proteins, the better the protection from a range of parasites.

## Defense and Counterdefense

Female sticklebacks prefer to mate with males that have many MHC proteins, and are likely to have few parasites.

Other species may use other cues to assess parasite loads.

Males of a cichlid fish court females by constructing a sand bower. Females prefer males that make large, smooth bowers.

## Defense and Counterdefense

Researchers have found that such males have fewer tapeworm parasites than do males that make smaller bowers.

Males with many tapeworms must spend more of their time eating to compensate for the nutrients they lose to the parasites, and hence cannot build large bowers.

## Defense and Counterdefense

Parasites also have adaptations to circumvent host defenses.

Ectoparasites face challenges similar to those of herbivores and predators as they cope with toxins and other defenses of their food organisms.

## Defense and Counterdefense

Endoparasites face different defense mechanisms.

Some hosts can *encapsulate* parasites or their eggs.

Some insects have lamellocytes—blood cells that can form multicellular capsules around large objects.

## Defense and Counterdefense

The parasites are under strong selection to develop a counterdefense.

Parasitoid wasps that attack fruit flies avoid encapsulation in several different ways.

When they lay eggs in the host fly, some species also inject virus-like particles that infect the lamellocytes and cause them to self-destruct.



## Defense and Counterdefense

Other parasitoid wasp species lay eggs covered with filaments.

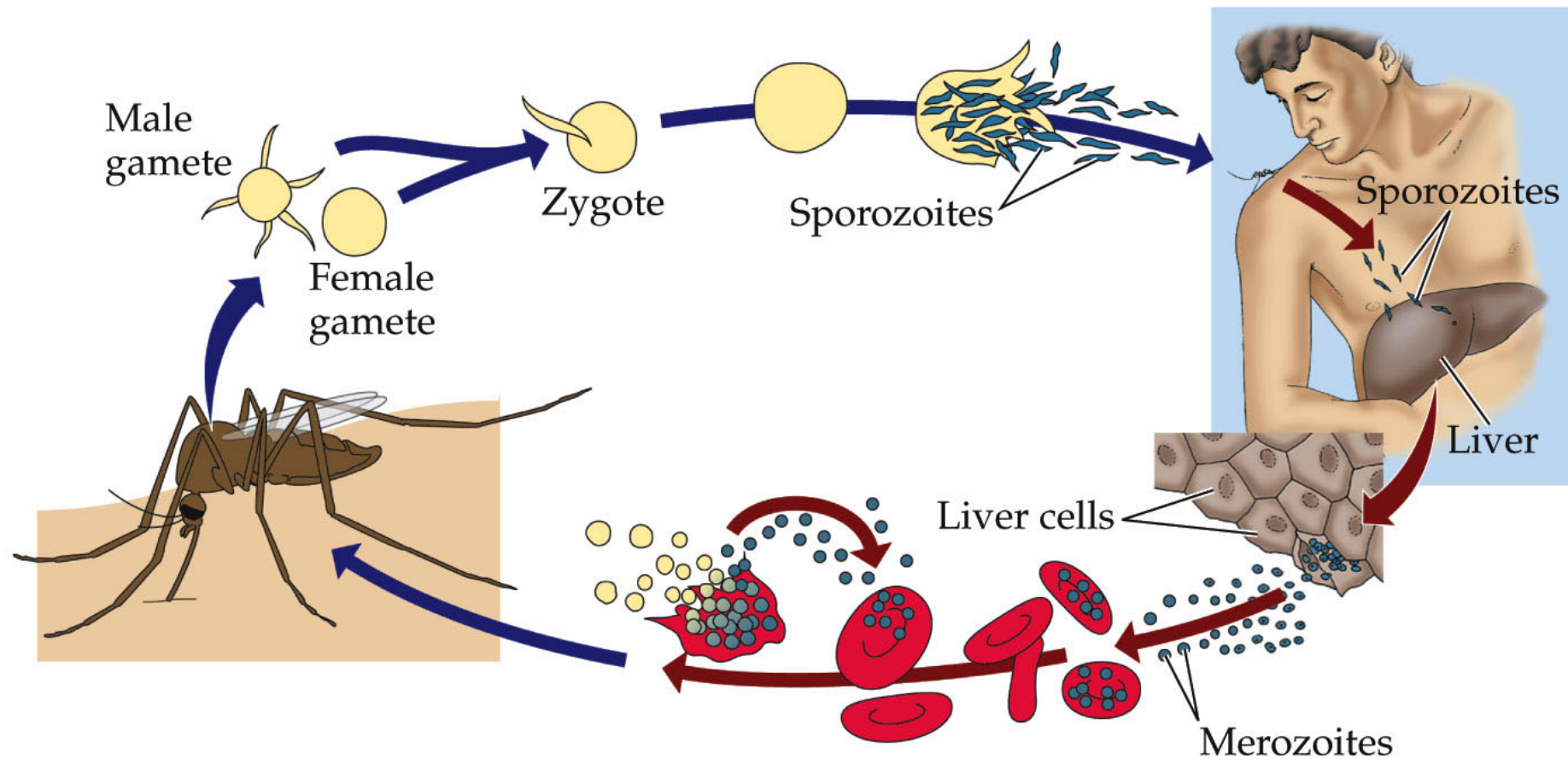
These filaments cause the eggs to stick to and become embedded in fat cells and other host cells, where they are not detected by circulating lamellocytes.

## Defense and Counterdefense

Some endoparasites have a complex set of adaptations.

*Plasmodium*, the protozoan that causes malaria, has a complex life cycle with two hosts, mosquitoes and humans.

Figure 13.9 Life Cycle of the Malaria Parasite, *Plasmodium*



*Plasmodium* faces two challenges in the human host:

- Red blood cells do not divide or grow, and thus can not import nutrients. *Plasmodium* merozoites must have a way to get nutrients.
- 24–48 hours after infection, *Plasmodium* causes red blood cells to have an abnormal shape that is detected by the spleen, where they are destroyed.

## Defense and Counterdefense

Plasmodium has hundreds of genes whose function is to modify the red blood cells.

Some genes cause transport proteins to be placed on the red blood cell surface so nutrients can be brought into the host cell.

## Defense and Counterdefense

Other genes direct production of special knobs on the surface of the red blood cells. The knobs cause red blood cells to stick to other cells, preventing them from reaching the spleen where they would be destroyed.

The proteins on the knobs vary greatly from one parasite to the next, making it very difficult for the human immune system to detect them.

## Coevolution

**Concept 13.3: Host and parasite populations can evolve together, each in response to selection imposed by the other.**

When a parasite and its host each possess specific adaptations, it suggests that the strong selection pressure hosts and parasites impose on each other has caused both of their populations to evolve.

## Coevolution

This has been observed in Australia, where European rabbits were introduced in 1859.

The rabbit population exploded, and consumed so much plant material that cattle and sheep pastureland was threatened.

Various control methods failed.



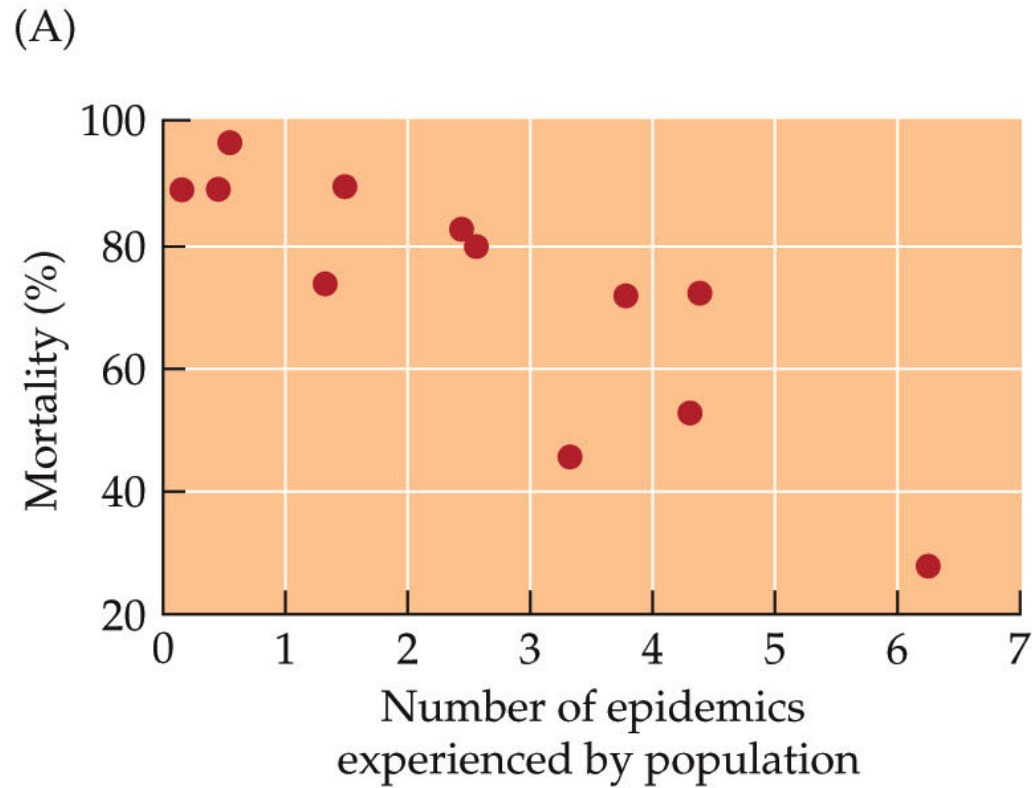
## Coevolution

In 1950, the *Myxoma* virus was introduced, which is transmitted by mosquitoes.

In the beginning, 99.8% of infected rabbits died. But over time, the rabbits evolved resistance to the virus, and the virus evolved to become less lethal.

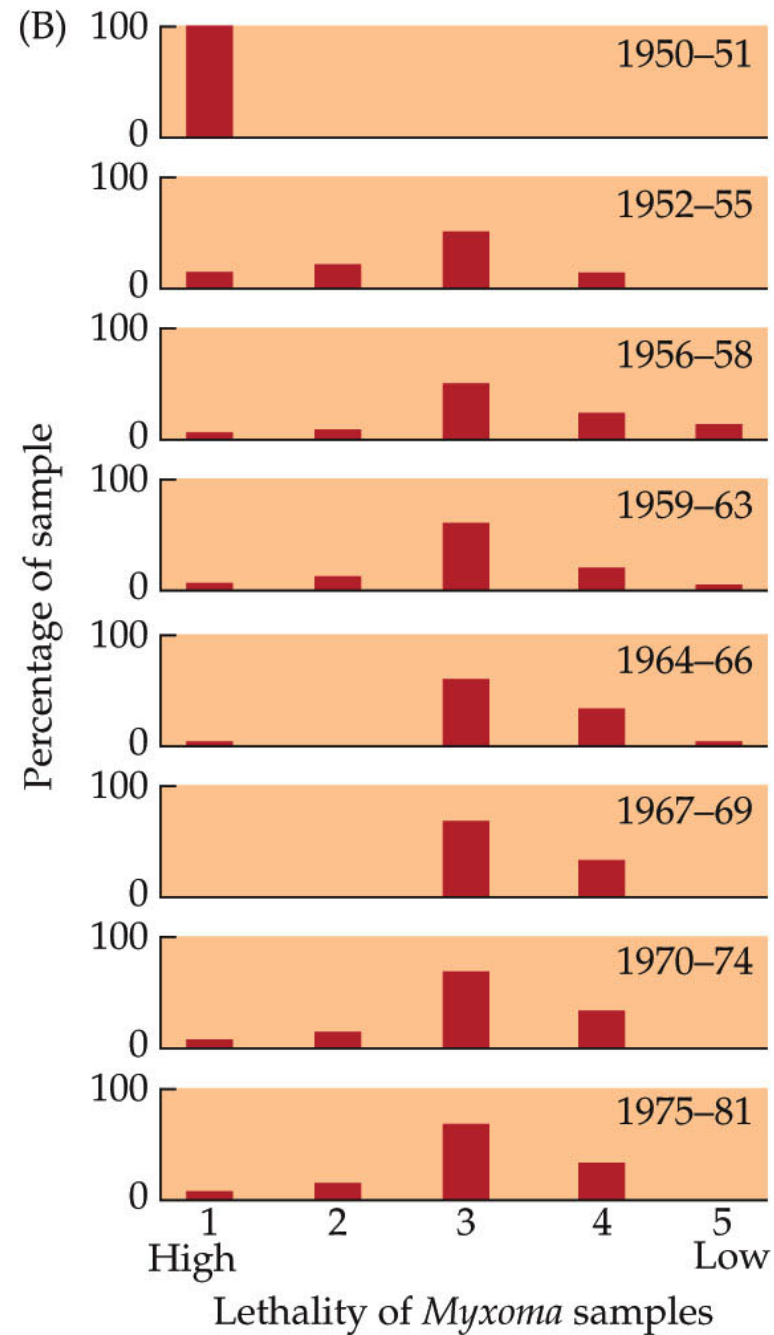
*Myxoma* is still used, but it requires a constant search for new strains of the virus.

Figure 13.10 Coevolution of the European Rabbit and the *Myxoma* Virus (Part 1)



A rabbit infected with the *Myxoma* virus

Figure 13.10 Coevolution of the European Rabbit and the *Myxoma* Virus (Part 2)



## Coevolution

The rabbits and *Myxoma* virus illustrate **coevolution**: When populations of two interacting species evolve together, each in response to selection imposed by the other.

**Gene-for-gene interactions**—a specific response that makes particular plant genotypes resistant to particular parasite genotypes.

## Coevolution

Wheat has dozens of different genes for resistance to fungi such as wheat rusts.

Different wheat rust genotypes can overcome different wheat resistance genes.

But periodically, mutations occur in wheat rusts that produce new genotypes to which wheat is not resistant.

## Coevolution

The frequencies of wheat rust genotypes vary considerably over time as farmers use different resistant varieties of wheat.

## Coevolution

Change in the frequencies of host and parasite genotypes has also been shown in a trematode worm and the snail it parasitizes in New Zealand lakes.

The trematode causes sterility in the snails.

The trematode parasite has a shorter generation time than the snail.

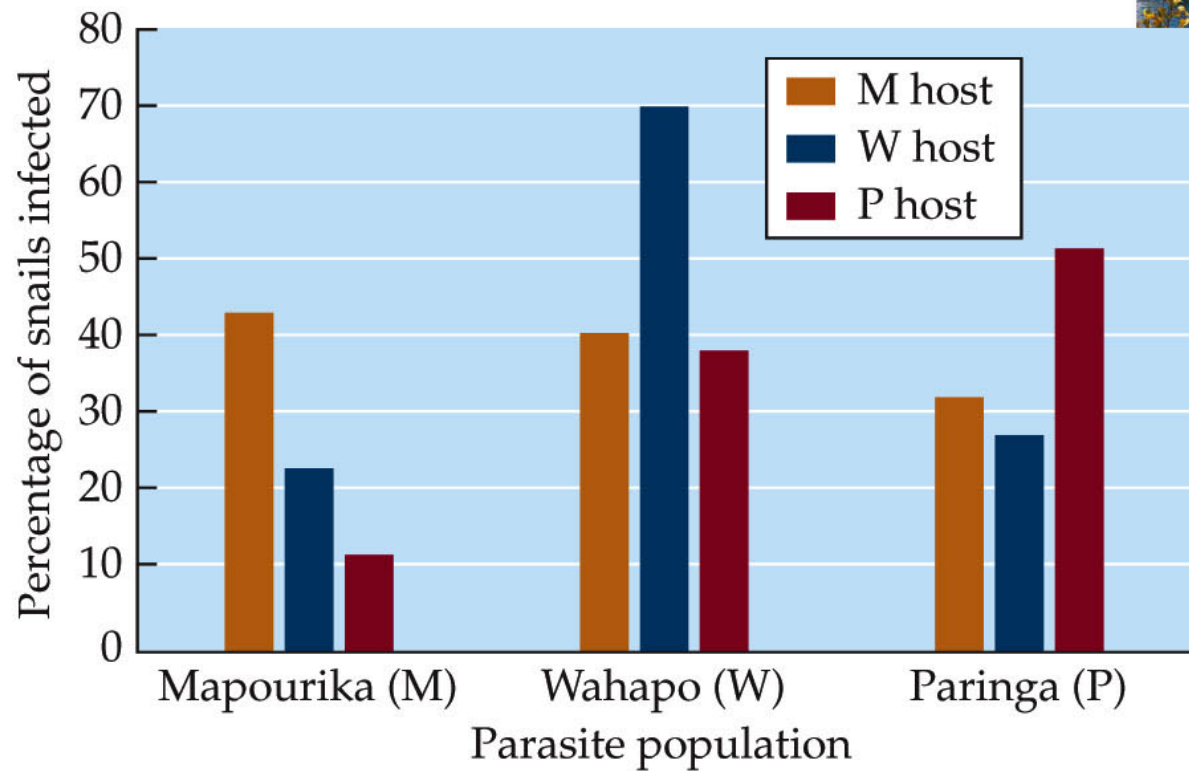
## Coevolution

When snails and parasites from three different lakes were tested, parasites infected snails from their home lake more effectively than they infected snails from the other two lakes (Lively 1989).

This suggested that parasite genotypes in each lake had evolved rapidly enough to overcome the defenses of the snail genotypes found in that lake.



Figure 13.11 Adaptation by Parasites to Local Host Populations



## Coevolution

The snails also evolved in response to the parasites.

Abundance of different snail genotypes in one lake was documented for 5 years (Dybdahl and Lively 1998).

The most abundant genotype changed from year to year.

## Coevolution

One year after a genotype was most abundant, that genotype had higher than usual number of parasites.

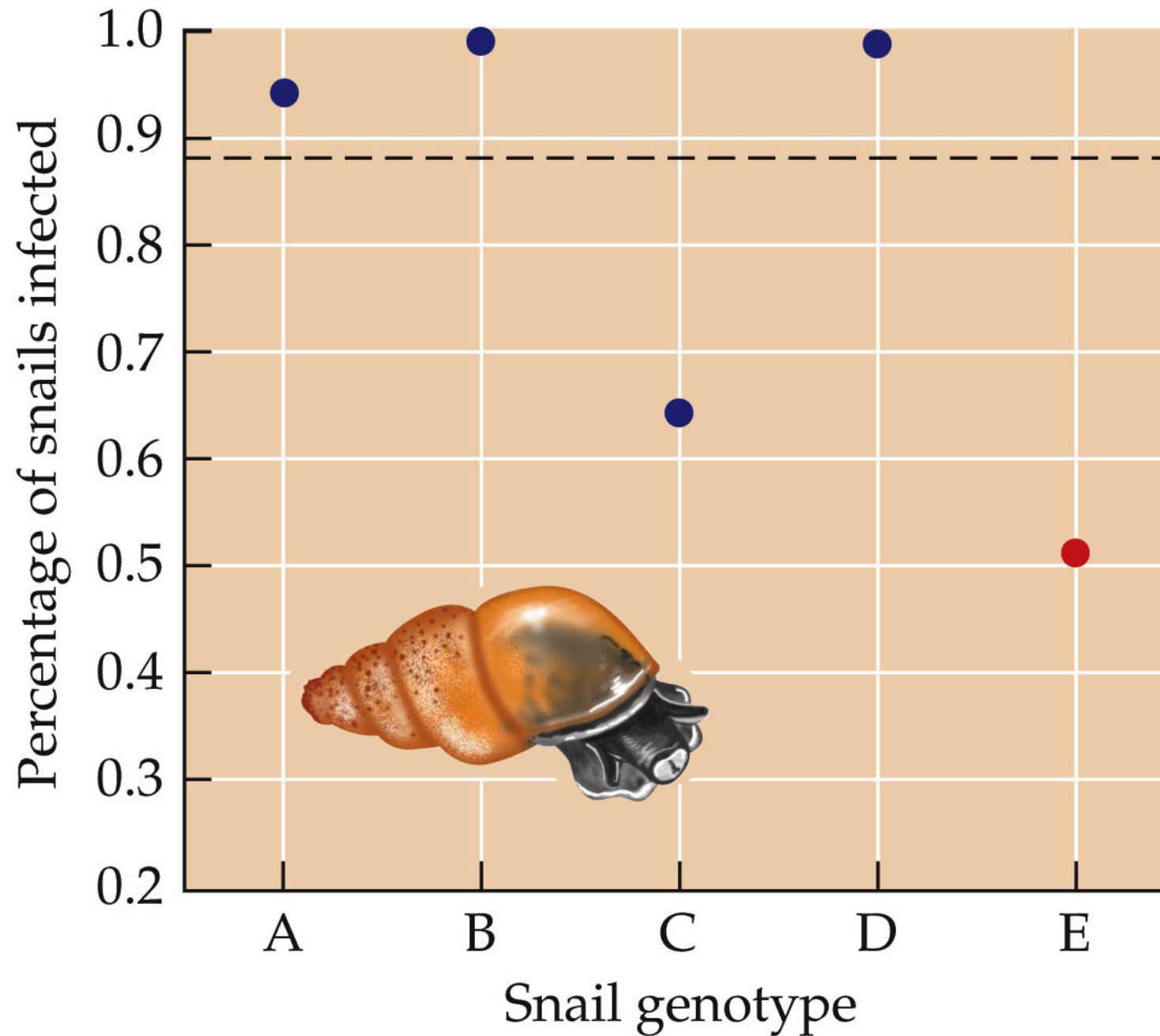
These results suggest that parasite populations evolve to exploit the snail genotypes found in their local environment.

## Coevolution

Lab experiments showed that parasites infect snails with a common genotype more often than snails with a rare genotype.

Snail genotype frequencies may change from year to year because common genotypes are attacked by many parasites, placing them at a disadvantage and driving down their numbers in future years.

Figure 13.12 Parasites Infect Common Host Genotypes More Easily Than Rare Genotypes



Ever-escalating “arms races” rarely occur.

As with the snails and trematodes, common host genotypes decrease in frequency because they are attacked by many; leading to increase in previously rare genotypes.

## Coevolution

An arms race may stop because a trait that improves host defenses or parasite counterdefenses reduces some other aspect of the organism's growth, survival, or reproduction.

In the case of the fruit flies and their parasitoids, there are costs for encapsulation and avoiding encapsulation.

## Coevolution

Ability to encapsulate is associated with lower larval survival rates.

Wasp eggs that avoid encapsulation by embedding in host tissue take longer to hatch than other eggs.



Studies of wild flax and a rust pathogen:

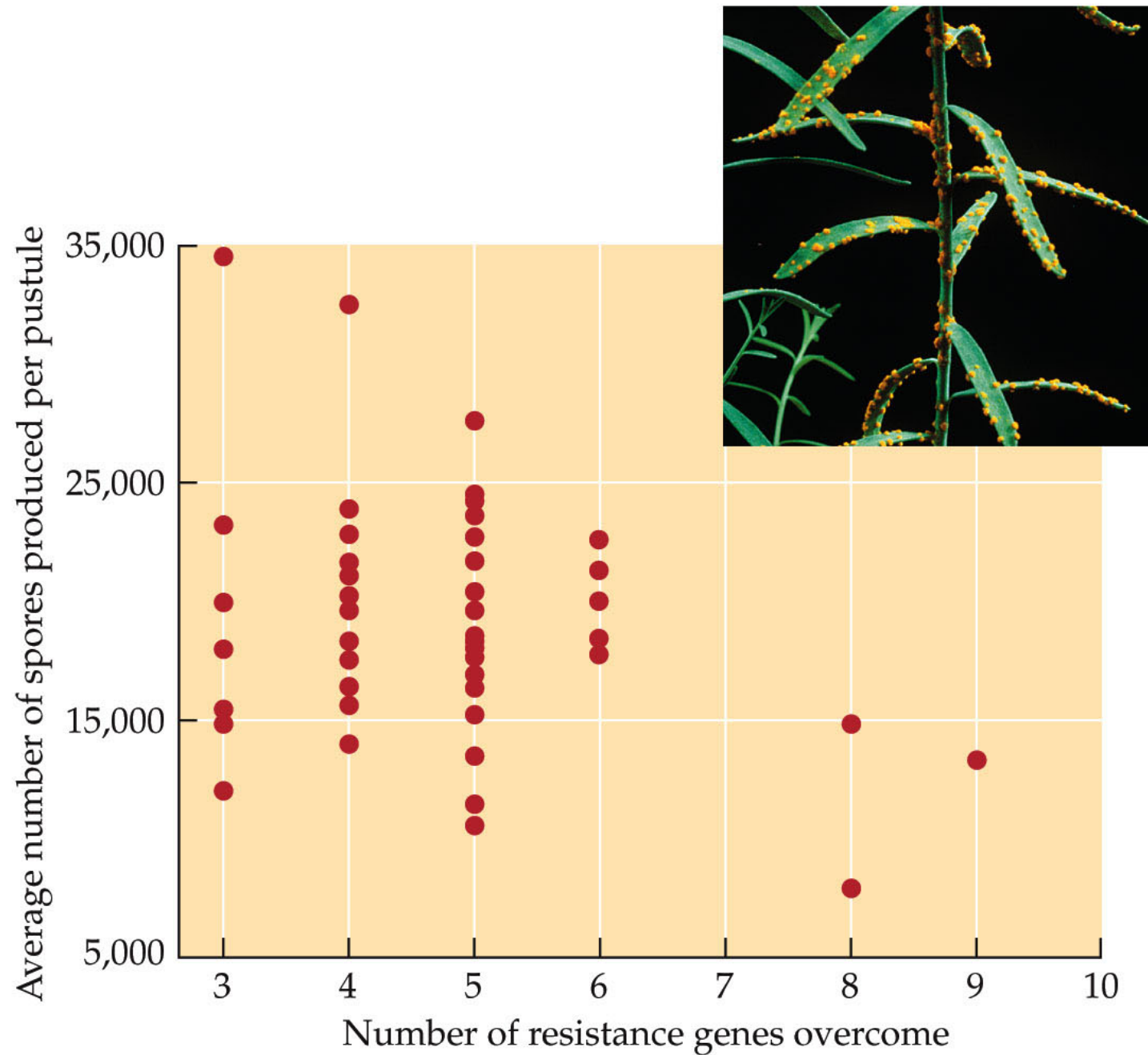
Some rust genotypes were more virulent than others (they can overcome more plant resistance genes).

Virulent rust genotypes were common only in host populations dominated by plants with many resistance genes.

A trade-off appears to be at work. Virulent rust genotypes produce fewer spores than other genotypes.

In flax populations with few resistance genes, it is not an advantage to be virulent. There are few resistance genes to overcome, and fewer spores are produced.

Figure 13.13 Virulent Rust Pathogens Reproduce Poorly



## Ecological Effects of Parasites

**Concept 13.4: Parasites can reduce the sizes of host populations and alter the outcomes of species interactions, thereby causing communities to change.**

Parasites can reduce survival or reproduction of their host.

Experiments with a beetle and a sexually transmitted mite showed a decrease in egg production by infected females.

Figure 13.14 Parasites Can Reduce Host Reproduction (Part 1)

(A) Females from control populations

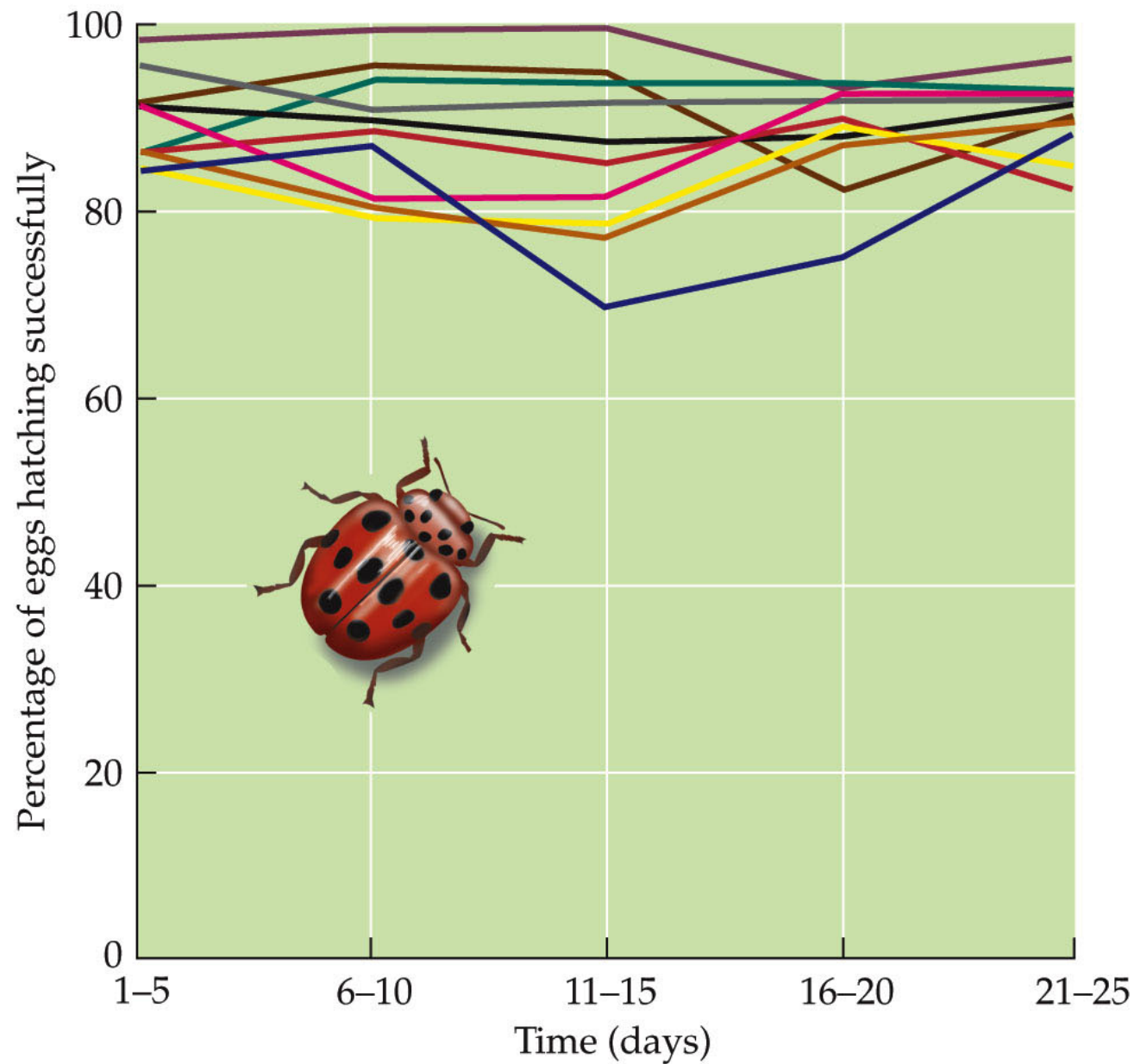
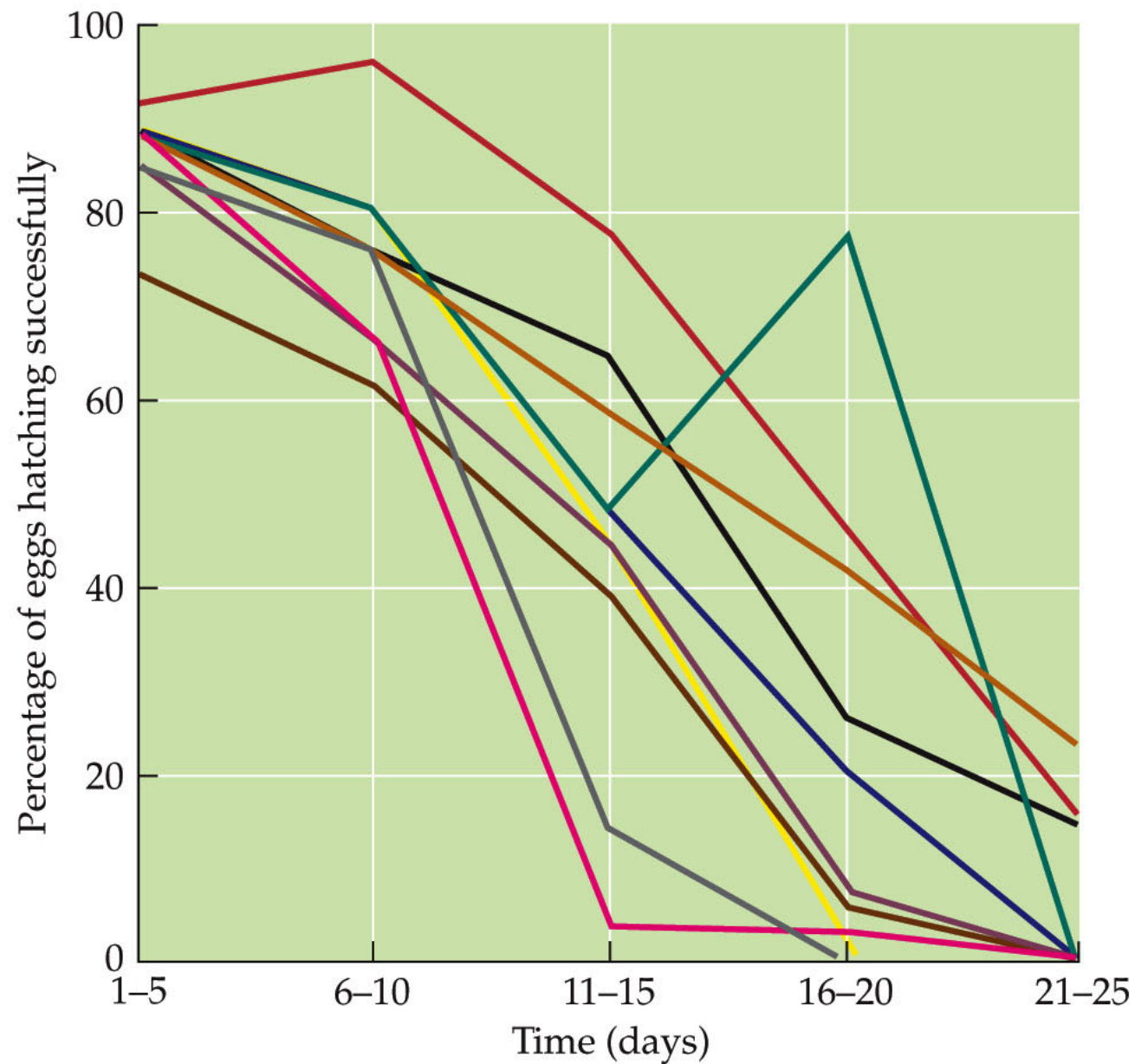


Figure 13.14 Parasites Can Reduce Host Reproduction (Part 2)

(B) Females from infected populations



## Ecological Effects of Parasites

At the population level, harm done by parasites translates into reduction of population growth rates.

Parasites can drive local host populations extinct and reduce their geographic ranges.

## Ecological Effects of Parasites

An amphipod (*Corophium*) in North Atlantic tidal mudflats can be extremely abundant—up to 100,000 / m<sup>2</sup>.

A trematode parasite can reduce amphipod populations dramatically.

In a 4-month period, attack by trematodes caused extinction of a *Corophium* population that initially had 18,000 / m<sup>2</sup> (Mouritsen et al. 1998).



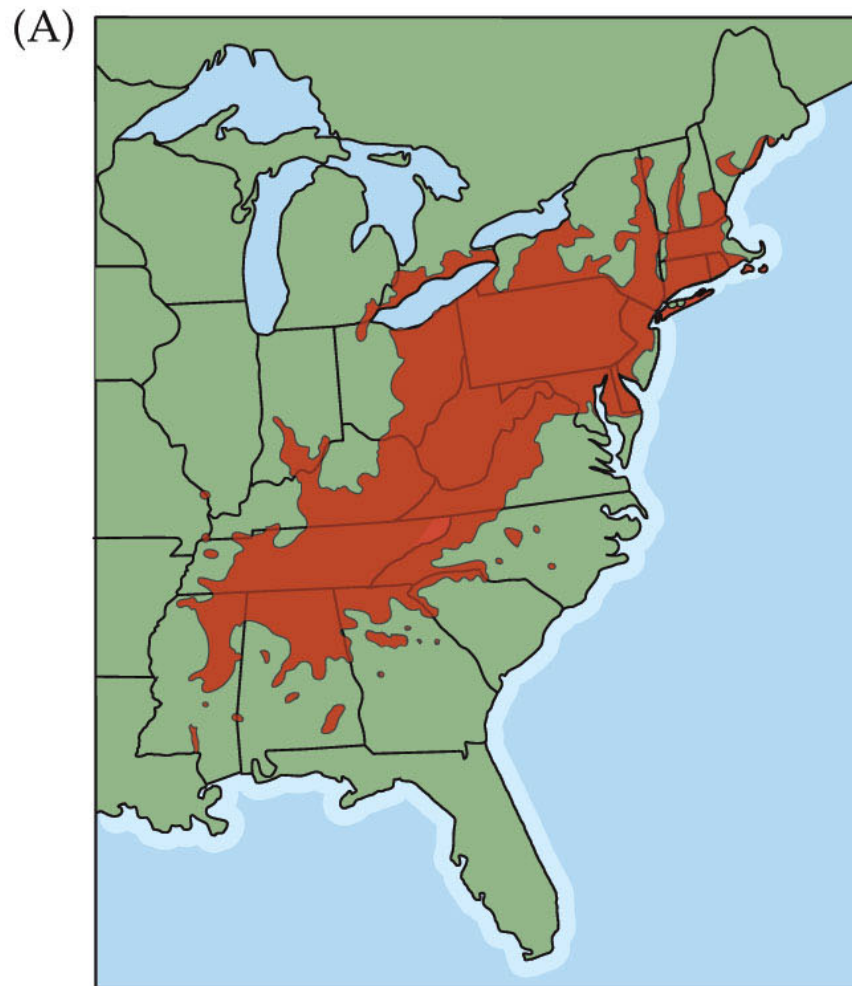
## Ecological Effects of Parasites

The American chestnut (*Castanea dentata*) once was a dominant tree in eastern North America.

A fungal pathogen that causes chestnut blight was introduced from Asia in 1904.

By mid-century, the fungus had wiped out most chestnut populations and greatly reduced the geographic range of this species.

Figure 13.15 Parasites Can Reduce Their Host's Geographic Range



## Ecological Effects of Parasites

Population cycles may be influenced by parasites.

Hudson et al. (1998) manipulated numbers of parasites in red grouse populations, which tend to crash every 4–8 years.

A parasitic trematode was known to decrease survival and reproductive success.

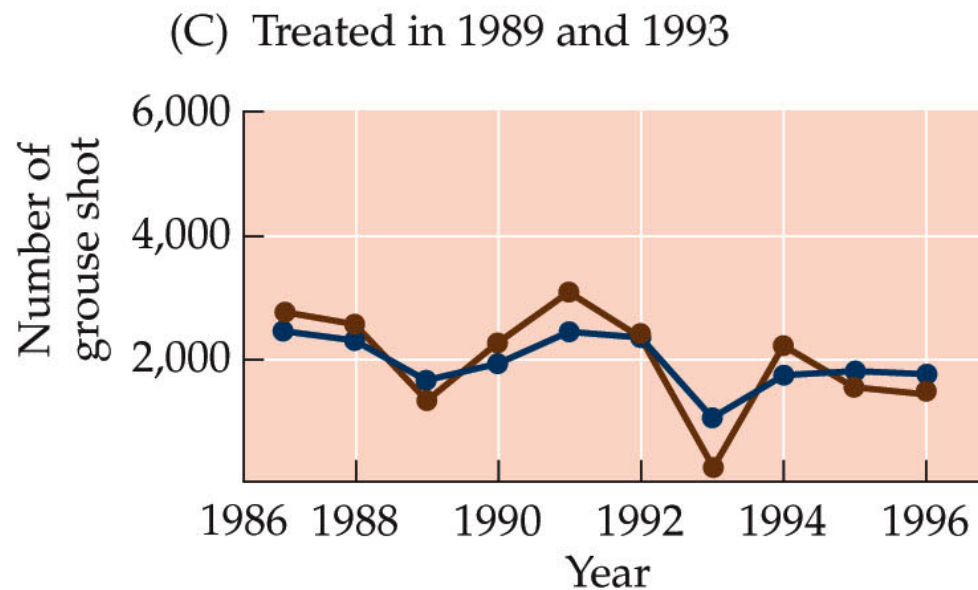
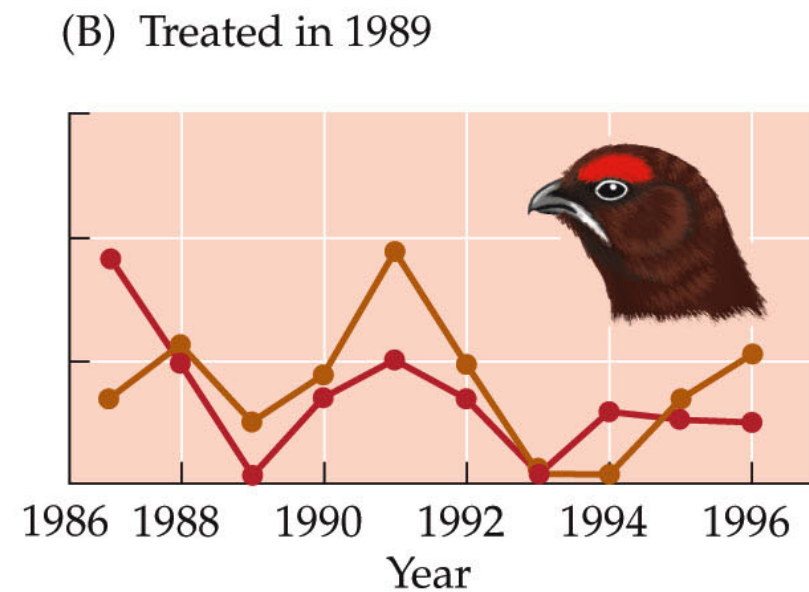
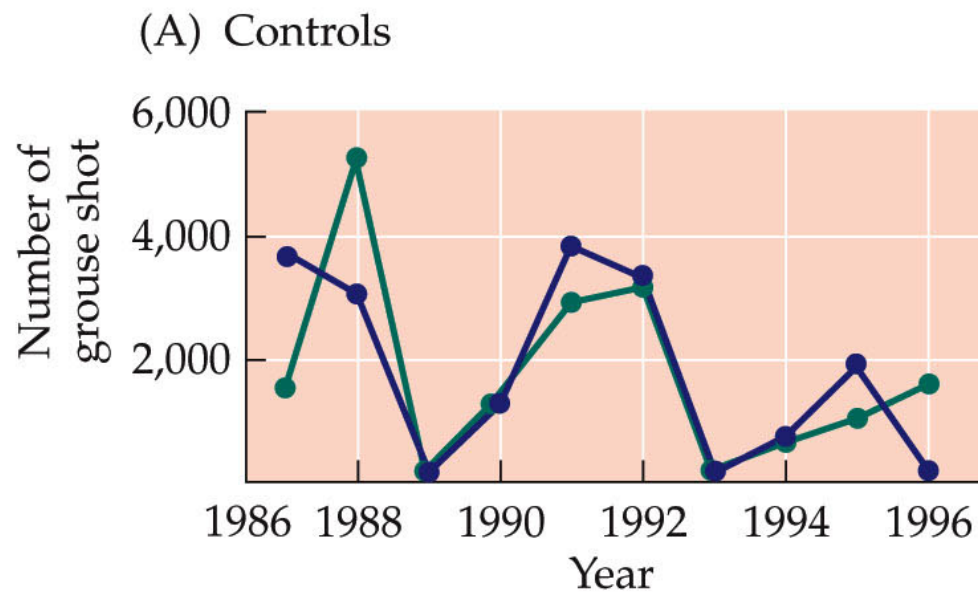
## Ecological Effects of Parasites

When grouse populations were expected to crash, two populations were treated with a drug to kill the parasite.

Population sizes were estimated based on numbers killed by hunters.

In control populations, numbers crashed as predicted. Parasite removal did reduce population fluctuations.

Figure 13.16 Parasite Removal Reduces Host Population Fluctuations



## Ecological Effects of Parasites

By reducing host performance and growth rates of host populations, parasites can change the outcome of species interactions, community composition, and even the physical environment.

## Ecological Effects of Parasites

Parasites can affect host performance, and thus they can affect the outcome of interactions with other species.

In a series of experiments, Park (1948) looked at two species of flour beetles (*Tribolium castaneum* and *T. confusum*) and a protozoan parasite.

## Ecological Effects of Parasites

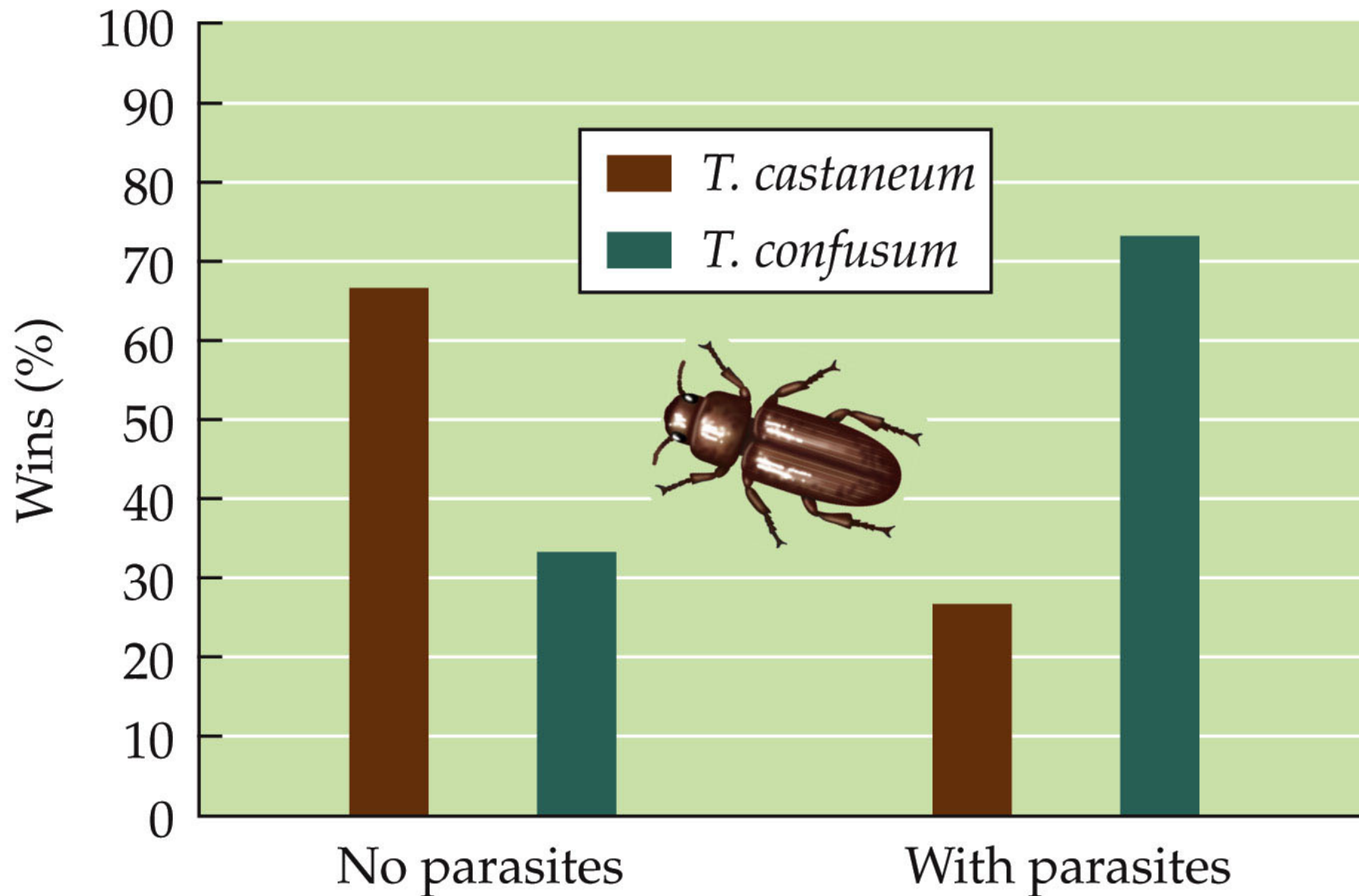
When the parasite was absent, *T. castaneum* usually outcompeted *T. confusum*, driving it to extinction in most cases.

When the parasite was present, the opposite occurred.

The outcome was reversed because the parasite had a large negative effect on *T. castaneum*, but virtually no effect on *T. confusum*.



Figure 13.17 Parasites Can Alter the Outcome of Competition



## Ecological Effects of Parasites

In the field, the malaria parasite *Plasmodium azurophilum* reduced the competitive superiority of the lizard *Anolis gingivinus* over its smaller counterpart, *A. wattsi* (Schall 1992).

## Ecological Effects of Parasites

Parasites can alter the outcome of predator–prey interactions by decreasing the physical condition of infected individuals.

Predators may be less able to catch their prey, or prey less able to escape predation.

## Ecological Effects of Parasites

Parasites can also alter behavior of their host, such as the protozoan that makes rats less wary of cats.

Some worm parasites cause amphipods to move from sheltered areas to areas of bright light, where they are more likely to be seen and eaten by fish or bird predators.

## Ecological Effects of Parasites

In both cases, the parasite induces a change in host behavior that makes the host more likely to be eaten by a species (the cat, fish, or bird) that the parasite requires to complete its life cycle.

## Ecological Effects of Parasites

A parasite that attacks a dominant competitor can suppress that species, causing other species to increase (just as a predator or herbivore can do).

This was documented in studies of stream communities by Kohler and Wiley (1997).

## Ecological Effects of Parasites

A caddisfly *Glossosoma nigrior* was the dominant herbivore before outbreaks of a fungal pathogen.

The fungus reduced *Glossosoma* population densities by 25-fold.

This allowed many other species to increase, including algae, other grazing insects, and filter feeders. Many species were previously rare.

## Ecological Effects of Parasites

The physical environment can be changed when a parasite attacks a species that is an *ecosystem engineer*—a species whose actions change the physical character of its environment, as when a beaver builds a dam.



## Ecological Effects of Parasites

The amphipod  
*Corophium* is an  
ecosystem engineer  
in the tidal mudflats.

The burrows it builds  
hold the mud  
together, preventing  
erosion and forming  
“mud islands” at low  
tide.

(C)



Figure 13.18 C

## Ecological Effects of Parasites

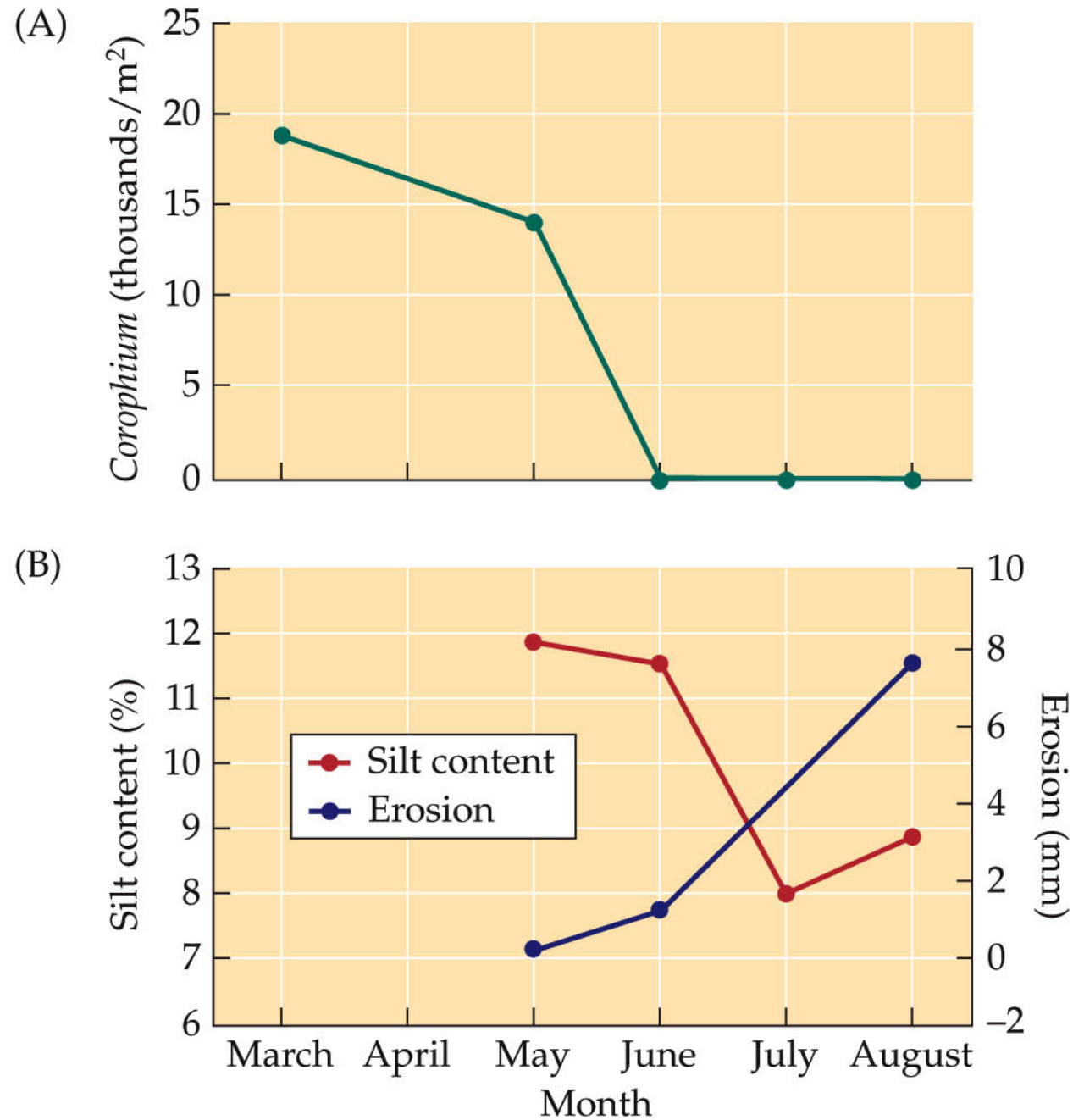
When the trematode parasite drives the amphipod populations to extinction, erosion increases, silt content increases, and the islands disappear.

(D)



Figure 13.18 D

Figure 13.18 A, B Parasites Can Alter the Physical Environment



## Dynamics and Spread of Diseases

**Concept 13.5: Simple models of host–pathogen dynamics suggest ways to control the establishment and spread of diseases.**

Pathogens have had a major effect on human populations—they are thought to have played a major role in the rise and fall of civilizations throughout history.

Despite medical advances, millions still die of diseases such as malaria.

Mathematical models of host–pathogen population dynamics differ from models discussed previously:

- Host population is divided into susceptible individuals ( $S$ ), infected individuals ( $I$ ), and recovered and immune individuals ( $R$ ).
- It is often necessary to keep track of both host and pathogen genotypes.

## Dynamics and Spread of Diseases

- Other factors can influence spread of the disease, such as:
  - 1) Different chances that hosts of different ages will become infected.
  - 2) A **latent period** in which an individual is infected but can not spread the disease.
  - 3) **Vertical transmission**—spread of the disease from mother to newborn, as can occur in AIDS.

## Dynamics and Spread of Diseases

These models can become quite complex.

Consider a simple model that looks only at host population density:

A disease will spread only if the density of susceptible hosts exceeds a critical, threshold density.

## Dynamics and Spread of Diseases

Density of susceptible individuals =  $S$ ,  
density of infected individuals =  $I$ .

For a disease to spread, infected individuals must encounter susceptible individuals. The probability of this is proportional to the densities of each ( $SI$ ).

A transmission coefficient ( $\beta$ ) indicates how effectively the disease spreads; the term is now  $\beta SI$ .



## Dynamics and Spread of Diseases

Density of infected individuals increases when the disease is transmitted successfully and decreases when infected individuals die or recover. Death and recovery rate =  $d$ .

$$\frac{dI}{dt} = \beta SI - dI$$

## Dynamics and Spread of Diseases

A disease will spread when  $dI/dt > 0$

This occurs when  $\beta SI - dI > 0$   
or  $S > d/\beta$ .

A disease will establish and spread when the number of susceptible individuals exceeds the **threshold density**,  $S_T = d/\beta$ .

## Dynamics and Spread of Diseases

There are several ways of keeping the number of susceptible individuals below the threshold.

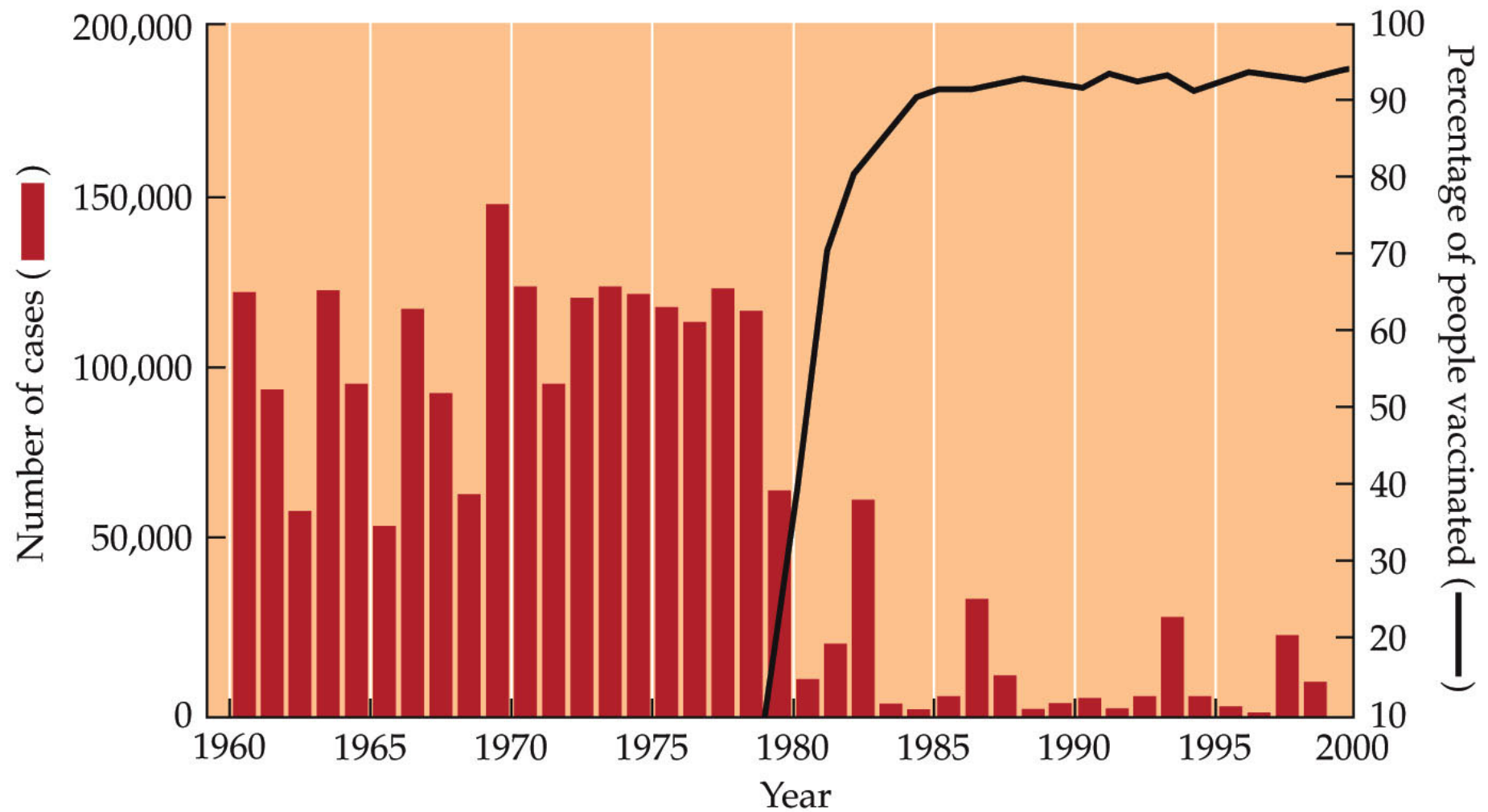
Susceptible domestic animals are sometimes slaughtered to reduce density, especially if the disease can also affect humans, such as bird flu.

## Dynamics and Spread of Diseases

For human populations, mass vaccination programs can reduce density of susceptible individuals.

These programs have been successful for several diseases, including small pox and measles.

Figure 13.19 Vaccination Reduces the Incidence of Disease



## Dynamics and Spread of Diseases

Public health measures can raise  $S_T$ :

Increase recovery rate of infected individuals who then have immunity, by early detection and improved treatment.

Decrease  $\beta$  by quarantining infected individuals or by convincing people to engage in behaviors that make it more difficult for the disease to be transmitted.

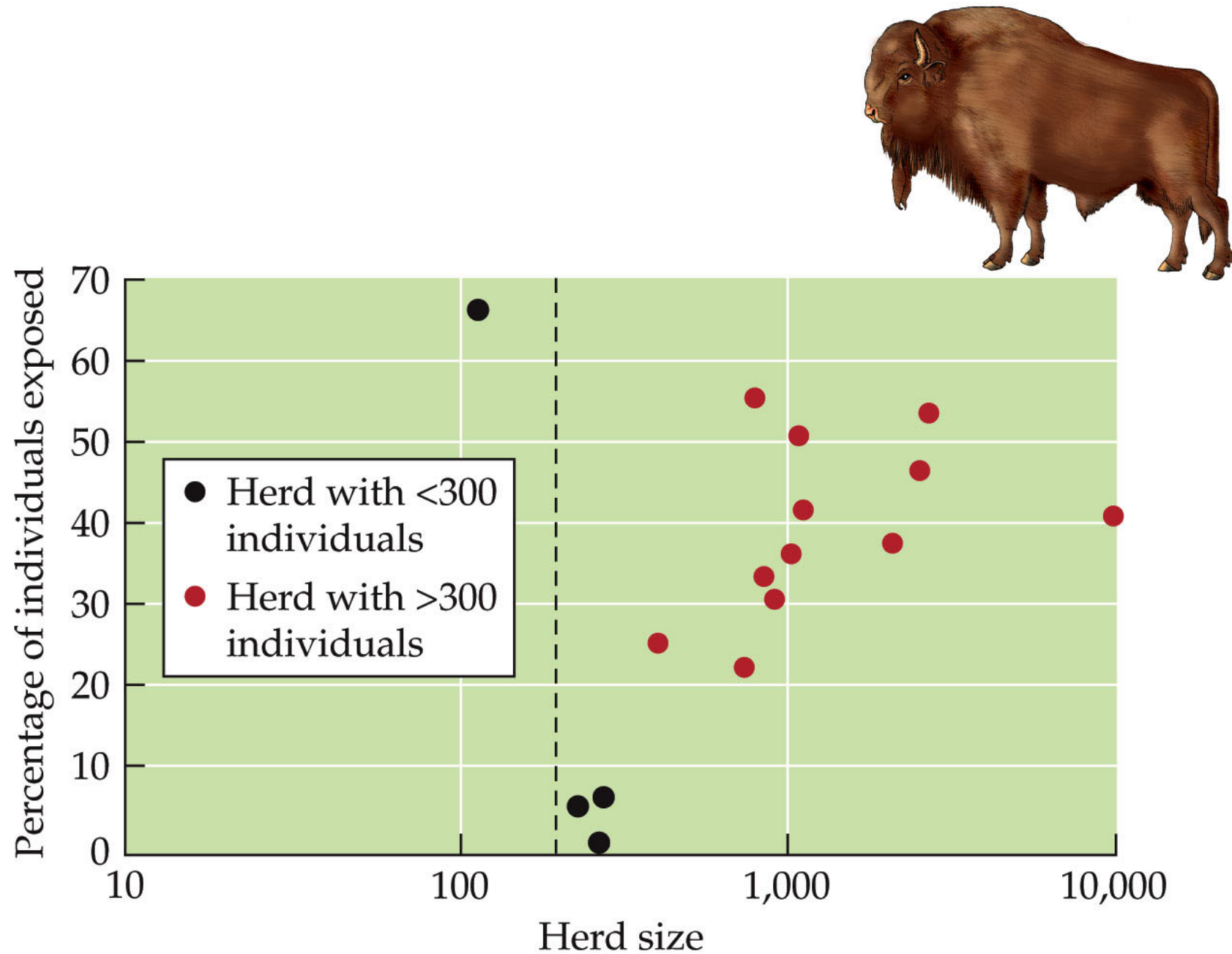
## Dynamics and Spread of Diseases

Threshold densities were determined for wild populations of bison susceptible to the bacterial disease brucellosis.

Dobson and Meagher (1996) used National Park data on previous exposure among bison herds and found  $S_T$  to be 200–300 per herd.

$S_T$  calculated by a model was 240.

Figure 13.20 Determining Threshold Population Densities





## Dynamics and Spread of Diseases

Herd sizes in the parks were 1000 to 3000 individuals.

Neither option for reducing  $S_T$  was feasible:

A vaccine was not available; killing large numbers of bison was not acceptable, politically or ecologically (small herds have higher risk of extinction).

## Case Study Revisited: Enslaver Parasites

Parasitoid wasp *Hymenoepimecis* larvae attach to the exterior of a host spider's abdomen and suck the body fluids.

When a larva is fully grown, it induces the spider to build a cocoon web, then the larva kills the spider and eats it.

The larva spins a cocoon and attaches it to the cocoon web.

Figure 13.21 Parasites Can Alter Host Behavior

(A)



(B)



## Case Study Revisited: Enslaver Parasites

If wasp larvae were removed from the host spiders just before a cocoon web would be made, the spiders constructed webs that were different from both normal webs and cocoon webs.

Some spiders recovered normal web-making ability after several days.

## Case Study Revisited: Enslaver Parasites

This suggests that the larva injects a fast-acting chemical into the spider to alter behavior.

The chemical appears to be dose-dependent, as evidenced by the intermediate web type. Otherwise, any exposure to the chemical would result in cocoon webs.

## Case Study Revisited: Enslaver Parasites

Spiders build cocoon webs by repeating the early steps of their normal web-building sequence; thus, the chemical appears to act by interrupting the spiders' usual sequence of web-building behaviors.

## Case Study Revisited: Enslaver Parasites

Other enslaver parasites appear to manipulate the host's biochemistry.

Hairworms alter concentrations of three amino acids in the brains of the cricket hosts.

The amino acid taurine is an important neurotransmitter in insects, and also regulates the sense of thirst.

## Case Study Revisited: Enslaver Parasites

The hairworm may induce the cricket to commit suicide by altering its perception of thirst.

Not all enslaver parasites appear to act by manipulating the host's chemistry, but the mechanisms are still unknown.

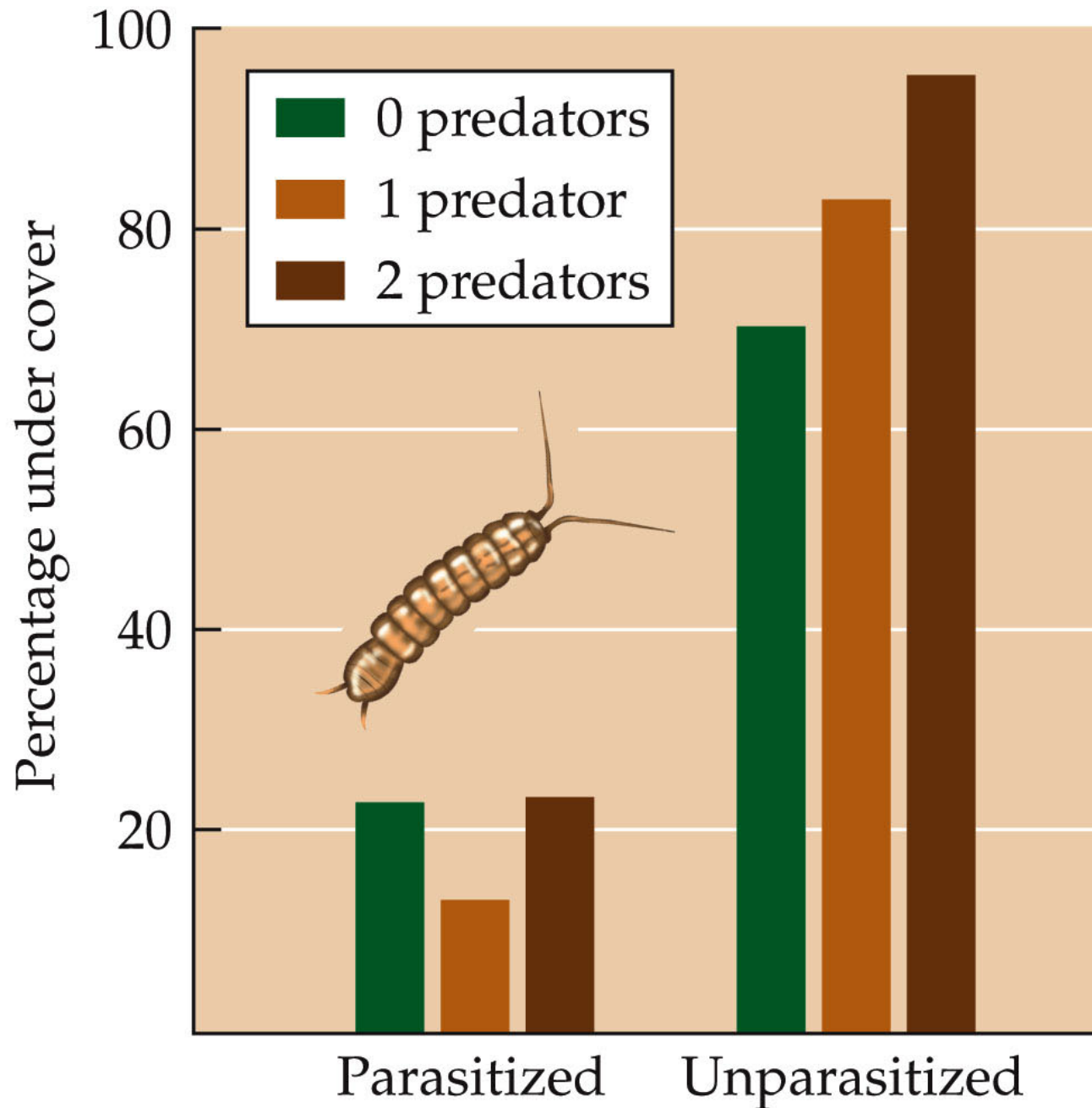


## Case Study Revisited: Enslaver Parasites

Isopods parasitized by a worm spent little time under cover, where they were protected from predation by the creek chub, the next host in the parasite's life cycle (Hechtel et al. 1993).

In a choice experiment, unparasitized isopods would avoid chubs, but parasitized isopods were drawn to the chubs; a benefit for the parasite but disaster for the isopod.

Figure 13.22 Making the Host Vulnerable to Predation



## Connections in Nature: From Chemicals to Evolution and Ecosystems

Interactions between enslaver parasites and their hosts provide evidence of previous evolutionary change.

An enslaver parasite has many adaptations that allow it to cope with host defenses.

A parasite that uses a chemical is well adapted to take advantage of the body chemistry of its host.

## Connections in Nature: From Chemicals to Evolution and Ecosystems

It can be difficult to separate host–parasite ecological interactions from host–parasite evolutionary interactions.

As evolutionary change tips the balance back and forth, first in favor of the host, then in favor of the parasite, we can expect concomitant changes in the dynamics of other species.

## Connections in Nature: From Chemicals to Evolution and Ecosystems

Communities and ecosystems are highly dynamic, always shifting in response to the ongoing ecological and evolutionary changes that occur within them.