CHALLENGE YOURSELF

Look at Figure 14.8.

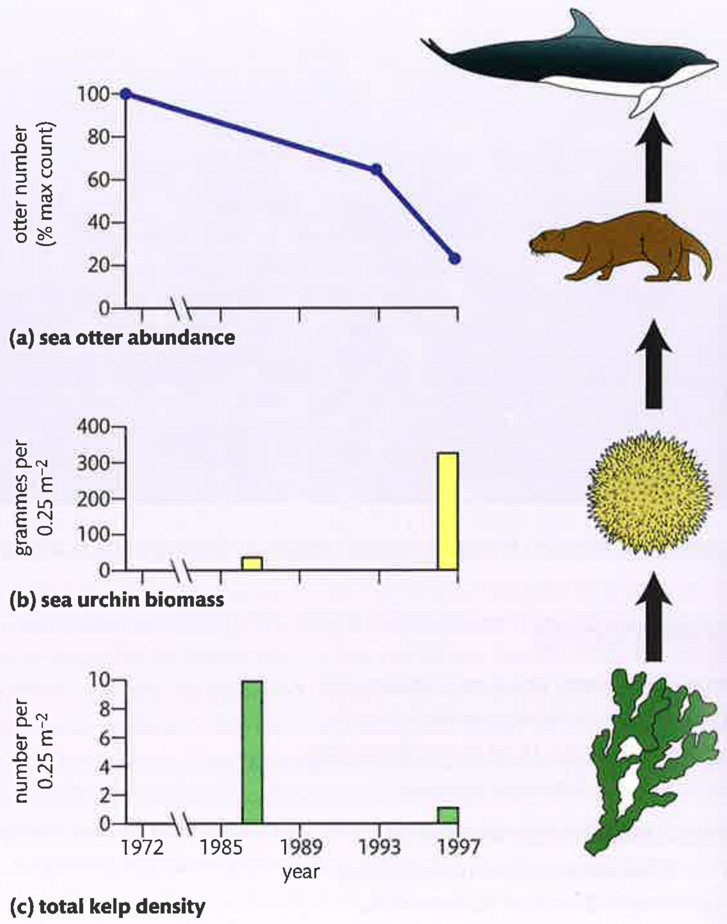


Figure 14.8 A food chain in the North Pacific of kelp–sea urchin–sea otter–orca. Adapted from Campbell and Reece 2002, Fig. 53.15

1. Look at the food chain shown on the sides of the graphs. Which organism would you hypothesize is the keystone species?
2. Use the graphs and explain why the data support your hypothesis.
3. The imbalance over 20 years is probably caused by the decline in seals and sea lions, which are also food for orca. Can you think of a reason for the decline in seals and sea lions?

Each species plays a unique role within a community

The unique role that a species plays in the community is called its niche. A famous ecologist, Eugene Odum, once said 'If an organism's habitat is its address, the niche is the habitat plus its occupation.' We could put it another way and say that the concept of niche includes where the organism lives (its spatial habitat), what and how it eats (its feeding activities), and its interactions with other species.

Spatial habitat

Every type of organism has a unique space in the ecosystem. The area inhabited by any particular organism is its spatial habitat. The ecosystem is changed by the presence of the organism. For example, leopard frogs, *Rana pipiens*, live in the ponds of Indiana (USA) dunes. They burrow in the mud in between the grasses on the edge of the pond.

Feeding activities

The feeding activities of an organism affect the ecosystem by keeping other populations in check. For example, the leopard frogs in the Indiana dunes eat the aquatic larvae of mosquitoes, dragonflies, and black flies. The presence of the leopard frog helps keep the populations of these insects in check.

Interactions with other species

The interactions of an organism with other species living in its ecosystem include competition, herbivory, predation, parasitism, and mutualism. The organism may be in competition with another organism for the food supply. It may itself be the prey for a larger predator. It may harbour parasites in its intestines. These complicated interactions are difficult to uncover, but they indicate the importance of the organism in the ecosystem. The predator of the green frog is the blue heron. Without the green frog in the sand dune ecosystem, the heron would have a significantly reduced food supply. Frogs are homes for flatworm parasites that live in their intestines. Without doubt there are many other relationships between the green frog and other species.

One of the jobs of an ecologist is to collect data on the niches of particular organisms in an ecosystem. If an organism is in danger of becoming extinct in an ecosystem, it is necessary to understand as many of its interactions as possible in an attempt to determine the cause of its extinction. What follows now are some explanations and examples of interactions between species.

Competition

When two species rely on the same limited resource, one species will be better adapted than the other to benefit from the resource.

The habitat of the red fox is disappearing.

The coyote is competing with the red fox for a small food supply. Removal of forests and creation of farmland has eliminated some of their food supply.

- Example 1: In the USA, coyotes, *Canis latrans*, and red foxes, *Vulpes vulpes*, are both predators that eat small rodents and birds. Coyotes inhabit grassland communities in the USA, while the red fox prefers the edges of forests and meadows. Because more farmland has been created and more forests removed, the habitat of the red fox is disappearing and is overlapping with that of the coyote in the grasslands. The two species are competing for a smaller food supply and it is possible that one will become extinct in that habitat.
- Example 2: In the coastal dunes of the UK, the natterjack toad, *Epidalea calamita*, is facing tough competition from the common toad, *Bufo bufo*. Disturbance of the dune area is limiting the habitat available to both toads.

Herbivory

A herbivore is a primary consumer (plant eater) that feeds on a producer (plant). The growth of the producer is critical to the well-being of the primary consumer. This is an interaction between plants and animals.

- Example 1: Rabbits, *Oryctolagus cuniculus*, eat marram grass in a sand dune ecosystem.
- Example 2: The monarch butterfly, *Asclepias syriaca*, larvae eat the leaves of the milkweed plant.

Predation

A predator is a consumer (animal) eating another consumer (animal). One consumer is the predator and another is the prey. The number of prey affects the number of predators and vice versa.

- Example 1: The Canadian lynx, *Lynx canadensis*, and the arctic hare, *Lepus articus*, form a classic example of predator–prey interaction. The lynx preys on the hare. Changes in the numbers of the lynx population are followed by changes in the numbers of the hare population.
- Example 2: The blue heron, *Ardea herodias*, is a predator on frogs in the ponds of American sand dune ecosystems.

Canadian lynx walking through deep snow tracking an Arctic hare.

Parasitism

A parasite is an organism that lives on or in a host and depends on the host for food for at least part of its life cycle. The host can be harmed by the parasite.

- Example 1: *Plasmodium* is a parasite that causes malaria in humans. It reproduces in the human liver and red blood cells. Part of the life cycle of the *Plasmodium* takes place in the body of the *Anopheles* mosquito. The mosquito is the vector that transmits the malaria parasite from one human to another.
- Example 2: Leeches, *Hirudo medicinalis*, are parasites that live in ponds. Their hosts are humans and other mammals. Leeches puncture the skin of a host and secrete an enzyme into the wound to prevent clotting. Leeches can ingest several times their weight in blood.

Mutualism

Two species living together where both organisms benefit from the relationship is termed mutualism.

- Example 1: Lichen is a mutualistic relationship between algae and fungi. The algae, *Trebouxia*, photosynthesize and make carbohydrates (food) that the fungi can use. The fungi, mainly *Ascomycota* species, absorb mineral ions needed and used by the algae.
- Example 2: *Rhizobium* is a nitrogen-fixing bacterium that lives in the roots of leguminous plants such as beans and peas. *Rhizobium* fixes nitrogen (transforms atmospheric nitrogen into a form that is useable by plants), which the plant can then use to make proteins. The plant makes carbohydrates (during photosynthesis), which can be used as food by the *Rhizobium*.
- Example 3: Clownfish, *Amphiprion ocellaris*, and sea anemones, *Anemonia sulcata*, live together for mutual benefit. Clownfish are small brightly coloured fish that live within the area of the tentacles of the poisonous sea anemone. The clownfish is covered with mucus that protects it from the sting of the sea anemone. Clownfish lure other fish to the waiting tentacles of the sea anemone. After the sea anemone kills the fish, the clownfish and the sea anemone both eat the remains. The clownfish also nibble off the remains of dead sea anemone tentacles.

Cavernous star coral, *Montastraea cavernosa*. The greenish colour on the coral is zooxanthellae algae.

- Example 4: Zooxanthellae are single-celled algae that live in the tissue of reef-building coral. The coral provides the compounds and the environment for photosynthesis for zooxanthellae. In turn, the algae provide food for the coral. The algae give the coral a boost of nutrients so that it can secrete the skeleton of calcium carbonate that it needs to build the reef. This is a highly efficient exchange of nutrients in a nutrient-poor environment. This relationship of mutual benefit is called mutualism or symbiosis, living together for mutual benefit.

CHALLENGE YOURSELF

4 What interactions between species have you learned about in this section? List four or five types of interactions and give an example of each.

The relationship between zooanthellae and coral is a type of symbiosis. The coral and algae live together. 'Bio' is the Greek word for living, and 'sym', is the Greek word for together.

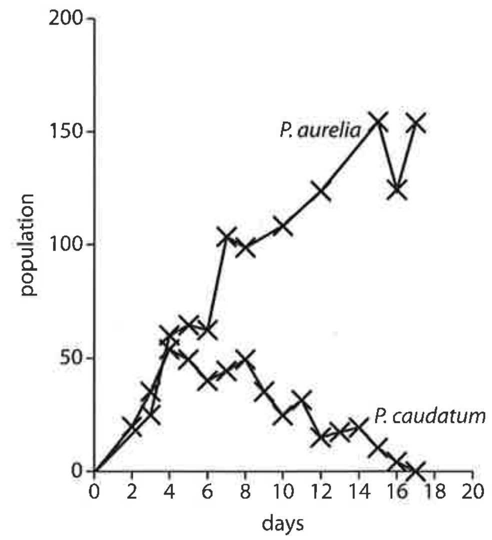
Competitive exclusion

You will recall that the red fox and coyote may now be in competition with each other for resources. They seem to both hunt for their food in the same areas, and the food supply may be dwindling as a result of the forests and grasslands being turned into farmland. If the fox and the coyote do begin to occupy the same niche in the ecosystem, the principle of competitive exclusion can be used to predict the end result.

The principle of competitive exclusion states that no two species in a community can occupy the same niche.

In 1934, the competitive exclusion principle was demonstrated by a Russian ecologist, G. F. Gause. He performed a laboratory experiment with two different species of *Paramecium*: *P. aurelia* and *P. caudatum* (see Figure 14.9). His experiments showed the effects of interspecific competition between two closely related organisms. When each species was grown in a separate culture, with the addition of bacteria for food, they did equally well. When the two were cultured together, with a constant food supply, *P. caudatum* died out and *P. aurelia* survived. *P. aurelia* out-competed *P. caudatum*. The experiment supported the Gausian hypothesis of competitive exclusion. When two species have a similar need for the same resources, one will be excluded. One species will die out in that ecosystem and the other will survive. *P. aurelia* must have had a slight advantage that allowed it to out-compete *P. caudatum*.

Figure 14.9 Competitive exclusion.



Fundamental niche versus realized niche

The red fox's habitat in the USA is the forest edge. Its food consists of small mammals, amphibians, and insects. It interacts with other species, such as the mosquitoes that suck its blood and scavengers that eat its leftovers. This is the fundamental niche of the red fox. The fundamental niche is the complete range of biological and physical conditions under which an organism can live.

What has happened to the red fox's fundamental niche? The forest edge has been turned into farmland in many places. Some of the species eaten by the red fox have disappeared. The red fox must survive in a narrower range of environmental conditions. Now there is direct competition from the coyote, whose niche has also been changed. This new and narrower niche is called the realized niche.

The fundamental niche of a species is the potential mode of existence, given the adaptations of the species.

The realized niche of a species is the actual mode of existence, which results from its adaptations and competition with other species.

Make sure to label all parts of a graph: the title, *x*-axis, *y*-axis, units, and uncertainties.

CHALLENGE YOURSELF

Paramecium caudatum is a single-celled organism that lives in fresh water. In an experiment researchers allowed *P. caudatum* to grow for 28 days in order to determine its normal growth curve. Every 7 days, ten random samples were collected from the population. The data recorded are shown in Table 14.1

Paramecium caudatum, seen under a light microscope.

Table 14.1 Random samples of the population density (number per mm^3, ±5 organisms) of a culture of *P. caudatum* taken over 28 days

Sample number	Day 7	Day 14	Day 21	Day 28
1	143	200	300	390
2	155	205	315	360
3	165	185	295	375
4	135	235	350	365
5	143	195	295	410
6	145	265	320	370
7	165	265	340	380
8	175	195	370	390
9	105	215	325	390
10	169	290	340	320
Mean				

5 Calculate the means of the data and graph them.

6 Will this give you a picture of the fundamental or realized niche? Give your hypothesis as to what the results will show.

A second experiment was performed where *P. caudatum* was placed in a culture with another species of *Paramecium*. The researchers wanted to know, when the two species are competing for resources, what will be the result?

Tables 14.2 and 14.3 show the data that were collected over 28 days.

Table 14.2 Random samples of the population density (number per mm^3, ±5 organisms) of *P. caudatum* taken over 28 days

Sample number	Day 7	Day 14	Day 21	Day 28
1	169	290	340	300
2	105	215	325	315
3	175	195	370	295
4	165	265	340	350
5	145	265	320	295
6	143	195	295	320
7	135	235	350	340
8	165	185	295	370
9	155	205	315	325
10	143	200	300	340
Mean	150	225	325	325

(The means have been calculated for you.)

Table 14.3 Random samples of the population density (number per mm^3, ±5 organisms) of *P. bursaria* taken over 28 days

Sample number	Day 7	Day 14	Day 21	Day 28
1	75	160	210	160
2	85	150	190	190
3	65	150	190	250
4	75	140	220	180
5	85	140	230	180
6	65	130	180	230
7	75	170	180	220
8	95	170	250	190
9	70	130	190	190
10	60	160	160	210
Mean	75	150	200	200

7 Graph the data from this experiment.

8 Is this graph showing the fundamental or realized niche of *P. caudatum*? Explain your answer.

Use of a transect to correlate the distribution of a plant with an abiotic variable

A transect is a method of sampling a population of plants or animals along a longitudinal section of an ecosystem. The observer moves along a fixed path to count the occurrences of the plant or animal along the path. It is much more accurate to use this type of transect with plants, because they do not move. Line transects are used to illustrate a particular gradient of an abiotic factor, such as sunlight or soil moisture, that is present in the ecosystem.

Marram grass.

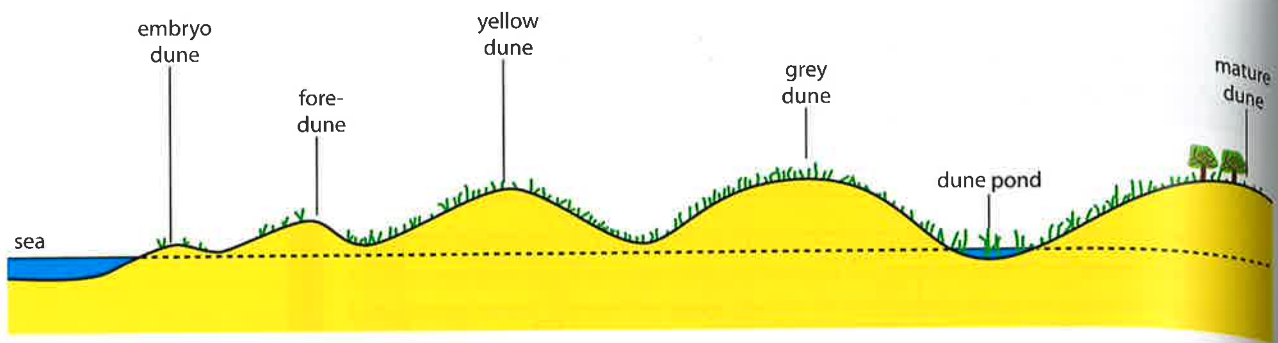


Figure 14.10 Transect of a coastal sand dune.

An example can be seen in Figure 14.10, showing the transect of a coastal dune. Let's look at the distribution of marram grass in the coastal dune ecosystem and how it is affected by the abiotic factor of soil pH.

If you were asked to do a transect, you would do the following.

- At right angles to the sea, lay a tape in a line all the way up the dunes.
- Every 10 or 20 m along the tape, mark out a quadrat (a square of a certain size).
- Identify and count the tufts of marram grass in the quadrat.
- Take several samples of the soil in each quadrat and use a soil test kit to determine the pH of the soil.
- Record all the data in a table
- Turn it in to a diagram of your choice.

You can now determine the pattern of distribution of marram grass from the youngest dune to the oldest dune and see if it correlates with changes in the soil pH.

Transect information can be very useful when making decisions about ecosystems that are important to us. Here is an example of how transects can be important in an ecosystem. In this example, an experiment was performed to determine whether artifical light would affect the foraging behaviour of salamanders in an ecosystem

Transects were used in forested areas at the Mountain Lake Biological Station in Virginia, USA. Half of the transects were lit by strings of white minilamps placed within the transects. The other half were not lit. The researchers walked each transect at night in order and counted the number of salamanders. There were significantly more active salamanders in the dark transects than in the light ones. The salamanders in the dark transects were foraging for food. The salamanders in artificial light were not foraging. This experiment shows how the use of artificial light to illuminate a campsite or even a research station can affect some organisms negatively.

To learn more about using sampling in fieldwork, and about using transects, go to the hotlinks site, search for the title or ISBN, and click on Chapter 14: Section C.1.

Exercises

1. Describe a method to determine whether an organism is a keystone species in an ecosystem.
2. Design an experiment using a transect to correlate the distribution of a plant with an abiotic factor.
3. Outline an example of symbiosis.

C.2 Communities and ecosystems

Understandings:

- Most species occupy different trophic levels in multiple food chains.
- A food web shows all the possible food chains in a community.
- The percentage of ingested energy converted to biomass is dependent on the respiration rate.
- The type of stable ecosystem that will emerge in an area is predictable based on climate.
- In closed ecosystems energy but not matter is exchanged with the surroundings.
- Disturbances influence the structure and rate of change within ecosystems.

Applications and skills:

- Application: Conversion ratio in sustainable food production practices.
- Application: Consideration of one example of how humans interfere with nutrient cycling.
- Skill: Comparison of pyramids of energy from different ecosystems.
- Skill: Analysis of a climograph showing the relationship between temperature, rainfall, and the type of ecosystem.
- Skill: Construction of Gersmehl diagrams to show the inter-relationships between nutrient stores and flows between taiga, desert, and tropical rainforest.
- Skill: Analysis of data showing primary succession.
- Skill: Investigation into the effect of an environmental disturbance on an ecosystem.

Guidance

- *Examples of aspects to investigate in the ecosystem could be species diversity, nutrient cycling, water movement, erosion, leaf area index, among others.*

NATURE OF SCIENCE

Use models as representations of the real world: pyramids of energy model the energy flow through ecosystems.

Energy flow through the ecosystem

What do you think is the direction of energy flow for any ecosystem? If you constructed a food chain like this one, then you know.

grass → cow → human

Plants are at the bottom of the food chain. They contain the highest amount of energy, which they obtain from sunlight. The source of energy for most ecosystems is the Sun. A few food chains are supported by bacteria that can trap chemical energy.

Only 5–20% of the Sun's energy that is trapped by plants is transferred to the primary consumers eating the plants. Why is this? Because 80–95% of the energy is lost as heat or used for maintenance by the plant. Energy is lost as heat as it moves from producer (e.g. grass) to primary consumer (e.g. a cow) to secondary consumer (e.g. a human).

This is the same reason why the fuel we put in a car is only partially used to run the car. A large percentage of the energy provided by the fuel is lost as heat. This is why there is a fan in the engine of a car. A law of physics called the second law of thermodynamics states that, when energy is transferred, a proportion of it is lost as heat energy. This law applies equally to cars and ecosystems.

Where is the energy from the Sun actually kept in the plant? Plants produce glucose during photosynthesis. Plants also break down the glucose molecules and use the energy released for maintenance activities. The breakdown is called respiration. Maintenance activities that need energy are growth, repair, and reproduction. When the glucose is used as fuel for these activities, some of the energy is lost. Some of the energy moves through the ecosystem as excretion. Some energy is left in undigested food and is passed on to decomposers. When an organism dies, its body is decomposed and the energy transferred to decomposers.

Gross production, net production, and biomass

Pyramids of energy show how much energy is left at each trophic level (see Figure 14.11). Each block in the pyramid represents a trophic level (producers, primary consumers, secondary consumers, tertiary consumers). The width of the block indicates how much energy it contains. At each level, the blocks get narrower, and the block at the top is very narrow. The number at each level represents the amount of energy at each level. Can you see that only 10% of the energy from one trophic level is transferred to the next level? This diagram represents the ideal situation. In an actual ecosystem, the percentage transfer from one level to the next depends on many factors and may vary between 5% and 20%. In animal husbandry (farming), the transfer value is often higher than 10%. However, the loss of energy between producer and consumer explains why a kilogramme of beef is more expensive than a kilogramme of corn.

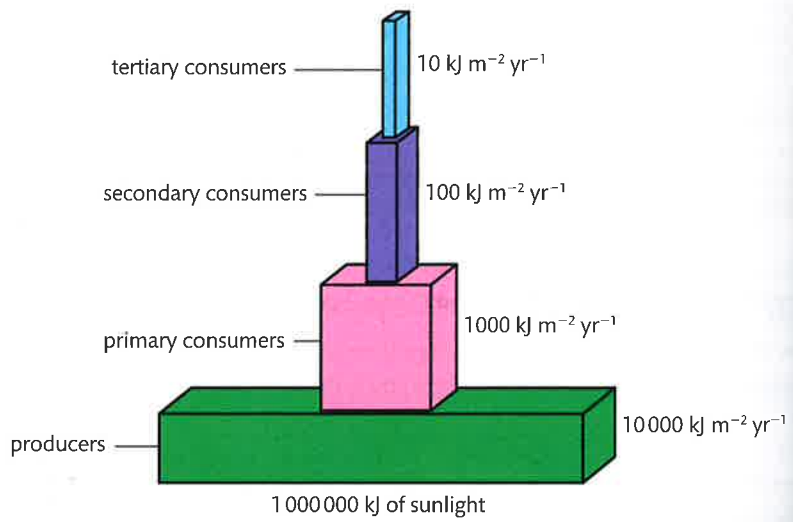


Figure 14.11 A pyramid of energy (not drawn to scale).

Figure 14.12 is a pyramid of energy with greater detail than the idealized pyramid shown in Figure 14.11. First, look at the simpler view at the bottom of the figure. The gross production of the producers is 20 810 kilojoules per metre squared per year ($kJ\ m^{-2}\ yr^{-1}$). Can you calculate what percentage of energy moved up to the herbivores?

Doing practice calculations like this will help you understand how this works.

About 16% of the energy moved up to herbivores. Now look at the detailed energy flowchart at the top half of Figure 14.12. Notice that 1 700 000 kJ of energy are input from the Sun and that only 1.2% of the Sun's energy was captured by the producers. The producers have a gross production of 20 810 $kJ\ m^{-2}\ yr^{-1}$. Gross production is the energy that they have available. Notice that some of that energy is lost as metabolic heat and net system loss (heat, respiration, and maintenance). Look on the other side of the figure, and you will see how much is transferred to 'organic wastes and remains'. This energy eventually flows through decomposers, like mould and bacteria in the soil, and detritivores, like earthworms. Calculate the percentage of energy that is lost as respiration (metabolic heat) as it moves to herbivores.

The answer is 63%. About 16% was transferred to herbivores and the rest was transferred to decomposers and detritivores. The energy reaching the carnivores is 11.4%, and only 5.5% flows up to the top carnivores. Look at the bottom of the energy

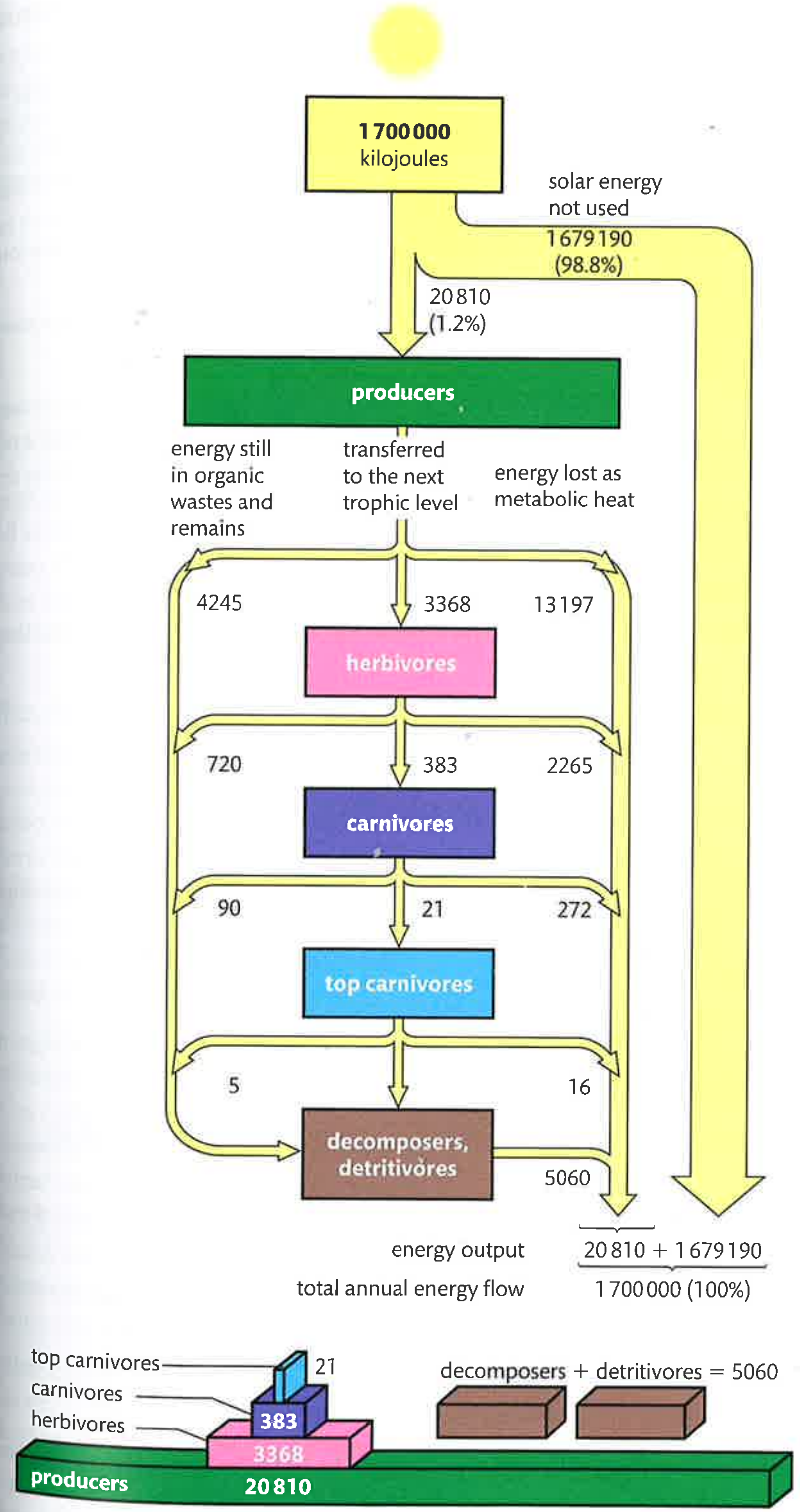


Figure 14.12 A pyramid of energy for the ecosystem in Silver Springs, Florida, USA measured in $kJ\ m^{-2}\ yr^{-1}$.

flow diagram and you will see that eventually all the energy that flows through the ecosystem is lost as metabolic heat.

However, within the specific time period covered by a diagram such as Figure 14.12, organisms are storing some of energy. For example, a young forest accumulates organic matter as the tree grows. The slow rate of decay in a peat bog causes peat to build up. Some energy-flow diagrams include a cube to represent storage.

Now that you understand energy pyramids, we can define some important terms.

- Gross production is the total amount of energy trapped in the organic matter produced by plants per area per time in kilojoules, measured as kilojules per metre squared per year (kJ m^{-2} yr^{-1}).
- Net production is the gross production minus the energy lost through respiration, also measured as kJ m^{-2} yr^{-1}.
- Biomass is the dry weight of an organism, measured in grammes per metre squared per year (g m^{-2} yr^{-1}).

In terms of an ecosystem, biomass is the dry weight of all the organisms at a certain tier of an ecosystem. The reason why we use dry weight is that the actual weight of the organisms includes a large amount of water. Water needs to be removed and the dry weight measured.

Calculating gross production and net production

In order to calculate the values of gross production and net production, we use the equation:

$$\text{gross production} - \text{respiration} = \text{net production}$$

So, if:

$$\text{gross production} = 809\ \text{kJ m}^{-2}\ \text{yr}^{-1}$$

and:

$$\text{respiration} = 729\ \text{kJ m}^{-2}\ \text{yr}^{-1}$$

then:

$$\text{net production} = 80\ \text{kJ m}^{-2}\ \text{yr}^{-1}$$

Constructing a pyramid of energy

Using the data below, construct a pyramid of energy without looking back at Figure 14.12.

Trophic level	Energy flow (kJ m^{-2} yr^{-1})
Producers	20 810
Primary consumers	3368
Secondary consumers	383
Tertiary consumers	21

After you have drawn the pyramid, check Figure 14.12 to see if yours is correct. Have you drawn each block in proportion to the numbers? Have you placed the correct labels at each trophic level? Have you remembered a title for your pyramid?

Pyramids of biomass

Pyramids of biomass are similar in shape to pyramids of energy. The higher trophic levels have a lower total biomass per unit area of ecosystem (see Figure 14.13). Biomass

is lost during respiration at each trophic level. When glucose is broken down for energy, it is converted into carbon dioxide gas and water. Carbon dioxide and water are excreted and the biomass of glucose is lost. Each successive level of the ecosystem loses more and more biomass. The energy per gramme of food does not decrease, but the total biomass of food is less at each trophic level. Notice in Figure 14.13 how little biomass is present in tertiary consumers compared with producers. It is very similar to what we saw when we looked at the pyramid of energy.

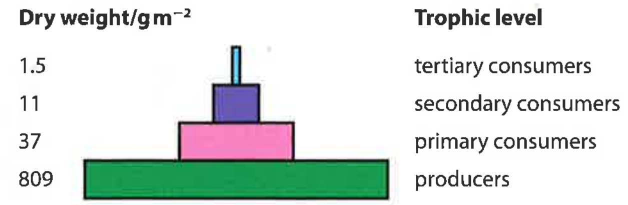


Figure 14.13 Pyramid of biomass.

A pyramid of numbers also has a similar shape as the pyramid of energy. Only a small amount of energy can flow all the way up to the highest trophic level. The total biomass of food available at the top trophic levels is also small. As the top predators, such as a shark or a lion, must be large enough to overwhelm their prey, there can be only relatively few of them.

Difficulties of classifying organisms into trophic levels

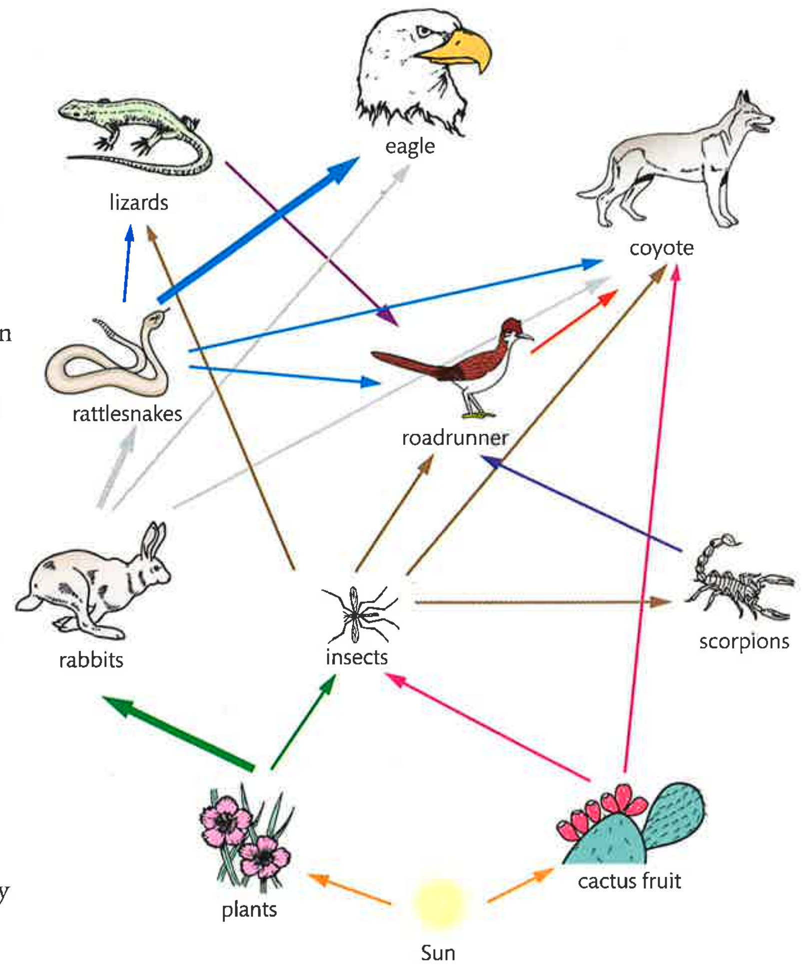
In order to understand the relationships of an ecosystem completely, something more than food chains and pyramids needs to be constructed. A food web gives a true but complicated picture of what is being eaten in an ecosystem (see Figure 14.14). Can you see the following difficulties when you look at the food web in Figure 14.14?

- An eagle is a tertiary consumer when eating rattlesnakes, but a secondary consumer when eating rabbits.
- A coyote is a primary consumer when it eats the fruit of a cactus, but a tertiary consumer when it eats a rattlesnake.
- A lizard is a tertiary consumer when it eats rattlesnake eggs, but a secondary consumer when it eats insects.

Another difficulty is where to put omnivores. For example, the following omnivores are difficult to classify into one trophic level.

- Grizzly bears eat plants, insects, and some mammals. Which food is eaten depends on the season, the temperature, and the bear's ability to forage for food. Are they primary consumers, secondary consumers, or tertiary consumers?

Figure 14.14 A desert food web.



TOK

Raymond Lindeman was an ecologist who formulated a new paradigm of energy flow through ecosystems. In addition to grouping organisms into primary producers, primary consumers, etc., he was the first scientist to measure trophic efficiency. Trophic efficiency is the production of one trophic level that is transferred to the next trophic level. This concept, first formulated in 1942, remains influential today.

- Raccoons eat mice, bird eggs, fish, frogs, nuts, and fruits. The food most dominant in the diet might depend on the season or competition from other animals. Is the raccoon mainly a primary consumer or a secondary consumer?
- Chimpanzees eat both fruit and termites. Is the chimpanzee mainly a primary consumer?

Comparing pyramids of energy

Table 14.4 A comparison of Cedar Bog and Lake Mendota, Wisconsin, USA

Trophic level	Cedar Bog		Lake Mendota	
	Productivity (cal cm^{-2} yr^{-1})	Efficiency (%)	Productivity (cal cm^{-2} yr^{-1})	Efficiency (%)
Solar radiation	119.000		119.000	
Plants	111	0.1	480	0.4
Herbivores	14.8	13.3	41.6	8.7
Carnivores	3.1	22.3	2.3	5.5
Higher carnivores			0.3	13.0

When comparing the energy pyramids of two different ecosystems you will notice that the difference is in their efficiency. Look Table 14.4 comparing the two lakes and you will see the transfer of energy at each trophic level. Notice that typically the organisms at higher and higher trophic levels are increasingly more efficient. Only a small percentage of the Sun's energy that plants absorb is available for transfer to the herbivores. Plants use up the energy through high assimilation and growth. Herbivores are slightly more efficient and carnivores are even more efficient. Cedar Bog has three trophic levels, while Lake Mendota has four. Five trophic levels are the limit for most systems. Lake Mendota can sustain another trophic level because it has a significantly larger biomass than Cedar Bog.

Here are two pyramids representing what we have just seen in Table 14.4.

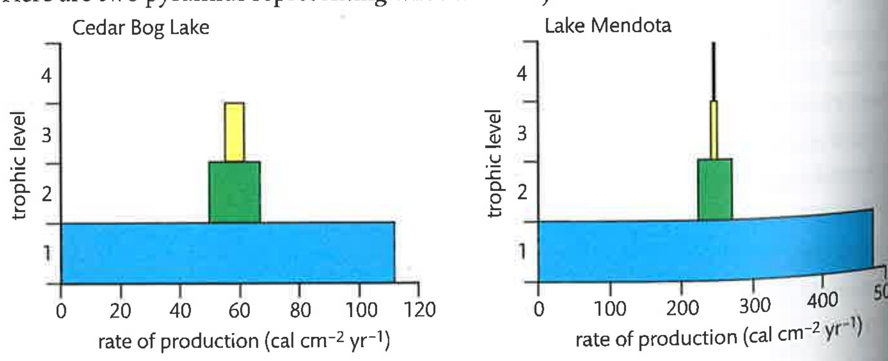


Figure 14.15 Annual production by trophic level in two lakes.
Molles, Jr. 2010,Fig. 18.16

CHALLENGE YOURSELF

9 Referring to Table 14.4, what percentage of energy is passed on to the next trophic level from the plants of Cedar Bog to the herbivores of Cedar Bog?

10 What percentage of energy is passed on to the next trophic level from the plants of Lake Mendota to the herbivores of Lake Mendota?

Conversion ratio in sustainable food production

The feed conversion ratio (FCR) is a measure of the efficiency of an animal's ability to convert feed mass into increased body mass. It is expressed as a ratio:

$$\frac{\text{mass of food eaten}}{\text{body mass gain}} \qquad \text{For example: } \frac{8 \text{ kg of food}}{1 \text{ kg of weight gain}} = 8$$

Table 14.5 shows some estimates for farmed animals.

Table 14.5 Animal FCR

Animal	FCR
Cattle	5–8
Sheep	4–5
Pork	3
Poultry	2
Carnivorous fish (salmon)	2
Herbivorous fish (tilapia)	1.2–1.6

Animals with low FCR can be seen to be efficient users of food. The FCR shows us how much energy is being lost during the transfer from plant to animals, as we have seen with energy pyramids.

Can sustainable agriculture methods improve the FCR? The principles of sustainable agriculture are:

- maintenance of food safety
- improving the environment
- using resources efficiently
- improving the lives of families and society as a whole.

One practical example of sustainable food production is fish farming. Notice from Table 14.5 that fish have a very low FCR. Fish farmers are attempting to lower the FCR to 1. This would mean that the amount of feed given to the fish would be changed into 'fish mass' equal to the mass of feed. Therefore nothing would be lost and everything is gained, so long as other resources are not wasted.

A fish farm, Corfu, Greece.

Warm-blooded animals (homeotherms) are less efficient at converting food to biomass than cold-blooded animals (poikilotherms). So you can see why a fish is more efficient than a cow.

Change in ecosystems over time by primary and secondary succession

Ecological succession is the change in the abiotic (non-living) and biotic (living) factors in an ecosystem over time. It is the reason why some species gradually replace other species in one particular area.

Primary succession

Primary succession begins when plants begin growing on a previously barren and lifeless area. Let's consider a newly created volcanic island. The plants that first colonize it are able to exist where temperature changes are extreme and there is little or no soil. The first colonizers are usually lichens. They are pioneer plants that can decompose thin layers of rock. As they die and decompose, a thin layer of soil is formed. This is just enough for some moss to get a foothold. This is the start of primary succession. Eventually, there will be enough soil for other seeds to germinate. Coconuts may be washed ashore and begin to germinate. Coconut palm trees will grow. Animals may swim, fly, or be carried on floating vegetation from other islands and populate the new island.

Secondary succession

In secondary succession, a new group of organisms takes over following a natural or artificial upheaval of the primary succession. Secondary succession is much faster than primary succession because soil is already present and there may be existing seeds and roots present. Recolonization of an area after a forest fire is an example of secondary succession.

Table 14.6 summarizes the differences between primary and secondary succession.

The World Health Organization recently reported that more than 3 billion people are undernourished. This is the largest number and proportion of malnourished people ever recorded in history. The food shortage and malnourishment problem is primarily related to rapid population growth in the world plus a declining per capita availability of land, water, and energy resources.

Table 14.6 Primary and secondary succession

Primary succession	Secondary succession
Begins with no life	Follows a disturbance of primary succession
No soil	Soil is present
New area, e.g. a volcanic island	Old area, e.g. following a forest fire
Lichen and mosses begin to grow on volcanic rocks	Seeds and roots are already present
Biomass low	Biomass higher
Low production*	Higher production*

*Production is the increase in biomass or energy m^{-2} yr^{-1}. When production is low, it is because there are only a few plants; higher production occurs when many plants are present.

Species diversity and production in a primary succession

Coastal sand dunes are excellent examples of primary succession that are both interesting to walk through and have been studied extensively. If you do not live near the coast, use the hotlinks at the end of this section to find some resources. If you do live near the coast, you may find it more interesting to walk in the dunes after you have learned about the animals and plants that live there. Dunes are areas that need public support in order to be preserved as natural habitats.

Foredune

Primary succession starts on the foredune, where there is no soil, only sand. Lyme grass, *Leymus arenarius*, and marram grass, *Ammophila arenaria*, are pioneer plants on a new dune. Lyme grass is the more salt tolerant of the two species. It is generally fast growing and its roots help bind the sand and stabilize the dune. Marram grass has long underground roots that also spread sideways. It can spread 3 m yr^{-1}. Marram grass also has a special adaptation for life on a foredune: it has a growth spurt when covered with sand. There is little diversity of plant life on the foredune.

Yellow dune

At the yellow dune stage, the dune is developing a thin layer of soil from years of marram grass plants living and dying there. It has now been invaded by other plants with roots that are even better at binding the sand. These plants are sand sedge and sand bindweed. Rabbits may be common in this dune, and their droppings add nutrients to the soil. In the summer, fast-growing plants like dandelions and thistles grow here. Humus (organic matter in the soil) begins to build up as the original pioneer plants die and decay. Notice that, at this stage, the community is more complicated. More species are present and soil is beginning to form.

Grey dune

The grey dune stage has developed a layer of humus from years of plants dying and decomposing. Humus holds water. This dune is much farther inland and sand is not deposited here. Eventually, thick shrubs will grow on this dune.

Mature dune

The final stage in dune succession is the mature dune, which can support a forest. At the Indiana dunes, the mature dune has an oak–hickory forest. Hundreds of species of wild flowers are protected by the shade of the trees. Mosses and ferns grow on the forest floor. The humus is thick as a result of 200 years of plants dying and decaying. The moisture content of the soil is high because of the high amount of humus. The forest is full of insects, birds, and mammals. The temperature is 10% cooler on the mature dune than on the foredune. Lack of wind and blowing sand makes this a comfortable place for both animals and plants.

During the development of the primary succession on sand dunes, you can see that the following changes have occurred:

- few species to many species
- pioneer species to species that compete with others for nutrients
- little diversity to high diversity, the mature forest is home to hundreds of different species
- simple relationships to more complex relationships of mutualism, competition, and predation
- more and more biomass at each stage of the succession.

A stable ecosystem will emerge based on climate

Ecological succession will occur until finally it develops enough complexity to become a stable community. The type of stable community that will emerge in an area is predicted by climate. This predicted ecosystem is called the climax community. When a climax community is extensive and well developed, it is called a biome. For example, at the Indiana dunes, the climax community is a temperate forest. This is because of the mean annual precipitation levels and mean annual temperatures that are common in the area of the Indiana dunes. Figure 14.10 shows the succession along a dune profile.

Since Britain has a similar mean annual precipitation and mean annual temperature to the Indiana dunes, the climax community of coastal sand dune succession is also a temperate forest. It is also formed in a similar fashion. Primary succession occurs along the coast as lyme grass and marram grass, which are the pioneer species, bind the sand in place. The youngest dune with these species is always closest to the shore. The woodland climax community is always the furthest from the shore, just as it is in the USA (see Figure 14.10).

NATURE OF SCIENCE

Theories of succession are now models being used by ecologists trying to restore the climax community to some natural areas that have been destroyed by human development. Restoration managers can manipulate the mechanisms of succession to achieve climax conditions more rapidly.

Sand dunes in the Outer Hebrides, UK

Marram grass

Analysis of data showing primary succession

In order to study primary succession, one group of researchers built a sand dike to model what would happen during 28 years of primary succession on a sand dune. See Figure 14.16.

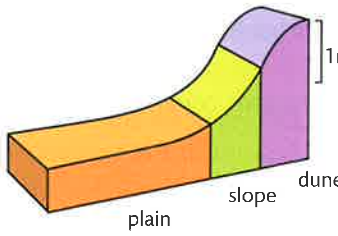


Figure 14.16 Sand dike study model showing plains, slope, and dune. Adapted from Olff et al. 1993, Fig. 1

The dike consisted of plains, slope, and dune. Over 28 years data were collected that are shown in these graphs.

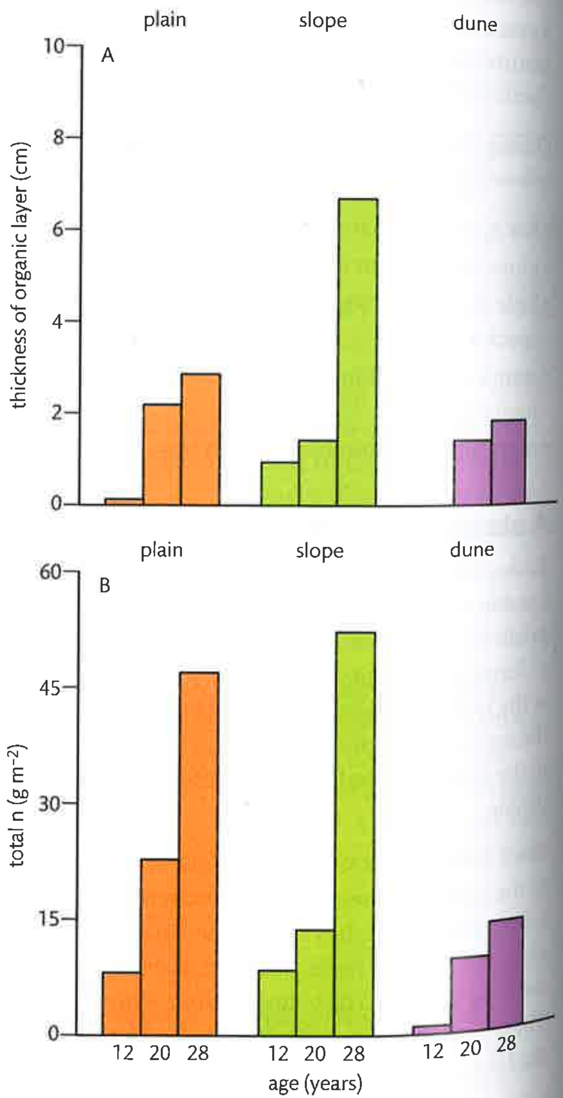


Figure 14.17 Primary succession as seen in the plain, slope, and dune dike. A: Growth of the thickness over 28 years on the sand dike model. B: Total amount of nitrogen in the organic layers over 28 years in three different areas on the sand dike model. Olff et al. 1993, Fig. 10

CHALLENGE YOURSELF

11 Using Figure 14.17, compare and contrast the thickness of the organic layer of each area over time.

12 Using Figure 14.17, describe the difference in total nitrogen among the three areas.

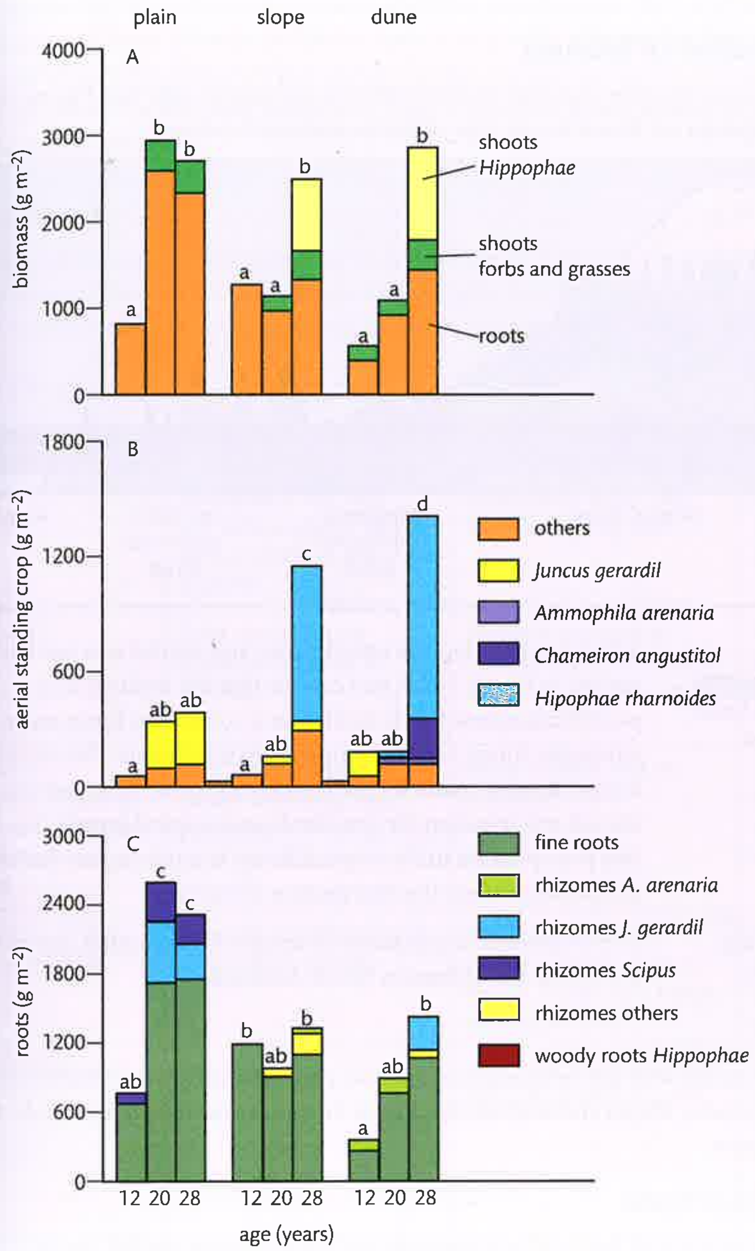


Figure 14.18 Reconstruction of total biomass **(A)**, above-ground biomass **(B)**, and below-ground biomass **(C)** of different plant species in Plain, Slope and Dune at three stages of primary succession. Totals with the same letter within each subfigure were not significantly different. Olff et al. 1993, Fig. 6

13 Using Figure 14.18, describe the changes in biomass over the 28 years.

14 Using Figure 14.18, compare the changes in aerial standing crop for the slope and the dune.

15 Using Figure 14.18, which area had the largest increase in root mass? What environmental factor could have caused this?

Biosphere and biomes

If you view the surface of the Earth in a satellite picture, you can see large swathes of land covered with trees, other areas covered with ice, and other areas with nothing that can be seen. The living part of the Earth that you can see is called the biosphere. The biosphere comprises all the parts of the Earth where organisms live. Some organisms live in the Earth's crust and some live in the atmosphere. Anywhere that organisms live is considered to be part of the biosphere.

Biomes are divisions of the biosphere. Each biome is a part of the biosphere and is defined by its vegetation and community structure.

Distribution of biomes

Biomes occur because of global weather patterns and topography (see Figure 14.19). Certain species are found in one type of biome and not in others.

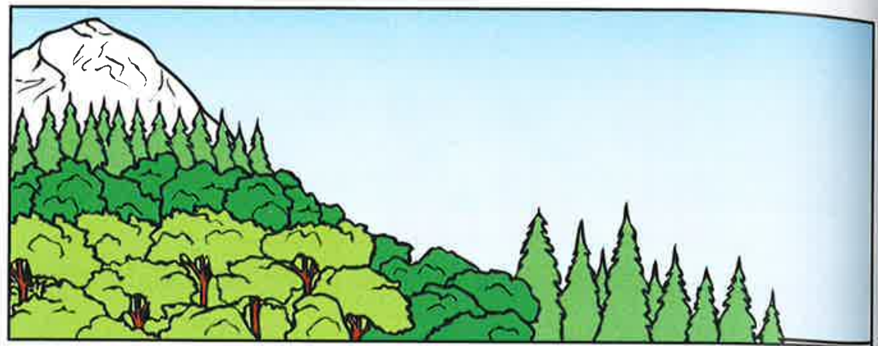


Figure 14.19 The distribution of some biomes by altitude and latitude.

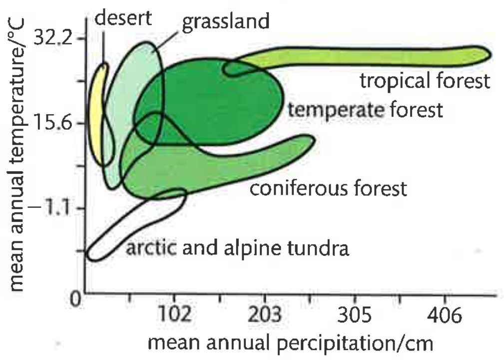


Figure 14.20 A climograph.

A climograph plots the temperature and rainfall in a particular region. In Figure 14.20, you can see that the mean annual precipitation (rainfall) is similar for a coniferous forest and a temperate forest, but the temperature is different. The mean annual temperature is colder for the coniferous forest. Compare the mean annual precipitation for grasslands and tropical forests. You can see that precipitation in the tropical forest is much higher. Rainfall and temperature affect the distribution of biomes.

The following combinations of temperature, rainfall, and elevation determine the biomes in North America.

Tundra

High elevations with low temperatures and low precipitation are the conditions that result in tundra. Plants and animals that live in the tundra are adapted to a cold and dry environment.

Coniferous forest

High elevations with less cold temperatures and slightly more rainfall are the conditions that result in coniferous forest. Because the ground freezes during some months of the year, coniferous (cone-bearing) trees are well adapted for conserving water when it is frozen. Animals have heavy coats of fur in the winter and lose some of the fur in the summer.

Temperate forest

At lower elevations, where temperatures are warmer and more water is available, the conditions produce temperate forest. Plants and animals in these forests must be adapted for a wide range of conditions: warm in the summer with lots of water, and

cool in the winter when water may be unavailable because it is frozen. Many trees in this forest will lose their leaves in the winter to reduce water loss.

Desert

At low elevations with warm temperatures and little precipitation, the conditions produce desert. Desert animals and plants have very specific adaptations that enable them to survive in this extremely hot and dry biome. A desert kangaroo rat has a specialized kidney for recycling water in its body. Cacti have spines instead of wide leaves to reduce water loss.

Tropical forest

At low elevations with warm temperatures and very high moisture, the conditions result in tropical forest. This forest is extremely productive, with high primary productivity as a result of the combination of high temperatures and high rainfall.

Table 14.7 Characteristics of the seven major biomes

Biome	Temperature	Moisture	Characteristics of vegetation
Desert	Mostly very hot with soil temperatures above 60°C (140°F) in the daytime	Low precipitation: less than 30 cm per year	Cacti and shrubs with water storage tissues, thick cuticles and other adaptations to reduce water loss
Grassland	Cold temperatures in winter and hot in summer	Seasonal drought is common with occasional fires, medium amount of moisture	Prairie grasses that hold the soil with their long roots; occasional fire prevents trees and shrubs from invading the grasslands
Shrubland (chaparral, matorral, maquis and garigue, dry heatherlands, fynbos)	Mild temperatures in winter and long, hot summers	Rainy winters and dry summers	Dry woody shrubs are killed by periodic fires. Shrubs store food in fire-resistant roots. They re-grow quickly and produce seed that germinates only after a fire
Temperate deciduous forest	Very hot in summer and very cold in winter	High rainfall spread evenly over the year. In winter, water may freeze for a short time	Deciduous trees like oak, hickory, and maple dominate the forest. In warmer seasons, a wide range of herbaceous plants grow and flower on the forest floor
Tropical rainforest	Very warm	Very high precipitation of more than 250 cm yr^{-1}	Plant diversity is high. A canopy of trees is the top layer. Next is a layer of shrubs. The ground layer is herbaceous plants and ferns. Large trees have vines climbing on them. Trees have orchids and bromeliads tucked in their branches
Tundra	Very cold; in summer, the upper layer of soil thaws but the lower layers remain frozen: this is permafrost	Little precipitation	Low-growing plants like lichen and mosses and a few grasses and shrubs. Permafrost prevents the roots from growing deeply. Continuous daylight in summer allows some plant growth and reproduction
Coniferous forest (taiga)	Slightly warmer than the tundra	Small amount of precipitation but wet due to lack of evaporation	Cone-bearing trees such as pine, spruce, fir and hemlock

Schmitt et al. 2011

CHALLENGE YOURSELF

Look at Figure 14.21.

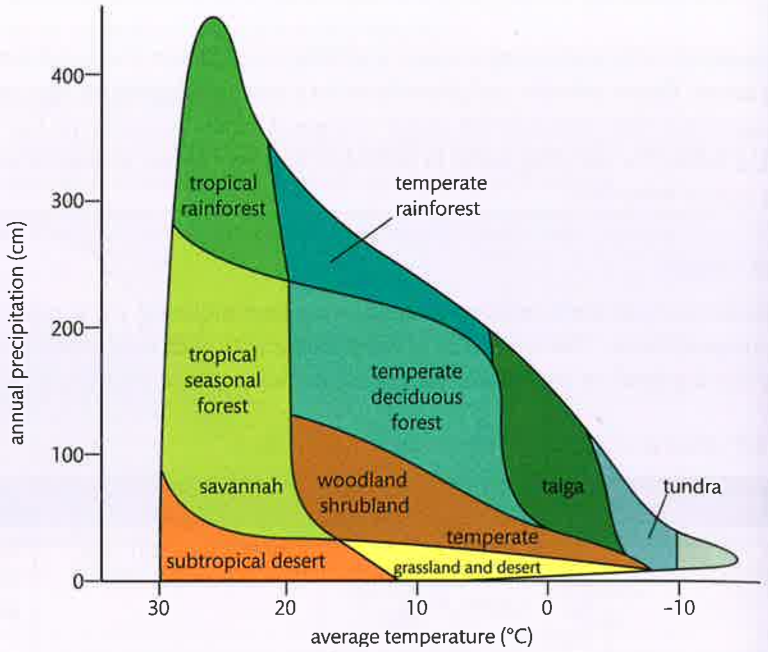


Figure 14.21 A climograph. This type of graph shows the relationship between temperature, rainfall, and ecosystem type. www.marietta.edu/-biol/biomes/desert.htm

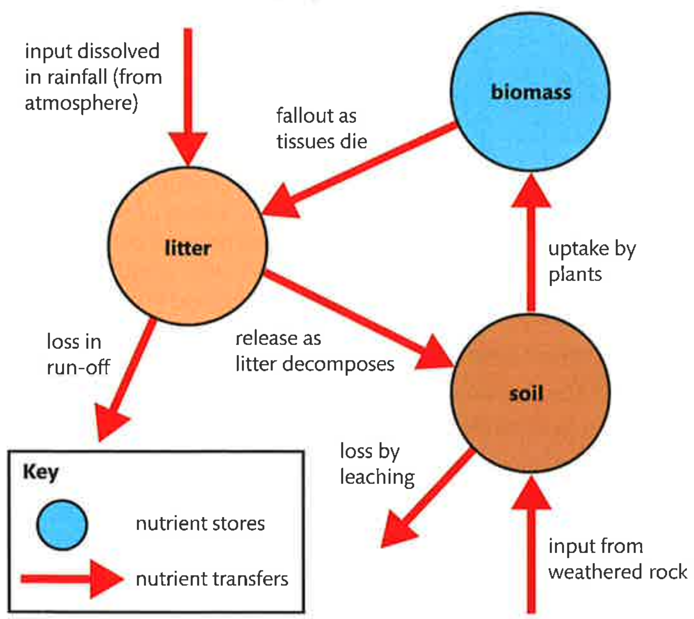
16 What is the average temperature range of a subtropical desert?

17 What is the highest amount of precipitation for a subtropical desert?

18 Compare the mean annual temperature for grasslands and tropical forests.

19 Compare and contrast the mean annual temperature for temperate deciduous forest and temperate rainforest.

Figure 14.22 A model of the mineral nutrient cycle.



Gersmehl diagrams

Another way of describing energy flows and nutrient recycling is to use Gersmehl diagrams of different biomes. These diagrams are a common method of demonstrating the cycling of nutrients within the main 'stores' of an ecosystem. As you will notice from the diagrams, the main stores of nutrients are soil, biomass (plants), and litter. Arrows of varying thickness represent nutrient transfer. Circles of varying size represent the size of the stores. Included in the diagrams are the following:

- input, such as of nitrogen, carbon, and minerals from weathered rock
- output, such as loses of nutrients by leaching and run-off
- flows, such as of leaf and needle fall from biomass to litter, and uptake of nutrients from the soil by plants.

Figure 14.22 shows a generalized model of a Gersmehl diagram.

Worked example

We will now look at a Gersmehl diagram for a specific biome, the tropical rainforest. First read this information about a rainforest, as it will help you make the diagram.

- Biomass is the main store of nutrients because the tropical rainforest has tall, dense vegetation with many layers and multiple species.
- Precipitation: rainfall is high all year.
- Litter has a very small store of nutrients because of the high rate of decomposition.
- Soil has a very small store of nutrients because of leaching and low soil fertility.
- Weathering (W) is rapid because of high heat and humidity.
- Leaching (Le) is high because of the high rainfall.
- Runoff (R) is high due to such large amounts of rain, that the soil cannot absorb it all.

Try to draw your own Gersmehl diagram before you look at Figure 14.23. Make sure to make the circles different sizes and use arrows of different thicknesses.

Solution

Now compare your diagram with the actual diagram.

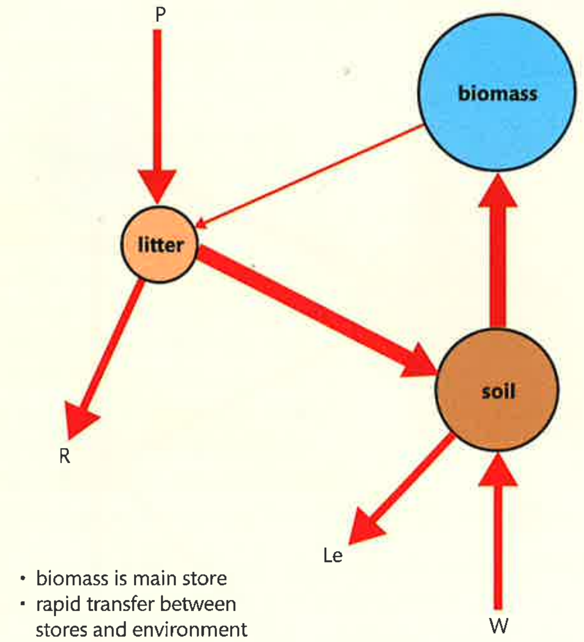


Figure 14.23 Gersmehl diagram of a tropical rainforest.

Gersmehl diagrams are models that predict and explain the natural world. TOK

Worked example

We will now construct another Gersmehl diagram. This time the biome is taiga. Here are the specifics for taiga.

- Litter is the largest store of nutrients because of the low rate of decomposition as a result of low temperatures.
- Run-off is high. The ground is still frozen when the snow is melting.
- Biomass is relatively low because conifers have only one layer of needles and there is no undergrowth.
- Transfer from biomass to litter is high because of the constant supply of needles falling from coniferous trees.
- Soil stores are very small. Poor soil is formed from glacial deposits and so there is low soil fertility.
- Weathering of rocks is slow because of the cold.

Have a go at drawing your own diagram before looking at Figure 14.24; see if you are more accurate than you were with your first diagram.

Solution

Figure 14.24 shows the actual diagram for taiga.

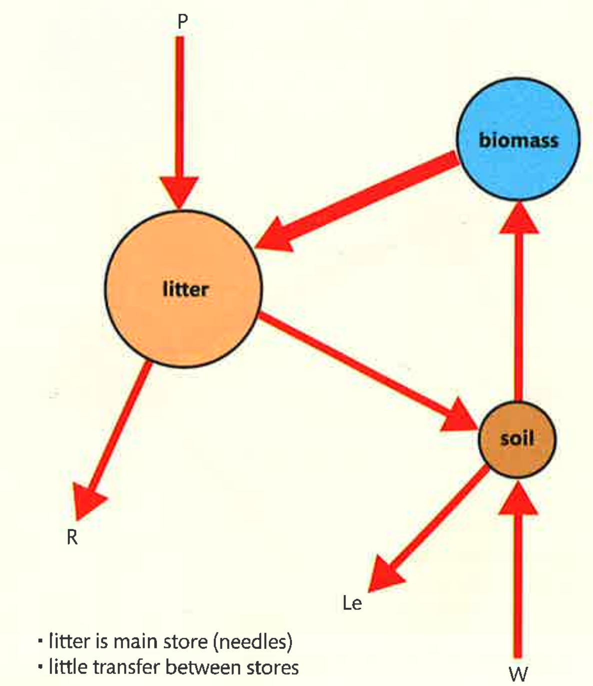


Figure 14.24 Gersmehl diagram of a boreal forest (taiga).

CHALLENGE YOURSELF

20 Draw a Gersmehl diagram for a desert biome. Here are the specifics you need:

- soil is rich in nutrients because there is little rain is available to wash them away
- biomass is small because of the extreme heat and lack of water
- litter or topsoil is practically non-existent because it is eroded by the wind
- run-off is high because there is no litter to hold on to the water
- loss as a result of leaching is low.

An example of humans interfering with nutrient cycling

In a study published in 2011 in the journal *Ecological Applications*, researchers documented how the collapse of marine fisheries as a result of overfishing and habitat loss has affected nutrient recycling in the marine environment.

Fish have a functional role in ecosystems. Through consumption and assimilation, fish recycle nutrients, especially nitrogen and phosphates, into forms that can be taken up by microorganisms and plants. The role of fish as nutrient recyclers is critical.

Eighty per cent of the nutrients that are used by primary producers are supplied by fish. Removal of fish tissues by marine fisheries in areas where nitrogen is low has affected primary production by plants. This has a negative effect on the herbivores in that community. In this study, estimates of nitrogen excretions rates for grey snapper in the Bahamas were 456% higher in unfished areas compared with fished areas. The excretion rates of phosphates were 451% higher in unfished areas compared with fished areas. The concern of these authors is that the sea grass beds that are the key habitat for young fish may be affected by this lack of recycled nutrients. Loss of primary production in the sea grass beds could cause the loss of even more fish.

A closed ecosystem

Most ecosystems are open. In a forest ecosystem, light enters and is trapped by plants. Herbivores eat the plants and their faeces fertilize the soil. After a fire, the soil may blow away to another ecosystem. Minerals may be leached by water after rain and be carried down the river to a new ecosystem.

Closed systems exchange energy but not matter. No natural system on Earth is considered to be a closed system, but the entire planet can be considered 'almost' closed. Large amounts of light energy enter the Earth and eventually return to space as heat, but matter is not exchanged.

Biosphere 2 Rainforest building.

Some experimentation has been done with artificial closed systems. A closed ecological system (CES) could be a space station. A space station does not rely on exchange of matter with its surroundings. In a closed ecosystem, waste products made by a species must be used by at least one other species. Waste products such as urine, faeces, and carbon dioxide must be converted into oxygen, food, and water. This involves at least one autotroph (green plant), which can use the waste products to make food as long as sunlight is available. Energy can be exchanged, but not matter.

An example of a large CES is Biosphere 2. Biosphere 2 is a large research facility, the size of two football fields, owned by the University of Arizona, USA. The research done here demonstrates the conditions that can affect a closed system. This facility has its own farm under a glass dome, and experiments are carried out with week-long periods of full closure, where humans live in the closed environment.

TOK The old paradigm of diversity in an ecosystem stated that the most diversity is found in the oldest ecosystem. The intermediate disturbance hypothesis changed the way that ecologists think about how disturbances affect ecosystems. This hypothesis predicts that intermediate levels of disturbance promote higher levels of diversity.

Disturbances influence the structure and rate of change in an ecosystem

A disturbance is a new environmental condition that affects the structure and rate of change in an ecosystem. Examples of disturbances can be natural (for example fire, flood, wind, and insect invasion) or caused by humans (for example the clearing of a forest, building a road, ploughing a field, or clearing a natural area to build a housing development.)

In 1975, Joseph Connell proposed a new idea. His theory stated that disturbance is a common phenomenon that can actually have a beneficial effect on species diversity in a community. For example, fire in a forest affects the structure of the forest. By burning down the trees that shade the forest floor, the structure of the community is then changed, many more shade-intolerant plants can grow quickly, so the rate of change is affected.

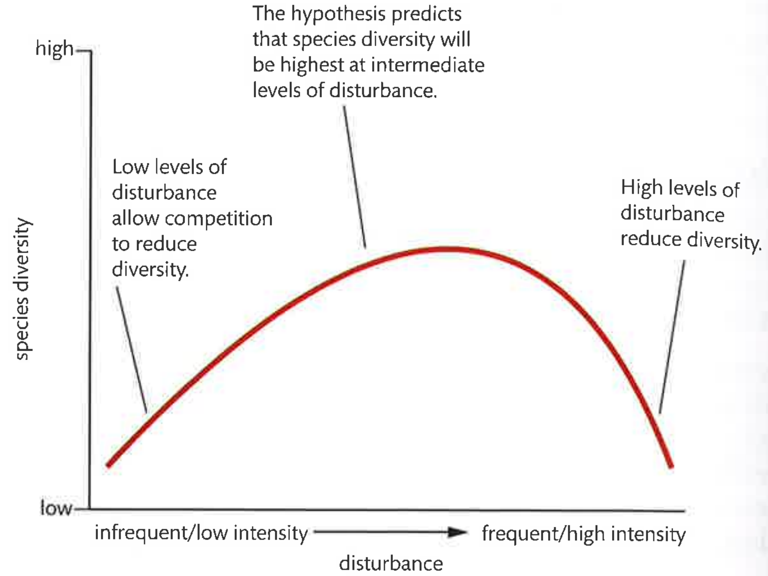


Figure 14.25 Graph of the disturbance hypothesis. Disturbance is a common phenomenon which may have a beneficial effect on species diversity in a community. Molles, Jr. 2010, Fig. 16.18

Look at Figure 14.25 and the points below.

- High levels of disturbance (e.g. constant mowing) reduce diversity. The community will only consist of the few species that can complete their life cycle between disturbances.
- Low (infrequent) disturbances will cause a decline in diversity because the species that are the best competitors will dominate.
- Intermediate levels of disturbances, such as a fire every few years, are the most effective at maintaining diversity. There is enough time between disturbances for a number of species to colonize an area. It can also slow the growth of dominant species.

Exercises

4 Describe a method of representing the cycling of nutrients in an ecosystem.
5 Explain how the Earth is a closed ecosystem.
6 Compare and contrast two energy pyramids from two different ecosystems.

C.3 Impact of humans on ecosystems

Understandings:

- Introduced alien species can escape into local ecosystems and become invasive.
- Competitive exclusion and the absence of predators can lead to reduction in the numbers of endemic species when alien species become invasive.
- Pollutants become concentrated in the tissues of organisms at higher trophic levels by biomagnification.
- Macroplastic and microplastic debris has accumulated in marine environments.

Applications and skills:

- Application: Study of the introduction of cane toads in Australia and one other local example of the introduction of an alien species.
- Application: Discussion of the trade-off between control of the malarial parasite and DDT pollution.
- Application: Case study of the impact of marine plastic debris on Laysan albatrosses and one other named species.
- Skills: Analysis of data illustrating the causes and consequences of biomagnification.
- Skills: Evaluation of eradication programmes and biological control as measures to reduce the impact of alien species.

NATURE OF SCIENCE

Assessing risks and benefits associated with scientific research: the use of biological control has associated risk and requires verification by tightly controlled experiments before it is approved.

Biological control: risks and benefits

Biological control is the idea of using a natural predator to control unwanted or invasive species. There are powerful arguments for using biological control. One argument is that biological control is an environmentally friendly alternative to chemical control. In fact a report by the National Academy of Sciences in 1987 argued that biological control should be the primary pest control method in the USA. When an invasive species is affecting an entire community, even cautious observers would agree that biological control should be considered. However, there is always a risk when introducing a new organism into an ecosystem. Unexpected consequences may occur even though rigorous testing is carried out beforehand. Scientists look at risk–benefit analyses and make decisions based on those analyses.

Introduced alien species can become invasive

One of the classic examples of biological control 'gone wrong' is the introduction of cane toads, *Rhinella marina*, into Australia in the 1930s. The cane toad was imported from Hawaii and released in Queensland to control the beetle pests of sugar cane.

The larvae of the beetle pests of sugar cane eat the roots of the cane and the plants die. Cane growers were interested in controlling the beetle pests because sugar cane crops are a major income producer in Australia. Entomologists researched many solutions to the sugar cane pest problem, such as chemical insecticides, soil fumigation methods, and physical removal. After 25 years, none showed much promise in field trials.

In 1935 one entomologist was sure he had found the solution. In Hawaii, the cane toad was being used to control beetle infestations of sugar cane crops. This idea was quickly accepted in Australia. In June 1935, 2400 toads were released in an area of Queensland. Other entomologists had argued against this quick release. Risk assessments of the potential harm of introducing these toads had not been done. Unfortunately, the outcome has been that this poisonous toad has multiplied very rapidly, currently the population has grown to more than 200 million, yet the beetles that the cane toad was brought in to eradicate have not been affected. It seems that the beetle pests were not affected because in Australia, compared with Hawaii, the toads have found other food sources, such as smaller beetles and moths. By 1950 the cane toad was recognized as a pest in the Vermin Act, but it wasn't until the 1980s that the cane toad was recognized as a national issue. Lessons learnt from the cane toad debacle are probably one of the reasons why Australia today has very strict quarantine laws and tough risk-assessment procedures.

Australia is the only nation with a specific law for classical biological control, the Australian Biological Control Act of 1984. Most state laws in the USA encourage the use of biological control, but adequate supervision is lacking. There is an international organization, the International Organization for Biological Control (IOBC), working to promote environmentally safe practices around the world.

- **Cane toads were brought to Australia to control the sugar cane beetles biologically.**
- **Cane toads have no natural predators in Australia because they are toxic to Australian crocodiles and large lizards.**
- **Cane toads reproduce rapidly.**
- **Cane toads have become more of a pest in Australia than the beetles they were meant to eat.**
- **Cane toads have found plenty of other species to eat in Australia, so they ignore the target beetle pests.**
- **The risk assessment carried out before the introduction of cane toads to Australia was not adequate.**

Competitive exclusion can affect endemic species

The principle of competitive exclusion states that no two species can occupy the same niche. When two species have a similar need for the same resources, such as food, one will be excluded. In Australia, when the cane toads attain high population densities, they consume a large number of invertebrates. Individual cane toads are thought to consume 200 beetles, ants, and termites per night. A report from the National Cane Toad Task Force of Australia in June 2005 showed that a decline in some small reptile species has coincided with the increase in the cane toad population. Competition for food is inferred as the reason for the population declines. A burrowing frog, *Limnodynastes omatus*, shows no survival of tadpoles in ponds where cane toad tadpoles are present. Direct predation on tadpoles is not significant, which is why competition for food is inferred. Small skinks (blue-tongued lizards) begin to disappear once the cane toad arrives. Both species are insectivores, and it is hypothesized that the skinks are outcompeted by the cane toad for insects because of the voracious appetite of the toad. These examples are evidence that endemic species are being outcompeted by the cane toads. Many more studies are being carried out by scientists in Australia to discover what exactly the results are of this attempt at biological control.

The eastern blue-tongued skink.

The cane toad.

Absence of predators can affect endemic species

Cane toads are extremely poisonous. Behind the ears of cane toads are glands that contain a toxic substance. Predator species in Australia are seriously affected by eating cane toads. Seventy-five species of turtles are at risk because they can eat toads large enough to kill them with their toxin; 90% of large lizards die after eating cane toads. Other evidence has shown an impact on snakes and crocodiles that have eaten cane toads. The absence of a successful predator of cane toads is a significant factor in the population explosion of cane toads in Australia.

New research on cane toads in northern Australia has suggested that a good way to control the cane toad invasion is to use parasites that are specific to cane toads.

Kudzu: an introduced alien species

What we do to the environment today may have unforeseen consequences for future generations. Kudzu was introduced from Japan to the USA in 1876 at the Philadelphia Centennial Exposition as an ornamental plant. In the 1930s it was promoted by the Soil Conservation Service of the US government as a fast-growing plant that could solve the problem of soil erosion. From 1935 to 1950 it was planted by the Civilian Conservation Corp sponsored by the federal government. Then, in 1953, it was recognized by the US Department of Agriculture as a pest weed.

TOK

Will our knowledge of the damage that biological control can do, if not monitored well, change the methods we use in the future?

Currently, kudzu is common throughout the southeastern states of the USA. It is often called 'the plant that ate the South'. Here is the reason why: kudzu grows rapidly, as much as 20 m per season. Thirty stems can emerge from one root. It grows both horizontally and vertically. Kudzu spreads by runners that can make roots and produce more plants. Kudzu grows well in many conditions, although prolonged freezing will kill it. The thick growth crushes other plants as it covers them. Its weight breaks tree branches. In the USA, the effects of kudzu cost $500 million annually.

Kudzu, the plant that ate the South.

Biomagnification

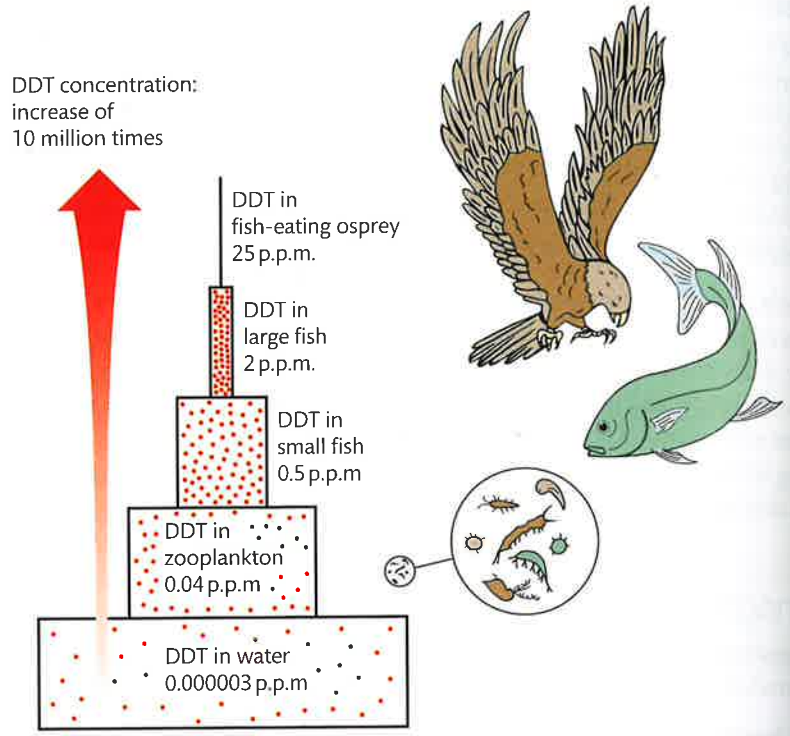
Biomagnification is a process by which chemical substances become more concentrated at each trophic level.

When chemicals are released into the environment they may be taken up by plants. The plants may not be affected by the small amount of a chemical that they absorb or have on their surface. But when large amounts of the affected plants are eaten by a primary consumer, the amount of chemical the consumer takes in is much greater. Similarly, if numbers of the primary consumer are eaten by a secondary consumer, the amount of chemical taken in by the secondary consumer is magnified even more. Chemicals that are biomagnified in this manner are fat soluble. After ingestion, they are stored in the fatty tissue of the consumer. When the consumer is caught and eaten, the fat is digested and the chemical moves to the fatty tissue of the secondary consumer.

Causes of biomagnification

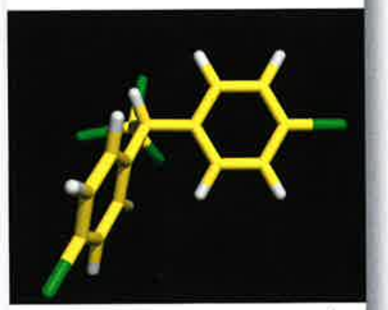
Some toxic chemicals have been put deliberately into the environment to kill insect pests. One of these pesticides is dichlorodiphenyltrichloroethane (DDT), which has been used to control mosquitoes and other insect pests. At the time it was first used, it was not known that DDT does not break down and can persist for decades in the environment. DDT was commonly sprayed on plants and eventually entered water supplies. There it was absorbed by microscopic organisms. These microorganisms were eaten by small fish, and the small fish were eaten by larger fish. DDT built up in the fatty tissues of the fish. When these fish were eaten by birds, the magnification of DDT was even greater (see Figure 14.26).

Figure 14.26 Biomagnification of DDT.



The proposal to commit to a deadline for a worldwide ban on the pesticide DDT by 2020 was rejected at the Sixth Conference of the Parties to the Stockholm Convention on Persistent Organic Pollutants. India, the largest producer of DDT, strongly opposed the proposal. India is the only country still manufacturing DDT.

A feeding mosquito.



DDT.

Consequences of biomagnification

The first sign of the problem with DDT was a decline in the number of predator birds. Studies showed that the eggs of these birds were easily cracked. In fact, the weight of the mother sitting on the eggs cracked them. It was finally discovered that DDT was building up in the tissue of the birds and interfering with the calcium needed for the shells to be hard. DDT was banned in the USA in 1971. The bird population has begun to recover following the ban. DDT was originally banned because of its effects on birds. However, It also affects humans who consume agricultural products and eat fish containing accumulations of DDT. Because DDT is stored in fat, levels of DDT in breast milk are often six times higher in a mother than in her blood.

The trade-off between DDT pollution and malarial parasite control

What are the challenges that must be overcome as we face decisions over DDT pollution and malarial parasite control? Malaria is the most deadly vector-borne disease in the world. It kills more than 1 million people per year. In the past 25 years, there has seen a dramatic rise in cases of malaria, despite the use of insecticide-treated bed nets (ITNs), indoor resident spraying (IRS), and artemesin combination therapy (ACTs, an antimalarial drug). How can we overcome this challenge? Should the trade-off be the environment or human health?

DDT pollution

We have just looked at some of the problems caused by biological magnification of DDT. DDT is a persistent organic pollutant (POP). These pay-offs have followed the

ban on DDT in the USA. Peregrine falcons have come off the endangered species list; bald eagles will soon follow. DDT levels in human blood samples have declined sharply. DDT has disappeared from the breast milk of nursing mothers.

Control of malaria for large human populations

The difficulties of malaria control for some nations are significant. When IRS is used in houses, DDT can be found in the breast milk of nursing mothers. Without IRS, hundreds of mosquitoes can enter a house, compared with no mosquitos entering a house that has been sprayed. In Africa and Indonesia, malaria is more of a problem than human immunodeficiency virus (HIV). Many health officials would like to use DDT to ease the suffering of human populations, but donor governments refuse to allow DDT spraying. A documentary movie shows the effect of refusing to spray DDT for human populations in underdeveloped countries; *3 Billion and Counting*, tells the story of the devastation of malaria on large populations of people.

Macroplastics in the marine environment

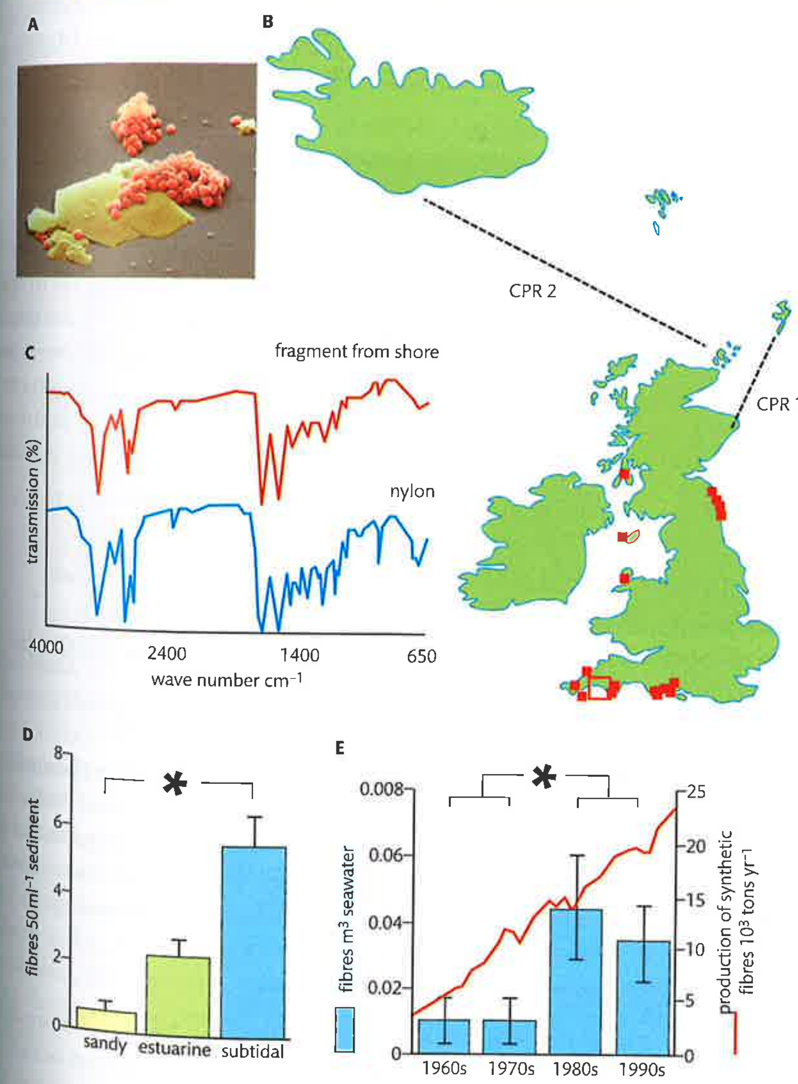


Figure 14.27 **(A)** Facial scrub particles shown in an electron micrograph are microplastics polluting the ocean. **(B)** Sampling locations in North-East Atlantic, showing Routes sampled by Continuous Plankton Recorder (CPR 1 and 2) since 1960 and used to assess the abundance of microplastics in the water column. Red squares indicate the abundance of microplastics. **(C)** Example showing how FT-IR spectroscopy was used to identify fragments from the environment. Here an unknown fragment is identified as nylon. **(D)** There were significant differences in abundance of microplastics between sandy beaches and subtidal habitats , but abundance was consistent among sites within habitat type. **(E)** Accumulation of microscopic plastic in CPR samples revealed a significant increase over time when comparing the 1960s and 1970s to the 1980s and 1990s. Approximate figures for global production of synthetic fibres (red line) overlain for comparison. Microplastics were also less abundant along the oceanic route CPR2 than CPR 1. To read the article where this figure is adapted from ('Lost at sea: Where is all the plastic?'), go to the hotlinks site, and click on Chapter 14: Section C.3.
http://www.kimointernational.org/MicroPlasticResearch.aspx

The Marine Conservancy has published the estimated decomposition rates of most plastic debris found on coasts.

- Polystyrene cups: 50 years.
- Plastic drinks containers: 400 years.
- Disposable nappies: 450 years.
- Plastic bottles: 450 years.

A Laysan albatross with regurgitated waste.

A sea lion caught in a fishing net.

Macroplastics are pieces of plastic bigger than 5 mm. The accumulation of macroplastics is very high adjacent to urban areas in the northern hemisphere. Macroplastic items such as plastic bottles, bags, nets, fishing lines, and many items of rubbish can pose a serious threat to marine wildlife.

- Marine mammals and turtles can ingest plastic bags and bottles, which then interfere with their digestive system.
- Drift nets can entangle birds, fish, and mammals.
- PCBs and other contaminants may be concentrated in pieces of plastic pieces that are ingested by birds, fish, and mammals.

The Laysan albatross

Seabirds can mistake plastic floating on the surface of water as food and ingest it. Because most adult birds regurgitate food to feed their young, the plastic is passed on to the chicks. One study discovered that 98% of Laysan albatross, *Phoebastria immutabilis*, chicks had been fed beads, toys, golf tees, buttons, and many other plastic items by their parents. It seems that the albatross prefers pink items. It is hypothesized that pink items are the same colour as, and are mistaken for, shrimps. These items can obstruct a chick's digestive system, leading to starvation and death. One Laysan albatross chick had a piece of plastic 11 cm long embedded in its gut.

Microplastics in the marine environment

Microplastics are defined as plastic particles smaller than 5 mm. They are produced directly as abrasives and exfoliants, or indirectly as a consequence of the breakdown of larger plastic material. The amount and distribution of microplastic particles in the marine environment has increased steadily over the past 20 years because of the rise in the use of plastics by humans. It has been found that microplastics act like sponges and soak up toxic chemicals such as PCBs in the marine environment. Microplastics have a large surface area in relation to their size, so there is plenty of surface for the chemicals to stick to. The potential impacts of microplastics on the marine environment include:

- accumulation of more and more plastic debris, because these plastics do not break down
- ingestion of microplastic pieces by marine organisms, causing damage to their digestive systems
- absorption of components of the plastic, or chemicals adsorbed on the plastics, by the ingesting organism
- accumulation of those chemicals in the body of the ingesting organism.

Research is ongoing to determine whether microplastics themselves or the chemicals they contain are carried across trophic levels. For example, do PCBs or other POPs adsorbed onto plastic pieces build up in the bodies of fish and become magnified as the small fish are eaten by larger fish, etc.? Biomagnification of chemicals from plastics, either within the plastics or adsorbed onto the plastic pieces, may be occurring.

Impact of microplastic debris on lugworms

Lugworms, *Arenicola marina*, are called the earthworms of the sea. They are commonly found in the USA and Europe and are used as bait by fishermen. They feed on ocean floor sediments by striping the sediment of debris and organic matter. They can eat sand particles and digest the microorganisms and nutrients on the surface of the sand particles. Because they are basically 'eating' what has fallen to the bottom of the sea, their health can tell us about the health of the oceans, making them indicator organisms. In one experiment, a California scientist, Mark Anthony Browne, found that, when lugworms eat microplastic pieces contaminated with common chemical pollutants, those pollutants are found in high concentrations in the lugworm's tissues. These high concentrations make the lugworms vulnerable to pathogens. They cause the worms to have less energy for churning up the bottom sediments, which is one of their most important functions in the ocean ecosystem. This is a key finding because the current policy in the USA considers microplastics to be non-hazardous.

A lugworm casting on a beach.

Mark Anthony Browne from the University of California at Santa Barbara has joined with UK scientists from Plymouth University to study lugworms as they feed on highly contaminated ocean sediments.

Biological control and eradication programmes to reduce the impact of alien species

Invasive alien species are recognized as a serious biological threat to the environment and to economic development. Without any natural predators, a plant or animal that has been moved out of its local ecosystem may multiply and threaten other species, agriculture, or public health. Many nations are grappling with the complex and costly problems caused by invasive alien species organisms, such as the black striped mussel and fire ants. The following examples describe some strategies that have been used to eradicate invasive alien species.

Water hyacinths are aquatic plants native to the Amazon basin, but are often considered an invasive species outside of their native range.

The black striped mussel, *Mytilopsis sallei*, was found to have invaded Cullen Bay in Darwin Harbor, Australia, in 1988. This mussel is capable of making a thick matt more than 10 cm thick and can foul anchors, pylons and buoys, storm water pipes, vessel hulls, and breakwaters. It is a very serious threat to tropical Australian waters. Regular surveys of Australian ports highlighted the discovery of the mussel within 6 months of its arrival. A rapid decision to eradicate it prevented the spread. The method of eradication was to close the gates to the marina where they were located and expose the entire area to copper sulfate and chlorine. These chemicals were poured into the water, killing the mussels and all other living organisms in the marina. The potential economic damage to the pearl industry from black mussels is $350 million a year, and damage to the prawn fishery catch is worth close to $120 million a year at today's values.

International Pellet Watch (IPW) was founded in 2005 by Dr Hideshige Takada of Tokoyo University. He has asked citizens across the globe to collect plastic pellets from the beaches they visit and send them to his laboratory. He analyses the POP content of the pellets and their global distribution. The results are sent back to donors by email and released on the web. So far pellet samples have been analysed from 200 locations and 40 countries. About 1000 pellets have been analysed, and POPs have been detected in every one of those 1000 samples.

Imported red fire ants on a wooden stick.

Fire ants, *Solenopsis invicta*, are notorious because of their painful, burning stings. The stings result in pustules, which continue to itch intensively. Fire ants attack humans as they walk across lawns and golf courses. Red fire ants also attack livestock grazing in the fields of Florida. Fire ants were brought to Florida from South America. Use of insecticides kills native ants as well as fire ants, but fire ants return much more quickly than the native ants. Insecticides are the primary control of fire ants today in Florida. The estimated cost of red fire ant control in Florida is $36 per household.

A biological control agent that is being tested against fire ants is a fly of the genus *Pseudacteon*. If the fly catches an ant, it lays its eggs inside the head of the fire ant. When the eggs hatch, the larvae eat through the head of the fire ant. *Pseudacteon* flies might work but they might not control the fire ants. They could also become a pest because they have no predators. In South America, the fire ant population is only one-fifth the size of that in southern USA. Scientists hypothesize that the 24 species of *Pseudacteon* flies native to South America keep the fire ant under control. In 2011, one species of *Pseudacteon* fly was introduced to control fire ants in Florida. It was found that it did not have a significant impact on the fire ant population after its release. The study concluded that multiple species of flies would be required in order to replicate the conditions of natural fire ant control seen in South America. Would Florida be inviting new pests to the sunshine state, in the hope of ridding themselves of an old pest?

The oriental fruit fly, *Bactrocera dorsalis*, was introduced into Okinawa Island in Japan in 1945. It damages fruit crops by laying eggs in the fruit: the larvae from the eggs eat the fruit. All Japanese territories were declared free of the oriental fruit fly in 1985, because of an 18-year eradication programme combining some insecticide use with sterile insect release (SIR). SIR entails raising large numbers of sterile male flies and releasing them to mate with wild females. The numbers of released sterile males are very high. In one study, 648 sterile males were released for every one wild male in the wild population. However, according to another study it is enough to release nine sterile males to one wild male. When the males are released and mate with wild females, the eggs from these females are not viable. After SIR release on one island, the percentage of infestation of host fruits decreased to zero in 3 months. The success of SIR and strict inspection of incoming produce that might contain this fruit fly means that Japan has been free of the oriental fruit fly for the past 20 years.

An adult female oriental fruit fly, *Bactrocera doralis*.

CHALLENGE YOURSELF

21 Evaluate the eradication programmes described above by yourself or with a friend.

Analysis of data illustrating the cause and effects of biomagnification

As we have learned previously, biomagnification is the build-up of heavy metals and POPs by successive trophic levels, resulting in higher concentrations in the predator organisms than in the prey. Bioaccumulation is the net accumulation over time of POPs or heavy metals (such as mercury, arsenic, and lead) within an organism from both biotic (other organisms) and abiotic (soil, water, etc.) sources.

Whenever a question in an IB exam asks you to 'evaluate' something, it means to state both the risks and the benefits. It does not mean give just your opinion. Creating a table is a good way of answering this type of question.

TOK: Can you use inductive reasoning to formulate a hypothesis about the effectiveness of biological control?

CHALLENGE YOURSELF

The data you will analyse were collected from streams in the USA, from the state of Missouri, in an area called the Ozarks. The heavy metal that is causing concern there is mercury. It is hypothesized that mercury is bioaccumulating in several fish that are commonly caught and eaten by the people in this area.

Mercury (Hg) is a pollutant from both natural and human sources. Mercury found in aquatic systems comes from leaf litter: leaves accumulate atmospheric mercury when alive and then fall into streams when dead. Wet areas are conducive to changing the inorganic mercury in the leaves into methyl mercury (MeHg), which is subject to bioaccumulation and biomagnification. MeHg is highly toxic to fish, wildlife, and humans. In the USA, nationwide fish consumption guidelines have been developed. For example, Missouri guidelines suggest not consuming a fillet of fish that is more than $0.3\ \mu g\ g^{-1}$ wet weight of the whole fish because of MeHg accumulation. Recreational fishermen in the Ozarks catch hogsuckers and smallmouth bass. The fatty tissues of both these fish typically exceed the amount of MeHg recommended as safe in Missouri.

Figure 14.28 shows the food web for the study you are about to analyse, and an explanation of the organisms that are involved in the biomagnification process.

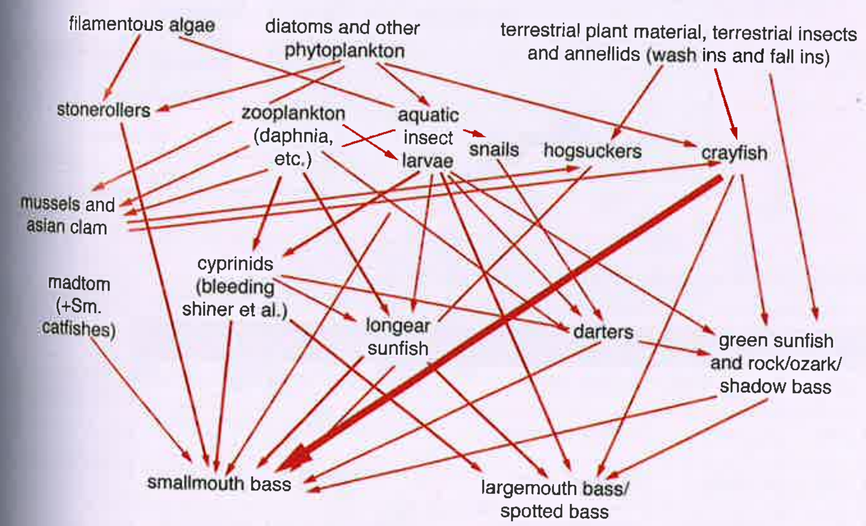


Figure 14.28 Simplified food web. Adapted from www.combat-fishing.com/ reproduced with permission

The organisms involved in this process are described below.

The Asian clam *Corbicula* is a filter-feeding mollusc that ingests fine particulate organic matter from leaf litter and algae.

Crayfish, *Cambarus*, are crustaceans that are omnivorous primary consumers; they eat leaf litter, and aquatic invertebrates such as clams and fish.

Hogsuckers, *Hypentelium nigricans*, are bottom-feeding fish that eat aquatic invertebrates such as crayfish, and organic matter from the stream bottom.

Smallmouth bass, *Micropterus dolomieu*, are fish that feed primarily on crayfish, along with other aquatic invertebrates and small fish.

Look at the map of sites (Figure 14.29) sampled by scientists from the University of Nebraska at Lincoln. Figure 14.29 and Table 14.7 tell you where the samples were taken and the name of the sites. You will need this information when you analyse the data from the following graphs.

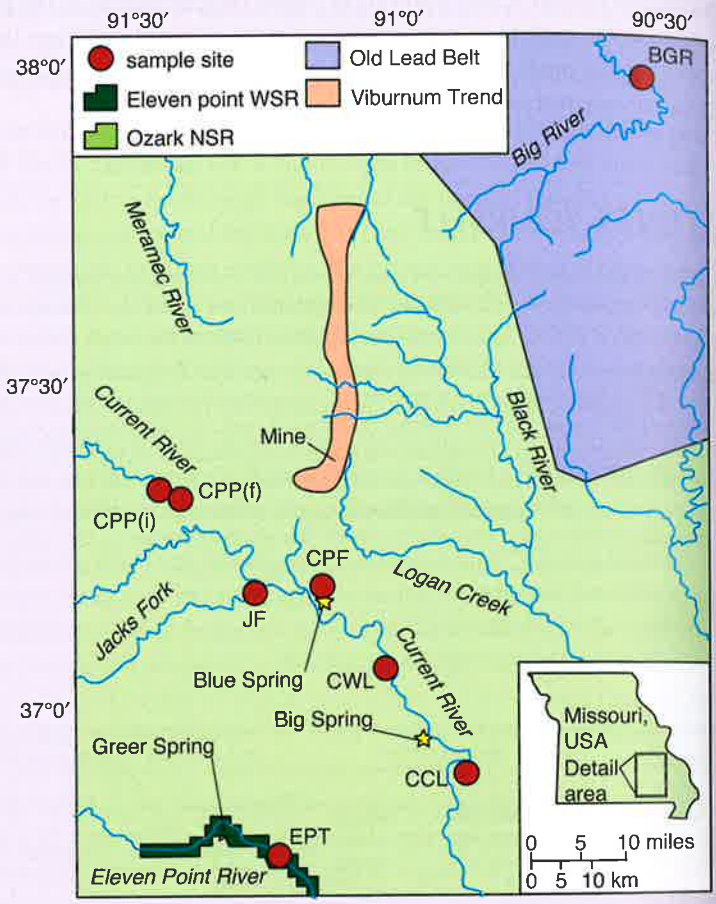


Figure 14.29 Map showing collection sites, lead-zinc mining area (Viburnum Trend and Old Lead Belt), and boundaries of the Eleven Point Wild and Scenic River and boundaries of the Ozark National Scenic Riverways. Schmitt et al. 2011, Fig.1

Table 14.7 The collection sites for the fish

Collection sites for fish (f) and invertebrate (i; crayfish and *Corbicula*).

Site	River	Location	Latitude, longitude [b]
$EPT_{i,f}$	Eleven Point	Turners Mill	36°45′56.7″N, 91°16′01.0″W
CPP_i	Current	Pulltite Landing	37°20′04.1″N, 91°28′33.8″W
CPP_f	Current	Presley Center	37°19′12.6″N, 91°26′14.6″W
$JF_{i,f}$	Jacks Fork	Shawnee Creek	37°10′21.3″N, 91°18′00.6″W
$CPF_{i,f}$	Current	Powdermill Ferry	37°10′48.0″N, 91°10′25.0″W
$CWL_{i,f}$	Current	Waymeyer Landing	37°03′15.1″N, 91°03′16.8″W
$CCL_{i,f}$	Current	Cataract Landing	36°53′22.2″N, 90°54′473″W
$BGR_{i,f}$	Big	St Francois State Park	37°57′23.7″N, 90°32′29.2″W

Schmitt et al. 2011, Tab. 1

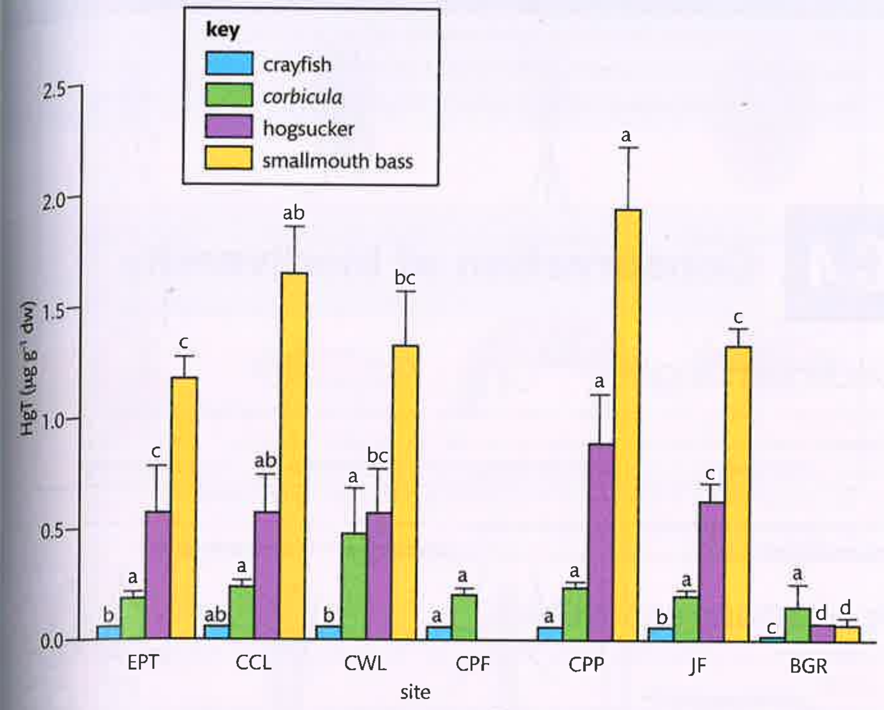


Figure 14.30 Total mercury (HgT) arithmetic site means (±standard errors) in *Corbicula*, crayfish, hogsuckers, and smallmouth bass. Within taxa, means sharing the same letter are not significantly different (ANOVA, $p<0.05$). See **Figure 14.29** and **Table 14.7** for site names and locations. Figure 14.30: Schmitt et al. 2011, Fig. 2

Look at the graph Figure 14.30 of mercury build-up at these sites.

22 Distinguish between the concentration of HgT in crayfish and smallmouth bass at all the sites where both were collected.

23 Compare and contrast HgT at the two sites CPP and BGR.

24 Across all the sites, which organism had the highest concentration of HgT? Suggest a reason for this.

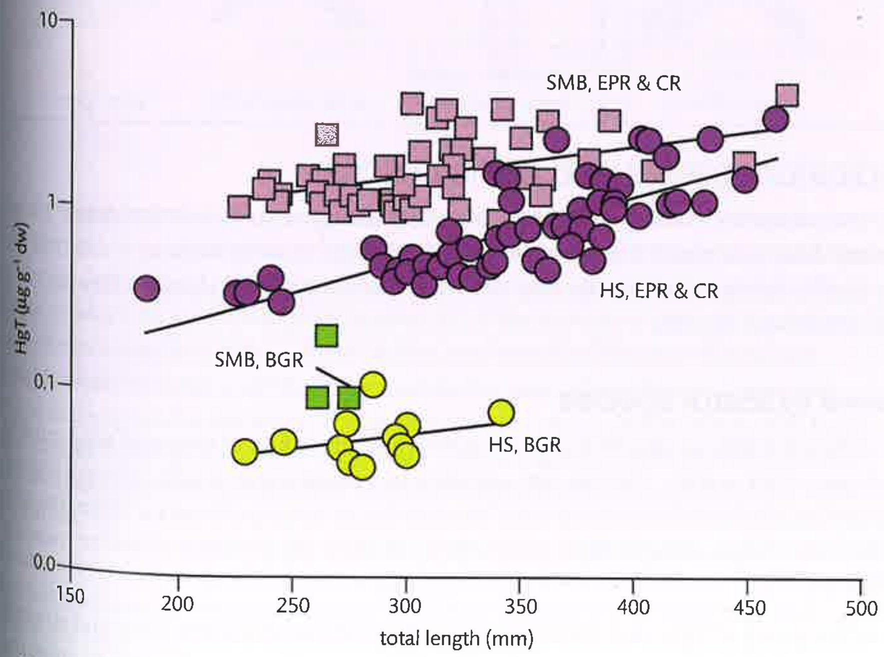


Figure 14.31 Total mercury (HgT; *y*) versus total length (*x*) in hogsuckers (HS) and smallmouth bass (SMB) from the Current River (CR), Eleven Point River (EPR), and Big River (BGR). Adapted from Schmitt et al. 2011, Fig. 3

25 Using Figure 14.31, was it length or site that contributed to HgT accumulation?

26 If you were an Ozark fisherman, at which site would you choose to fish? Explain your answer.

To learn more about the DDT controversy, go to the hotlinks site, search for the title or ISBN, and click on Chapter 14: Section C.3

NATURE OF SCIENCE

Scientists collaborate with other agencies: the preservation of species involves international cooperation through intergovernmental and non-governmental organizations.

Exercises

7 Explain how competitive exclusion can affect endemic species.
8 Describe the effect of microplastics on the marine ecosystem.
9 Discuss the trade-offs between DDT and control of malarial parasites.

C.4 Conservation of biodiversity

Understandings:

- An indicator species is an organism used to assess a specific environmental condition.
- Relative numbers of indicator species can be used to calculate the value of a biotic index.
- *In situ* conservation may require active management of nature reserves or national parks.
- *Ex situ* conservation is the preservation of species outside their natural habitats.
- Biogeographic factors affect species diversity.
- Richness and evenness are components of biodiversity.

Applications and skills:

- Application: Case study of the captive breeding and reintroduction of an endangered animal species.
- Application: Analysis of the impact of biogeographic factors on diversity limited to island size and edge effects.
- Skill: Analysis of the biodiversity of two local communities using Simpson's reciprocal index of diversity.

Guidance

- *The formula for Simpson's reciprocal index of diversity is:*

$$D = \frac{N(N-1)}{\Sigma n(n-1)}$$

D = diversity index, N = total number of organisms of all species found, and n = number of individuals of a particular species.

Indicator species and biotic indices

Do you remember reading stories of coal miners taking canaries into the mines? If the canary died, it indicated the presence of poisonous gas. In an ecosystem, some species are like those canaries. They are very sensitive to environmental change. They are called indicator species.

Some indicator species

A common indicator species is lichen. Lichens live on rocks and trees and are a reliable indicator of air quality. They are very sensitive to pollution in the atmosphere. Lichens are not usually found on trees in a city because the air is too polluted for them. Because lichens also retain metal in their tissues, they can show the presence of lead or mercury in the air.

Another group of indicator species are macroinvertebrates found in rivers and streams (see Figure 14.32). The presence or absence of these organisms can be used to judge the water quality.

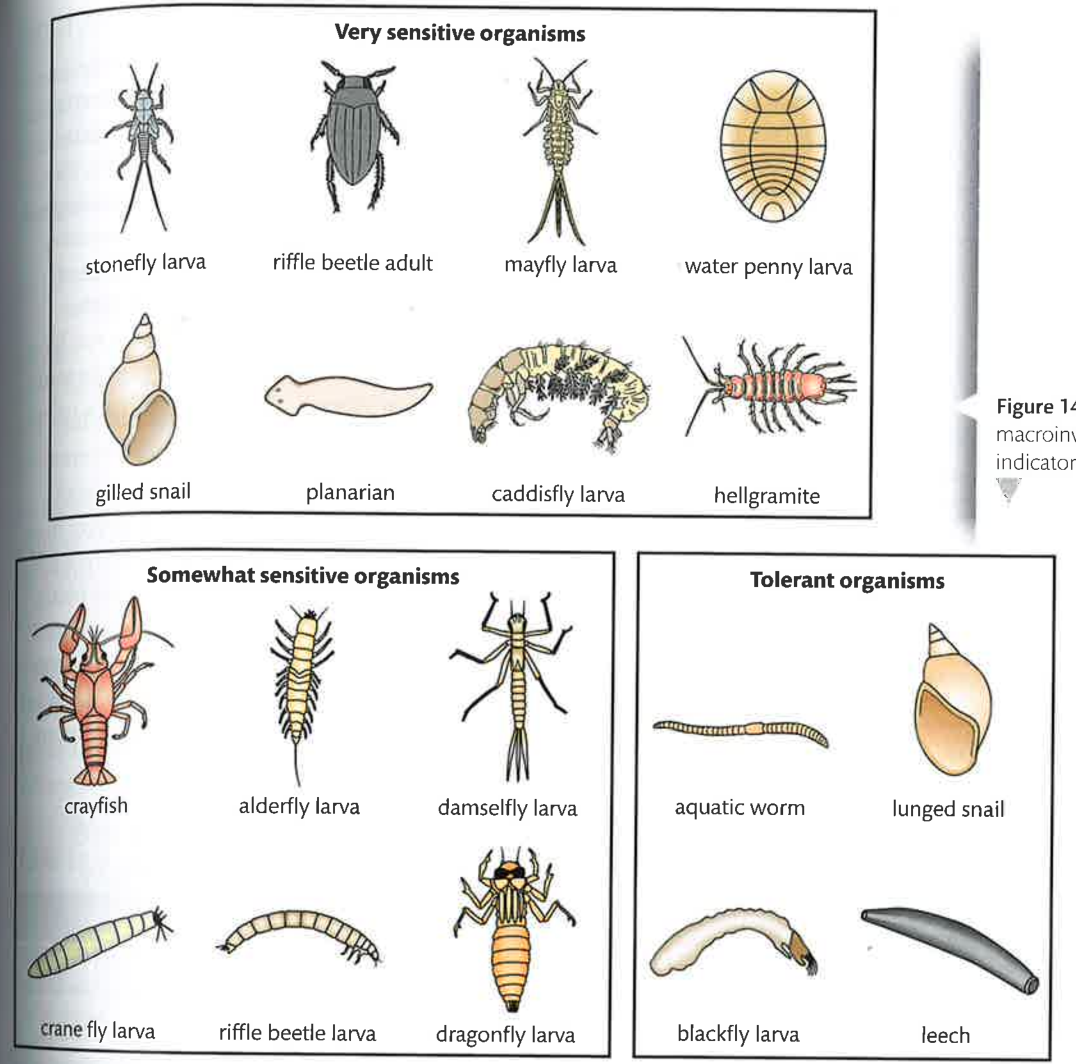


Figure 14.32 Some macroinvertebrates that are indicator species.

We are all interested in the quality of our rivers and streams. In the recent past, rivers and streams were often used as dumping grounds for toxic chemicals and unwanted materials. In Chicago, USA, around 1900, the river was a dumping ground for the waste products from the slaughter houses. All of the unwanted parts of the animals were thrown into the Chicago River. In fact, one branch of the river was named 'bubbly creek' because of all the fermentation that was taking place as the animal tissue decomposed in the water. Today, that river is a much cleaner place, with boats and canoes floating on it rather than waste. This change has come about because of our increased awareness that water and waterways are precious commodities to be treasured.

Freshwater indicator species have various levels of pollution tolerance. Organisms like leeches and aquatic worms are not very sensitive and can live in water with low oxygen levels and high amounts of organic matter. Organisms like the larvae of alderfly and damselfly are moderately sensitive, whereas the larvae of the mayfly and caddisfly are very sensitive to pollution. The very sensitive organisms must have high levels of oxygen and little organic matter in the water in order to survive. The cleaner the water, the higher the number of sensitive organisms present.

Stream study: Sample record and assessment

Stream ____________ Site number ____________

County or city ____________ State ____________

Collection date ________ Collectors ____________

Weather conditions (last 3 days) ____________

Average depth at site ________ Average width at site ________

Water temperature ______ °C ______ °F

Flow rate: ☐ High ☐ Normal ☐ Low

Appearance: ☐ Clear ☐ Cloudy ☐ Muddy

Macroinvertebrate count

Sensitive	Somewhat sensitive	Tolerant
☐ __ caddisfly larvae	☐ __ beetle larvae	☐ __ aquatic worms
☐ __ hellgramite	☐ __ clams	☐ __ blackfly larvae
☐ __ mayfly larvae	☐ __ crane fly larvae	☐ __ leeches
☐ __ gilled snails	☐ __ crayfish	☐ __ midge larvae
☐ __ riffle beetle adult	☐ __ damselfly larvae	☐ __ lunged snails
☐ __ stonefly larvae	☐ __ dragonfly larvae	
☐ __ water penny larvae	☐ __ scuds	
	☐ __ sowbugs	
	☐ __ fishfly larvae	
	☐ __ alderfly larvae	
	☐ __ watersnipe larvae	
boxes checked × 3 = ____ index value	boxes checked × 2 = ____ index value	boxes checked × 1 = ____ index value

Water quality rating ☐ Excellent (>22) ☐ Fair (11–16)

Total index count ____ ☐ Good (17–22) ☐ Poor (<11)

Figure 14.33 Stream study sampling form.

Biotic index

When you perform a river or stream study, you count the number of macroinvertebrates collected in each sample and record the data on a stream study form (see Figure 14.33). The number of organisms in each group is multiplied by a factor that is determined by how sensitive the organism is to pollution. The presence of sensitive organisms is multiplied by a higher number. The more sensitive organisms you have in the sample, the higher the quality of the water in the river or stream. The total number is called the biotic index.

Periodic sampling gives an idea of the overall health of the river or stream. After a storm, there will be a lot of run-off from the areas surrounding the river. How does the run-off affect the biotic index? Is any sewage diverted into a river after a big storm? Is the biotic index different in winter and spring? Sampling provides us with biological data that can be used to answer these questions.

Richness and evenness are components of biodiversity

Biological diversity can be described in two ways: evenness and richness. The number of different organisms in a particular area is the richness. Evenness is how the quantity of each organism compares with the other. Richness only takes into account the kinds of species present in the ecosystem, while evenness take abundance into account.

For example, Table 14.8 compares the numbers of different larvae in samples from two interdunal ponds at the Indiana dunes.

Table 14.8 Dune samples

Larva species	Number of individuals in sample 1	Number of individuals in sample 2
Caddisfly larva	200	20
Dragonfly larva	425	55
Mosquito larva	375	925
Total	1000	1000

Both samples have the same number of individuals, but in sample 2 the numbers are not distributed evenly between the species. Both samples have the same species richness: each has three types of larvae. But they do not have the same evenness.

The individuals in sample 2 are mainly mosquito larvae. A community is not considered diverse if it is dominated by one species.

Analysis of the biodiversity of two local communities

A measure that takes into account both richness and evenness is the Simpson diversity index. To see how this works, let's consider the community of plants on the foredune at the Indiana dunes and the community of plants on the mature dune. Which would you hypothesize is more diverse and why? To calculate the Simpson diversity index, we need the formula

$$D = \frac{N(N-1)}{\text{sum of } n(n-1)}$$

where
D = diversity index
N = total number of organisms in the ecosystem
n = number of individuals of each species

So, for each community we need to know the number of organisms present and the number of individuals of each species present. This information is found by sampling the two dunes with quadrats as follows:

- record the number of plant species in each quadrat
- count the number of individuals of each species
- record the data for each area in tables.

Tables 14.9 and 14.10 record the plant species on the foredune and mature dune of the Indiana dunes.

Table 14.9 Plant species recorded on the foredune of the Indiana dunes

Plant species	Number of individuals, n	$n(n-1)$
Marram grass	50	50(49) = 2450
Milkweed	10	10(9) = 90
Poison ivy	10	10(9) = 90
Sand cress	4	4(3) = 12
Rose	1	1(0) = 0
Sand cherry	3	3(2) = 6
Totals	N = 78	2648

Table 14.10 Plant species recorded on the mature dune of the Indiana dunes

Plant species	Number of individuals, n	$n(n-1)$
Oak tree	3	3(2) = 6
Hickory tree	1	1(0) = 0
Maple tree	1	1(0) = 0
Beech tree	1	1(0) = 0
Fern	5	5(4) = 20

Plant species	Number of individuals, n	$n(n-1)$
Moss	3	3(2) = 6
Columbine	3	3(2) = 6
Trillium	3	3(2) = 6
Virginia creeper	4	4(3) = 12
Solomon seal	3	3(2) = 6
Totals	$N = 27$	62

Using the formula given above, the calculation for the foredune is:

$$D = \frac{78(77)}{2648}$$

$$D = 2.27$$

The calculation for the mature dune is:

$$D = \frac{27(26)}{62}$$

$$D = 11.3$$

Was your hypothesis correct? According to Simpson's diversity index, the mature dune is more diverse even though the total number of plants is less. The mature dune has a higher diversity index because it has a higher number of different species. Periodic sampling of an area and calculation of its Simpson index provides an assessment of the health of an ecosystem.

Investigation into the effect of an environmental disturbance in an ecosystem

Ecological disturbances remove biomass from an ecosystem. The general effect of an ecological disturbance is to shift the community to an earlier stage in succession, which may be more diverse. The aim of this lab it to compare the species diversity in a disturbed area with the species diversity in an area that has not experienced a disturbance, by taking a series of quadrat samples along a transect line in each area.

For this lab, you will take a trip to an ecosystem that has experienced some disturbance. You will use a combination of transect and quadrat sampling techniques to determine plant species diversity along a disturbance gradient. You will also use the same techniques to determine the plant species diversity along a similar gradient that has not been disturbed. Finally, you will calculate Simpson's index for each quadrat in the plant communities along the transect lines and compare the diversity along each transect.

At the site:

- determine the disturbance you will analyse (for example a path made in the dunes, trampling of an area by visitors, a fire, a blow-out, or a windy side of a dune)
- decide when it occurred (how long ago) and whether it is a repeated, intermediate, occurrence, or a one-time disturbance.

Based on the information you have learned about the effect of disturbances on an ecosystem, you can then make a hypothesis about the effect of the disturbance on this part of the ecosystem. Has the diversity of species increased, decreased, or remained the same as a result of the disturbance? Explain why you have made this hypothesis.

The materials you will need are:

- metre-square quadrats
- rolls of thick twine for the transects, or landscape paint
- soil hooks to hold the transect (twine) in place
- a data table to record the plants species present
- graph paper
- a digital camera
- metre sticks
- field guides.

Follow these procedures.

- Work in teams
- Lay out one transect along the gradient of the ecosystem to be examined where a disturbance has occurred (for example along a trampled area).
- Lay out another transect in parallel where no disturbance has occurred.
- Choose the sampling points along the transect.
- Record the distance along the transect at which you located each quadrat (make a map on graph paper).
- Each team should sample at least two transects, with a minimum of 10 quadrats per transect.
- At each quadrat:
  - identify each species within the quadrat
  - if you cannot identify every species, take a picture of it and give it a name of your own, count it, and, if you see it again, it can be counted again (later it may be identified, but the correct name is not necessary to calculate the diversity index)
  - count the number of each species present and record it
  - photograph each quadrat (make sure to label the photograph with the quadrat number and transect name, disturbed or not disturbed)
  - record qualitative observations at each quadrat site, such as the amount of shade and soil type
  - record as much qualitative data as you can about the disturbance.
- Each team can choose its own disturbance, or several teams can do the same disturbance. Working in teams on the same disturbance will allow more data points to be pooled and give a better estimate of the actual diversity.
- Calculate Simpson's diversity index for each quadrat by using the formula that follows and following the example shown based on the data in Table 14.11.

Table 14.11

Species	Number	N(n - 1)
Lyme grass, *Leymus arenarius*	2	2
Sand couch grass, *Elytrigia*	8	56
Marram grass, *Ammophilia arenaria*	1	0
Sea sand wort, *Honckenya*	1	0
European searocket, *Cakile maritima*	3	6
Total (N)	15	64

The real cost of damaging nature, it turns out, is at least 10 times greater than the cost of maintaining an ecosystem. Using Simpson's index of biodiversity helps ecologists keep track of the changes in diversity that can indicate problems in an ecosystem.

TOK

How do we justify our knowledge? Is an indicator organism sufficient evidence?

NATURE OF SCIENCE

The World Association of Zoos and Aquariums (WAZA) is the lead organization for the world zoo and aquarium community. Its mission is to provide leadership and support for zoos and aquariums. It is dedicated to the preservation of species and involves international cooperation in order to promote conservation of biodiversity around the world.

$$D = \frac{\text{sum of } n(n-1)}{N(N-1)}$$

$$D = \frac{64}{15(14)}$$

$$D = \frac{64}{210}$$

Where D = diversity index, N = total number of organisms in an ecosystem, and n = number of individuals in each species.

$D = 0.3$, which is Simpson index

$1 - D = 0.7$, which is Simpson's index of diversity.

1 Construct a graph showing how Simpson's index of diversity is related to a factor in the ecosystem, such as the distance from the shore to the first dune for both the disturbed and undisturbed areas in the ecosystem.
2 Draw a conclusion a based on the data you (and your classmates) have collected. Restate the data supporting your conclusion. Discuss any uncertainties.
3 Describe how the design of the experiment or data collection method could be improved. Many websites discuss the pros and cons of various sampling methods. What improvements would you make?

As an alternative lab, you could perform a similar investigation of an aquatic environment, such as a river or stream where some disturbance has occurred. Sample benthic organisms along a disturbed and an undisturbed area. Calculate the species diversity using Simpson's index.

Another alternative would be to perform the entire investigation as a class so that repeat samples can be made at each point in the transect or each area of the river or stream. Or either investigation could be performed over time, returning to the site periodically to collect data.

Management of conservation areas

In order to keep the beauty and diversity of a nature reserve, it is important to manage it effectively. Nature reserves cannot just be left to nature. Active intervention is required to restore areas and protect native species. Examples of good management practices are discussed below.

Restoration

Restoration attempts to return the land to its natural state. To restore land on which vegetation has been destroyed may require managers to use active management techniques such as scrub clearance, cutting or burning, and replanting. A UK project is restoring the heathlands within an area designated as a nature reserve in 2007: the Dorset Heathland Project set up in 1989 and completed in 2006, and regular monitoring is ongoing.

The gopher tortoise is a keystone species. Many other species depend on it for survival.

Recovery of threatened species

Threatened species are usually helped when we restore their habitat. Active management maintains the areas needed for the habitat of the endangered species. In a Florida nature reserve, the habitat of the endangered gopher tortoise is being restored. This tortoise lives in deep burrows in a sandhill ecosystem. As many as 350 other animal species live in the burrow with the gopher tortoise. Restoration of the sandhill ecosystem is necessary for the existence of all these species, not just the gopher tortoise. Some insects are obligates with the gopher tortoise, which means they are rarely found anywhere except in the burrow that the tortoise digs.

Removal of introduced species

Most of the exotic species (species that are not native to an area when it is introduced) that are introduced into an area die out because they do not have adaptations for the local ecosystem. However, when an exotic species can survive and takes over, it can have devastating results. In parts of the UK, plants called rhododendrons have taken over large areas and almost eliminated the native plants in those areas. Active management is needed to remove rhododendrons from nature reserves in the UK. In the southern USA, the kudzu plant is a very aggressive invader. Active management of kudzu requires removing it as soon as it is spotted.

Legal protection against development or pollution

Nature reserves protected by the government or private organizations can prohibit activities that might harm the native animals and plants. Such activities might be extraction of minerals, development of recreational facilities, hunting of animals, or over-use by the public. Active management measures include posting warning signs and using security personnel to ensure the nature reserve is protected from harmful human activities.

Funding and prioritizing

Because all activities require funding, which should take priority? Should funds be used to remove all exotic species, or can we assume most exotics will die out? Should we repair the habitat of a few endangered species, or use the limited funds to maintain the habitat for the majority of organisms? Should we build footpaths for the public even though that will bring destruction to some of the habitat? Increasing public awareness of reserves can help provide the funds needed to support the reserves. Management of nature reserves requires a balance between the health of the ecosystem, maintenance of diversity, and the costs involved.

In situ conservation methods

Nature reserves help endangered species by maintaining their habitat and preventing competition from invasive species. Keeping these organisms *in situ* means putting them in the ecosystem where they belong. Organisms have adapted over hundreds of years to a certain set of conditions. These conditions include the other species present in the ecosystem as well as abiotic factors. It is the goal of *in situ* conservation to allow the target species to continue to adapt to conditions in the reserve without interference from outside influences, such as invasive species and human incursions.

Reserves can be terrestrial (land-based) and aquatic (water-based). Terrestrial reserves can be found in most communities. Lake and pond areas are also common. Marine reserves are rare and are lagging behind in their development. Terrestrial reserves have been around for centuries, but there is no tradition of conservation of species using marine reserves. The ocean is a large ecosystem that needs protection. The same *in situ* strategies as used in terrestrial reserves can be put into practice in a marine reserve.

In situ conservation aims to achieve the following:

- protect the target species by maintaining the habitat
- defend the target species from predators
- remove invasive species
- have a large enough area in the reserve to maintain a large population
- have a large enough population of the target species to maintain genetic diversity.

On occasion, the *in situ* area is unable to protect the targeted species. For example:

- the species is so endangered that it needs more protection
- the population is not large enough to maintain genetic diversity
- destructive forces cannot be controlled, such as invasive species, human incursion, and natural disasters.

Ex situ conservation methods

Ex situ methods are usually used as a last resort. If a species cannot be kept in its natural habitat safely, or the population is so small that the species is in danger of extinction, then *ex situ* methods of conservation are used. There are three methods: captive breeding of animals, cultivation of plants in botanic gardens, and storage of seeds in seed banks.

Captive breeding

Some zoos have large facilities devoted to breeding. They have staff trained in animal husbandry. Breeding programmes capture the interest of the public and can generate new funds for the zoo. The San Diego Zoo in California, USA, has devoted a large part of its resources to captive breeding programmes. The goal of captive breeding is to try to increase the reproductive output of a species and ensure survival of the offspring. Here are some of the techniques used.

- Artificial insemination. If the animals are reluctant to mate, semen is taken from the male and placed into the body of the female.
- Embryo transfer to a surrogate mother. To increase the number of offspring, 'test-tube' babies are produced and implanted in surrogate mothers. Sperm and eggs are harvested from each parent, respectively, and then joined together in a Petri dish. The resulting zygote is implanted in the female uterus. The mothers can be a closely related species.
- Cryogenics. Eggs, sperm cells, and embryos can be frozen for future use.
- Human-raised young. If a mother is not interested or able to care for her young, then staff can hand-raise the young in the nursery of the zoo.
- Keeping a pedigree. If artificial insemination is a common occurrence in the management of a species, it is important that the relatedness of the individuals is known, to keep inbreeding to a minimum.

One problem with captive-breeding programmes is that the introduction into the wild of captive-bred individuals can spread disease to a non-infected wild population. When some captive-bred desert tortoises were introduced to their native habitat, they infected the wild population with a respiratory disease. Another problem is that animals bred in captivity have not experienced the process of *in situ* learning that their wild relatives undergo. This may put them at a severe disadvantage in the wild.

Mexican gray wolf.

Captive breeding and the reintroduction of an endangered animal species

Captive breeding has helped save the Mexican gray wolf from extinction. At the beginning of the breeding programme only five wolves, of which only one was a female, could be found in the wild. This lone female gave birth to one male and three females. One male and three females were captured and protected at a site for captive breeding. Today's wild Mexican gray wolves can all be traced back to those first wolves used for the captive breeding programme that began in 1981.

In the western USA, during the early 1900s, the most important prey for wolves were bison and moose. However, these prey species were severely depleted by the actions of human settlers. As a consequence, the wolves began preying on sheep and other livestock. Pressure was put on the government to kill the wolves, and bounty programmes were established. Up until 1965, $50 was offered per wolf. As a result, the wolf population was devastated. After the US Congress passed the Endangered Species Preservation Act in 1966, the gray wolf made it on to the endangered species list. Studies in 2004 showed that when wolves were eliminated the elk population exploded, leading to overgrazing of plants, especially along rivers. A significant decline in plant species such as willow and aspen then led to a reduction in beaver and songbird populations. Evidence was collected showing that removal of wolves led to instability in some environmentally sensitive areas.

In 1997, because of the availability of wolves bred in captivity, the USA reintroduced the gray wolf into areas of Arizona and New Mexico. In 2010 there were 59 wolves living in these areas. Radio-tracking methods are used to monitor the population size and health of these important animals. Hopefully, their populations will continue to increase. This is a case where scientists have collaborated with government agencies and wildlife organizations to preserve a species and also to preserve biodiversity in an important ecosystem.

To learn more about the Mexican gray wolf recovery programme, go to the hotlinks site, search for the title or ISBN, and click on Chapter 14: Section C.4.

Botanical gardens

Plants are easily kept in captivity. They have simple needs and usually breeding them is not difficult. About 80 000 plant species are grown in private gardens, arboretums, and botanical gardens all over the world. It is much easier to take care of and breed plants outside their natural setting than it is to take care of and breed animals. One problem with the collections of botanical gardens, however, is that the wild relatives of commercial crops are underrepresented. These plants may have genes that confer resistance to diseases and pests. Adding these wild plant relatives to collections at botanical gardens would provide gene banks for commercial crops.

Zoos play an important role in species preservation internationally. A zoo in South Carolina is supporting the preservation of species from all over the world.

Seed banks

Seeds in a seed bank are kept in cold, dark conditions. Under these conditions, the metabolism of the seed slows down and prevents it from germinating. Seed can be kept this way for decades. Some seeds are grown, allowed to mature, and their new seed

In 2006 the Norwegian government established a global seed bank. The Millennium Seed Bank Project at the Royal Botanical Gardens in the UK aims to safeguard 24 000 plant species from around the globe.

collected. Currently, seeds from 10 000 to 20 000 plant species from all over the world are stored in seed banks.

Biogeographical factors affect species diversity

Species diversity is defined as the number of species and their relative abundance. Three factors influence species diversity: latitude gradient, elevation gradient, and the area effect.

- Latitude gradient is the effect of climate on species diversity. The farther you travel away from the equator, the fewer species you will find. For example, the growing season at the equator is five times longer than in a tundra community. Many more plants have an opportunity to grow in a much longer growing season. The short season of the tundra allows only a few plants to grow.

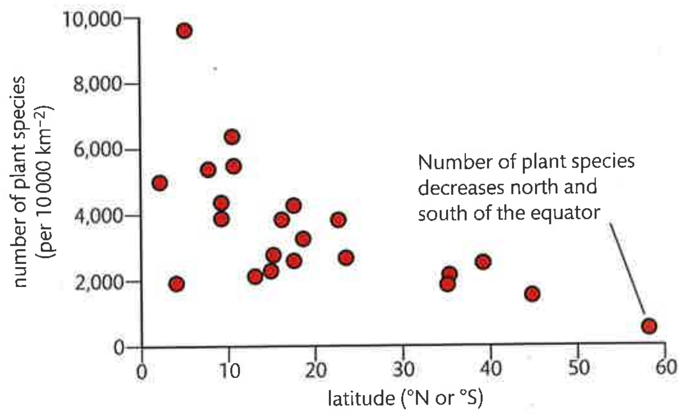


Figure 14.34A Graph of the number of plant species versus latitude. Molles, Jr. 2010, p. 502, Fig. 22.15

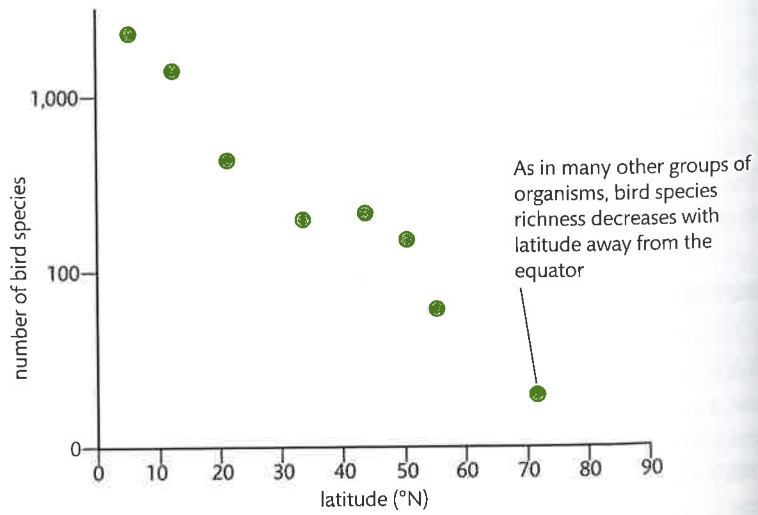


Figure 14.34B Graph of the number of bird species versus latitude. Molles, Jr. 2010, p. 502, Fig. 22.16

- Elevation gradient is the effect of altitude on species richness. As you travel up to higher altitudes, species richness increases until you reach a certain point, and then it declines again. That point is about half way up the elevation gradient and is called the mid-point bulge. At the mid-point bulge the diversity of species is at its greatest. After the mid-point bulge the species diversity declines.
- The area effect is the effect of area on species richness. The larger the geographic area, the more species it can support. Larger areas can offer a greater diversity of habitats

than a smaller area. The area affect concept began with a study of islands: the larger the island, the more diverse the species on the island. The concept of 'islands' has been extended to mean any area that is so isolated it can be considered as an island. For example, a lake can be an island because it is an aquatic environment isolated from other aquatic environments by the surrounding land. A mountain peak, or a woodland fragment isolated from other woodlands by a housing development, can also be considered as islands.

CHALLENGE YOURSELF

In an experiment in 1962, Frank Preston examined the relationship between the areas of islands in the West Indies and number of species.

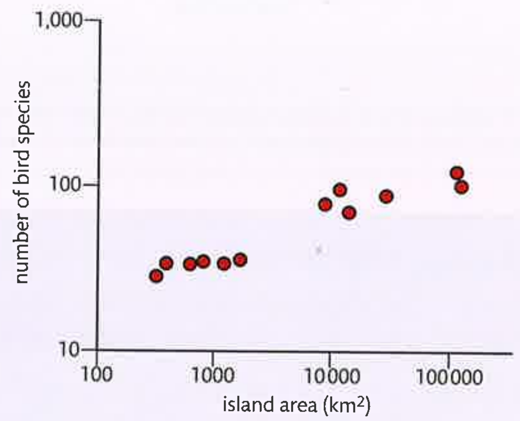


Figure 14.35 Island area versus number of bird species. Molles, Jr. 2010, p. 493, Fig. 22.2 (a)

27 Interpret the results of the Preston experiment from the data shown in Figure 14.35.

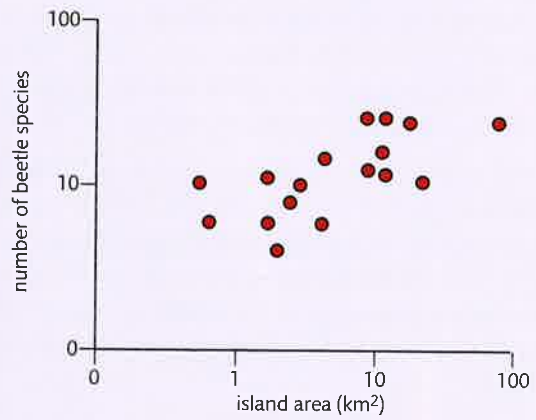


Figure 14.36 The relationship between island area and number of species. Molles, Jr. 2010, p. 493, Fig. 22.2 (b)

28 Look at Figure 14.36, which shows the patterns of species richness in 17 lake islands in Sweden. Interpret the results of this experiment from the data shown on the graph.

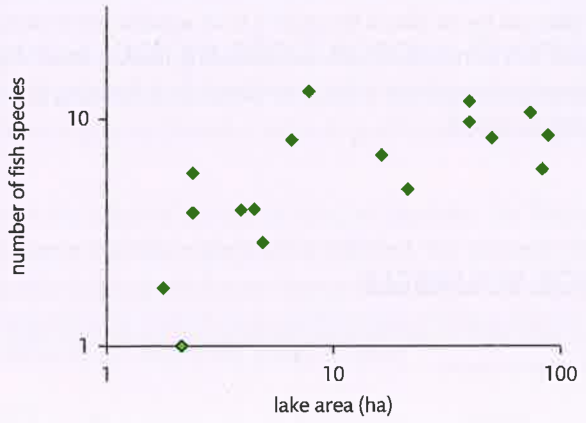


Figure 14.37 Lake area and the number of fish species in the lakes of northern Wisconsin. http://sky.scnu.edu.cn/life/class/ecology/chapter/Chapter22.htm

29 Look at Figure 14.37. Lakes can be considered as habitat 'islands'. Three scientists studied 18 lakes in Wisconsin. Interpret the results of their experiment from the data shown on the graph.

The impact of edge effect on diversity

Edge effect describes what occurs at habitat boundaries where two bordering communities influence each other. Factors that affect the edge can be:

- abiotic, such as more or less sunlight or moisture at the edge of a forest
- biotic, such as the presence of certain predators at the edge.

Does the edge effect promote species diversity in an ecosystem? Some species thrive only at the edges of a habitat because they depend on unique resources that are not present in the interior environment of the habitat. Other species thrive only in the interior environment. High habitat diversity, which includes both the interior and the edge of a habitat, promotes species richness in an ecosystem.

Edge effect plays an important role in the habitat suitability of the western meadowlark and other grassland birds. A study of how the edge effect affects the presence of the western meadowlark provided evidence that species diversity could be increased in the ecosystem if woody plant encroachment was curtailed so that populations of grassland bird species that live at the edge of the woodland could be maintained. A consistent decline in grassland bird populations because of woody plant encroachment decreases species diversity.

CHALLENGE YOURSELF

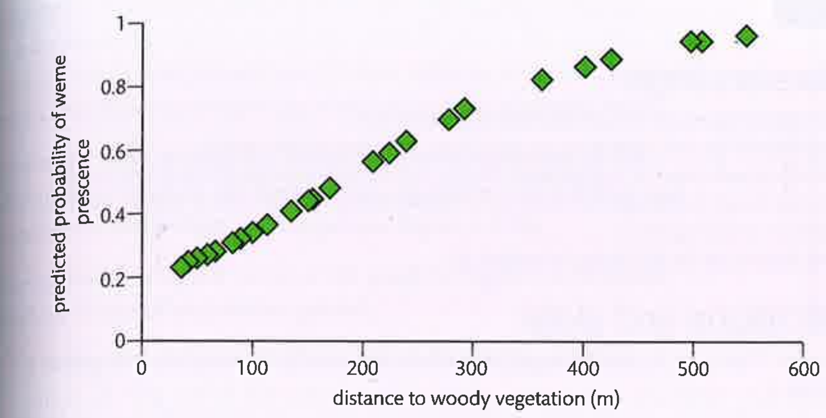


Figure 14.38 Scatterplot of the predicted probabilities from a logistic regression model of western meadowlark presence in relation to the distance to woody vegetation. http://nature.berkeley.edu/classes/es196/projects/2013final/LeeL_2013.pdf

30 What is the effect of woody vegetation on the presence of the western meadowlark?

31 Give a hypothesis regarding the cause for this effect.

32 What other 'edge' factor that might affect grassland birds could be studied?

The western meadowlark.

Exercises

10 Describe a case study of the captive breeding and reintroduction of an endangered animal species.

11 Explain how the edge effect affects species diversity.

12 Describe three factors that influence species diversity.

To find out more about the Mexican gray wolf, go to the hotlinks site, search for the title or ISBN, and click on Chapter 14: Section C.4.

NATURE OF SCIENCE

Avoiding bias: a random number generator helps to ensure population sampling is free from bias.

C.5 Population ecology

Understandings:

- Sampling techniques are used to estimate population size.
- The exponential growth pattern occurs in an ideal, unlimited environment.
- Population growth slows as a population reaches the carrying capacity of the environment.
- The phases shown in the sigmoid curve can be explained by relative rates of natality, mortality, immigration, and emigration.
- Limiting factors can be top down or bottom up.

Applications and skills:

- Application: Evaluating the methods used to estimate the size of commercial stock of marine resources.
- Application: Use of the capture-mark-release-recapture method to estimate the population size of an animal species.
- Application: Discussion of the effect of natality, mortality, immigration, and emigration on population size.
- Application: Analysis of the effect of population size, age, and reproduction status on sustainable fishing practices.
- Application: Bottom-up control of algal bloom by shortage of nutrients and top-down control by herbivory.
- Skills: Modelling the growth curve using a simple organism such as yeast or species of *Lemna*.

Population dynamics

Remember the example of the major volcanic catastrophe at Mount Saint Helens from Chapter 4. From this example, it can be deduced that there are four main factors that affect population size:

- natality, i.e. the number of new individuals after successful reproduction
- mortality, i.e. the number of deaths
- immigration, i.e. the number of individuals arriving from other places
- emigration, i.e. the number of individuals leaving the population.

These trees were knocked down by the Mount Saint Helens blast in 1980.

In the example of Mount Saint Helens, the massive mortality rate as a result of the eruption reduced the populations of birds, trees, mammals, and just about everything else in the vicinity to zero. Emigration before and immediately following the eruption greatly decreased populations in the wider vicinity surrounding the volcano. But today immigration and natality are improving the numbers dramatically.

Shortly after total destruction, life started to repopulate the volcanic region.

Population growth curve

The case of Mount Saint Helens shows that, even from a non-existent or very small population of individuals, there can soon be a dramatic increase in numbers. Over the years, the number of trees and birds near Mount Saint Helens will rise at ever-increasing rates as the organisms reproduce and occupy the available space.

Eventually, when a complete forest has grown again and all the habitats are occupied, the numbers of organisms will stabilize and populations will not get any bigger (see Figure 14.39).

The sigmoid (S-shaped) curve of the graph in Figure 14.39 shows the three stages of population growth.

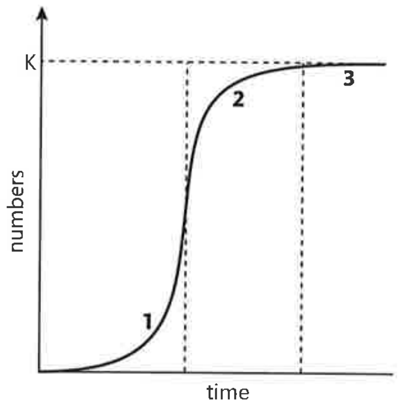


Figure 14.39 Population growth curve. The letter K at the top left is the carrying capacity, which is explained later.

1 The exponential growth phase, also called the logarithmic phase, during which the number of individuals increases at a faster and faster rate.
2 The transitional phase, during which the growth rate slows down considerably, the population is still increasing but at a slower and slower rate
3 The plateau phase or stationary phase, during which the number of individuals has stabilized, and there is no more growth.

So what causes the different phases of the population growth curve?

The exponential phase

In ideal conditions, a population can double in size on a regular basis. Not counting mortality, for example, a population of bacteria can theoretically double its population every few hours: 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024, and so on. Without predators, introduced species, such as the cane toads in Australia, can take over habitats with uncontrolled population growth. The reasons for this first phase of exponential growth are:

- plentiful resources, such as food, space, and light
- little or no competition from other inhabitants
- favourable abiotic factors, such as temperature and dissolved oxygen levels
- little or no predation or disease.

The transitional phase

Eventually, after the exponential increase in the number of individuals of a population, some of the factors listed above no longer hold true. This leads to the transitional phase. The causes of the transitional phase are:

- with so many individuals in the population, there is increasing competition for resources
- predators, attracted by a growing food supply, start to move in to the area
- because of the large numbers of individuals living together in a limited space, opportunities for diseases to spread within the population increase.

When asked to draw an S-shaped or sigmoid curve, remember to label it.

The plateau phase

Consider the land around Mount Saint Helens slowly being taken over by vegetation. Once all the fertile ground is covered with plants, the space available will be occupied

Two centuries ago, there were only about 1 billion humans on Earth. Today there are over 7 billion. In which phase of the S-curve is the current human population?

to its maximum. Thus, there is gradually less and less available space for any seeds produced by the plants to germinate, and the number of plants stabilizes.

With increasing numbers of herbivores, there is a limited supply of food. In response to limited food supplies, animals tend to have smaller numbers of offspring.

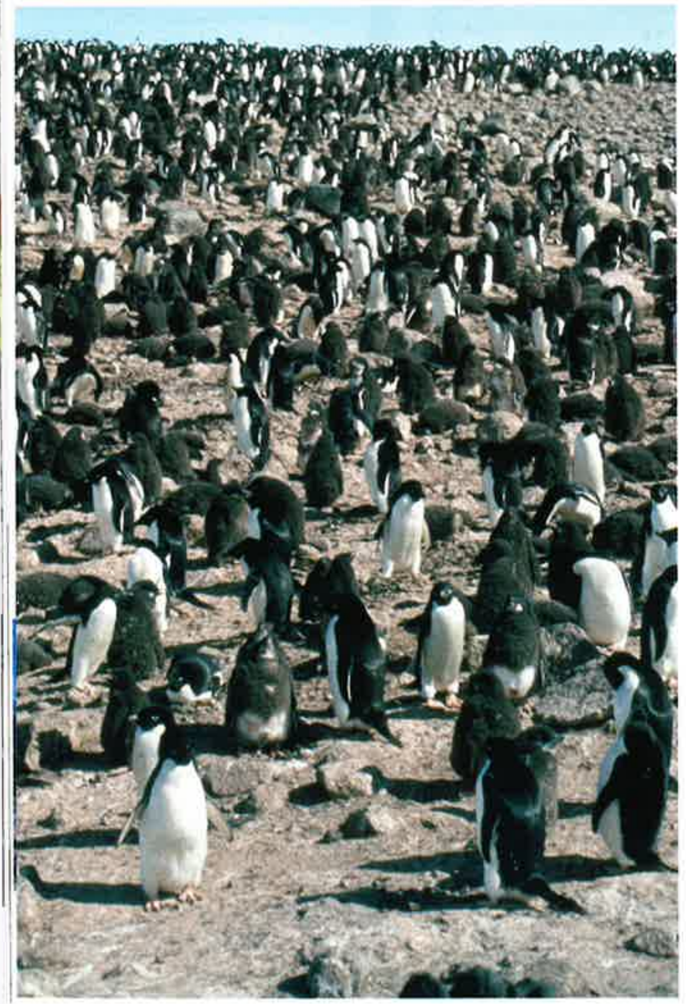
Predators and disease increase mortality, and the growth curve tends to level off. In this phase, the number of births plus the number of immigrations is balanced by the number of deaths plus the number of emigrations.

Carrying capacity (K)

No habitat can accommodate an unlimited number of organisms: populations cannot continue to grow forever. As you have just seen, there comes a time in the growth of a population when its numbers stabilize. This number, the maximum number of individuals that a particular habitat can support, is called the carrying capacity and it is represented by the letter K (see Figure 14.39).

Consider, for example, a given area of soil in a forest. There is a maximum number of trees that can grow there. This number is attained when enough trees are present to catch all the sunlight, leaving every square metre of the forest floor in shade. New tree seedlings trying to grow under the adult trees will have difficulty getting sunlight.

The penguins in Antarctica may be facing many limiting factors in their habitat.



But many young trees can store up energy for years with very little vertical growth, until a big tree dies, leaving a hole in the canopy. The young trees then race up towards the opening to take the old tree's place. Those that lose this race usually die; and for a young tree to join the mature population, an old tree must die and free up some space.

Limiting factors that define the carrying capacity of a habitat include:

- availability of resources, such as water, food, sunlight, shelter, space, and oxygen (the latter notably in aquatic habitats)
- build-up of waste, such as excrement and excess carbon dioxide
- predation
- disease.

Many biologists, environmental groups, economists, and governments wonder what the carrying capacity of Earth is for the human population. Will the number of people continue in an exponential growth phase, or will diseases, climate change, or competition for resources lead to a transitional phase or a plateau? Only time will tell.

Limiting factors can be top down or bottom up

The limiting factors that define the carrying capacity of a population can exert top-down control, such as predators, or can be a source of bottom-up control, such as nutrients. This concept is illustrated by the example in the Challenge yourself.

CHALLENGE YOURSELF

The study of a tropical coral reef revealed the effects of top-down and bottom-up limiting factors. The bottom-up limiting factor was the nutrients that increased the algal blooms that negatively affected the coral. The top-down limiting factor was the fish that ate the algae, so keeping the coral reef healthy. Two study sites on the coral reef, A and B, were isolated for 24 months and conditions were manipulated. Controlled experiments were performed pairing high and low herbivory (the amount of algae eaten by fish) with high and low nutrient levels. See Table 4.12.

Table 14.12 Mean percent cover (standard error) of benthic functional groups colonizing clay diffusers following 24 months under reduced and elevated nutrients in low- and high-herbivory study sites ($n = 4$)

Functional groups	Study site A (low herbivory) Nutrients		Study site B (high herbivory) Nutrients		Significant differences ($p < 0.05$)
	Reduced A	Elevated B	Reduced C	Elevated D	
Crustose corallines	41.2 ± 4.6	1.8 ± 1.8	<0.1	71.7 ± 3.0	D > A > B, C
Frondose macroalgae	20.8 ± 4.3	63.7 ± 8.2	0.6 ± 0.3	16.9 ± 4.1	B > A, D > C
Algal turfs	37.1 ± 3.9	14.5 ± 4.7	<0.1	22.1 ± 2.9	A > D > B > C
Predicted dominants	Turfs	Macroalgae	Corals	Corallines	

Three types of algae were included in the study, as shown in Table 14.12:

- crustose corallines, which are beneficial algae that help the coral build the reef
- frondose macroalgae, which are fleshy and filamentous, and can overgrow the coral and prevent healthy reef building because of their algal blooms
- algal turfs, which are microalgae and their blooms are also detrimental to reef building.

Parrot fish.

The herbivorous fish were parrotfish and surgeonfish.

The question posed by the study was how the effect of top-down herbivore and bottom-up nutrients affected the competition of harmful and beneficial algae. The percentage of reef cover by each type of algae was a measure of their success.

33 For study site A, compare the mean percentage cover of all three alga types with reduced and elevated nutrients. What were the resulting effects on the coral?

34 For site A, the prediction was that macroalgae would be dominant in the competition for percentage cover with elevated nutrients. Was that prediction correct? Give evidence to support your answer.

35 Describe a benefit to the coral reef that occurred over the 24 months at site D.

36 Explain the conditions under which eutrophication-induced microalgae blooms decreased the growth of the reef-building corals.

Surgeon fish.

Natality, mortality, immigration, and emigration, and the sigmoid growth curve

The equation below describes the relationship between natality, mortality, immigration, and emigration, and change in population density

Change in population density =	**(natality + immigration) minus (mortality + emigration)**

The sigmoid growth curve is an idealized version of population growth. It tells us that, in the exponential phase, natality is high and mortality is low. This causes the population to grow geometrically. However, when space and food begin to be limiting factors, then natality is lower and mortality higher. At the plateau of this curve, natality and mortality are equal, and emigration and immigration are equal. The ideal population is in dynamic equilibrium at the carrying capacity of the environment (the plateau on the graph).

Factors that change the sigmoid growth curve

Four factors that influence change in the sigmoid growth curve are:

- abiotic
- biotic
- density independent
- density dependent.

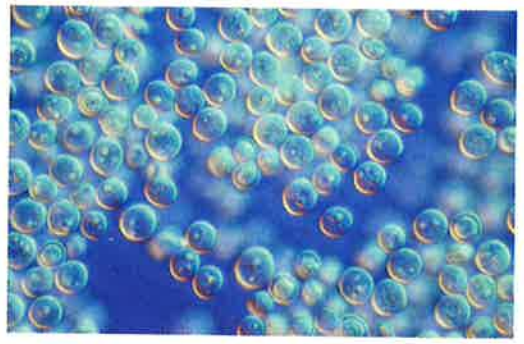
An example of an abiotic factor is temperature. For example, cold temperatures could increase mortality in an exponentially growing population of fruit fly larva. The population may have been growing exponentially until a sudden freeze. This causes natality to immediately decrease and mortality to dramatically increase.

An example of a biotic factor is the cane toad that was introduced into Australia for biological control. Because the cane toads are toxic, no predators can eat them. The population of cane toads has grown exponentially. Natality was high and immigration was high where they were introduced to eat cane beetles. Mortality was low. As they reached the carry capacity of the environment in some areas, emigration began. Some of the cane toads moved to other areas in Australia. In those new areas the immigration started a new population explosion (increased natality).

A density-independent factor affects all of the population equally. For example, a hard frost will kill all leaf hoppers equally, whether the population is 10 leaf hoppers or 100 leaf hoppers. Natality will fall to zero and mortality to 100%. Hurricanes or wildfires are other examples of density-independent factors that affect a population growth curve.

A density-dependent factor affects large populations and small populations differently. For example, a large, dense population will exhibit a greater increase in mortality with the spread of a contagious disease than a small population that is not so densely crowded. A larger, dense population is more likely to experience emigration as individuals move to other areas in search of more food and space. Predators may emigrate to an area of high prey density; this will increase mortality and reduce natality in that area.

You can see how environmental factors affect birth, death, immigration, and emigration. These factors change the shape of the idealized curve.



Yeast cells.

Modelling the growth curve of yeast

The yeast *Saccharomyces cerevisiae* is a single-celled organism that reproduces by budding. In this lab you will watch the population growth of yeast over several days. Would you predict exponential growth for the first few days? It will be interesting to discover whether the yeast will reach the carrying capacity of the environment that you design. This can be done as a class activity.

Day 1 (Monday)

1. Pour 20 ml of nutrient broth into a clean 100-ml beaker.
2. Obtain 20 ml of the yeast culture from your teacher in another 100-ml beaker.
3. Obtain five test tubes and place them in a test tube rack.
4. Using a sterile plastic pipette, place 3 ml of nutrient broth in each test tube.
5. Next add 3 ml of yeast solution to each test tube.
6. Cover each tube tightly with parafilm (clingfilm). Shake the tubes hard for 30 seconds and then lift the parafilm to allow any gas to escape.
7. Number the tubes (1–5) with a glass marking pencil.

Day 2 (Tuesday)

1. Add 5 drops of methylene blue solution to tube number 1.
2. Replace the parafilm and invert the tube, shaking gently.
3. Obtain a microscope, slide, and cover slip. Remove a small drop of the culture from the middle of the tube. Place a drop on your slide and gently add a cover slip.
4. Focus first with low power and then switch to high power.
5. Living cells will be white because they change methylene blue to white. Count the number of live yeast cells you can see in one the field of view of the microscope. If a cell is blue, it is dead so don't count it. If a cell is budding, count it as two. If the field is too full to count, mentally divide it into fourths or eighths, count the cells within that fraction, and multiply that number to get the count as accurately as possible for one field of view. Now you can determine your accuracy, for example ±10 yeast cells. Count a second field of view if time permits.

On days 3 and 4, repeat the above procedure. You may have to let the culture sit two days over the weekend without being counted. Day 5 should be the last count and should be on Monday.

Use your team data and also your class data, if it is available, to determine whether the yeast has shown the sigmoid growth curve that would be expected based on the theory of population growth over time.

Alternative lab 1

Grow duckweed or *Lemna* in pond water over several months under grow lights. Collect population samples periodically to determine whether there is exponential growth that slows and finally reaches the carrying capacity of the container in which the plant is growing.

Alternative lab 2

Begin with a vial of fruit fly media and ten flies in a vial. Count the population of flies in that vial every week for 8 weeks. Your vial can be considered as a sample of the entire population. Using class data will make your results more accurate.

Use of capture–mark–release–recapture method

The capture–mark–release–recapture method is a sampling technique that enables you to estimate the number of animals in an ecosystem. The technique involves catching some of the population and marking them. The marked animals are released back into the ecosystem and allowed to mix with the others in the population. A second sample of the population is then captured. Some in the second sample will be marked and some will be unmarked. The proportion of marked to unmarked individuals in the second sample is the same as the proportion of the originally marked individuals to the whole population. Here is the formula:

$$\frac{\text{number marked in the second sample } (n_3)}{\text{total number caught in second sample } (n_2)} = \frac{\text{number marked in the first sample } (n_1)}{\text{size of the whole population } (N)}$$

or

$$\text{population size } (N) = \frac{(n_1 \times n_2)}{n_3}$$

Worked example

Suppose you capture and mark 100 grasshoppers and release them back into the ecosystem. Then you capture another sample of 100 grasshoppers and find ten of them are marked. Estimate the population size.

Solution

or

N = 1000

The capture–mark–release–recapture method does have limitations:

- marking the animals may injure them
- the mark may make an animal more visible to predators (if marked animals are eaten, your second sample will not be reliable)
- it assumes that the population is closed, with no immigration or emigration (very few populations are closed).

Does the method really work? You can try it at home with popcorn kernels.

- Count out 200 popcorn kernels and put them in a bag.
- Remove 40 kernels and mark with a permanent marker.
- Put the marked kernels back into the bag and shake the bag.
- Remove 40 more kernels and record how many are marked.
- Use the formula to determine population size.

Did you come close to 200? One sample is not enough data. To be accurate, you should repeat the sampling technique at least five times (10 times is even better). Now average your the results. How close are you to 200 now?

Estimating the size of commercial fishing stocks

How do scientists really know what is in the ocean or a lake? The following are methods used to predict the size of commercial fish stocks.

Studying catches

For the North Atlantic Ocean, scientists from the International Council for Exploration of the Sea (ICES) sample fish catches at seaports. Data are collected on the type of fish, age, length, and breeding condition.

Gathering information from fishermen

Who is better informed about the number of fish caught than the people who catch them? Scientists from ICES also collect information on-board fishing vessels. Their tasks on-board include:

- recording the number and kinds of fish that are thrown back
- tagging and releasing some fish
- developing questionnaires for fishermen about their perception of the catch
- reviewing the ship logbooks, which provide data on catch per unit effort (increased effort for the same catch indicates that fish are getting scarcer).

Global demand for fish has doubled in less than 30 years because of human population growth in poor countries and a matching increase in demand for fish in those countries.

Using research vessels

Research vessels collect information in a variety of ways.

Casting nets in hundreds of selected locations

Sampling with nets is called trawling. Scientists need to make random samples, not visit locations where fish are known to congregate. They must be careful to use the same sampling methods every time they sample so that results can be compared.

Using sound to monitor fish populations

An echo sounder reads information from a pulse that it sends into the water. The returning echo indicates the presence of a shoal of fish. After doing hundreds of soundings, the scientists reading the data can even tell what species of fish has been located. To verify the type of species, a trawl is done and a sample collected. The remote sensing hydroacoustic method can determine both the number and biomass of fish populations.

Calculating the age of fish in a population

Knowing how many younger fish and how many older fish are present is very useful. Too few young fish indicates lack of spawning, and too few old fish may mean that over-fishing is taking place. One method of calculating age is to measure the rings in the otoliths (ear bones) of a fish. As a fish grows, new material is deposited in its ear bones. When the rings are counted under a microscope, it indicates the age of the fish. Another method is to measure the rings of fish scales.

Using coded wire tag detectors

Fish populations can be marked by attaching tags to the fish. As the fish are recaptured, the total population can be estimated. This is similar to the mark–release–recapture method. The Michigan Department of Natural Resources (MDNR) puts a coded microscopic wire tag in the nose of chinook salmon and lake trout that have been planted (stocked) in the Great Lakes. Tagged fish also have their adipose fin clipped. Recollecting fish with tags helps the MDNR evaluate the behaviour and survival of these fish. In order to read the tag, a hand-held detector is used. The fish must be caught and the tag read by hand. In small cities around the Great Lakes there is a programme for fishermen to help with the sampling. If they catch a fish that is missing the adipose fin, they place the head in a special box provided by the MDNR. Fish heads are collected and each is then checked with the handheld detector for the presence of a tag.

Analysing data using mathematical models

Mathematical models are used to turn all of the data into a form that can be used by the fishing industry and governments to plan the future of the fish in our oceans and lakes.

Evaluating these methods

- Gathering data from fishermen: data should be gathered from several sources to cross-check the fishermen's individual data. Data from log books should be cross-checked against sales receipts.
- Computers: using computers on large fishing vessels with automatic data-logging software improves the counting accuracy and communication of total fish counts to a central location.
- Observers: direct observation on fishing vessels, in processing plants, and in fish markets can provide scientists with helpful data for improving the count of fish being caught sold and processed.
- Sound-tracking equipment placement: a new modelling method has been designed to predict where sound-tracking equipment should be located. Previously, the location was random. Now researchers can predict with 95% accuracy where certain fish will be located, so they can be more easily counted.

TOK

New paradigms are emerging to guide the management of marine fisheries. The focus is on solving the problem before it begins, rather than solving the problem after it has already decimated the fishing stock.

Improvements in fish stock estimates will ensure that we do not go over the maximum sustainable yield (MSY) for the fish populations. The MSY is the highest proportion of fish that can be removed from the total population without jeopardizing the maximum yield in the future.

If the fish stock is too small, there are not enough adult fish to produce sufficient young fish. Fishing from a stock that is too small leads to over-fishing of the stock. If the fish stock is too large, annual reproductive rates may be low because of competition for food. Between these two extremes is a fish stock size that can produce the MSY. To maintain the MSY, enough fish stock must be left to spawn a new population of healthy fish.

Black grouper drifting through a coral reef.

The effect of population size, age, and reproductive status on sustainable fishing practices

Commercial fishing is not the only fishing pressure exerted on fish populations. In a study performed by the US Department of the Interior on Key Biscayne National Park in southern Florida, a large rise in the number of people living and fishing in Florida has negatively affected the population of fish.

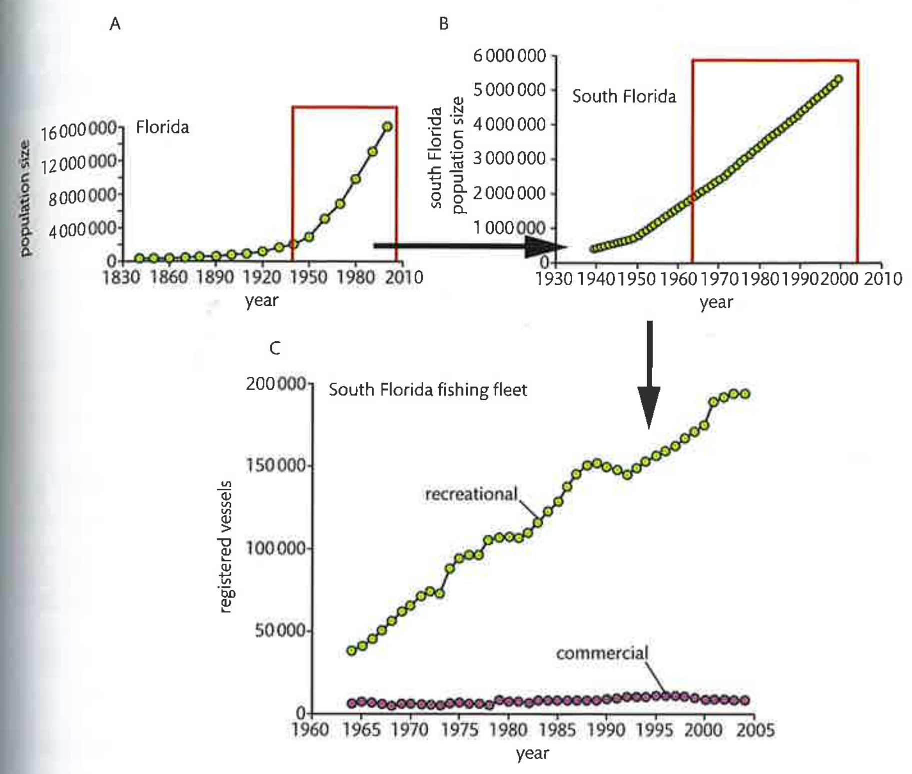


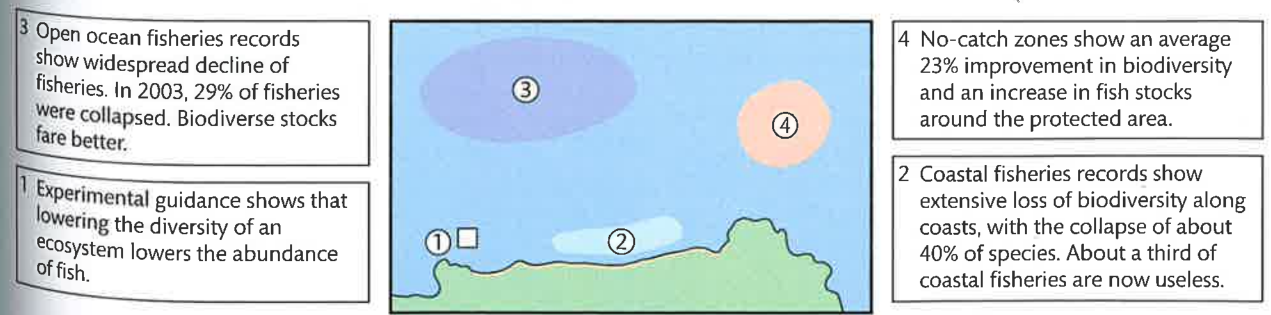
Figure 14.40 Growth of: (A) Florida's human population from 1840–2000; (B) south Florida region human population 1940–2000; and (C) south Florida commercial and recreational fishing fleets from 1964–2004.
Ault et al. 2007, Fig. 1

Establishing marine reserves and no-catch zones can improve biodiversity and increase fish stocks in areas that are protected. The journal *Science* has published small-scale experiments that show that less diverse ecosystems produce less yield. The implication is that it is a loss of biodiversity that is driving the reduction in fish stocks. The *Science* article quotes other studies that show that having protected zones, like marine reserves, restores biodiversity, and also restores populations of fish outside the protected areas (see Figure 14.41). It is difficult to enforce and monitor such regulations. Often, international trust does not exist to keep these practices functioning.

The aim of the study was to give the fishery management in Key Biscayne strategies for promoting sustainable fishing practices. The study concluded that fish population densities can be improved by regulations aimed at both recreational and commercial fishers. Such as:

- a reduction in the mortality rate of the fish, by reducing bag limits (the number of fish a fisherman is allowed to be catch each day)
- an improvement in reproductive status, by shifting the harvest to larger fish sizes, thus increasing the size limits for fish that can be kept and the fish have a longer time to reproduce before they can be caught and not released back into the ocean
- an improvement in the age of fish caught, thus increasing spawning potential, which would also be accomplished by increasing size limits, again because the older the age of the fish that can be kept and not released, the more time it has to reproduce. Catching younger and smaller fish lowers reproduction rates.

Figure 14.41 Fisheries and biodiversity: the evidence.



CHALLENGE YOURSELF

Harvesting strongly affects long-lived fish such as the black grouper, *Mycteroperca bonaci*, which lives to a maximum age of 33 years. As exploitation (fishing) increases, there is a significant effect on the number of mature and larger size grouper.

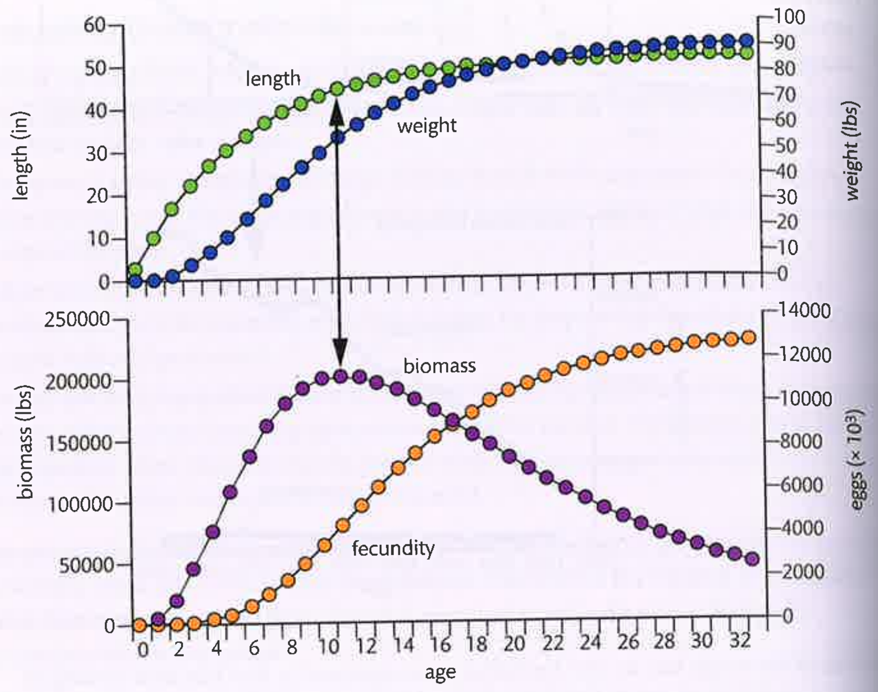


Figure 14.42 Demographic and population-dynamic relationships for black grouper, *Mycteroperca bonaci*. Ault et al. 2007, Fig. 8

37 Use Figure 14.42 to explain what is happening to the population of large, mature groupers.

38 How does this affect the reproductive (fecundity) status of the grouper populations? Explain your answer.

39 The current size limit for black grouper is 24 inches. The current bag limit is two grouper per person per day. In 1995, less than 2% of surveyed fishing trips kept more than one grouper. What does that suggest to you about the size of the fish in the grouper population?

40 Suggest a solution to this problem using evidence from the graphs.

41 How can you convince recreational fisherman that this solution is necessary?

Exercises

13 Describe the factors that can influence the sigmoid growth curve of a population.

14 Compare top-down and bottom-up limiting factors that can affect population growth.

15 Evaluate one method used to determine the size of commercial stock of marine fish.

C.6 Nitrogen and phosphorus cycles

NATURE OF SCIENCE

Assessing risks and benefits of scientific research: agricultural practices can disrupt the phosphorus cycle.

Understandings:

- Nitrogen-fixing bacteria convert atmospheric nitrogen to ammonia.
- *Rhizobium* associates with roots in a mutualistic relationship.
- In the absence of oxygen, denitrifying bacteria reduce nitrate in the soil.
- Phosphorous can be added to the phosphorous cycle by application of fertilizer, or removed by the harvesting of agricultural crops.
- The rate of turnover in the phosphorous cycle is much lower than the nitrogen cycle.
- Availability of phosphorous may become limiting to agriculture in the future.
- Leaching of mineral nutrients from agricultural land into rivers causes eutrophication and leads to increased biochemical oxygen demand.

Applications and skills:

- Application: The impact of waterlogging on the nitrogen cycle.
- Application: Insectivorous plants as an adaptation for low nitrogen availability in waterlogged soils.
- Skills: Drawing and labelling a diagram of the nitrogen cycle.
- Skills: Assess the nutrient content of a soil sample.

The nitrogen cycle

Bacteria play a hugely important part in the processes by which nitrogen is continuously recycled through the environment. Roles of bacteria in the nitrogen cycle are summarized in Figure 14.43 and the accompanying numbered points.

Rhizobium lives in the root nodules of legumes and fixes atmospheric nitrogen. These bacteria are symbiotic and receive carbohydrates and a favourable environment from their host plant.

Nitrobacter lives in well-oxygenated soils and changes nitrites into nitrates, which are useable by plants.

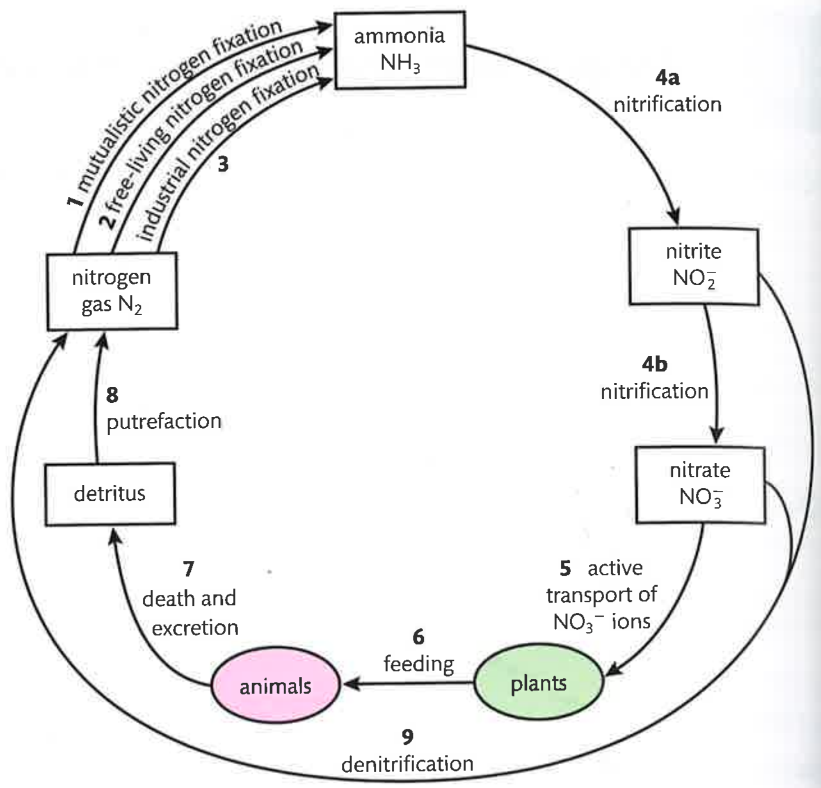


Figure 14.43 Steps of the nitrogen cycle and roles of bacteria.

1. Mutualistic nitrogen fixation. Certain bacteria form a symbiotic relationship with a host plant and fix nitrogen for it, e.g. *Rhizobium* lives in symbiosis with legumes (beans, peas, and clover).
2. Free-living nitrogen fixation. Nitrogen-fixing bacteria, e.g. *Azotobacter*, live freely in the soil and do not need a host.
3. Industrial nitrogen fixation. Burning fossil fuels to produce fertilizer is an important source of fixed nitrogen.

4a Nitrification. Oxygen is needed to turn ammonia into nitrites by bacteria in the soil, e.g. *Nitrosomonas*.

4b Nitrification. Oxygen is also required to change nitrites into nitrates by soil bacteria, e.g. *Nitrobacter*.

5. Active transport of nitrates. Nitrates are actively transported by plants (using ATP for energy) into their roots.
6. Plants and animals. Plants use nitrates to make their own proteins. This process is called assimilation. Animals feed on plants, digest, and rearrange plant proteins to make their own proteins.
7. Death and excretion. The waste products of digestion and dead bodies of plants and animals are full of molecules containing nitrogen.
8. Putrefaction. Decomposers such as bacteria and fungi break down complex proteins, and release nitrogen gas into the atmosphere.
9. Denitrification. Some bacteria, e.g. *Pseudomonas denitrificans*, remove nitrates and nitrites, and put nitrogen gas back into the atmosphere.

Conditions that favour nitrification and denitrification

Nitrification occurs as a result of the actions of two bacteria. *Nitrosomonas* converts ammonia (NH_3) into nitrite (NO_2^-). Then *Nitrobacter* changes nitrite (NO_2^-) into nitrate (NO_3^-), which is useable by plants. These are aerobic reactions carried out by two autotrophic bacteria that are beneficial to the environment. The conditions required for nitrification are:

- available oxygen (the reaction is aerobic)
- neutral pH (preferred by the two bacteria)
- warm temperature (preferred by the two bacteria).

Denitrification is the conversion of nitrates to nitrogen gas. This takes place in anaerobic conditions by autotrophic bacteria. Bacteria such as *Pseudomonas denitrificans* use NO_3^- instead of oxygen as the final electron acceptor. The conditions required for denitrification are:

- no available oxygen (e.g. flooding or compacted soil)
- a high nitrogen input.

Denitrification is not good for soils because it removes the beneficial nitrates needed by plants to make proteins. Denitrification also destroys the ozone layer. Another product, nitrous oxide (NO), can contribute to global warming, as it is a minor greenhouse gas.

Release of raw sewage and nitrate fertilizer into rivers

As societies become urbanized (living in towns), the common problem of waste disposal grows, particularly in relation to sewage. A related problem is the run-off of excess nitrate fertilizer from farms, golf courses, and lawns, which flows into rivers and streams. Effective waste management is a rising cost in our society, but these problems must be solved in order to prevent dire consequences.

Releasing raw sewage into water systems was common until, in the 1850s, it was shown that cholera was transmitted by water contaminated with faeces. *Escherichia coli* (an intestinal bacterium) is frequently in the news in the western world for causing outbreaks of food poisoning: it is spread by contaminated water and lack of hand-washing. The Ganges River in India is the site of a hugely popular festival where people ritualistically bathe in the river, which is now contaminated with human faeces. There are many, many places in the world where a clean water supply is desperately needed. Pathogens should not be found in bathing and drinking water, or water used to irrigate crops.

Crop rotation is the process whereby a series of different types of plants are grown in the same area. This allows nitrogen to be replenished in the soil by plants such as beans, which have nitrogen-fixing bacteria in their root nodules.

Nitrates may not sound as dramatic a problem as raw sewage, but they can be disastrous to ecosystems. The presence of excess nitrates and phosphates in rivers and streams is termed eutrophication. The process of eutrophication proceeds as follows:

- high nitrates and phosphates fertilize the algae present in water
- there is increased growth of algae (called an algal bloom)
- the algae are decomposed by aerobic bacteria, which use up the oxygen in the water (a high use of oxygen is called biochemical oxygen demand, BOD)
- the water becomes low in oxygen (deoxygenation), and fish and other organisms that need oxygen die.

A pitcher plant.

Insectivorous plants in waterlogged soils with low nitrogen

Plants need nitrogen for protein synthesis and to make new DNA molecules. You may remember that part of DNA is made from nitrogen bases like adenine and thymine. Insectivorous plants such as the pitcher plant derive their nitrogen from trapping and consuming insects. Pitcher plants are adapted to living in waterlogged areas where nitrogen is lacking. Pitcher plants also need a large amount of the nitrogen-rich enzyme rubisco. This enzyme is involved in the first major step of making glucose during photosynthesis (see Chapter 2).

Impact of waterlogging on the nitrogen cycle

Healthy plant roots need oxygen. Soil that is waterlogged is so saturated with water that oxygen cannot get into the soil. Waterlogged soils create anaerobic soil conditions with no oxygen. Anaerobic conditions facilitate the growth of denitrifying bacteria, which convert the nitrates needed by plants back to gaseous nitrogen. Waterlogged soils become nitrate depleted and plant (crop) growth is reduced significantly. Waterlogging can interfere with the normal cycle of nitrogen moving from the atmosphere to plants as nitrates and then back to the atmosphere. If waterlogging becomes a large problem because of climate change causing floods, food crops could be seriously affected.

Spreading fertilizer.

The phosphorous cycle

Phosphorous is an essential element in living systems. For example, phosphorous forms part of ATP, RNA, DNA, and phospholipid molecules. Phosphorous is not very abundant in the biosphere and there is not a substantial atmospheric pool of phosphorous as there is for carbon and nitrogen. The largest quantity of phosphorous is found in marine sediments and mineral deposits. Sedimentary rocks that are rich in phosphorous are mined for fertilizer and applied to soils. When crops are harvested, the phosphorous is removed. The only method of replacing it again is to add more fertilizer. Unlike nitrogen, which can be fixed by bacteria and added back to the soil, phosphorous is not recycled easily. Composting is one method of recycling phosphorus; however, composting is not easily done on a large scale.

The rate of turnover in the phosphorous cycle is low

Phosphorous is slowly released into ecosystems from weathering rocks. As it is released it can be absorbed by the roots of plants or washed into rivers. The phosphorous that is washed away eventually finds its way into oceans, where it remains in a dissolved form until finding its way into ocean sediments. The sediments eventually form sedimentary rocks. Sedimentary rocks that slowly wear away make phosphorus available again to plants.

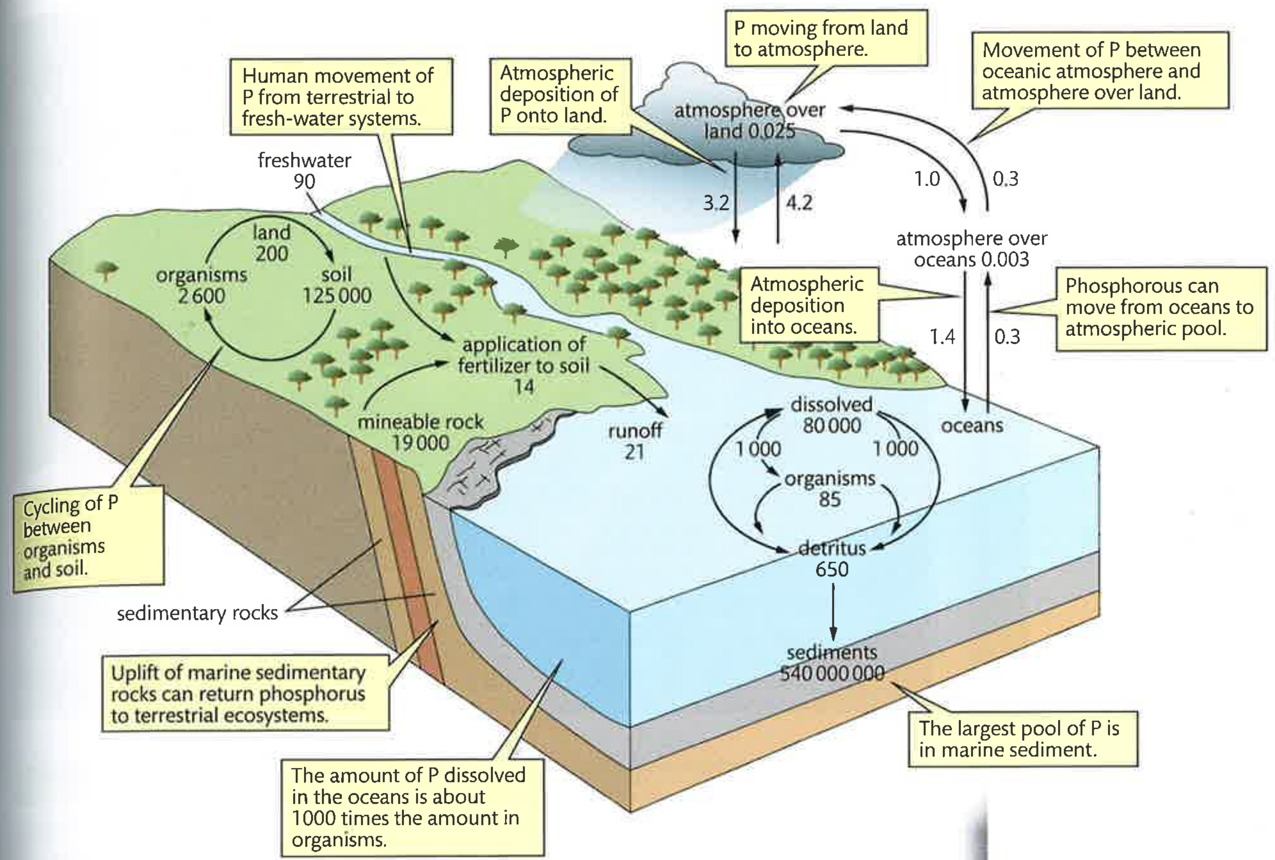


Figure 14.44 The phosphorus cycle.
Molles, Jr. 2010, Fig. 19.2

The availability of phosphorous may become limiting to agriculture

Currently, the major use of phosphate is in chemical fertilizer, which is used in modern agricultural production. Mining phosphorous for fertilizer is consuming the phosphorus more quickly than geological cycles can replace it, and crops remove phosphate from the soil. Most of the world's farms do not have enough phosphate. Phosphate reserves are limited, and it is estimated that the world phosphate reserves will only last another 50–100 years. Feeding the world's increasing population requires more and more crop production, and more and more phosphate. This is accelerating the rate of the depletion of phosphate reserves.

According to an article in *Scientific American* in 2009, the USA is the second largest producer of phosphates after China; 19% of phosphate comes from the USA, and the source of all the USA phosphate mining is from one area in Tampa, Florida. The USA may run out of this accessible, domestic source in a few decades. As the phosphate reserves run out, food prices are expected to increase as rock phosphate reserves become more and more expensive to extract. In the long term, phosphate will have to be recycled from animal and human waste.

Phosphate rock grinding mill at a phosphate mine.

The phosphorous cycle is being disrupted by:

- **massive human use**
- **the difficulty in recycling phosphorous**
- **the difficulty in obtaining phosphorous**
- **the short supply of phosphorous.**

The disruption may affect agriculture in the future and raise food prices. Improvements could be made if we are willing to change agricultural practices and including composting and recycling of human and animals waste.

NATURE OF SCIENCE

Assessing the risks and benefits of scientific research: should we grow fuel crops or food crops with our limited phosphorous reserves? The production of biofuels can only compound the problem. The phosphorous needed to grow food is being used to grow biofuel.

Testing soil samples for nutrients

1. Purchase a soil testing kit that can determine the pH, nitrogen, phosphorous, and potassium levels of your soil. The kit should determine your pH in 0.5 increments from pH 4.5 to 7.5. The kit should also determine nitrate, phosphate, and potassium levels in 5-unit increments.
2. Dilute your soil sample 1:5 with distilled water.
3. Perform each test according to the directions in the soil test kit.
4. Record the data.

Possible variations are listed below.

Test three different areas with different types of soil, e.g. farmland, parkland, and a garden. Repeat each test five times. Calculate an average and standard deviation for each site for each nutrient and pH. Graph the data. Use an online calculator to calculate a Student's *t*-test to examine whether the differences measured are significant.

Test farmland or a vegetable garden over a whole season to determine whether the nutrient content and pH change from one season to the next based on the crops present or harvested, or whether the farmland/garden has just been fertilized. Repeat the procedure so that each test is done five times.

Use class data to build up a larger database. Plan the procedure as a class so that all the variables are controlled and the data collection process is exactly the same for each student.

To use a *t*-test calculator, go to the hotlinks site, search for the title or ISBN, and click on Chapter 14: Section C.6.

Exercises

16 Explain the effect of denitrifying bacteria.

17 Compare and contrast nitrogen and phosphate as minerals necessary for plant growth.

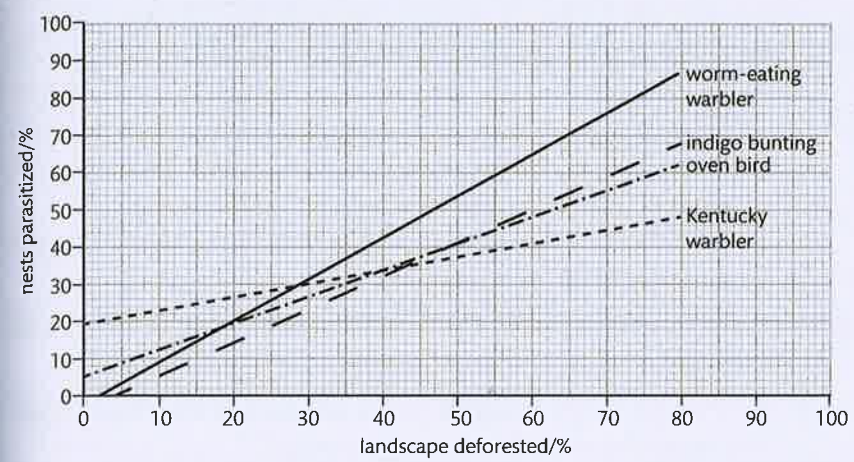
18 Describe the three methods of fixing nitrogen in the nitrogen cycle.

Practice questions

1 The brown-headed cowbird, *Molothrus ater*, is a parasitic bird that lays its eggs in the nests of other species. The parasitized hosts often raise the resulting cowbird offspring as their own. The true offspring may starve while the larger cowbird offspring consume most of the food brought by the parents.

The preferred habitat of the brown-headed cowbird is open agricultural areas.

The results of a study into the effects of deforestation on cowbird parasitism of four different host species are shown below.



Robinson et al. 1995

(a) State the effect of deforestation on cowbird parasitism. (1)

(b) Compare the effect of deforestation on cowbird parasitism of the worm-eating warbler and the Kentucky warbler. (2)

(c) Determine the percentage of worm-eating warbler nests parasitized by cowbirds at a level of 60% deforestation (1)

(d) Suggest reasons for the relationship between deforestation and cowbird parasitism. (2)

(*Total 6 marks*)

2 **(a)** Outline the use of Simpson's diversity index. (3)

(b) Explain the use of biotic indices and indicator species. (6)

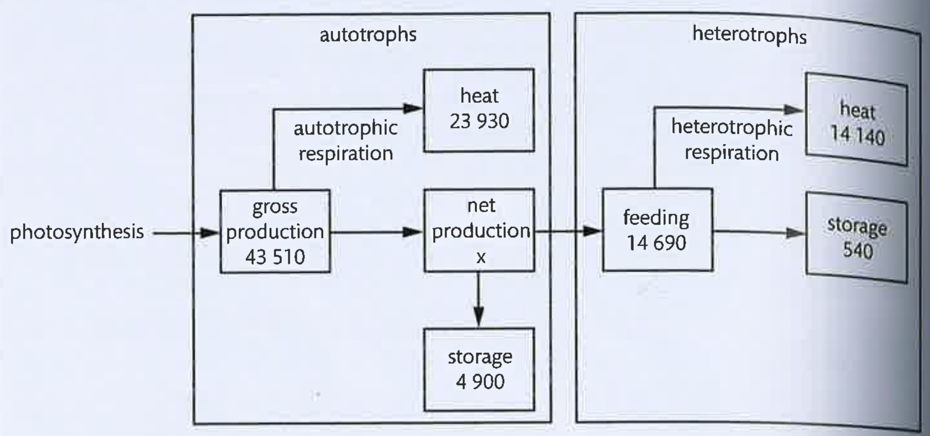
(*Total 9 marks*)

3 **(a)** Draw a labelled diagram of the nitrogen cycle. (3)

(b) State **two** fuels that can be produced from biomass. (2)

(*Total 5 marks*)

4 The energy flow diagram below for a temperate ecosystem has been divided into two parts. One part shows autotrophic use of energy and the other shows the heterotrophic use of energy. All values are kJ m^{-2} yr^{-1}.



(a) Calculate the net production of the autotrophs. (1)

(b) (i) Compare the percentage of heat lost through respiration by the autotrophs with the heterotrophs. (1)

(ii) Most of the heterotrophs are animals. Suggest **one** reason for the difference in heat losses between the autotrophs and animal heterotrophs. (1)

The heterotrophic community can be divided into food webs based upon decomposers and food webs based upon herbivores. It has been shown that of the energy consumed by the heterotrophs, 99% is consumed by the decomposer food webs.

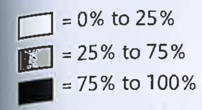
(c) State the importance of decomposers in an ecosystem. (1)

(d) Deduce the long-term effects of sustained pollution that kills decomposers on autotrophic productivity (2)

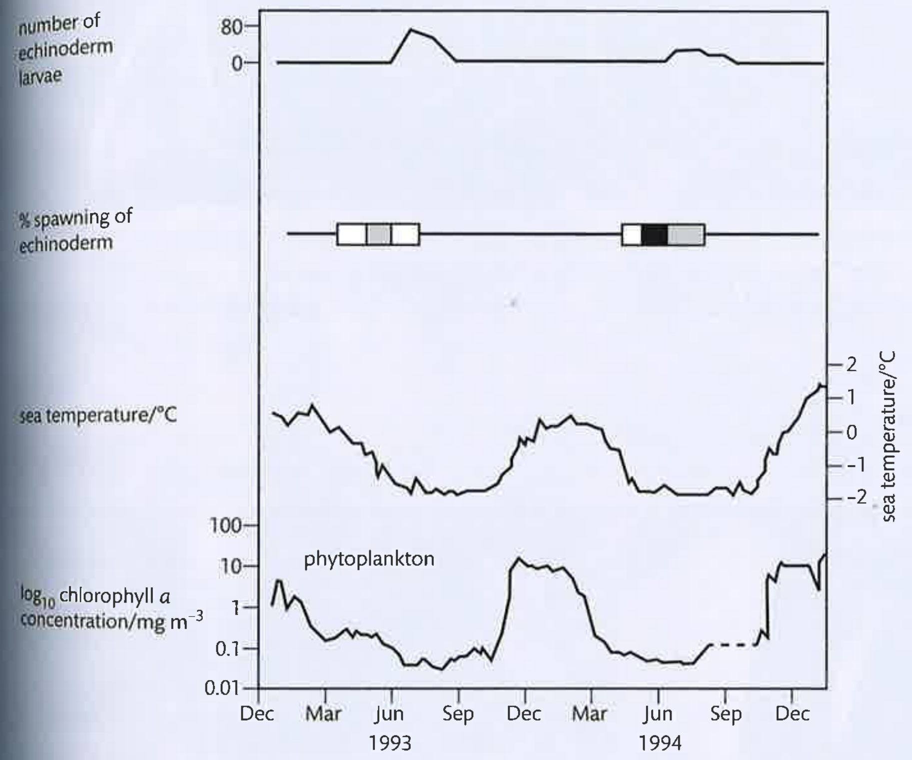
(Total 6 marks)

5 Sea-water temperature has an effect on the spawning (release of eggs) of echinoderms living in Antarctic waters. Echinoderm larvae feed on phytoplankton. In this investigation, the spawning of echinoderms and its effect on phytoplankton was studied.

In the figure below, the top line indicates the number of larvae caught (per 5000 l of seawater). The shaded bars below show when spawning occurred in echinoderms.



The concentration of chlorophyll gives an indication of the concentration of phytoplankton.
Note: the seasons in the Antarctic are reversed from those in the northern hemisphere.



Adapted from Stanwell-Smith and Peck 1998

(a) State the trophic level of echinoderm larvae. (1)

(b) Identify the period during which the spawning of echinoderm lies between 25% and 75%. (1)

(c) Explain the relationship between the seasons and the concentration of phytoplankton. (2)

(d) (i) Outline the effect of sea water temperature on echinoderm larvae numbers. (2)

(ii) Using the data in the figure, predict the effect of global warming on echinoderm larvae numbers. (2)

(Total 8 marks)