

## 2.3 Effects of Bioaccumulation on Ecosystems

Synthetic chemicals enter the environment in air, water, and soil. Plants take up some of these chemicals, and the chemicals bioaccumulate in the fat tissue of herbivores and carnivores. Synthetic chemicals become biomagnified in food pyramids and harm organisms. Heavy metals such as lead, cadmium, and mercury also bioaccumulate in the environment and negatively affect organisms. Scientists are working to find ways to remove harmful environmental chemicals. Methods include bioremediation in which organisms are used to help clean up chemical pollution.

### Words to Know

bioaccumulation  
bioremediation  
heavy metals  
keystone species  
parts per million  
PCBs



**Figure 2.51** Malformations in frogs have greatly increased since 1980. This frog has three hind legs.

### Did You Know?

A major cause of frog malformations is the flatworm *Ribeiroia*. This parasite can spend part of its life cycle in snails and then move into tadpoles, hindering their development. Epidemics of this parasite may be caused by fertilizer run-off and the presence of cattle manure near water habitats. These pollutants produce large algae blooms that feed the snail hosts, increasing their numbers.

Amphibians, such as frogs, are vertebrates that can live in two different environments. As larvae, they live in water and breathe by means of gills. As adults, they move onto land and breathe with lungs. Because amphibians live both in water and on land, they are useful to scientists as indicators of the health of an ecosystem.

In the water phase of their life cycle, amphibians are sensitive to the effects of chemical run-off and other pollutants in the environment. Their egg casings are permeable and can be penetrated by harmful chemicals. Their skin, which is a partial breathing organ, also makes them more sensitive to toxic substances. Scientists believe that factors harming amphibians today are also harming other species.

Since the 1980s, the number of amphibians in the world has fallen dramatically. Of the more than 5700 known species of amphibians, currently 43 percent are declining in number, 32 percent are threatened,

and 168 species are thought to be extinct. At the same time, scientists have found that malformations in frogs, such as missing or additional legs, have greatly increased (Figure 2.51 on the previous page). In some locations, up to 50 percent of the frogs are malformed. Similar deformities have been reported for salamanders and toads.

Scientists have confirmed several causes of the amphibian loss, such as prolonged drought and increased ultraviolet radiation due to depletion of the ozone layer. Other causes include habitat loss, pollution, overhunting, parasites, and diseases caused by viruses and fungi. Researchers have found that tadpoles exposed to increased doses of ultraviolet radiation die or develop incorrectly, gaining extra limbs or eyes. Exposure to certain pesticides also interferes with tadpole development. **Pesticides** are chemicals used to eliminate pests, such as insecticides that kill insects and herbicides that kill weeds.

## 2-3A

### Simulating Toxic Effects in an Ocean Ecosystem

#### Find Out ACTIVITY

Pesticides are one group of compounds that may harm many different organisms. The negative impact of an accidental spill of pesticides can be felt in ocean ecosystems. In this activity, you will simulate these effects.

#### Safety

- Do not eat any food in the laboratory.

#### Materials

- 0.5 kg of coloured candies
- 1 killer whale name tag
- 3 seal name tags
- 5 large fish name tags
- 6 small fish name tags
- 15 krill name tags
- 15 small bags or containers

#### What to Do

1. You will select or be assigned a role in an ocean ecosystem as a killer whale, seal, big fish, small fish, or krill. Determine your role in the food chain.
2. If you are a krill, you will simulate feeding on zooplankton and phytoplankton by gathering the candies distributed in the classroom. Put your collected candy in the container provided. You have 15 seconds to "feed" (do not eat the candy). At the end of 15 seconds, you must stay where you are.

3. Students representing the next members of the food chain continue the simulation by tapping the prey on the elbow and obtaining all the candy from the prey. At the end of 15 seconds, the eaten prey must stay where they are, as they are now dead. The simulation is complete when the killer whale has eaten.
4. Your teacher will tell you which candy colours represent food contaminated by pesticide. If red and orange candies contain the pesticide, determine the percentage of toxic candies "eaten" by each member of the food chain:
$$\frac{\text{red candies} + \text{orange candies}}{\text{total candies}} \times 100$$
5. If there are any krill still alive who consumed any red or orange candy, they are now dead. If there are any small fish still alive that consumed 20 percent or more red or orange candy, they are now dead. If any higher carnivores consumed 20 percent or more red or orange candy, they are now sick. If they consumed 30 percent or more, they are now dead.
6. Determine how many organisms are still alive.

#### What Did You Find Out?

1. What effect did the pesticide have on the ecosystem?
2. What effect would a pesticide have on an ecosystem if it remained in the ecosystem for 50 years instead of degrading rapidly?



**Figure 2.52** Pollution entering a lake from a steel mill (A). Pollution entering a stream from an abandoned car (B)

### Suggested Activity

Conduct an Investigation 2-3B on page 100



**Figure 2.53** Organisms are frequently exposed to chemicals that can build up in their bodies.

## How Pollutants Climb the Food Chain

Human activities can make natural disturbances such as forest fires and insect infestations much worse. Over the past century, human activity has resulted in many new disturbances. Rapid changes have been very stressful for many organisms. Some organisms have died, and in some cases complete extinction of a species has occurred. One of the biggest changes has been the introduction into the environment of synthetic (human-made) chemicals (Figure 2.52).

## Bioaccumulation

Synthetic and organic chemicals build up in the environment when decomposers cannot break them down through the biodegradation process. **Bioaccumulation** is the gradual build-up of these chemicals in living organisms (Figure 2.53). A chemical will accumulate if it is taken up and stored faster than it is broken down and excreted. Chemicals enter organisms through food intake, skin contact, or respiration. If the accumulation of a substance is too high, it can be harmful. Some chemicals are temporarily stored in fat tissue but are released from storage when fat is burned for energy. These chemicals can be harmful to the animal if they are not metabolized (chemically changed) or are not excreted in the feces or urine.

Synthetic and organic chemicals can affect the nervous, immune, and reproductive systems of animals. Bioaccumulation of these chemicals can cause birth defects in offspring or a complete failure to reproduce. These chemicals affect not only individual organisms but also entire ecosystems when keystone species are affected. **Keystone species** are species that can greatly affect population numbers and the health of an ecosystem. Salmon are a keystone species in many British Columbia forest ecosystems. In fall, salmon are an important food source for bears, wolves, eagles, and otters. Salmon alter the ecosystem as their decaying bodies become a rich source of nutrients such as nitrogen for trees. Salmon can also retain harmful chemicals in their body fat and transfer these chemicals to other organisms.

**Biomagnification** is the process in which chemicals not only accumulate but become more concentrated at each trophic level. Chemicals bioaccumulate and become biomagnified when pollutants are stored in plant tissue and in the fat tissue of animals. Chemicals remain trapped in plants and animals until they are eaten and the tissues and fats are broken down for energy.

As you learned in section 2.1, herbivores eat large quantities of plants and carnivores eat many times their body weight of prey during their lifetimes. For this reason, even small concentrations of chemicals in producers and primary and secondary consumers can build up to cause problems at higher trophic levels. For example, a red tide is caused by an algae bloom in which the algae become so numerous that they can turn coastal seawaters red. Red tides produce toxic organic chemicals that can affect organisms such as clams, mussels, and oysters. As the shellfish eat the algae, the toxins bioaccumulate to a level that is poisonous to other organisms such as fish, humans, and other mammals. If eaten, these shellfish can cause paralytic shellfish poisoning, which can result in serious illness or death.



## PCBs and the Orca

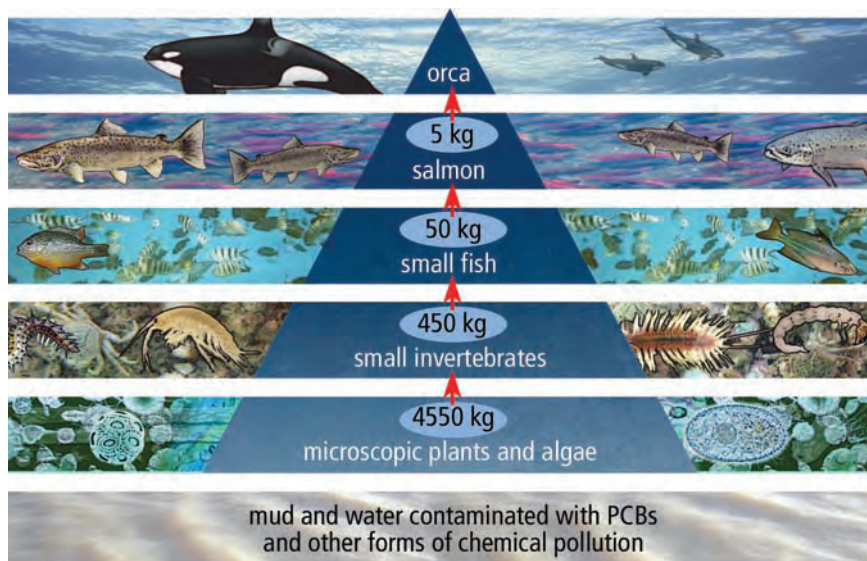
The significance of bioaccumulation is seen in the way PCBs affect orcas (killer whales). **PCBs** (polychlorinated biphenyls) are synthetic chemicals that were widely used from the 1930s to the 1970s in industrial products such as heat exchange fluids, paints, plastics, and lubricants for electrical transformers. In 1977, they were banned in North America as concerns grew about their impact on the environment and human health. Many synthetic chemicals such as PCBs that bioaccumulate and biomagnify also have a long half-life. **Half-life** is the time it takes for the amount of a substance to decrease by half. PCBs stay in organisms and the environment a very long time, suppress the immune system, and probably cause cancer in humans. Aquatic ecosystems and species that feed on aquatic organisms are especially sensitive to the effect of PCBs.

Hardest hit of all are orcas (Figure 2.54). One study found that PCBs will interfere with the reproductive success of British Columbia's resident orcas until at least 2030. Even though these chemicals have been banned for decades, orcas retain high levels of PCBs, especially the calves.

Figure 2.55 shows how biomagnification occurs in an orca. Even if the PCBs enter the food chain at a relatively low level, by the time they get to the orca, they are highly concentrated in the blubber. When salmon stocks are low, magnification is increased, since blubber is then burned for energy. The PCBs are released into the orca's bloodstream where they interfere with immune function, making the orca more susceptible to disease.



**Figure 2.54** A newborn orca calf has the same PCB level as its mother and then receives more through its mother's fat-rich milk.



**Figure 2.55** The PCB load of orcas is much higher than that of any other animal in the world. When an orca eats 5 kg of salmon, it is ingesting PCBs and other pollutants from about 4550 kg of microscopic plants and algae.

## Persistent Organic Pollutants

PCBs belong to a class of compounds called **persistent organic pollutants** or POPs. POPs are carbon-containing compounds that remain in water and soil for many years. Many POPs enter ecosystems in the form of insecticide sprays (Figure 2.56).



**Figure 2.56** Insecticide spraying is a common method by which POPs are introduced into ecosystems.

**Table 2.2** Bioaccumulation of DDT in a Food Chain

Consumer	Bioaccumulation (ppm)
Plankton	0.04
Minnow	0.94
Adult fish	2.07
Heron	3.57
Osprey	13.80
Cormorant	26.40

One well-known POP is the insecticide **DDT** (dichlorodiphenyl trichloroethane). DDT was introduced in 1941 to control disease-carrying mosquitoes. Although now banned in many countries because it biomagnifies, it has a long half-life and persists in the environment. DDT binds strongly to soil particles and persists for as long as 15 years. Bound in soil, DDT begins to bioaccumulate in plants and then in the fatty tissue of the fish, birds, and animals that eat the plants. Washed into streams and lakes, it affects aquatic food chains by first accumulating in plankton. In Table 2.2, you can see how low levels of DDT become magnified through the food chain.

Chemical accumulation is measured in **parts per million (ppm)**. One ppm means one particle of a given substance mixed with 999 999 other particles, which is equivalent to one drop of dye mixed with 150 L of water (about what a home hot-water tank holds). DDT is considered toxic or harmful at levels of 5 ppm. In animals, DDT is changed into a chemical form that bioaccumulates in fat tissue and can cause nervous system, immune system, and reproductive disorders.

### internet connect

Some chemicals, called endocrine disruptors, affect the endocrine (hormone) system by mimicking the female hormone estrogen. One effect is eggshell thinning in birds of prey such as eagles. To find out more about endocrine disruptors, go to [www.bcscience10.ca](http://www.bcscience10.ca).

### Reading Check

1. What is bioaccumulation?
2. What is biomagnification?
3. How does a chemical bioaccumulate in an organism?
4. What are persistent organic pollutants?
5. What does ppm mean?

## Heavy Metals

**Heavy metals** are metallic elements with a high density that are toxic to organisms at low concentrations. Within the biosphere, they do not degrade and cannot be destroyed. Some heavy metals such as copper, selenium, and zinc are essential to human health in very small quantities. Heavy metals can be found in water and air and are taken in through the food chain. They can bioaccumulate within organisms and biomagnify, moving up the food chain like POPs. The three most polluting heavy metals are lead (Pb), cadmium (Cd), and mercury (Hg).

## Lead

Lead is naturally present in all soils, generally in the range of 15 ppm to 40 ppm. However, these levels have increased due to human activities. In the past, lead was used in insecticides, in paints, and as an anti-knock ingredient in gasoline. Today, most products and manufacturing processes have been changed to reduce the amount of lead entering the environment, and nearly all lead-acid batteries are recycled. Other uses of lead, such as in electronics where it is contained in radiation shielding and soldered joints, still contribute to lead levels in the environment. However, much smaller percentages of electronics are recycled. Consumer electronics waste makes up 40 percent of the lead found in landfills (Figure 2.57).

Lead is extremely toxic. It has an accepted toxic level of 0.0012 ppm, although it is not considered safe at any level. Lead particles can be ingested (eaten), absorbed through the skin, or inhaled. Harmful effects in humans may include anemia (a blood condition), nervous system damage, sterility in men, low fertility rates in women, impaired mental development, and kidney failure. Similar effects are seen in fish and birds.

## Cadmium

Cadmium is found in Earth's crust and is released into the environment through rock weathering, volcanoes, and forest fires. (The cadmium stored in trees is released into the air when trees burn.) Cadmium is also released in the manufacture of plastics and nickel-cadmium rechargeable batteries, and it enters soil and water through zinc production and phosphate ore mining. Cadmium is strongly chemically attracted to organic matter in soil. When present in soil, it can be extremely dangerous, as plants take up the cadmium in their roots and animals eat the plants. Cadmium is highly toxic to earthworms and other soil organisms at very low levels. In fish, it is associated with higher death rates and lower reproduction and growth rates.



**Figure 2.57** Electronics waste has introduced a large amount of lead into ecosystems.

### *Did You Know?*

Although synthetic chemicals can be hazardous, many also have enormous benefits. Even DDT reduced the number of deaths from malaria when it was first introduced. When countries banned DDT, malaria-related death rates increased.





**Figure 2.58** Smoking is the major source of cadmium poisoning in humans.

For humans, the most serious source of cadmium poisoning is smoking, as tobacco plants easily absorb the metal (Figure 2.58). Cadmium can accumulate in lung tissue, causing lung diseases such as cancer. Non-smokers ingest cadmium mainly through foods such as mushrooms, shellfish, fish, and seaweed. Cadmium moves from the digestive system to the liver and then to the kidneys. The half-life of cadmium in the kidneys and in bone tissue is 30 years. Cadmium exposure can lead to infertility and damage to the central nervous system, immune system, and DNA.

## Mercury

Every year, up to 6000 tonnes of mercury are released through natural sources such as volcanoes, geothermal springs, and rock weathering. In the last 150 years, this annual amount has doubled through the burning of fossil fuels, waste incineration, mining, and industrial uses such as the manufacture of batteries (including the kind many of us throw out each week). Coal burning accounts for more than 40 percent of mercury released into the atmosphere (Figure 2.59). Mercury returns to the Earth in rainfall and dust and binds to soil particles to form compounds that are then transported by air and water.

### Explore More

Many Canadian First Nations and Inuit people have suffered mercury poisoning by eating contaminated fish. Find out about the Grassy Narrows tragedy of the 1970s and mercury poisoning among the Inuit in northern Quebec, whose diets include large amounts of fish. Start your research at [www.bcscience10.ca](http://www.bcscience10.ca).



**Figure 2.59** Coal burning is a major source of mercury.

Organisms also circulate mercury through the food chain. Some bacteria in soils change compounds such as mercury sulfide into methylmercury, a highly toxic compound that bioaccumulates in the brain, heart, and kidneys of vertebrates. In humans, methylmercury is absorbed during digestion, then enters the blood and is stored in the brain. It affects nerve cells, the heart, kidneys, and lungs and suppresses the immune system. In fish, levels of methylmercury depend on what they eat, how long they live, and how high they are in the food chain.

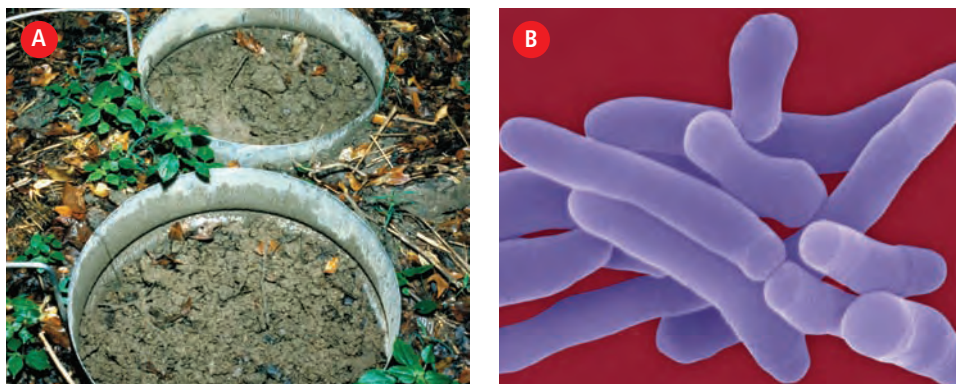
## Reading Check

1. What are heavy metals?
2. How was lead introduced into ecosystems in the past?
3. How does cadmium enter the environment?
4. What are some natural sources of mercury?
5. Explain how methylmercury is formed.

## Reducing the Effects of Chemical Pollution

The effects of chemical pollution on the environment can be large, but scientists are constantly working to find new ways to solve these problems. One method is to trap the contaminant in the soil. For example, phosphate fertilizer is added to lead-contaminated soil, causing a chemical reaction between the phosphate and the lead that produces lead pyromorphite. This mineral is highly insoluble, so it cannot be easily spread by water and is less likely to enter the food chain. The lead remains in the soil but in a much less harmful form.

Another approach looks to nature and the process of biodegradation for help. **Bioremediation** (the prefix “bio-” means living things, and “remediation” means to remedy) is the use of living organisms—usually micro-organisms or plants—to do the clean-up naturally, only faster through biodegradation. Micro-organisms that naturally feed on chemicals and reduce them to non-toxic compounds can be added to contaminated soil (Figure 2.60). Working at the molecular level, scientists have extracted enzymes from chemical-eating bacteria or pesticide-resistant insects and used these to create new environmental clean-up technologies.



**Figure 2.60** Soil tests of the effectiveness of PCB biodegradation by micro-organisms (A). *Rhodococcus* bacteria can biodegrade PCBs (B).

Plants such as fescue, alfalfa, juniper, and poplar trees also act as natural traps to biodegrade hazardous wastes in soil, taking in and concentrating heavy metals in their tissues. In wetland ecosystems, water hyacinth and bulrushes may be used. Plants can also act as stabilizers, reducing wind and water erosion that could spread the contaminants. Bioremediation is often used in resource industries such as forestry, mining, and energy production. The oil industry, for instance, often uses bacteria to clean up pollution created by spills and underground leaks.



**SkillCheck**

- Measuring
- Controlling variables
- Graphing
- Evaluating information

**Safety**

- Glassware can break. Handle with care.
- Wash your hands thoroughly after doing this investigation

**Materials**

- 30 lettuce seeds previously soaked in 10 percent bleach solution
- six 9 cm petri dishes
- labelling marker
- 6 pieces of 7.5 cm filter paper
- graduated cylinder
- 2 mL 0.2 M NaCl
- 2 mL 0.1 M NaCl
- 2 mL 0.075 M NaCl
- 2 mL 0.050 M NaCl
- 2 mL 0.025 M NaCl
- 2 mL tap water
- sealable plastic bag

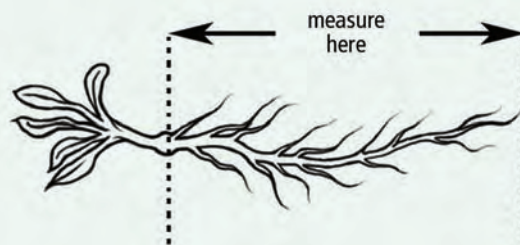
A bioassay is an experiment that tests how toxic a chemical will be to a living organism. The organism is exposed to different concentrations of the chemical to determine at what point the chemical causes harm. Salt is used on roads in the winter to help de-ice highways. The salt eventually ends up in streams. Scientists often use lettuce seeds as test organisms because they are inexpensive yet effective for testing pollutants in water and soil. In this investigation, you will test the effect of different concentrations of salt on lettuce seeds to see how lettuce growth is affected. You will determine the effect on growth by measuring germination rates and root lengths.

**Question**

How will saltwater affect the growth of lettuce seeds?

**Procedure**

1. Obtain 30 lettuce seeds from your teacher.
2. Label the lids of the petri dishes with your initials, and number them from 1 to 6.
3. Place a paper filter into each petri dish.
4. To petri dish number 1, add the 0.2 M NaCl solution. Repeat this procedure for petri dishes number 2 to number 5, each time adding a lower concentration of NaCl as specified in the materials list. Add 2 mL of tap water to dish number 6.
5. Add five lettuce seeds to each dish. Space the seeds out over the filter paper. Do not let the seeds touch the sides of the petri dish. Put the lids on the petri dishes.
6. Place the six dishes in the plastic bag and seal the bag. Keep the bag in the dark at a constant temperature (if possible, about 24°C) for 5 d.
7. After the 5 d period, count how many seeds have begun to germinate and measure the root length of each to the nearest millimetre. Make sure you measure only the root, not the shoot, as shown below.



8. Record your results in a table like the one on the next page.
9. Share results as a class, and calculate class averages. Record those results in your table.
10. Clean up and put away the equipment you have used.

Petri Dish Number	NaCl Concentration	Group		Class Average	
		Number of Seeds Germinated	Root Length (mm)	Number of Seeds Germinated	Root Length (mm)
1	0.2 M				
2	0.1 M				
3	0.075 M				
4	0.050 M				
5	0.025 M				
6	0 M				

### Analyze

1. Construct a line graph that shows the effect on lettuce seed germination of different NaCl concentrations. Put the concentration of NaCl on the *x*-axis and the number of seeds germinating on the *y*-axis.
2. Construct a line graph that shows the effect on lettuce seed root length of different NaCl concentrations. Put the concentration of NaCl on the *x*-axis and the average root length on the *y*-axis.
3. Do you observe a relationship between seed germination and the concentration of salt in your graph? Explain any pattern you observe.

### Science Skills

Go to Science Skill 5 for information on how to construct a graph.

### Conclude and Apply

1. From your results, do you think salt is toxic to lettuce seeds? Explain.
2. Would you recommend that a department of highways use salt on roads in winter? Give reasons for your answer.
3. If you were going to repeat this experiment, what changes would you make to improve your results?

# Science Watch

## Pollution in the North

In recent years, tonnes of hazardous chemicals have been carried northward thousands of kilometres to the Arctic. More than 3.7 million people in eight countries are constantly exposed to these toxins.

Persistent organic pollutants such as DDT, toxaphene, and chlordane are applied in fields or sprayed on crops in temperate and tropical climates, where they evaporate. Fossil fuels, PCBs, and the heavy metals cadmium and mercury are present in air emissions from burning fuel for energy and from waste incineration. These toxic substances in low concentrations are carried in warm ocean and wind currents. They then are carried in water vapour into the atmosphere, deposited back down in rain, carried up again, and returned again as rain. This process continues to move toxins up the continent until they reach the North, where the cold locks them away. Chemical breakdown is very slow in this area of frigid temperatures and little sunlight. The Arctic lacks the soil and plant life that absorb pollution elsewhere, so the toxins remain for decades, even centuries.

Once in these cold ecosystems, the contaminants enter food chains and bioaccumulate in fish, birds, marine mammals, and humans. Inuit hunters are reporting abnormalities in animals such as seals without hair, polar bears without reproductive organs, and seals with burn-like holes on their skin. Researchers have found that these toxins not only harm wildlife but also accumulate in the breast milk of Inuit women at levels nine times higher than in women to the south.

Some scientists are trying to identify the properties that cause chemicals to accumulate. Others are looking for ways to get rid of the heavy metals left from the disposal of electronic products. Scientists continue to find solutions to these problems, but the once pristine North will continue to suffer for centuries from the consequences of pollution that comes from far away.



Checking water pollution levels in the Arctic Ocean

### Questions

1. How are toxic substances transported to the Arctic?
2. State two ways in which contamination from toxic chemicals harms this ecosystem.
3. What effects of contamination have been seen in wildlife?



## Checking Concepts

1. Provide several reasons to explain why amphibians are disappearing.
2. Describe how synthetic chemicals become biomagnified in organisms.
3. What factors determine whether or not a chemical will bioaccumulate?
4. What are PCBs?
5. List some sources of PCBs.
6. Give an example of a persistent organic pollutant (POP).
7. How does DDT bioaccumulate?
8. Explain what 2 ppm means.
9. Which is more toxic—a chemical with a toxic level of 3 ppm or a chemical with a toxic level of 0.03 ppm? Explain.
10. What effect does DDT have on humans?
11. Explain why the effect of biomagnification is so great in killer whales.
12. List three health effects of methylmercury.
13. (a) What type of heavy metal poisoning is caused by the activity shown below?  
(b) Explain how this heavy metal can harm the human body.



14. What is bioremediation?

## Understanding Key Ideas

15. Scientists study the health of amphibians, such as frogs, in order to evaluate the health of an ecosystem. Explain why.
16. Create a chart to summarize the environmental effects of the heavy metals lead, cadmium, and mercury. Use the following headings in your chart: Natural Sources, Human-made Sources, Effects on Plants and Animals, Effects on Humans.
17. Explain why a chemical with a long half-life may create problems in the environment.
18. A persistent organic pollutant is estimated to have a half-life of 30 y. If 3 tonnes of the chemical exists in a polluted area today, how much of the chemical will remain after 120 y?
19. Explain how an organism could be affected by a persistent organic pollutant when the chemical was applied 1000 km from the organism's habitat.
20. How can plants be used for bioremediation?
21. Design an experiment to determine what level of a new synthetic insect killer called Beegone is lethal to geraniums.

## Pause and Reflect

You are a journalist writing a story about the effects of bioaccumulation of certain synthetic chemicals. What questions would you ask a group of scientists who have recently announced a new chemical discovery?

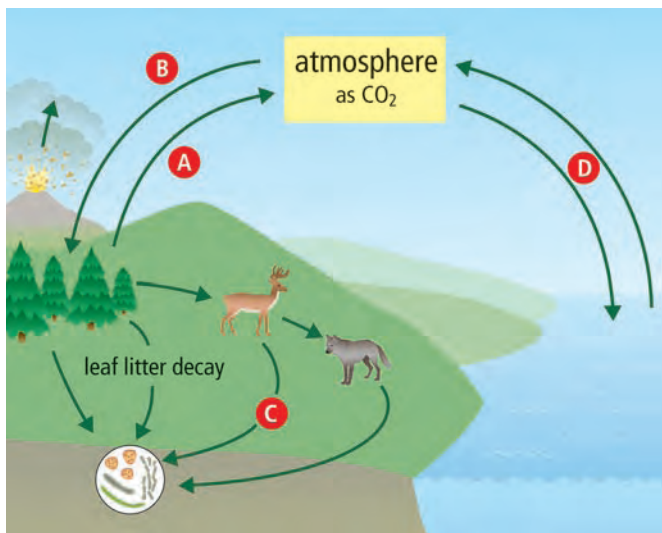
## Prepare Your Own Summary

In this chapter, you investigated energy flow, nutrient cycles, and the bioaccumulation of chemicals in ecosystems. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. (See Science Skill 11 for help with using graphic organizers.) Use the following headings to organize your notes:

1. Energy Flow in Ecosystems
2. Nutrient Cycles in Ecosystems
3. Human Activities and Ecosystems
4. Effects of Bioaccumulation

## Checking Concepts

1. Describe two ways in which decomposers contribute to ecosystems.
2. Describe the flow of energy from the Sun to a wolf.
3. What happens to most of the energy from the Sun that is trapped by plants?
4. What are the two major life processes that involve both carbon and oxygen?
5. Write the equation that summarizes the process of cellular respiration.
6. (a) Identify the nutrient cycle shown in the illustration below.  
(b) Identify the processes indicated by the arrows labelled A to D.



7. What are two major ways in which nitrogen is fixed in ecosystems?
8. Identify the product formed as a result of:
  - (a) nitrification
  - (b) denitrification
9. Explain how weathering releases phosphate from rock.
10. (a) What is happening in the photograph below?  
(b) How does this activity affect the phosphorus cycle?



11. Give an example in which carbon moves from the abiotic to the biotic part of an ecosystem.
12. How do shelled marine organisms contribute to the carbon cycle?
13. (a) Where and in what form does carbon enter long-term stores?  
(b) Where and in what form does carbon leave long-term stores?
14. Explain how the phosphorus cycle differs from:
  - (a) the carbon cycle
  - (b) the nitrogen cycle
15. A food web contains green plants, rabbits, squirrels, mice, seed-eating birds, hawks, and owls.
  - (a) Which organisms in this food web would contain the greatest biomass? Explain.
  - (b) Which organisms in this food web would contain the least biomass? Explain.

16. How do bacteria enable plants to take up nitrogen?
17. (a) Name the two largest stores of carbon.  
(b) Explain how these carbon stores have become so substantial.
18. Why are heavy metals harmful to the environment?
19. How do PCBs harm orcas?
20. List two effects of persistent organic pollutants on organisms.

### Understanding Key Ideas

21. How does the flow of energy through an ecosystem differ from the cycle of nutrients in an ecosystem?
22. Scientists are studying an ecosystem that has 452 individuals of species A and 12 individuals of species B. Answer the following questions in terms of energy flow and trophic levels.
  - (a) Which species is most likely to consist of herbivores?
  - (b) Which species is most likely to consist of carnivores?
23. Explain why you would not gain 450 g if you were to eat a 450 g meal.
24. Explain how an increase in agricultural activity might affect a local fishery.
25. How is volcanic activity involved in the following?
  - (a) the carbon cycle
  - (b) the nitrogen cycle
26. Explain the role of decomposers in the carbon cycle.
27. Farmers often add nitrogen and phosphorus to their crops but not carbon. Explain why.
28. At which trophic level are organisms most affected by biomagnification? Explain.
29. (a) If the secondary consumers in a food chain use  $4200 \text{ kcal/m}^2$  of energy, what amount of energy was used by the producers in that food chain?  
(b) What amount of energy will be available to the tertiary consumers?
30. Explain how zooplankton and phytoplankton in a water ecosystem can contain levels of 0.04 ppm of a chemical but adult fish living in the same ecosystem contain levels of 5 ppm.

### Applying Your Understanding

31. Each cigarette contains  $1 \mu\text{g}$  to  $2 \mu\text{g}$  of cadmium, 40 to 60 percent of which is inhaled into the lungs and from there passes throughout the body. Cadmium absorption appears to be higher from smoking than from environmental exposure in the workplace, probably because the cadmium particles in cigarette smoke are so small they pass through the cigarette filter and become deposited in lung tissue. Smoke from a smouldering cigarette is also very high in cadmium. Breathing air with high levels of cadmium can severely damage the lungs or cause death. Breathing in lower levels over years is also risky, as cadmium can build up in the kidneys and result in kidney disease.
  - (a) What evidence is there that cadmium bioaccumulates in humans?
  - (b) Are individuals exposed to secondhand smoke at risk?
  - (c) Suppose a person smoked 15 cigarettes per day, and 50 percent of the cadmium in each cigarette was absorbed. Calculate the daily intake of cadmium.
  - (d) Cadmium has a half-life of 30 y. Once a person stops smoking, how long will it be before the body is rid of the cadmium inhaled?

### Pause and Reflect

The biosphere is like a sealed terrarium in which all the nutrients that support life and all the wastes that are produced are constantly recycled within its boundaries. Refer to one of the nutrient cycles you studied in this chapter to explain this concept.