

# 20

## *Energy Flow and Food Webs*



## 20 Energy Flow and Food Webs

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## Case Study: Toxins in Remote Places

The Arctic has been thought of as one of the most remote and pristine areas on Earth.

But, starting with studies of PCBs in human breast milk, researchers began to realize there were high levels of pollutants in the Arctic.

## Case Study: Toxins in Remote Places

PCBs belong to a group of chemical compounds called persistent organic pollutants (POPs) because they remain in the environment for a long time.

A study of PCBs in breast milk of women in southern Ontario required a population from a pristine area for comparison.

## Case Study: Toxins in Remote Places

Inuit mothers from northern Canada were used as a “control.”

The Inuit are primarily subsistence hunters, and have no developed industry or agriculture that would expose them to POPs.

Figure 20.1 Subsistence Hunting



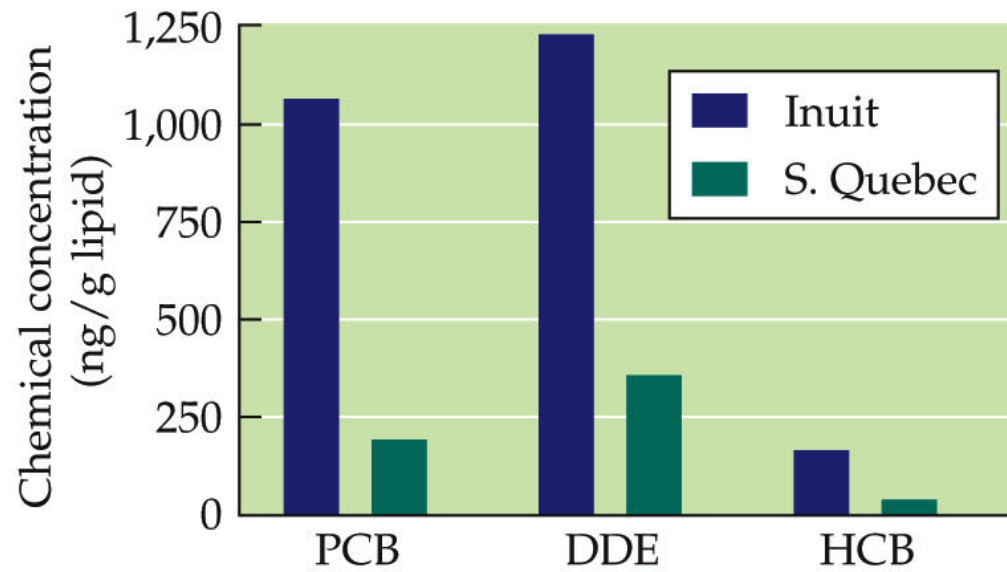
## Case Study: Toxins in Remote Places

However, the Inuit women had concentrations of PCBs in their breast milk that were seven times higher than in women to the south (Dewailly et al. 1993).

Other studies also reported high levels of PCBs in Inuit from Canada and Greenland.



Figure 20.2 Persistent Organic Pollutants in Canadian Women





## Case Study: Toxins in Remote Places

How do these toxins make their way to the Arctic?

POPs produced at low latitudes enter the atmosphere (they are in gaseous form at the temperatures there).

They are carried by atmospheric circulation patterns to the Arctic, where they condense to liquid forms and fall from the atmosphere.

## Case Study: Toxins in Remote Places

Manufacture and use of POPs has been banned in North America but some developing countries still use them.

Emissions of POPs have decreased, but they may remain in Arctic snow and ice for many decades, being released slowly during snowmelt every spring and summer.

## Case Study: Toxins in Remote Places

There is a correlation between POPs and diet.

Communities that rely on marine mammals for their food tend to have the highest levels of POPs.

Communities that consume herbivorous caribou tend to have lower levels.

## Introduction

What links organisms together in the context of ecological functioning is their *trophic* interactions—what they eat and what eats them.

The influence of an organism on the movement of energy and nutrients through an ecosystem is determined by the type of food it consumes, and by what consumes it.

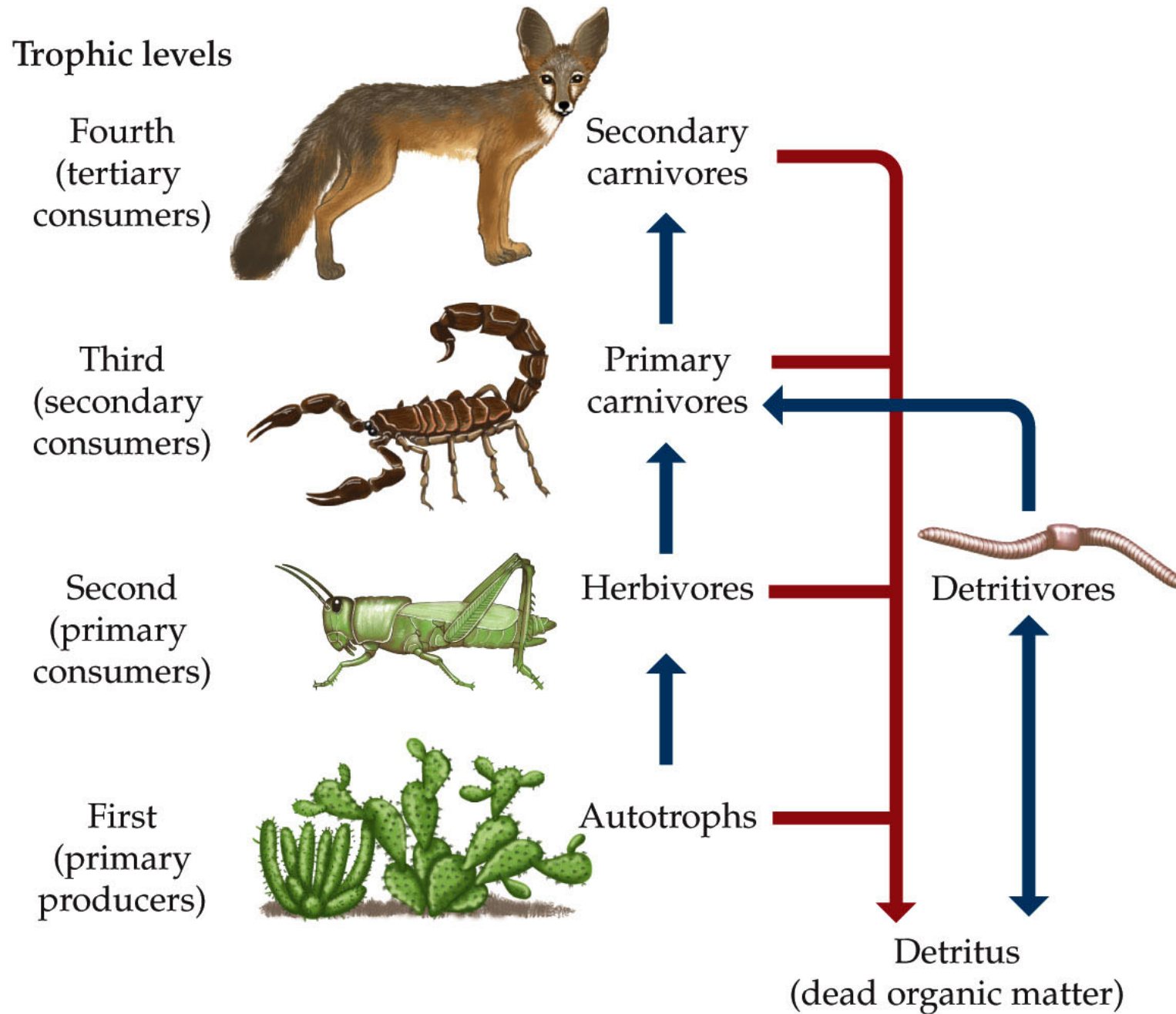
## Feeding Relationships

**Concept 20.1: Trophic levels describe the feeding positions of groups of organisms in ecosystems.**

Each feeding category, or **trophic level**, is based on the number of feeding steps by which it is separated from autotrophs.

The first trophic level consists of autotrophs (primary producers) .

Figure 20.3 Trophic Levels in a Desert Ecosystem





## Feeding Relationships

The first trophic level generates chemical energy from sunlight or inorganic chemical compounds.

The first trophic level also generates most of the dead organic matter in an ecosystem.

## Feeding Relationships

Second trophic level—herbivores that consume autotrophs. It also includes the detritivores that consume dead organic matter.

Third (and higher) trophic levels—carnivores that consume animals from the level below.

## Feeding Relationships

Some organisms do not conveniently fit into trophic levels.

Omnivores feed at multiple trophic levels.

Example: Coyotes are opportunistic feeders, consuming vegetation, mice, other carnivores, and old leather boots.

## Feeding Relationships

All organisms in an ecosystem are either consumed by other organisms or enter the pool of dead organic matter (detritus).

In terrestrial ecosystems, only a small portion of the biomass is consumed, and most of the energy flow passes through the detritus.

## Figure 20.4 Ecosystem Energy Flow through Detritus (Part 1)

(A)



Figure 20.4 Ecosystem Energy Flow through Detritus (Part 2)

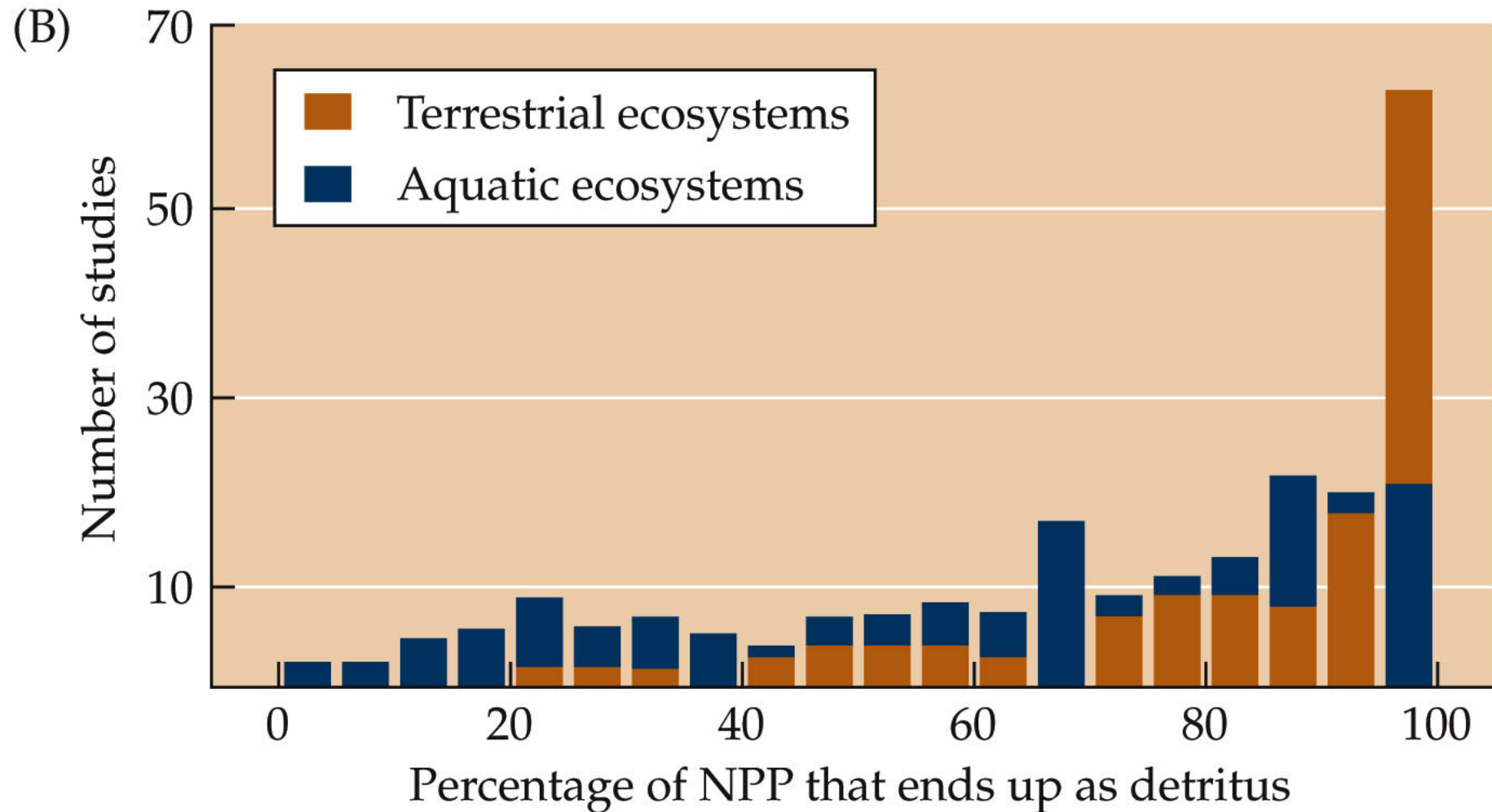
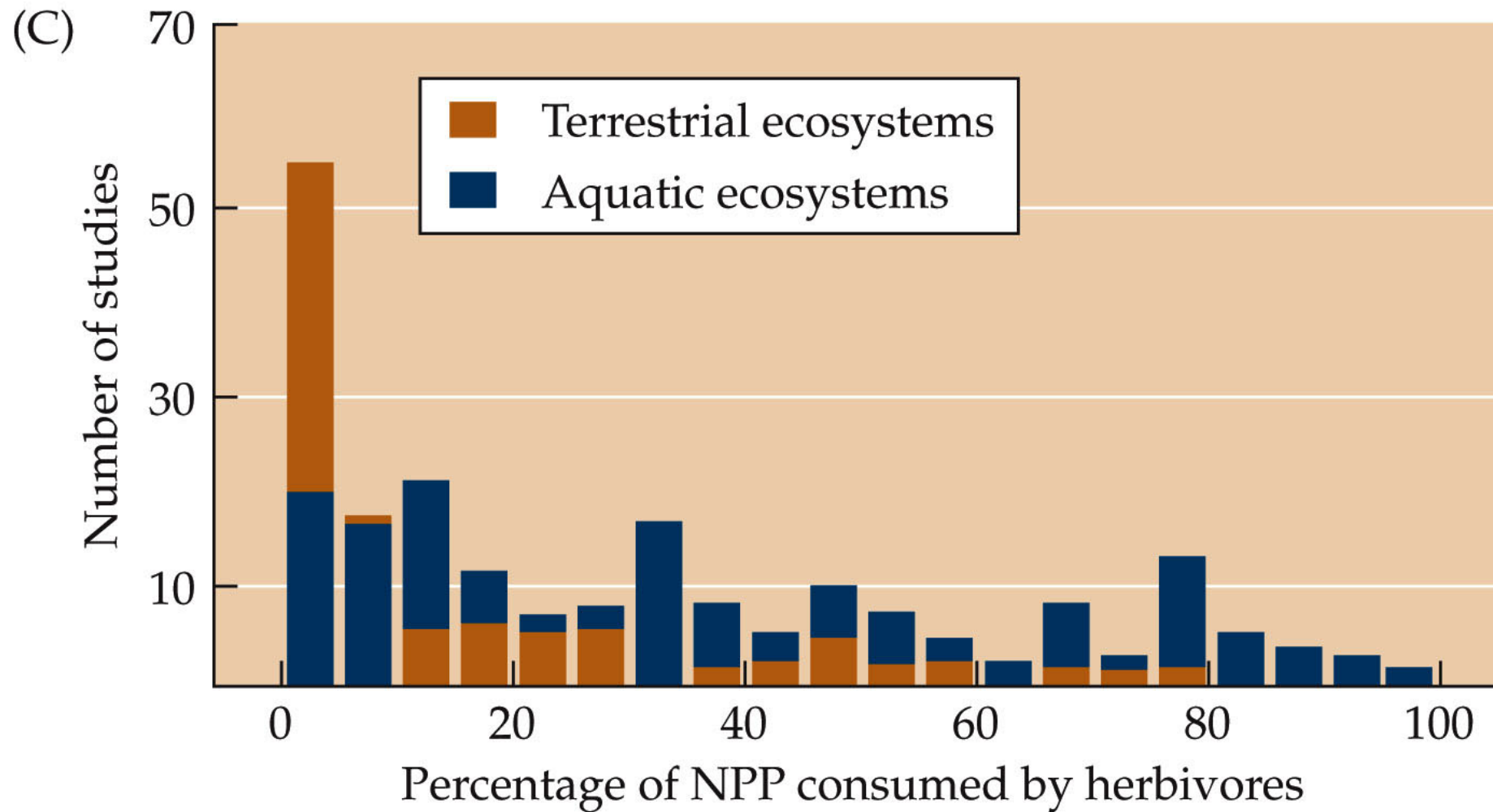




Figure 20.4 Ecosystem Energy Flow through Detritus (Part 3)



## Feeding Relationships

Dead plant, microbial, and animal matter, and feces, are consumed by organisms called detritivores (primarily bacteria and fungi), in a process known as *decomposition*.

Detritus is considered part of the first trophic level, and thus detritivores are part of the second level.

## Feeding Relationships

Much of the input of detritus into streams, lakes, and estuarine ecosystems is derived from terrestrial organic matter.

These external energy inputs are called **allochthonous** inputs.

Energy produced by autotrophs within the system is **autochthonous** energy.

## Feeding Relationships

Allochthonous inputs can be very important in stream ecosystems.

Example: Bear Brook in New Hampshire receives 99.8% of its energy as allochthonous inputs.

In nearby Mirror Lake, autochthonous energy accounts for almost 80% of the energy budget.

## Feeding Relationships

The river continuum concept states that the importance of autochthonous energy inputs increases from the headwaters toward the lower reaches of a river.

Water velocity decreases, and nutrient concentrations tend to increase as you go downstream.

## Energy Flow among Trophic Levels

**Concept 20.2: The amount of energy transferred from one trophic level to the next depends on food quality and consumer abundance and physiology.**

The second law of thermodynamics states that during any transfer of energy, some is lost due to the tendency toward an increase in disorder (entropy).

Energy will decrease with each trophic level.



## Energy Flow among Trophic Levels

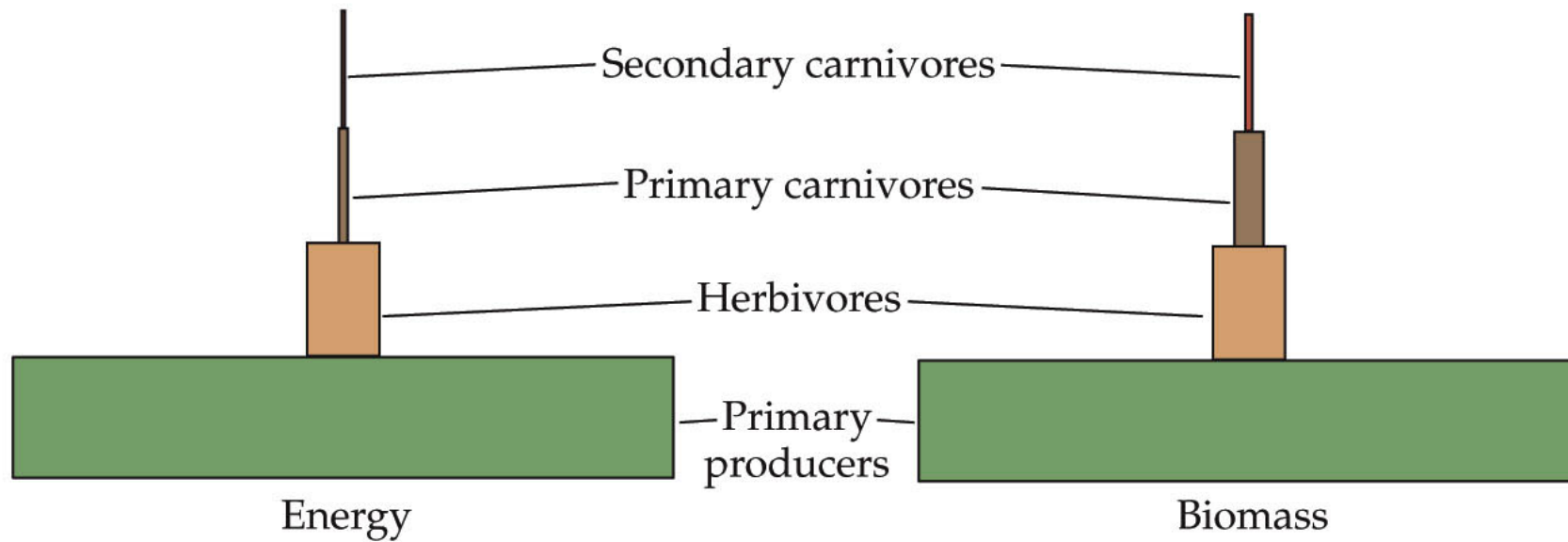
A **trophic pyramid** is a graphical representation of trophic relationships.

A series of rectangles portray the relative amounts of energy or biomass of each level.

A proportion of the biomass at each trophic level is not consumed, and a proportion of the energy at each trophic level is lost in the transfer to the next trophic level.

Figure 20.5 A Trophic Pyramid Schemes

(A) Terrestrial ecosystems



## Energy Flow among Trophic Levels

In terrestrial ecosystems, energy and biomass pyramids are usually similar because biomass is closely associated with energy production.

In aquatic ecosystems, the biomass pyramid may be inverted. The primary producers are phytoplankton with short life spans and high turnover.

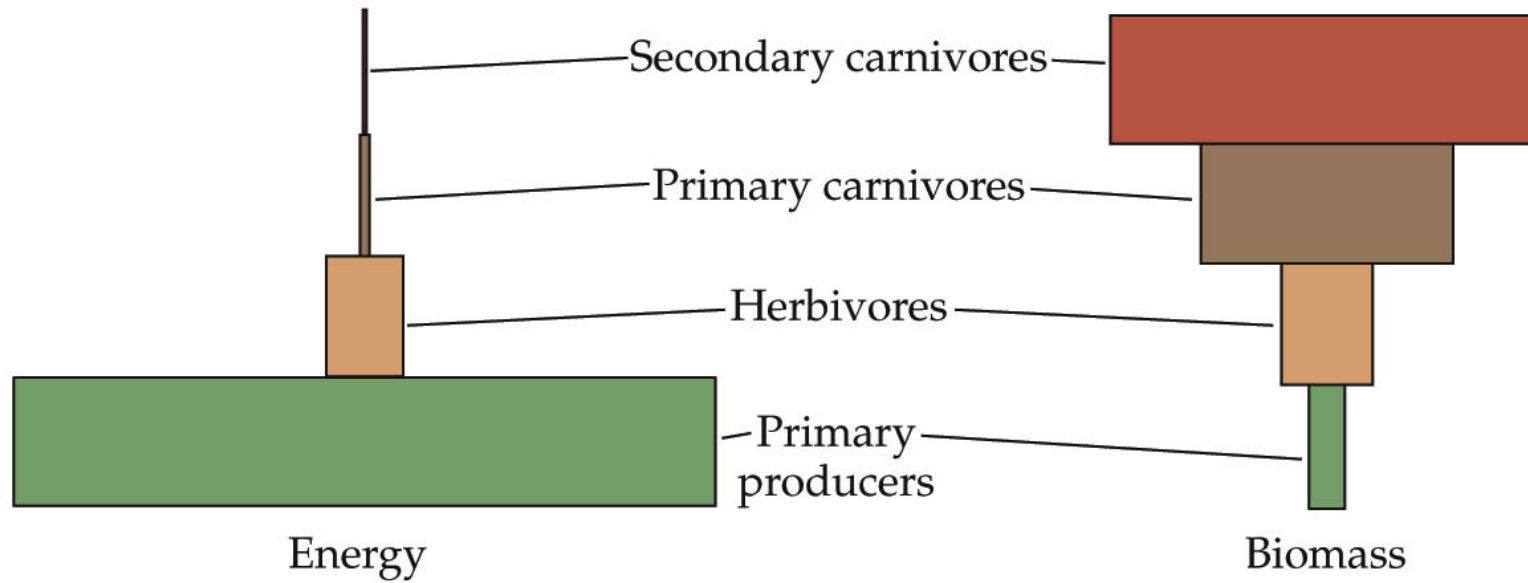
## Energy Flow among Trophic Levels

The tendency toward inverted biomass pyramids is greatest where productivity is lowest, such as in nutrient-poor regions of the open ocean.

This results from more rapid turnover of phytoplankton, associated with higher growth rate and shorter life span compared with phytoplankton of more nutrient-rich waters.

Figure 20.5 B Trophic Pyramid Schemes

(B) Aquatic ecosystems



## Energy Flow among Trophic Levels

Herbivores on land consume a much lower proportion of autotroph biomass than herbivores in most aquatic ecosystems.

On average, about 13% of terrestrial NPP is consumed; in aquatic ecosystems, an average of 35% NPP is consumed.



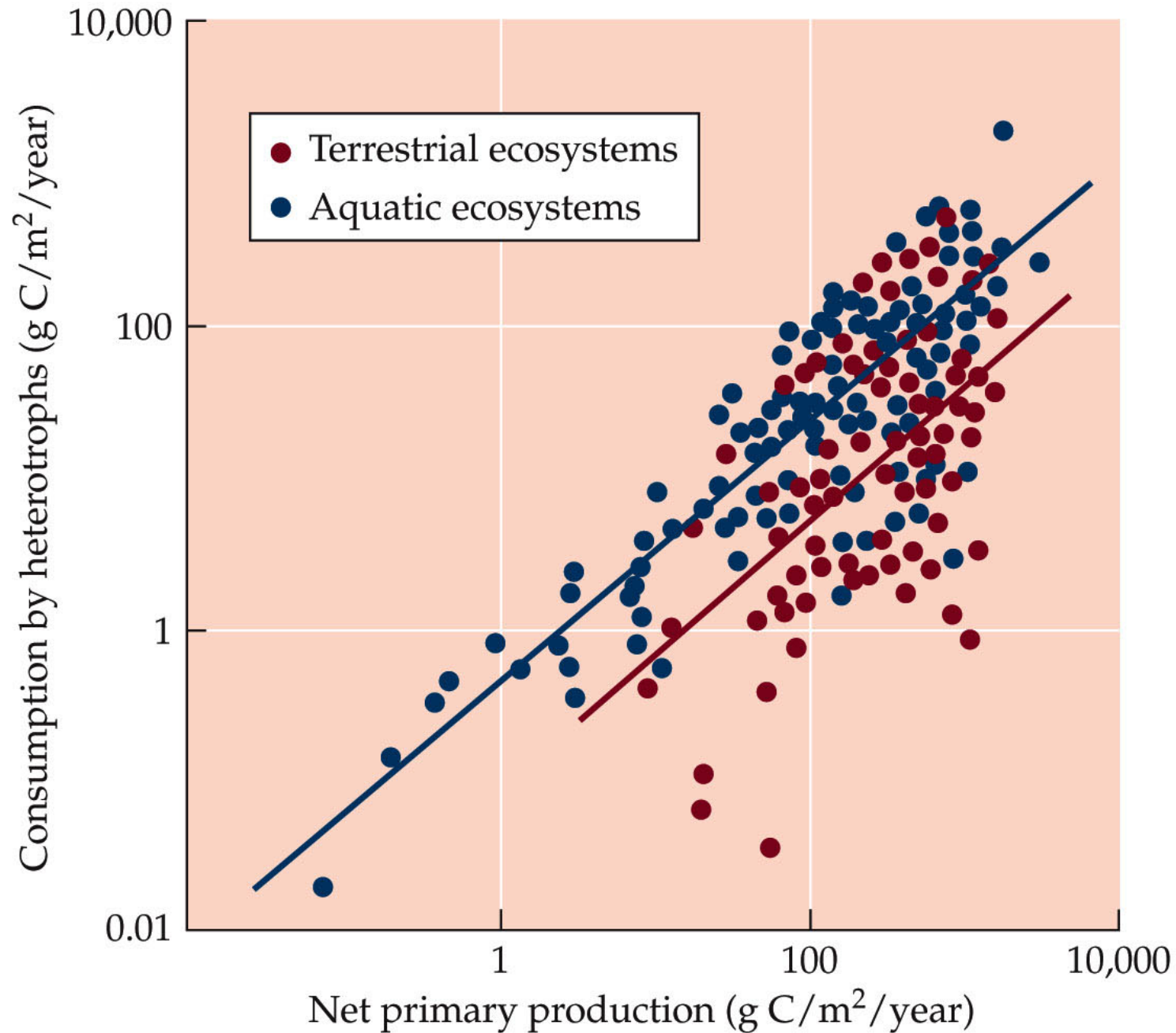
## Energy Flow among Trophic Levels

There is a positive relationship between net primary production and the amount of biomass consumed by herbivores.

This suggests that herbivore production is limited by the amount of food available.

Why don't terrestrial herbivores consume more of the available biomass?

Figure 20.6 Consumption of Autotroph Biomass Is Correlated with NPP



## Energy Flow among Trophic Levels

Several hypotheses have been proposed.

- Herbivore populations are constrained by predators, and never reach carrying capacity.

Predator removal experiments support this hypothesis in some ecosystems.

## Energy Flow among Trophic Levels

- Autotrophs have defenses against herbivory, such as secondary compounds and structural defenses, like spines.

Plants of resource-poor environments tend to have stronger defenses than plants from resource-rich environments.

## Energy Flow among Trophic Levels

- Terrestrial plants have nutrient-poor structural materials such as stems and wood, which are typically absent in aquatic autotrophs.

Phytoplankton are more nutritious for herbivores than are terrestrial plants.

## Energy Flow among Trophic Levels

The quality of food can be indicated by the ratio of carbon to nutrients such as N and P.

Freshwater phytoplankton have carbon:nutrient ratios closer to those of herbivores than to those of terrestrial plants.

## Energy Flow among Trophic Levels

**Trophic efficiency**—the amount of energy at one trophic level divided by the amount of energy at the trophic level immediately below it.

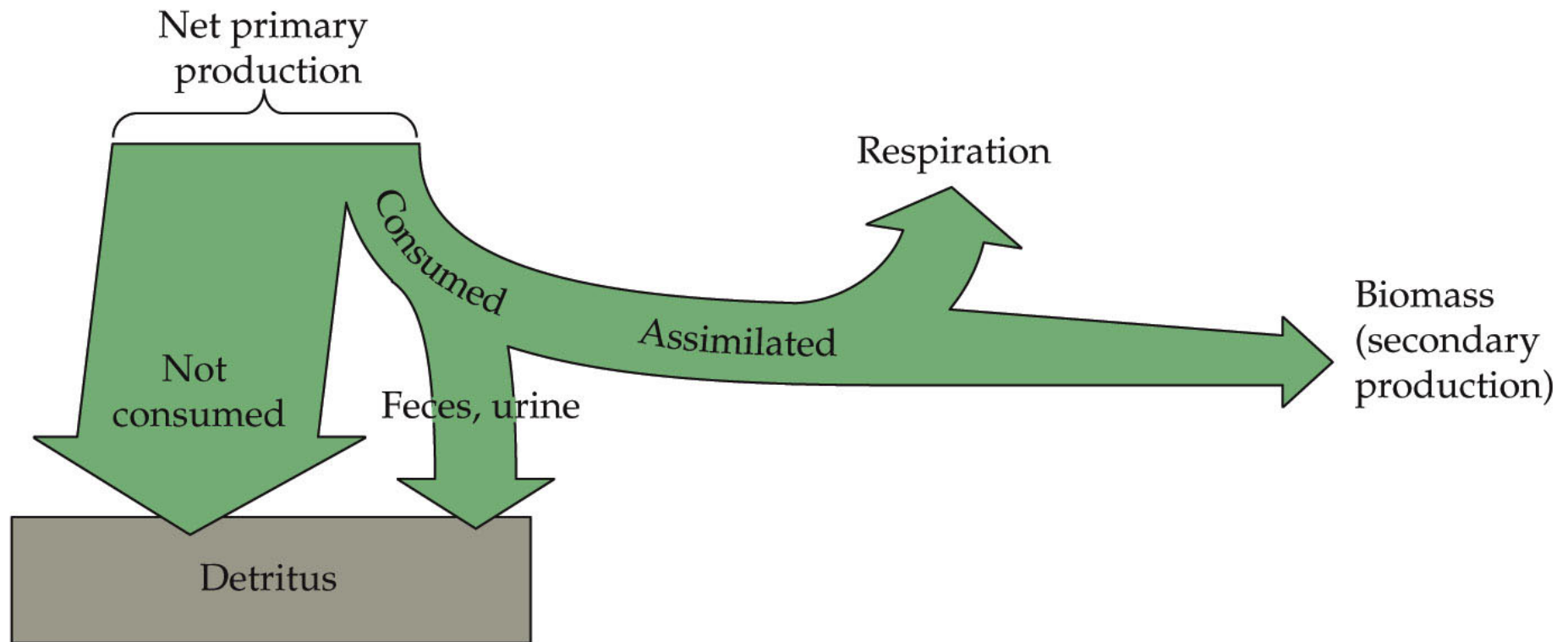
## Energy Flow among Trophic Levels

Trophic efficiency incorporates three types of efficiency:

- The proportion of available energy that is consumed (**consumption efficiency**).
- The proportion of ingested food that is assimilated (**assimilation efficiency**).
- The proportion of assimilated food that goes into new consumer biomass (**production efficiency**).



Figure 20.7 Energy Flow and Trophic Efficiency



## Energy Flow among Trophic Levels

Consumption efficiency is higher in aquatic ecosystems than in terrestrial ecosystems.

Consumption efficiencies also tend to be higher for carnivores than for herbivores.

## Energy Flow among Trophic Levels

Assimilation efficiency is determined by the quality of the food and the physiology of the consumer.

Food quality of plants and detritus is lower than animals because of complex compounds such as cellulose, lignins, and humic acids, that are not easily digested, and low concentrations of nutrients such as N and P.

## Energy Flow among Trophic Levels

Animal bodies have carbon:nutrient ratios similar to that of the animal consuming them, and so are assimilated more readily.

Assimilation efficiencies of herbivores and detritivores vary between 20%–50%, carnivores are about 80%.

## Energy Flow among Trophic Levels

Endotherms tend to digest food more completely than ectotherms and thus have higher assimilation efficiencies.

Some herbivores have mutualistic symbionts that help them digest cellulose.

## Energy Flow among Trophic Levels

Ruminants (cattle, deer, camels) have a modified foregut that contains bacteria and protists that break down cellulose-rich foods. This gives ruminants higher assimilation efficiencies than nonruminant herbivores.

## Energy Flow among Trophic Levels

Production efficiency is strongly related to the thermal physiology and size of the consumer.

Endotherms allocate more energy to heat production, and have less for growth and reproduction than ectotherms.

**TABLE 20.1****Production Efficiencies of Consumers**

<b>Consumer group</b>	<b>Production efficiency (%)</b>
Endotherms	
Birds	1.3
Small mammals	1.5
Large mammals	3.1
Ectotherms	
Fishes and social insects	9.8
Nonsocial insects	40.7
Herbivores	38.8
Detritivores	47.0
Carnivores	55.6
Non-insect invertebrates	25.0
Herbivores	20.9
Detritivores	36.2
Carnivores	27.6

*Source:* Chapin et al. 2002; data from Humphreys 1979.



## Energy Flow among Trophic Levels

Body size affects heat loss in endotherms. As body size increases, the surface area-to-volume ratio decreases.

A small endotherm, such as a shrew, will lose a greater proportion of its internally generated heat across its body surface than a large endotherm, such as a grizzly bear, and will have lower production efficiency.

## Energy Flow among Trophic Levels

Changes in food quantity and quality, and the resulting changes in trophic efficiency, can determine consumer population sizes.

Steller sea lion populations in Alaska declined by about 80% over 25 years.

Smaller body size and decreased birth rates suggested food quantity or quality might be a problem.

## Energy Flow among Trophic Levels

Various lines of evidence suggested that prey quantity was not declining.

The sea lions had shifted from a diet of mostly herring (high in fats) to one with greater proportion of cod and pollock. This reflected a shift in the fish community.

Pollock and cod have half the fat and energy as herring.

**TABLE 20.2****Proportion of Steller Sea Lion Scats and Stomachs Containing Five Prey Categories**

	<b>Gadids (cod, pollock, hake)</b>	<b>Salmon</b>	<b>Small schooling fish (herring, capelin, eulachon, sand lance)</b>	<b>Cephalopods (squid)</b>	<b>Flatfish (flounder, sole)</b>
1990–1993	85.2	18.5	18.5	11.1	13.0
1985–1986	60.0	20.0	20.0	20.0	5.0
1976–1978	32.1	17.9	60.7	0.0	0.0

Source: Trites and Donnelly 2003; data from Merrick et al. 1997.

## Trophic Cascades

**Concept 20.3: Changes in the abundances of organisms at one trophic level can influence energy flow at multiple trophic levels.**

What controls energy flow through ecosystems?

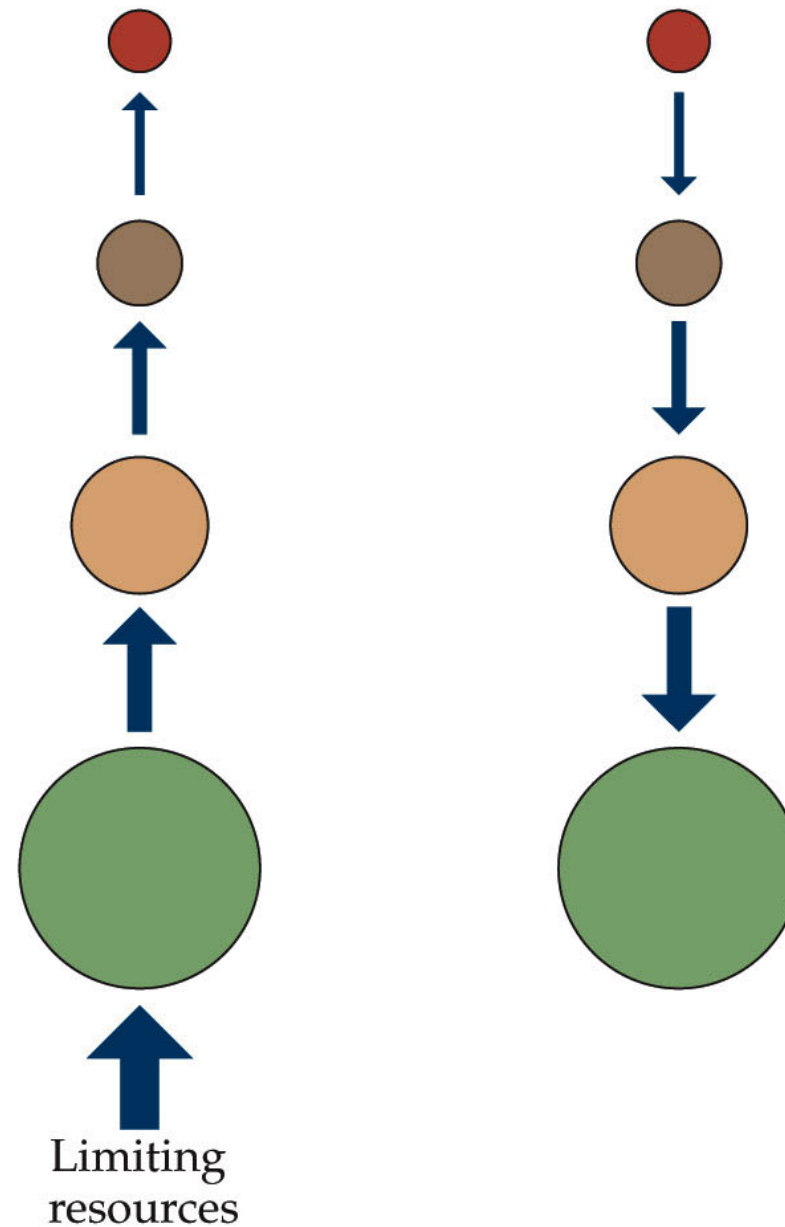
The “bottom-up” view holds that resources that limit NPP determine energy flow through an ecosystem.

## Trophic Cascades

The “top-down” view holds that energy flow is governed by rates of consumption by predators at the highest trophic level, which influences abundance and species composition of multiple trophic levels below them.

Figure 20.9 Bottom-up and Top-down Control of Productivity

(A) Bottom-up control      (B) Top-down control



# Trophic Cascades

In reality, both bottom-up and top-down controls are operating simultaneously in ecosystems.

Top-down control has implications for the ways in which trophic interactions affect energy flow in ecosystems.



## Trophic Cascades

A **trophic cascade** is a series of trophic interactions that result in change in energy and species composition.

Predation by a top carnivore (fourth level) would decrease abundance of third level carnivores. This would lead to an increase in herbivores (second level), and a decrease in primary producers.

## Trophic Cascades

Trophic cascades have been described mostly in aquatic ecosystems, and are most often associated with a change in abundance of a top predator.

Omnivory in food webs may act to buffer the effects of trophic cascades.

# Trophic Cascades

Many examples come from accidental introductions of non-native species, or near extinctions of native species.

Example: The removal of sea otters by hunting, which allowed sea urchin abundance to increase, which then reduced the kelp in the kelp forest ecosystems.

## Trophic Cascades

Example of an introduction: Brown trout were introduced to New Zealand in the 1860s.

In a study in the Shag River, Flecker and Townsend (1994) compared the effects of brown trout and native galaxias on stream invertebrates and primary production by algae.

## Trophic Cascades

To manipulate presence and absence of fish species, they constructed artificial stream channels that allowed free passage of algae and invertebrates, but not fish.

After 10 days of colonization by algae and invertebrates, brown trout, or galaxias, or no fish were placed in the artificial channels.

## Trophic Cascades

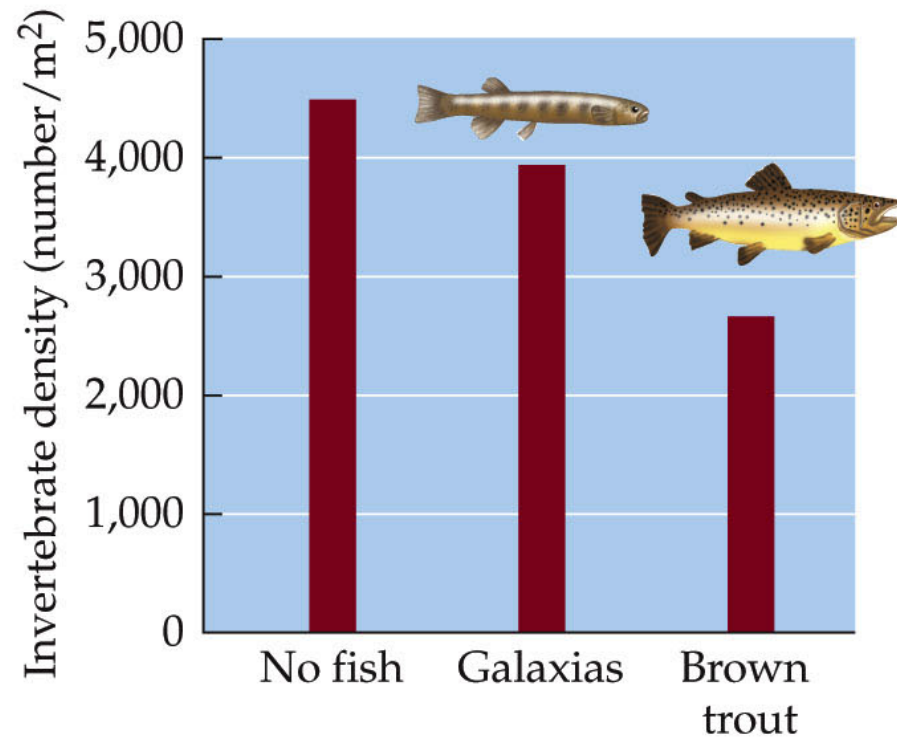
There was no difference in the effect of the two fish predators on diversity of invertebrates.

But brown trout reduced total invertebrate density by 40%, more than the galaxias did.

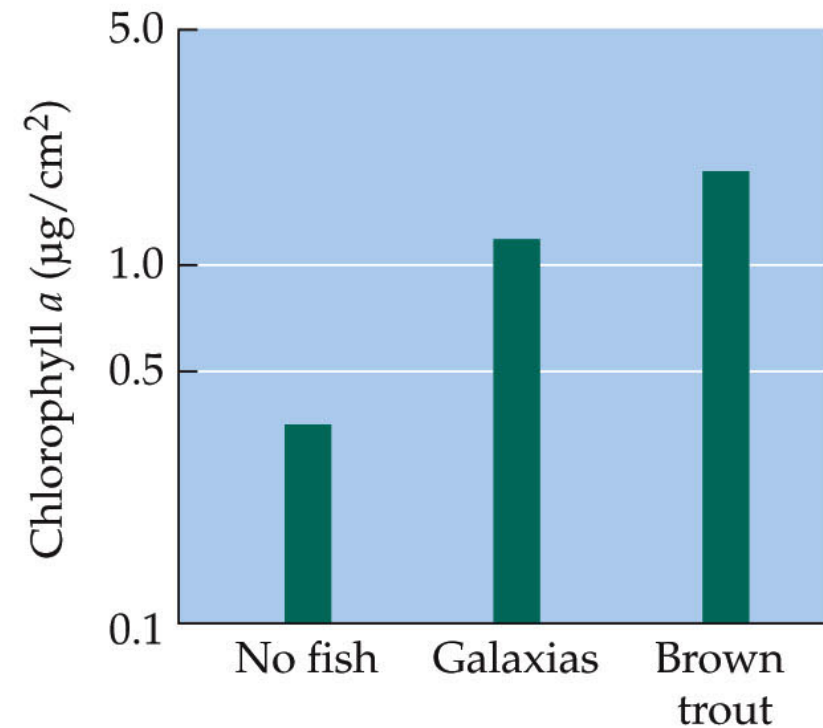
Abundance of algae increased with both fish but was greater with brown trout present.

Figure 20.10 An Aquatic Trophic Cascade

(A) Invertebrates



(B) Algal standing crop



## Trophic Cascades

The trophic cascade affected algal biomass because fish predation not only reduced the density of stream invertebrates, but also caused them to spend more time in refugia on the stream bottom rather than feeding on algae.



## Trophic Cascades

Terrestrial ecosystems are thought to be more complex than aquatic ecosystems, and the existence of trophic cascades is less certain.

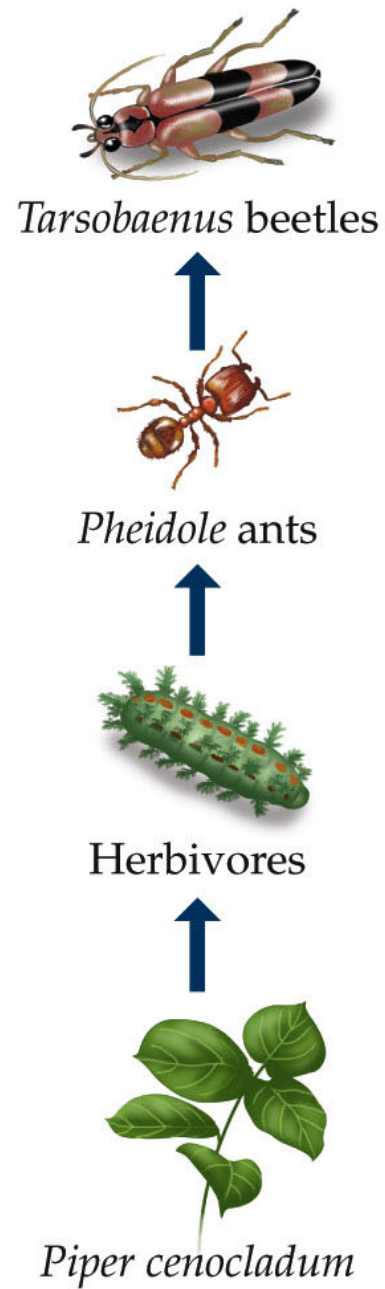
It was thought that a decrease in the abundance of one species was more likely to be compensated for by an increase in the abundance of similar species that were not being consumed as heavily.

## Trophic Cascades

A tropical forest trophic cascade was studied by Dyer and Letourneau (1999).

The system had four trophic levels: *Piper cenocladum* trees; herbivores; ants (*Pheidole*) that live in the petioles of the *Piper* trees and eat herbivores; and beetles (*Tarsobaenus*) that eat the ants.

Figure 20.11 A Terrestrial Trophic Cascade



## Trophic Cascades

In experimental plots, they used insecticides to kill all ants, then introduced beetles to some of the plots, but not others. Untreated plots were the control.

They also tested bottom-up factors—the plots had variation in soil fertility and light levels.

## Trophic Cascades

If production by *Piper* trees was limited primarily by resource supply, the beetle predator should have little effect.

They found that the trophic cascade was the only significant influence on leaf production by *Piper*.

## Trophic Cascades

Addition of beetles reduced ant abundance fivefold, increased herbivory threefold, and decreased leaf production by half.

Figure 20.12 Effects of a Trophic Cascade on Production (Part 1)

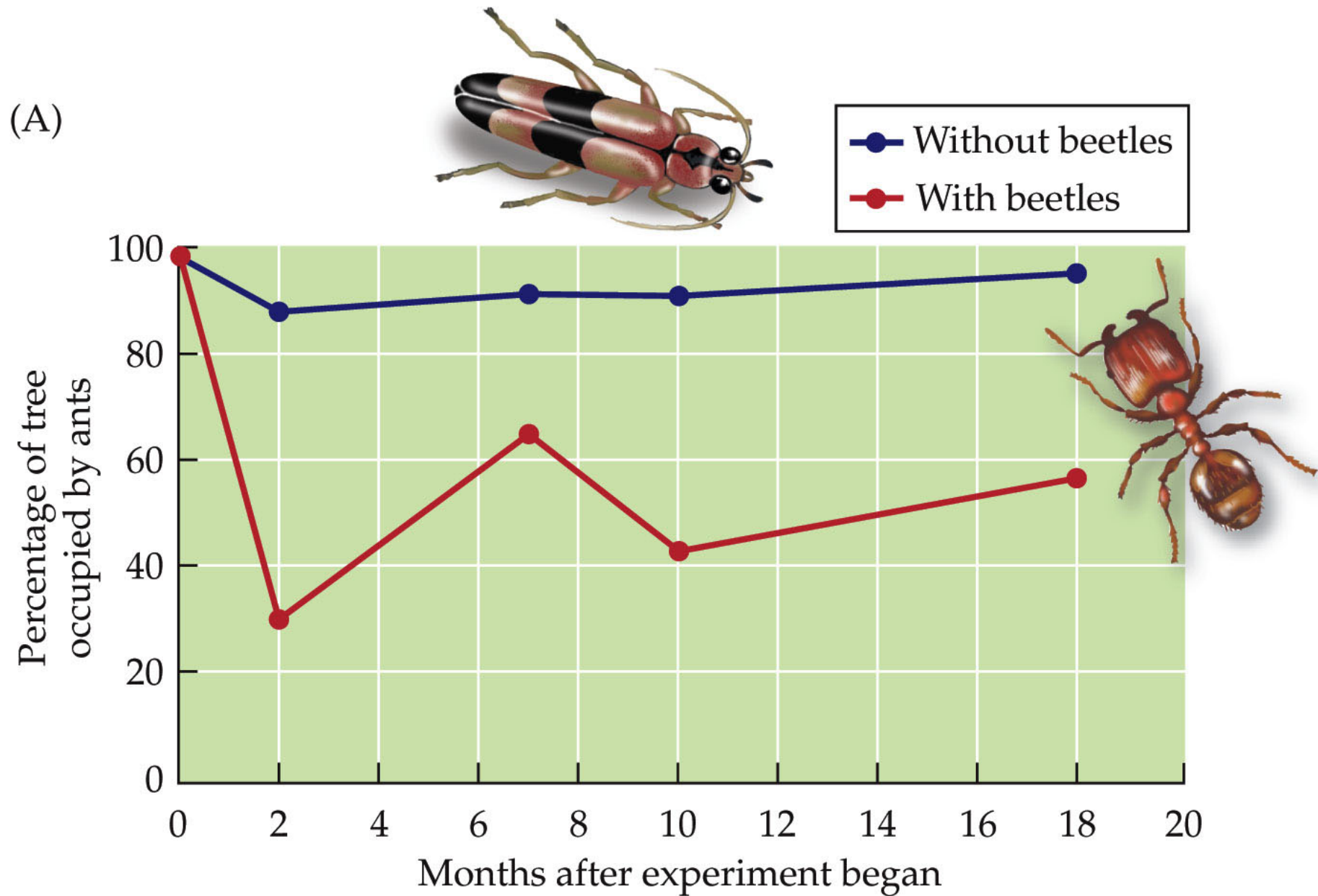


Figure 20.12 Effects of a Trophic Cascade on Production (Part 2)

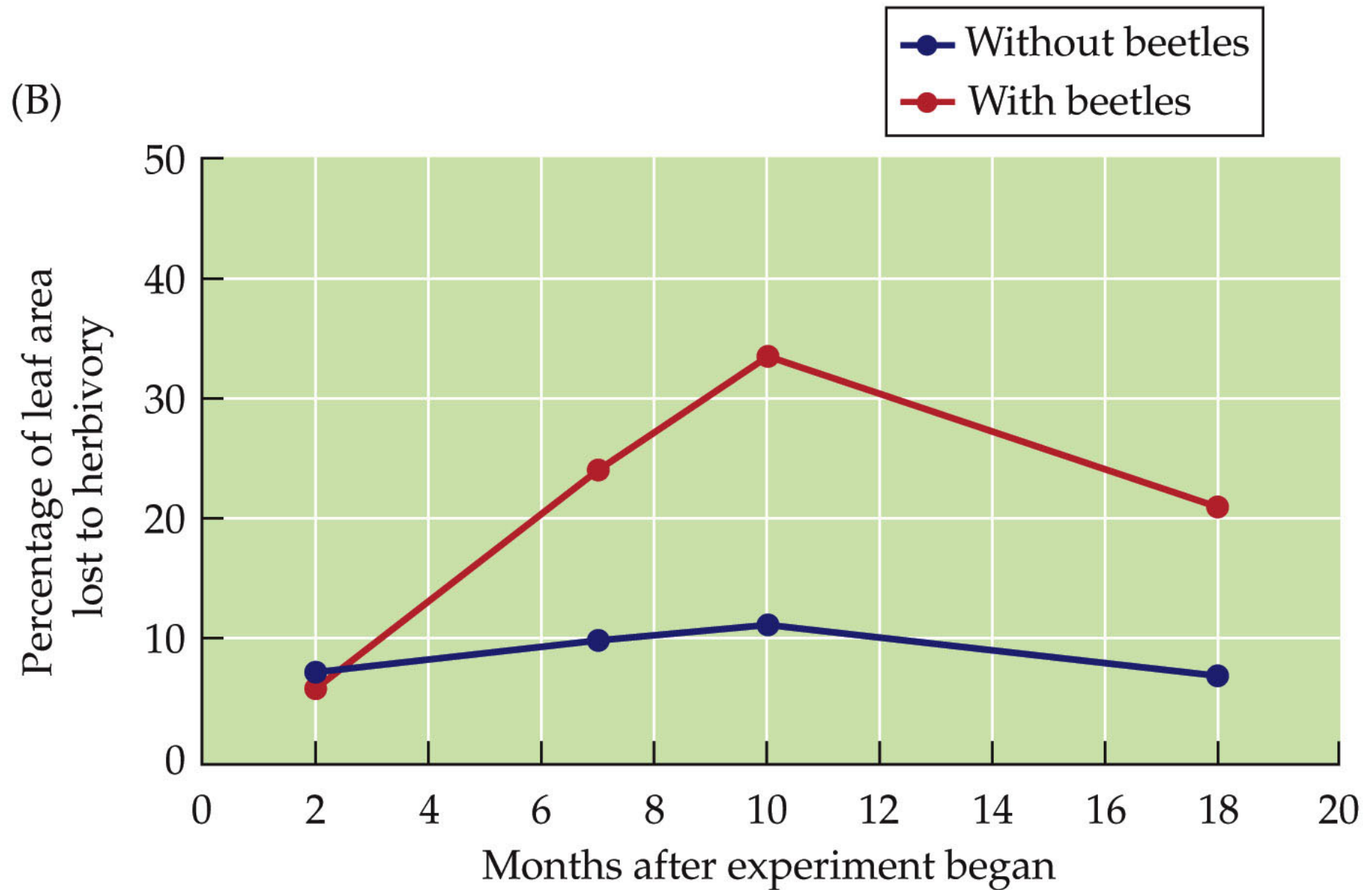
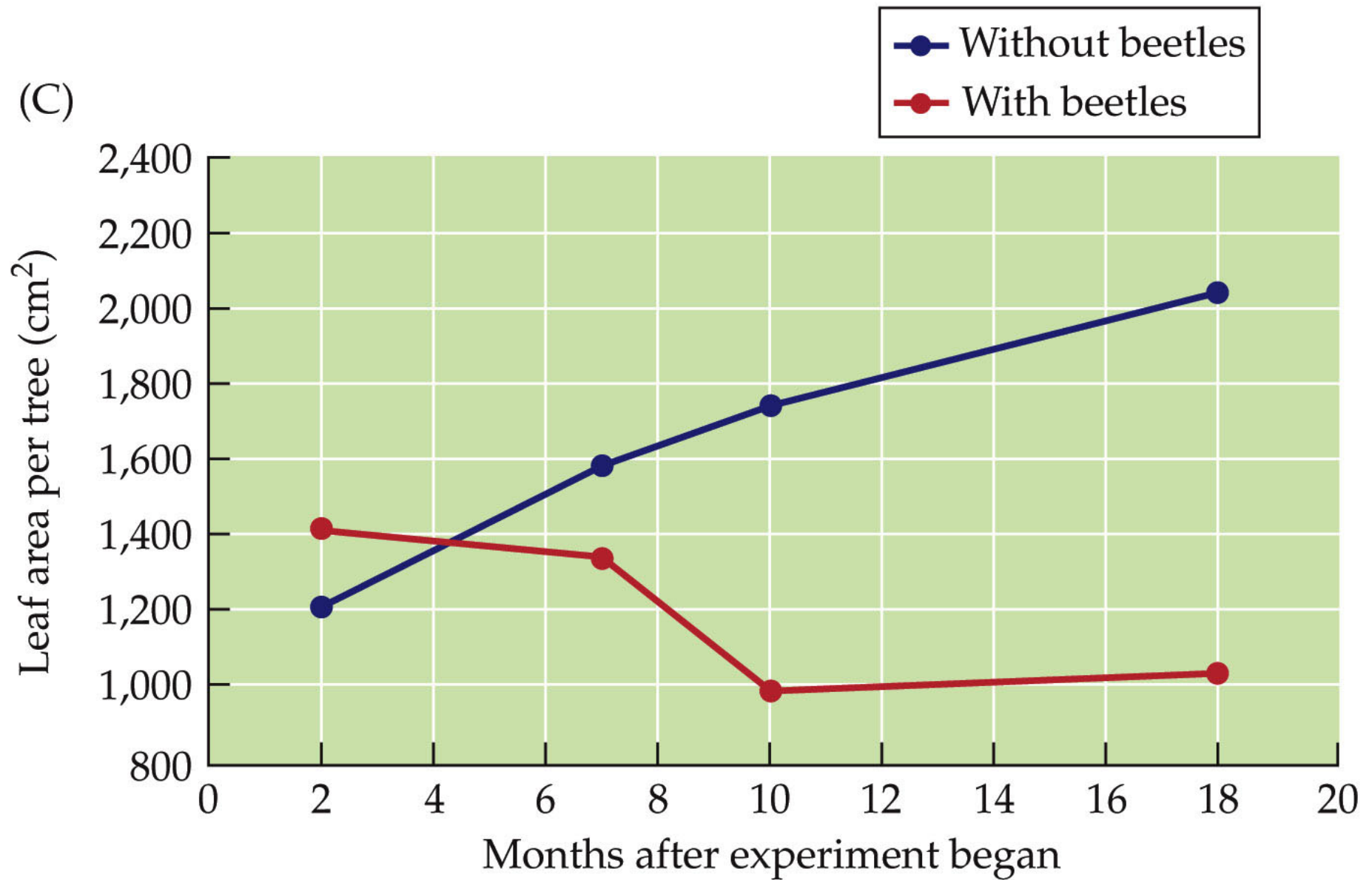




Figure 20.12 Effects of a Trophic Cascade on Production (Part 3)



## Trophic Cascades

In other experiments with light levels and fertility, it was shown that these factors also have significant influence on leaf production, but the strong effect of herbivory persisted.

# Trophic Cascades

What determines the number of trophic levels in an ecosystem?

There are three basic, interacting controls.

1. Dispersal ability may constrain the ability of top predators to enter an ecosystem.

## Trophic Cascades

2. The amount of energy entering an ecosystem through primary production.
3. The frequency of disturbances or other agents of change can determine whether populations of top predators can be sustained.

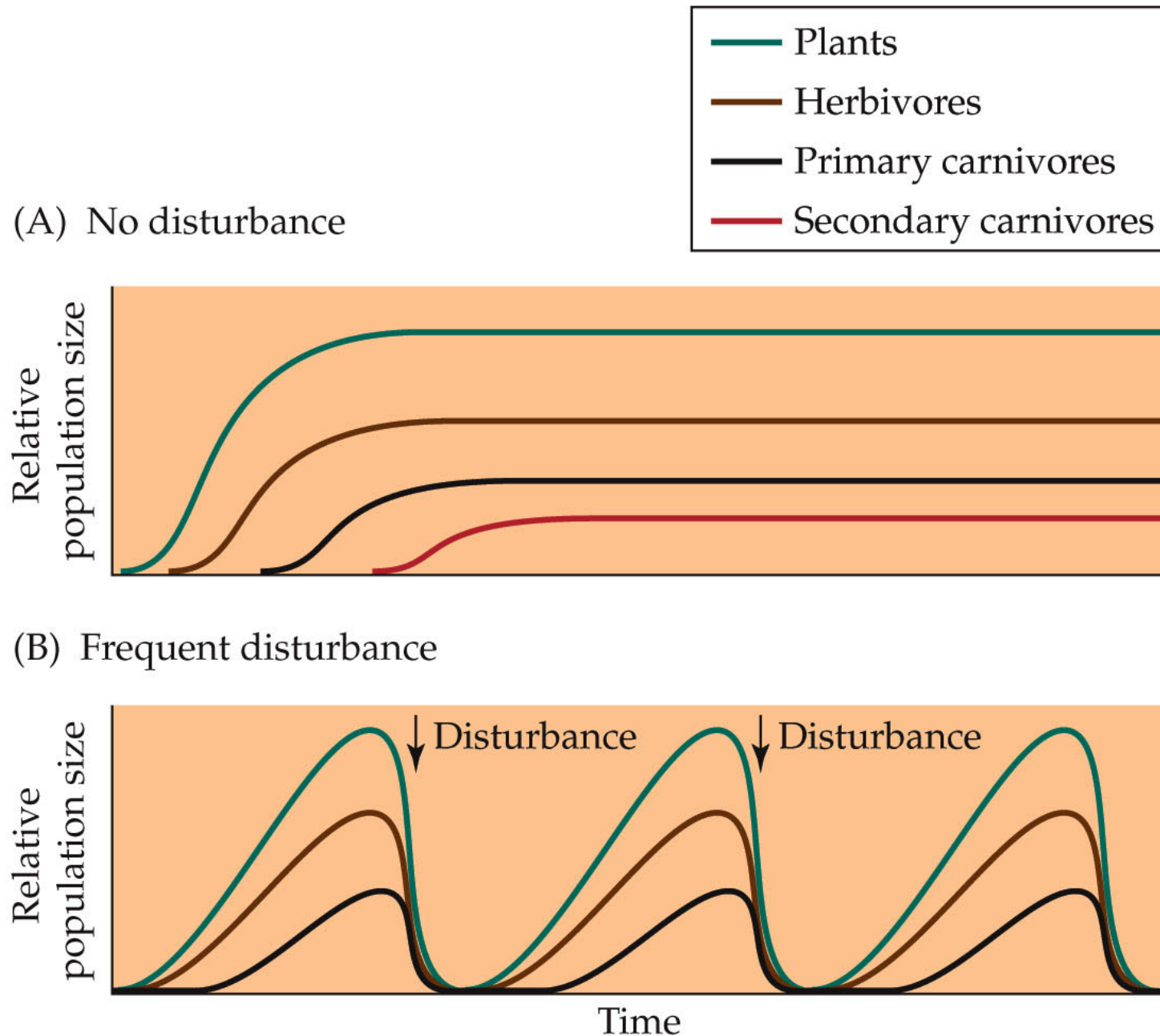
## Trophic Cascades

Following a disturbance, there is a time lag before the community returns to its original state.

Lower trophic levels sustain higher trophic levels, so there is a longer time lag to reestablish higher trophic levels.

If disturbance is frequent, higher trophic levels may never become established, no matter how much energy is entering the system.

Figure 20.13 Disturbance Influences the Number of Trophic Levels in an Ecosystem



## Trophic Cascades

Grassland ecosystems may have very different NPP rates, but they all have three trophic levels, occasionally four.

This appears to be related to disturbance frequency, which doesn't vary among grasslands.

## Trophic Cascades

The constraints imposed on energy transfer to higher trophic levels by trophic efficiency and disturbance dynamics are manifested in a rarity of “big, fierce animals” (Colinvaux 1978).

These constraints also explain why carnivores are the most common threatened and endangered mammals.



## Food Webs

**Concept 20.4: Food webs are conceptual models of the trophic interactions of organisms in an ecosystem.**

A **food web** is a diagram showing the connections between organisms and the food they consume.

Food webs are an important tool for modeling ecological interactions.

## Food Webs

A food web shows qualitatively how energy flows from one component of an ecosystem to another, and how that energy flow may determine changes in population sizes and in the composition of communities.

As more organisms are added to a food web, the complexity increases (see Figure 20.14 B).

Figure 20.14 A Desert Food Webs

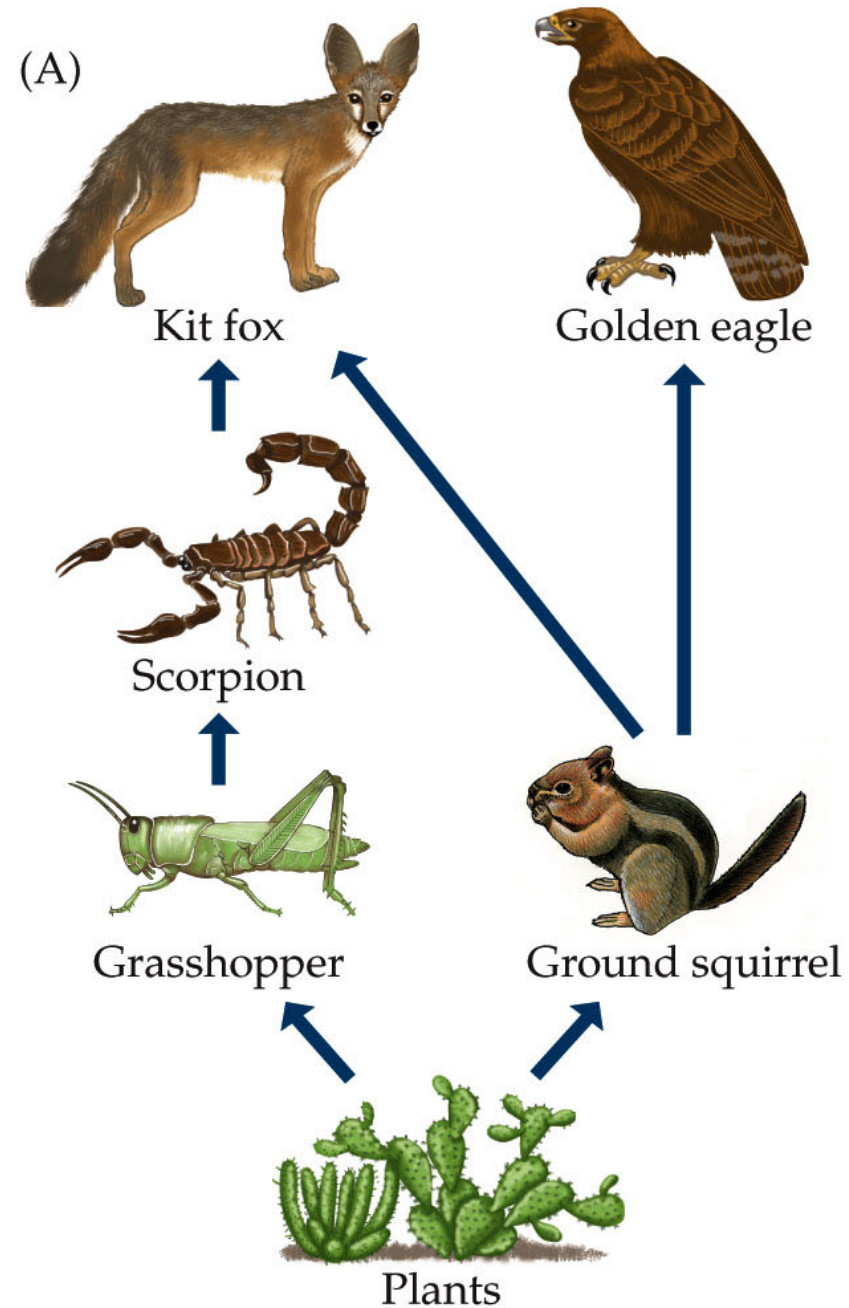
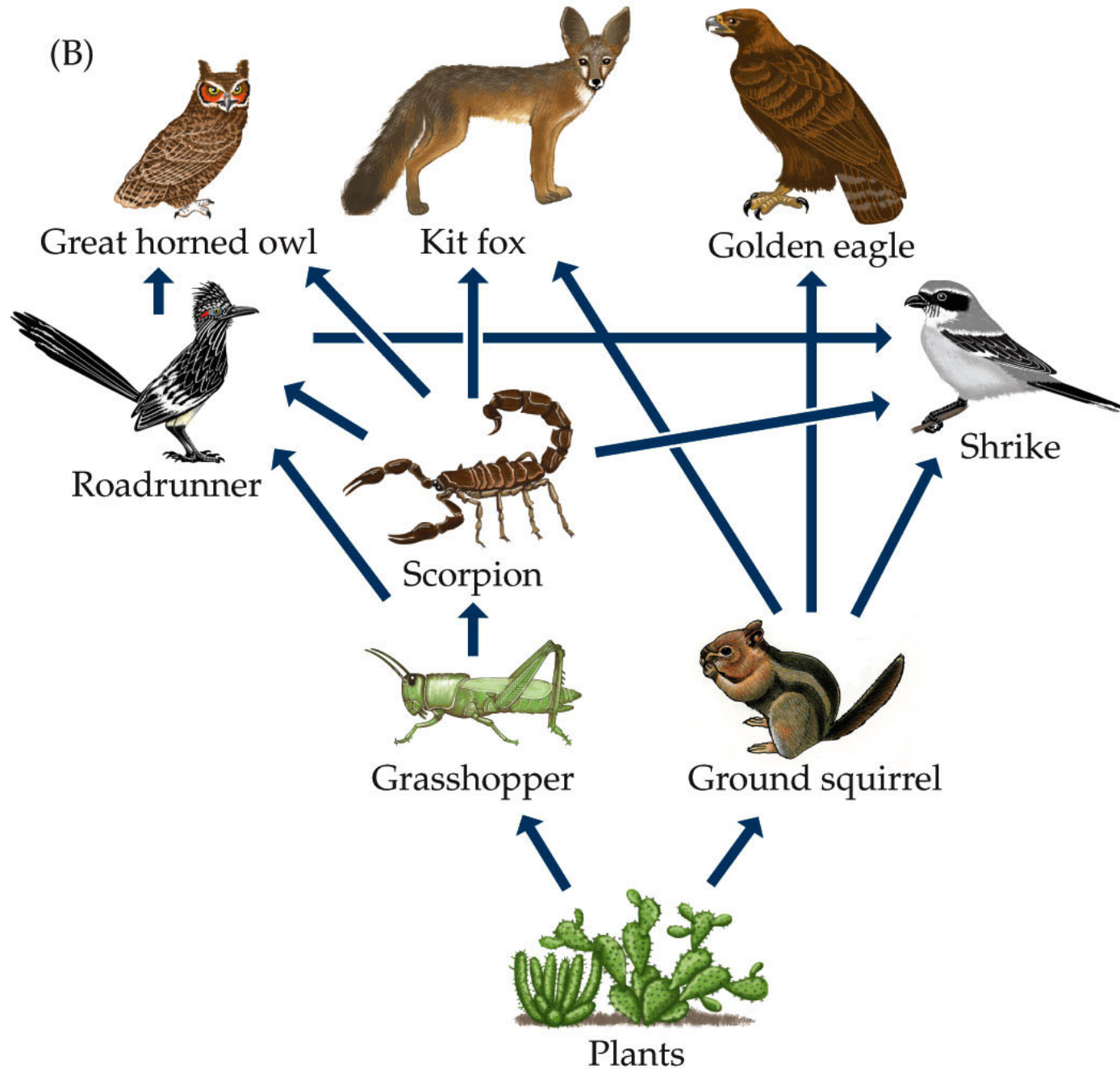


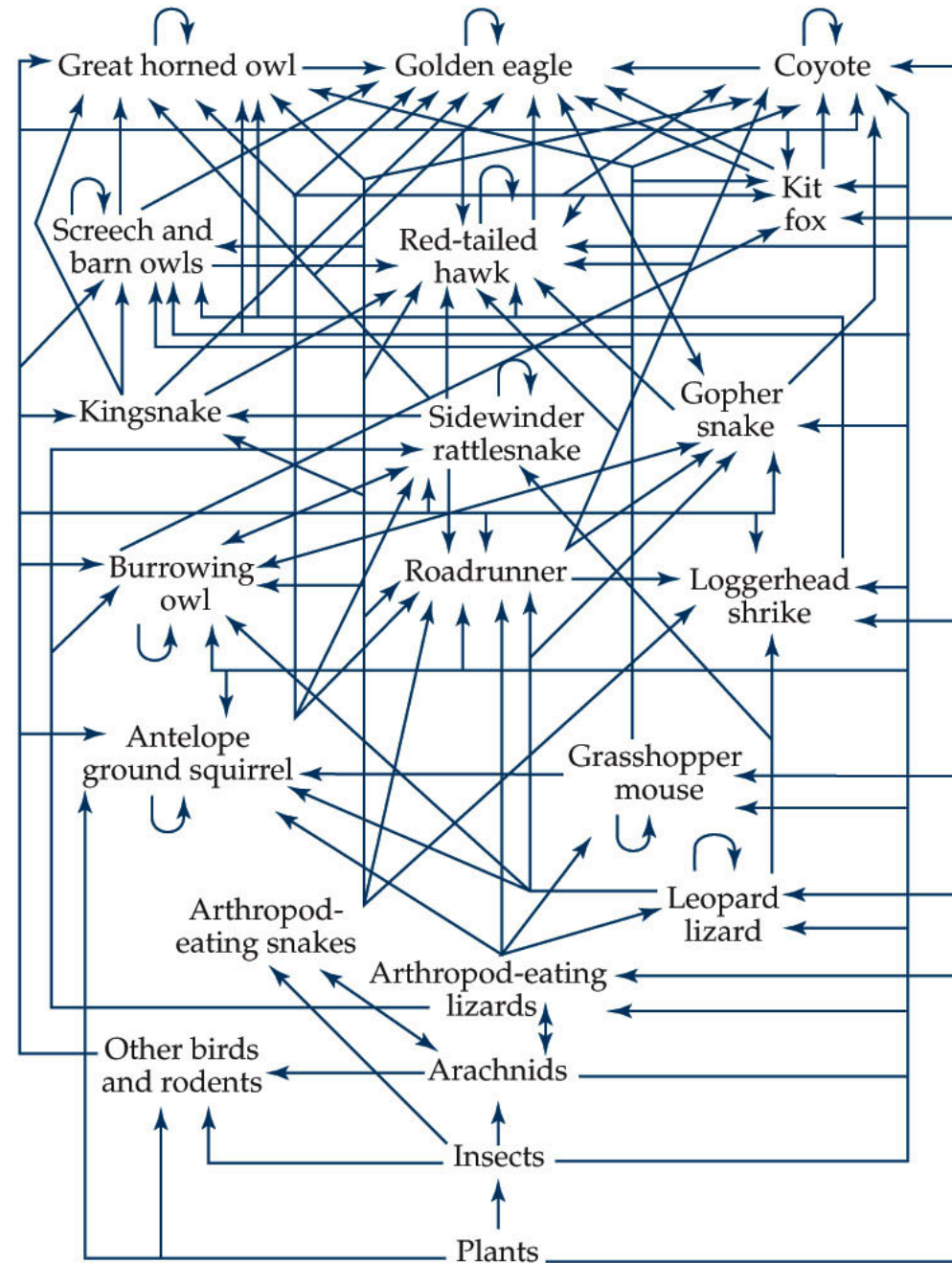
Figure 20.14 B Desert Food Webs



## Food Webs

In order to add greater realism, it is important to recognize that feeding relationships can span multiple trophic levels and may even include cannibalism (circular arrows in Figure 20.15).

Figure 20.15 Complexity of Desert Food Webs



## Food Webs

Food webs are static descriptions of energy flow and trophic interactions.

Actual trophic interactions can change over time.

Some organisms change feeding patterns over their lifetime. Example: Frogs shift from omnivorous aquatic tadpoles to carnivorous adults.

## Food Webs

Some organisms, such as migratory birds, are components of multiple food webs.

Most food webs don't include other types of interactions, such as pollination.

The role of microorganisms is often ignored, despite their processing of a substantial amount of the energy moving through an ecosystem.



## Food Webs

But food webs are important conceptual tools for understanding the dynamics of energy flow in ecosystems, and hence the community and population dynamics of their component organisms.

## Food Webs

Not all trophic connections are equally important.

**Interaction strength**—measure of the effect of one species' population on the size of another species' population.

Determining interaction strengths can help simplify a complex food web by focusing on links that are most important for research and conservation.

## Food Webs

Interaction strengths can be determined through removal experiments, but it is usually impossible to do this for all links in a food web.

Less direct methods include observation of feeding preferences of predators and change in the population size of predators and prey over time.

Comparisons of food webs with predators present or absent can also be used to estimate interaction strengths.

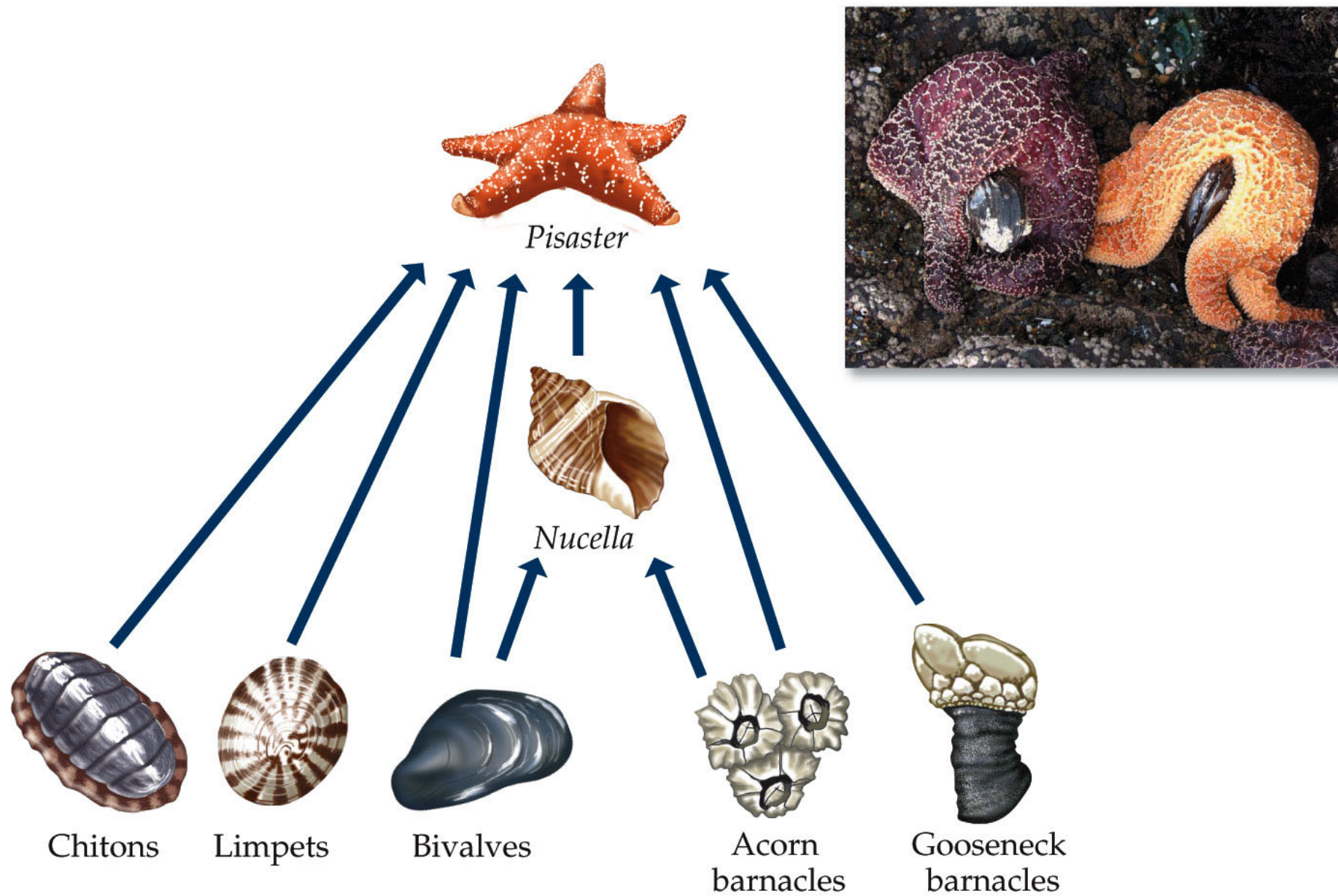
Predator and prey body size has been used to predict strengths of predator–prey interactions because feeding rate is related to metabolic rate, which in turn is governed by body size.

## Food Webs

Interaction strengths in the rocky intertidal zones were estimated by removing the top predator, the sea star *Pisaster*.

After removal, the mussel *Mytilus* and gooseneck barnacles became dominant, and species richness went from 15 to 8 (Paine 1966).

Figure 20.16 An Intertidal Food Web



## Food Webs

Even when sea stars were no longer removed, mussels continued to dominate. They had grown to sizes that prevented predation by sea stars.

Diversity remained lower in experimental plots than in adjacent plots.

Paine and others' work showed that despite the complexity of trophic interactions, energy flow and community structure might be controlled by a few key species.

Paine called *Pisaster* a **keystone species**—having a greater influence on energy flow and community composition than its abundance or biomass would predict.



The keystone species concept is important in conservation. It implies that protecting a keystone species may be critical for protecting the many other species that depend on it.

Keystone species tend to be top predators, but not always.

## Food Webs

Interaction strengths depend on the environmental context.

Menge et al. 1994 found that *Pisaster* had much less influence on the community in wave-sheltered sites.

Mussel populations at these sites were determined more by sparse recruitment of young individuals than by sea star predation.

Determining the strength of indirect effects can also be important.

Removal experiments can provide estimates of the *net* effect of a species.

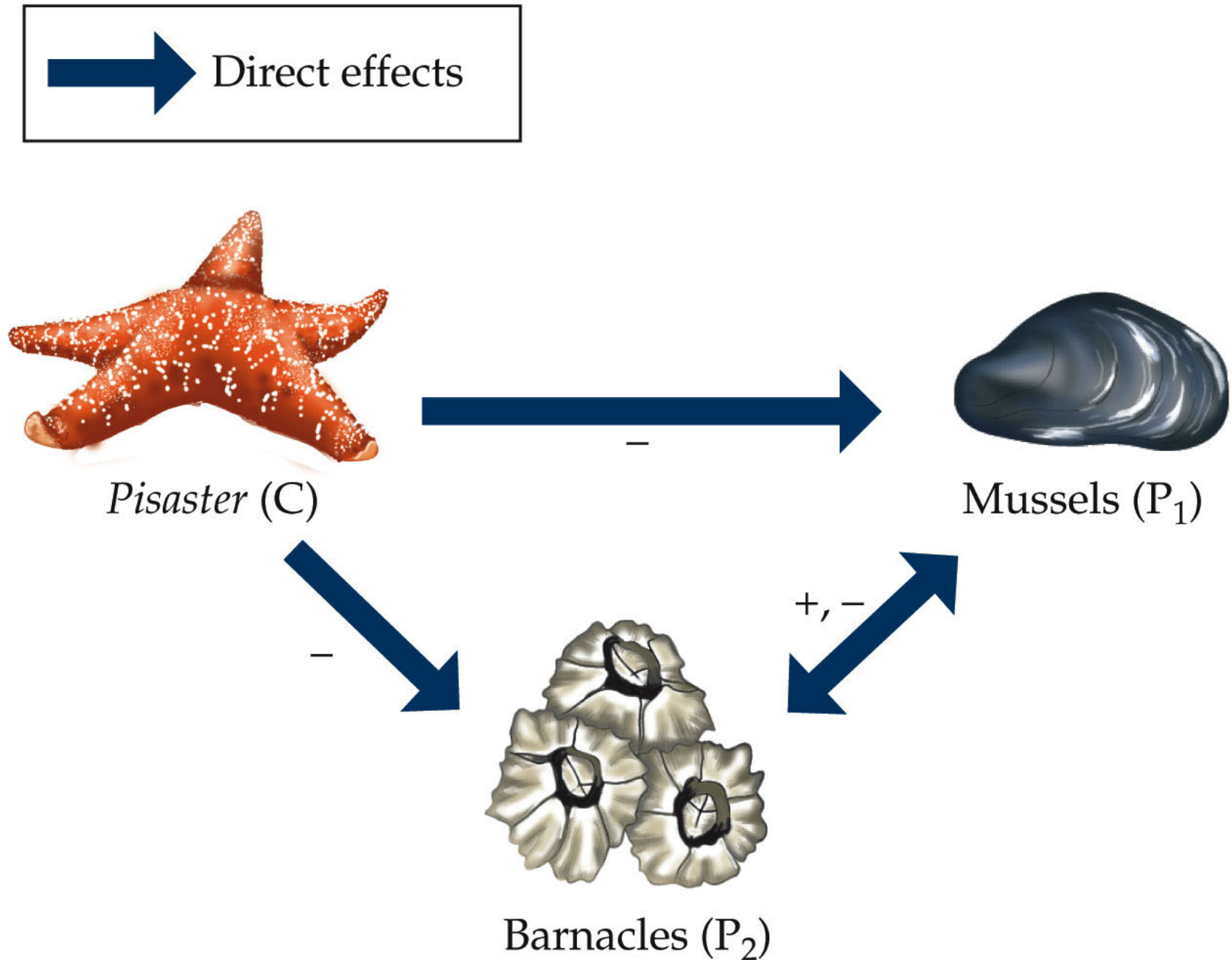
This net effect includes the sum of the direct effect and all possible indirect effects.

## Food Webs

A predator has a direct effect on its prey, and also indirect effects on other species that compete with, facilitate, or modify the environment of the prey species.

*Pisaster* has a negative effect on barnacles by consuming them, but a positive effect by consuming their competitor, the mussels; resulting in a net positive effect.

Figure 20.17 Direct and Indirect Effects of Trophic Interactions



Indirect effects may offset or reinforce direct effect of a predator, especially if the direct effect is weak.

This idea was tested by Berlow (1999) using predatory whelks, mussels, and acorn barnacles.

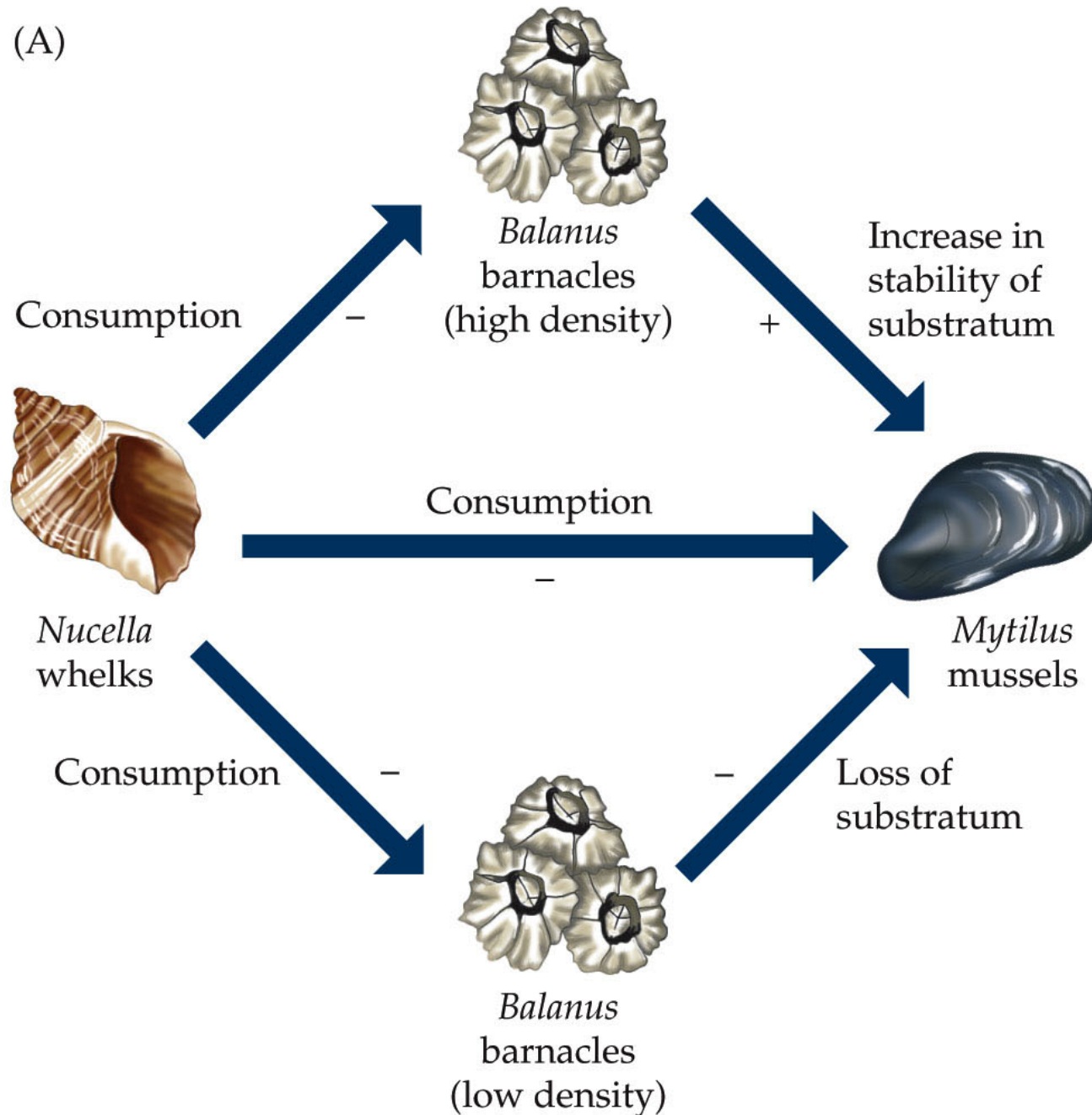
## Food Webs

Barnacles facilitate mussels by providing crevices for mussel larvae to settle in.

At low barnacle densities, whelk predation on barnacles has a negative indirect effect on mussels because it removes their preferred substratum.

At high barnacle densities, thinning by whelks provides more stable substratum and thus has an indirect positive effect.

Figure 20.18 A Strong and Weak Interactions Produce Variable Net Effects





Berlow measured the effects of high and low densities of whelks, with and without barnacles present.

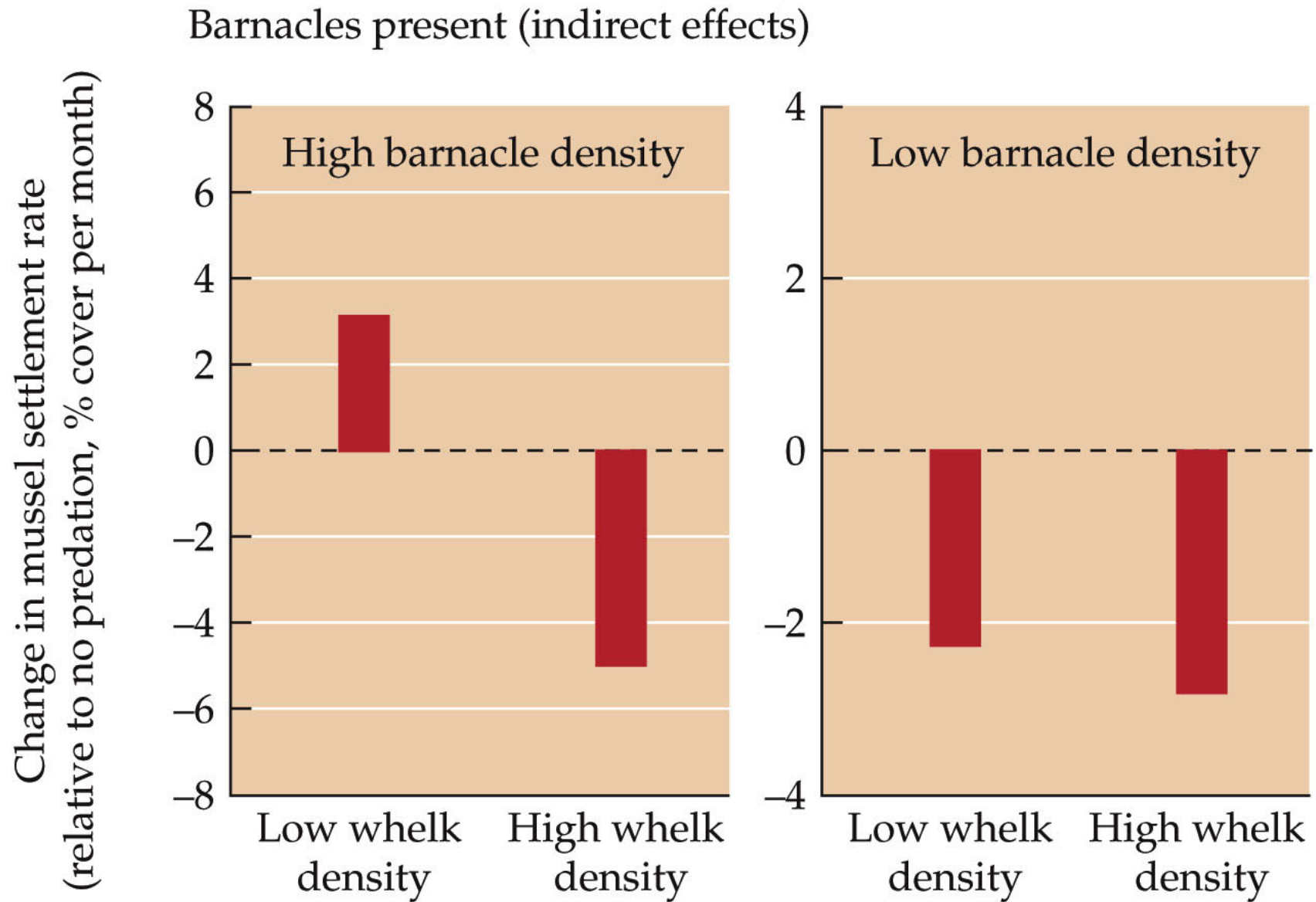
Without the indirect effects mediated by barnacles, whelks had a consistent negative direct effect on the settlement rate of mussels, regardless of whelk density.

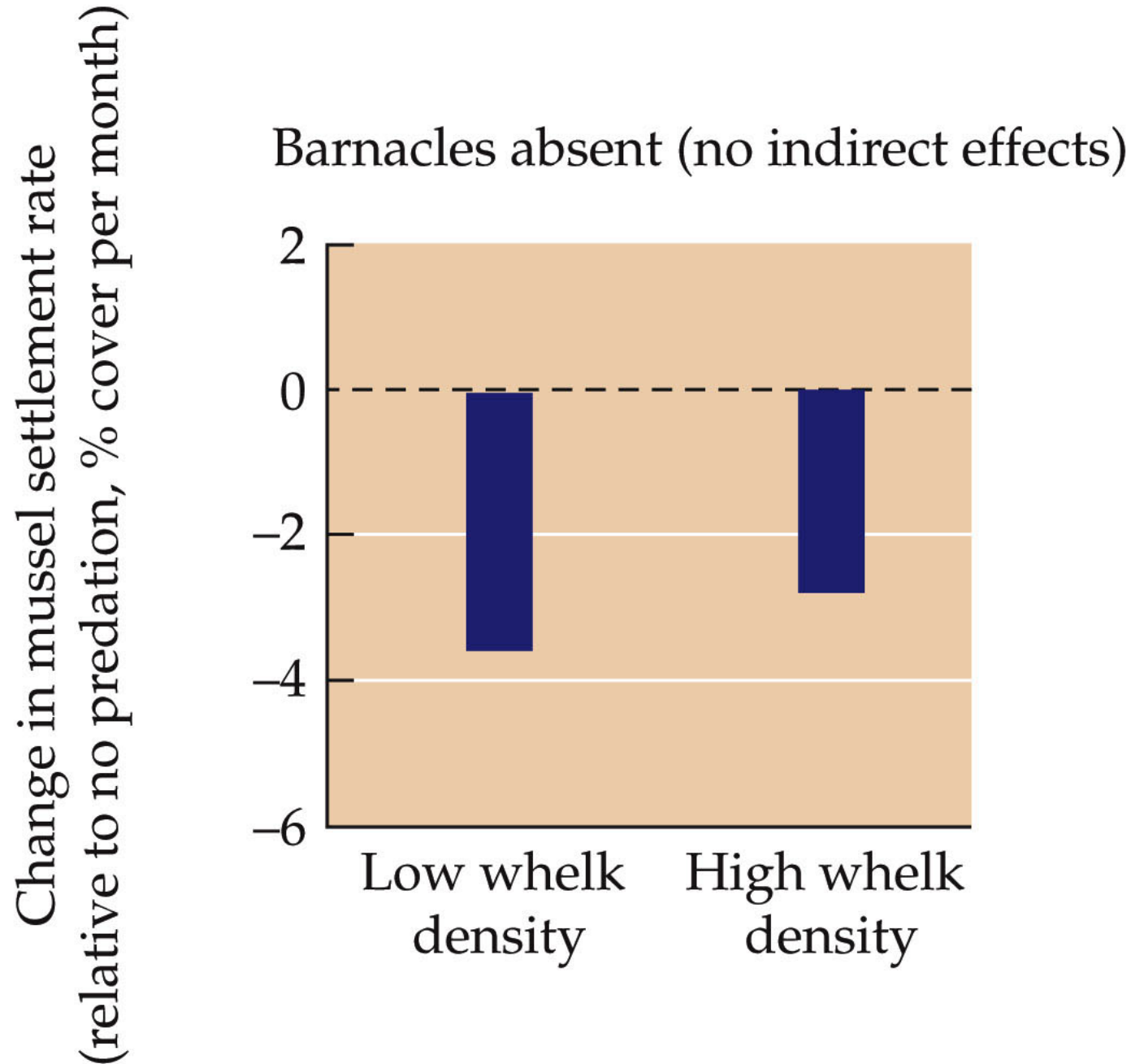
## Food Webs

When barnacles were present and whelks were at low densities, the net effect of whelks on mussel settlement depended on barnacle density.

At high whelk densities (direct effect of whelks was “strong”), the whelks had a consistently negative net effect on mussel settlement, regardless of the densities of barnacles.

(B)





## Food Webs

If a predator has varying effects on a prey species depending on the presence or absence of other species, the potential for the predator to eliminate that prey species throughout its range is less.

Thus, variation associated with weak interactions may promote coexistence of multiple prey species.

## Food Webs

Are more complex food webs (more species and more links) more stable than simple food webs?

Stability is gauged by the magnitude of change in the population sizes of species in the food web over time.

How an ecosystem responds to species loss or gain is strongly related to the stability of food webs.

## Food Webs

Ecologists such as Charles Elton and Eugene Odum argued that simpler, less diverse food webs should be more easily perturbed.

But mathematical analyses by Robert May (1973) used random assemblages of organisms to demonstrate that food webs with higher diversity are less stable than those with lower diversity.

## Food Webs

In May's model, strong trophic interactions accentuated population fluctuations.

The more interacting species there were, the more likely that population fluctuations would reinforce one another, leading to extinction of one or more of the species.



## Food Webs

What then, are the factors that allow naturally complex food webs to be stable?

As shown by Berlow, weak interactions can stabilize trophic interactions.

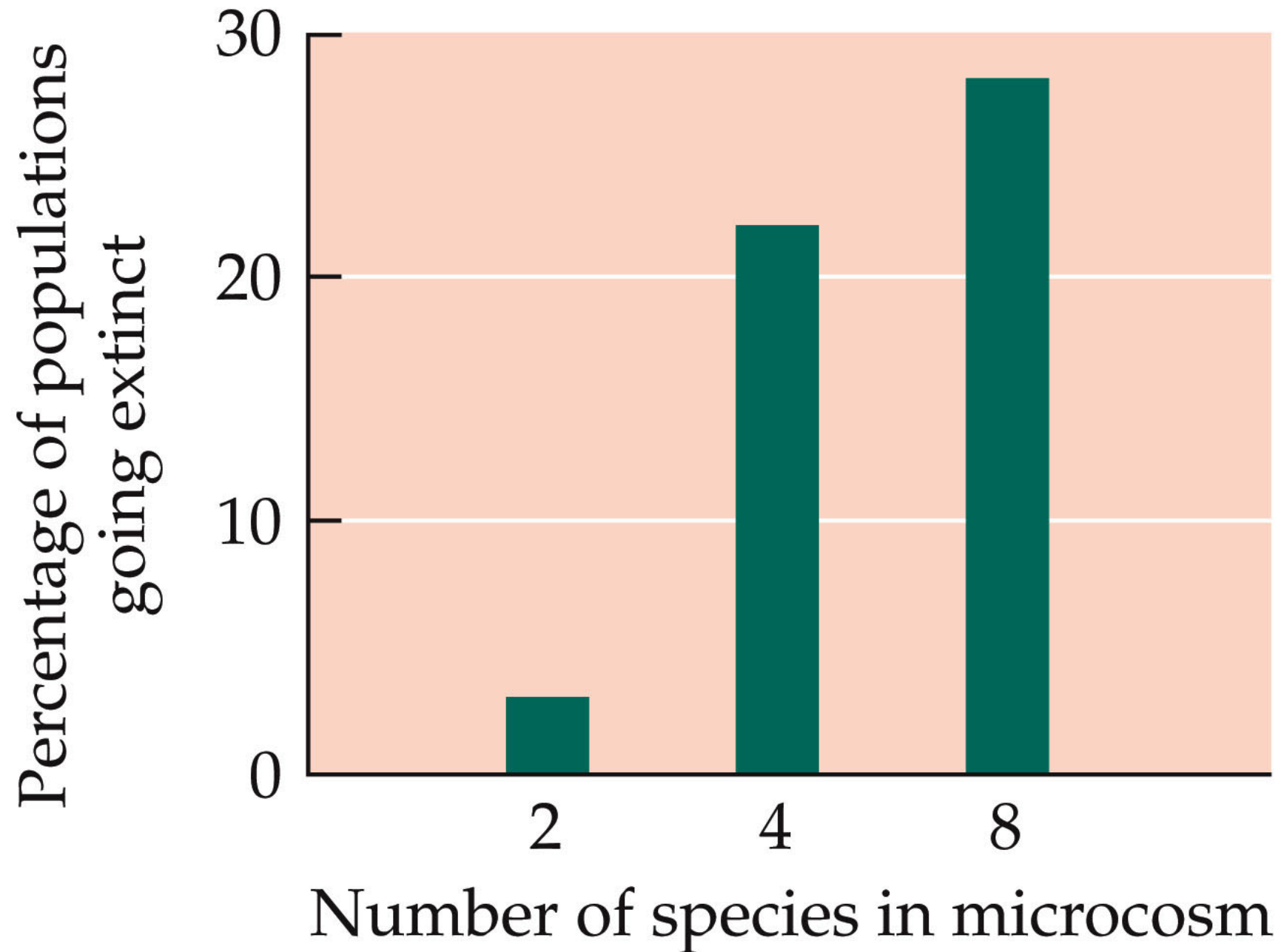
## Food Webs

An experiment using microcosms (small closed-system containers) containing protozoan food webs of varying complexity (Lawler 1993):

Population sizes of the protozoan species were monitored over time.

Increasing the number of species resulted in more extinctions, but no changes in variation in population sizes over time.

Figure 20.19 Diversity and Stability in a Food Web



## Food Webs

The species composition of the food web was also an important influence in this experiment.

Some species were more likely to go extinct, some populations varied depending on which other species were present.

Both species diversity and composition appeared to be important in determining the stability of these food webs.

## Case Study Revisited: Toxins in Remote Places

Understanding energy flow in ecosystems is important in understanding the effects of POPs.

Some chemical compounds can become concentrated in the tissues of organisms.

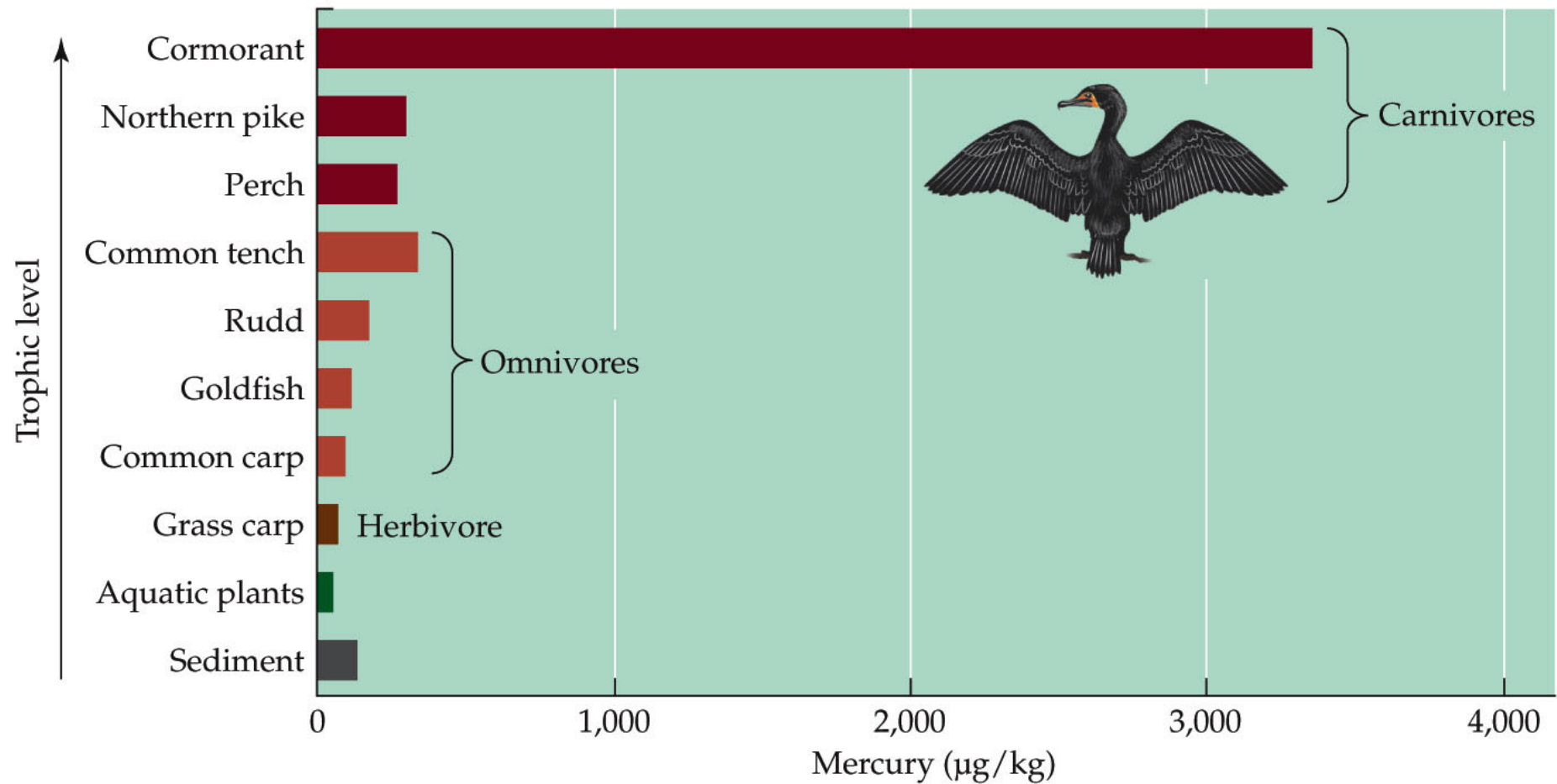
They may not be metabolized or excreted for a variety of reasons, so they become progressively more concentrated over the organism's lifetime—  
**bioaccumulation.**

## Case Study Revisited: Toxins in Remote Places

The concentration of these compounds increases in animals at higher trophic levels, as animals at each trophic level consume prey with higher concentrations of the compounds.

This process is known as **biomagnification**.

Figure 20.20 Bioaccumulation and Biomagnification



## Case Study Revisited: Toxins in Remote Places

The potential dangers of bioaccumulation and biomagnification of POPs were publicized by Rachel Carson in *Silent Spring* (1962).

She described the devastating effects of pesticides, especially DDT, on non-target bird species.



## Case Study Revisited: Toxins in Remote Places

DDT was thought to be a “miracle” in the 1940s and 1950s, and was used extensively on crops and to control mosquitoes.

But it was also building up in top predators, contributing to the near-extinction of some birds of prey, including the peregrine falcon and the bald eagle.

## Case Study Revisited: Toxins in Remote Places

Carson's careful documentation and ability to communicate with the general public, led to increased scrutiny of the use of chemical pesticides, eventually resulting in a ban on manufacture and use of DDT in the U.S.

## Case Study Revisited: Toxins in Remote Places

The concept of biomagnification also applies to the Inuit, and their position in the top trophic level in the Arctic ecosystem.

Inuit that consumed marine mammals had greater concentrations of POPs. These animals occupy the third, fourth, or fifth trophic levels.

Inuit who consumed mostly caribou (herbivores) had lower POP levels.

## Case Study Revisited: Toxins in Remote Places

Although use and concentration of POPs is decreasing, there is great potential for storage of these compounds in Arctic snow and ice.

Concentrations of PCBs and DDT in Arctic lake sediments have continued to increase over time, while they have decreased in more southern lakes.

## Connections in Nature: Biological Transport of Pollutants

Anthropogenic pollutants have been reported in all environments on Earth.

Organisms in remote areas have high concentrations of these pollutants, related to the trophic positions of the animals.

Consumers at the highest trophic levels, such as polar bears, seals, and birds of prey, contain the highest amounts of pollutants.

## Connections in Nature: Biological Transport of Pollutants

POPs and other pollutants are transported via atmospheric circulation.

Migratory animals can also be responsible for some transport.

Salmon move nutrients from the ocean where they spend several years, to upstream ecosystems when they return for spawning. The potential exists for them to move toxins as well.

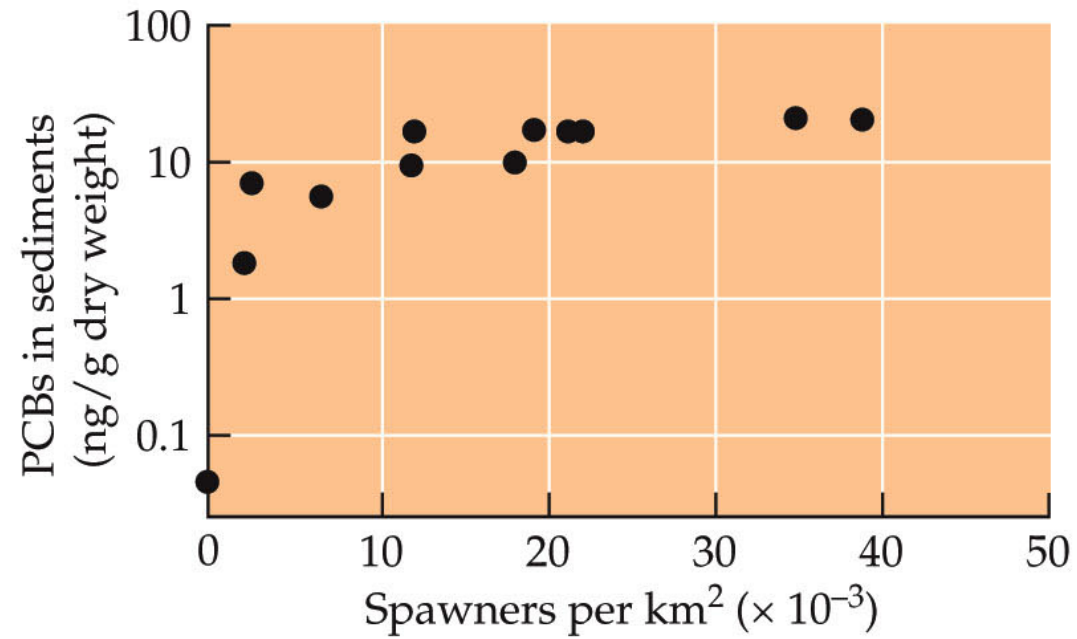
## Connections in Nature: Biological Transport of Pollutants

Salmon occupy the fourth trophic level, and accumulate toxins in their tissues.

Krümmel et al. (2003) sampled sockeye salmon in eight lakes in southern Alaska. Sediment cores were also collected and analyzed for PCBs.

Sedimentary PCB concentration was positively correlated with salmon density.

Figure 20.21 Biological Pumping of Pollutants





## Connections in Nature: Biological Transport of Pollutants

The lake with highest density of spawning fish had PCB concentrations that were six times higher than “background” levels associated with atmospheric transport.

Another study found that mercury and POPs are transported by northern fulmars (pelagic fish-eating seabirds) from the ocean to small ponds near their nesting colonies (Blais et al. 2005).