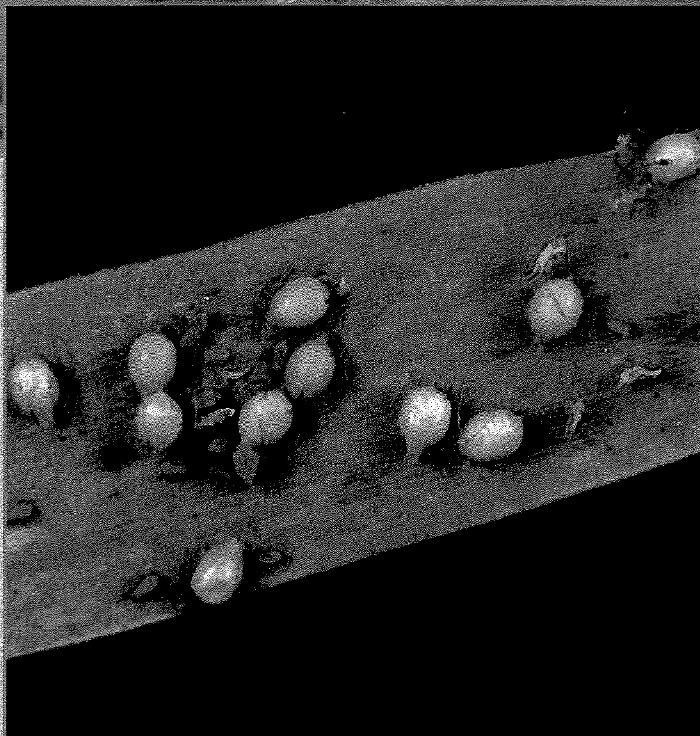
22

Pest Management



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Parasitized pest. Grain aphid (*Sitobion avenae*) parasitized and mummified by a parasitoid wasp (*Aphidius*). When pesticides are used to control pests, natural enemies of pests are also killed. Pest control methods can either foster or damage populations of beneficial insects.

Most people think of wasps as pest insects. Although wasps are indeed predators, many wasps are actually the enemies of our enemies: insect pests. Many wasps, like *Aphidius* (see photograph), kill pests by laying the eggs of their young inside herbivorous insects that consume crop plants. When the young wasp emerges, the larva eats the pest insect from the inside. Although the pest insect continues to survive for some time—long enough for the young wasp to reach adulthood—the pest insect dies before it is able to reproduce. The wasps keep pest insect populations from increasing to damaging levels.

When pesticides are used to kill crop pests, beneficial insects, like these wasps, are also killed. Since the wasp populations grow more slowly than the pest populations, the pest population can actually rebound to a higher level than before the pesticide was applied, sometimes within weeks after pesticide application. Other wildlife also consume crop pests. Many birds, bats, and amphibians are important predators of crop pests. Farmers and researchers have found that enhancing habitat for these beneficial organisms helps reduce crop damage by pests.

We are consumers—eating producers (plants) and other consumers (animals). We compete with other consumers, which we often call pests. We have a mutualistic relationship with bees and apple trees: We eat apples and honey, and we provide homes for the bees near the apples. We plant, water, and fertilize apples and protect them from other consumers (worms, birds) and competing plants (weeds).

However, while our relationship with bees and apples is similar to those found in natural systems, there are some profound differences in the details. We often dedicate large areas to growing a single crop—in this case, apple orchards. In a system without humans, we would find a combination of apples and other plants, as well as a range of animals that eat apples. We must rely on energy inputs and chemicals to maintain the "unnatural" agricultural system, and we send the produce long distances to sell to consumers who are too far away to pick the apples themselves. Parasitic wasps in apple orchards help control aphids, which damage apple trees and fruit. More commonly, chemical pesticides are used to kill weeds and insects.

Agriculture is the sector that uses the most pesticides worldwide—approximately 85% of the estimated 2.6 million metric tons (2.9 million tons) used each year. Highly developed countries use about three-fourths of all pesticides, but pesticide use is increasing most rapidly in developing countries.

We discuss here the types and uses of pesticides, their benefits, and their disadvantages. Pesticides have saved millions of lives by killing insects that carry disease and by increasing the amount of food we grow. Modern agriculture depends on pesticides to produce blemish-free fruits and vegetables while keeping labor costs low. Pesticides, however, cause environmental and health problems, and their harmful effects can outweigh their benefits. Pesticides rarely affect only the targeted pest species, and the balance of a natural system, such as predator-prey relationships, is upset. Certain pesticides concentrate at higher levels of the food chain. Humans who apply and work with pesticides may be at risk for pesticide poisoning (short term) and cancer (long term), and people who eat traces of pesticide on food are concerned about the long-term effects. In this chapter we discuss some alternatives to pesticides and examine the pesticide laws that protect our health and the environment.

In Your Own Backyard...

Most homes deal with a range of pests, from dandelions in lawns to mice and ants. What pest management methods are used where you live?

What Is a Pesticide?

LEARNING OBJECTIVE

- Distinguish between narrow-spectrum and broad-spectrum pesticides, and describe the various types of pesticides, such as insecticides and herbicides.

Any organism that interferes in some way with human welfare or activities is a **pest**. Some plants, insects, rodents, bacteria, fungi, nematodes (microscopic worms), and other organisms compete with humans for food; other pests cause or spread disease. The definition of *pest* is subjective. A dandelion may be a pest to one lawn owner, but a food plant to someone else. People try to control pests, usually by reducing the size of the pest population. **Pesticides** are a common way of controlling pests, particularly in agriculture. Pesticides are grouped by their target organisms—that is, by the pests they are supposed to eliminate. **Insecticides** kill insects, **herbicides** kill plants, **fungicides** kill fungi, and **rodenticides** kill rodents, such as rats and mice. Although used as medicines, **antibiotics**, can also be considered a type of pesticide, because they kill bacteria.

The ideal pesticide would be a **narrow-spectrum pesticide** that would kill only the organism for which it was intended and not harm any other species. The perfect pesticide would be readily broken down, either by natural chemical decomposition or by biological organisms, into safe materials such as water, carbon dioxide, and oxygen. The ideal pesticide would stay exactly where it was put and would not move around in the environment.

Unfortunately, there is no such thing as an ideal pesticide. Most pesticides are **broad-spectrum pesticides.** Some pesticides do not degrade readily or else break down into compounds as dangerous as, if not more dangerous than, the original pesticide. Most pesticides move around in the environment, via air, soil, and especially water.

broad-spectrum ...**ticides** Pesticides that kill a variety ...ganisms, including ...ficial organisms, in addition to the target pest.

FIRST-GENERATION AND SECOND-GENERATION PESTICIDES

Before the 1940s, pesticides were of two main types, inorganic compounds (also called minerals) and organic compounds. Inorganic compounds that contain lead, mercury, copper, and arsenic are extremely toxic to pests but are not used much today, in part because of their chemical stability in the environment. Natural processes do not degrade inorganic compounds, which persist and accumulate in the soil and water. This accumulation poses a threat to humans and other organisms, which, like the target pests, are susceptible to poisoning by inorganic compounds.

Many plants, which have been fighting pests longer than humans, have evolved natural organic compounds that are poisonous to insects or inhibit growth of other plants. Such plant-derived pesticides are called **botanicals**. Examples of botanicals include nicotine from tobacco, pyrethrin from chrysanthemum flowers, and rotenone from roots of the derris plant, all of which are used to kill insects (**Figure 22.1**). Juglans, from black walnut trees, is a botanical herbicide. Botanicals, which are easily degraded by microorganisms, do not persist for long in the environment.

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Figure 22.1 Pesticide derived from plants. Chrysanthemum flowers, shown here as they are harvested in Rwanda, are the source of the insecticide pyrethrin. Botanicals are plant chemicals used as pesticides.

However, they are highly toxic to aquatic organisms and to bees (beneficial insects that pollinate crops).

Synthetic botanicals are human-made insecticides produced by chemically modifying the structure of natural botanicals. An important group of synthetic botanicals is the pyrethroids, which are chemically similar to pyrethrin. Pyrethroids do not persist in the environment; they are slightly toxic to mammals and bees but very toxic to fishes. Allethrin is an example of a pyrethroid. However, neonicotinoids are a synthetic botanical insecticide family which is highly toxic to bees, despite the fact that they are chemically similar to a natural botanical (nicotine, from tobacco).

In the 1940s, chemical companies began to produce many synthetic organic pesticides. Earlier pesticides, both inorganic compounds and botanicals, are called **first-generation pesticides** to distinguish them from the vast array of synthetic poisons in use today, called **second-generation pesticides**. The insect-killing ability of dichlorodiphenyltrichloroethane (DDT), the first of the second-generation pesticides, was recognized in 1939 (**Figure 22.2**). Currently about 20,000 commercial pesticide products are registered; these consist of combinations of about 675 active chemical ingredients.

THE MAJOR GROUPS OF INSECTICIDES

Insecticides, the largest category of pesticides, are usually classified into groups based on chemical structure. Three of the most important groups of second-generation insecticides are the chlorinated hydrocarbons, organophosphates, and carbamates.

DDT is a **chlorinated hydrocarbon**, an organic compound containing chlorine. After DDT's insecticidal properties were recognized, many more chlorinated hydrocarbons were synthesized as

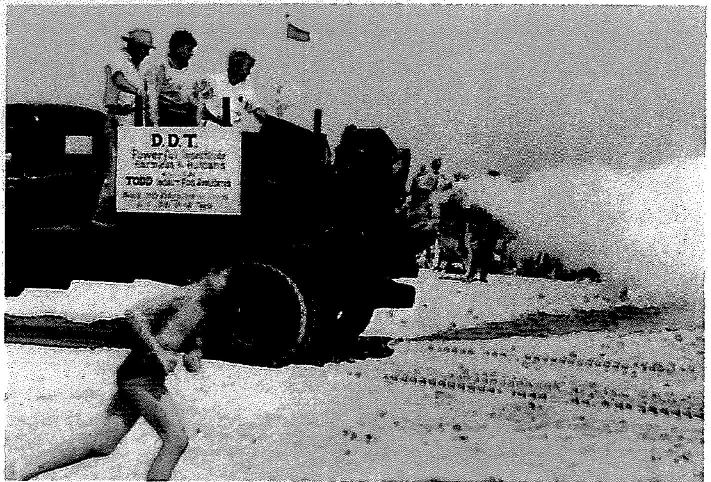

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Figure 22.2 Applying DDT in 1945. Pesticides such as DDT, shown as it was sprayed to control mosquitoes at New York's Jones Beach State Park in 1945, were used in ways that would be unacceptable now. The sign on the truck reads, in part, "D.D.T. Powerful Insecticide. Harmless to Humans." The harmful environmental effects of DDT were unknown to the public until many years later.

pesticides. Generally speaking, chlorinated hydrocarbons are broad-spectrum insecticides. Most are slow to degrade and may persist in the environment (even inside organisms) for many months or even years. They were widely used from the 1940s until the 1960s, but since then many have been banned or restricted, mainly because of problems associated with their persistence and impacts on humans and wildlife. Three chlorinated hydrocarbons still in use in the United States are endosulfan, lindane, and methoxychlor. Many people first became aware of the problems with pesticides in 1963, when Rachel Carson published *Silent Spring* (see Chapter 2).

Organophosphates, organic compounds that contain phosphorus, are more poisonous than other types of insecticides, and many are highly toxic to birds, bees, and aquatic organisms. The toxicity of many organophosphates in mammals, including humans, is comparable to that of some of our most dangerous poisons—arsenic, strychnine, and cyanide. Organophosphates do not persist in the environment as long as chlorinated hydrocarbons do. As a result, organophosphates have generally replaced the chlorinated hydrocarbons in large-scale uses such as agriculture, although many are not widely available to consumers because of their high level of toxicity. Methamidophos, dimethoate, and malathion are three examples of organophosphates. Some of these products have recently become restricted in their use due to their toxicity.

Carbamates, the third group of insecticides, are broad-spectrum insecticides derived from carbamic acid. Carbamates are generally not as toxic to mammals as the organophosphates, although they still show broad, nontarget toxicity. Two common carbamates are carbaryl and aldicarb.

THE MAJOR KINDS OF HERBICIDES

Herbicides are chemicals that kill or inhibit the growth of unwanted vegetation such as weeds in crops or lawns. Like insecticides, herbicides can be classified into groups on the basis of chemical structure, but this method is cumbersome because at least 12 different chemical groups are used as herbicides. More simply, **selective herbicides** kill only certain types of plants, whereas **nonselective herbicides** kill all or most vegetation. Selective herbicides can be further classified according to the types of plants they affect. **Broad-leaf herbicides** kill plants with broad leaves but do not kill grasses; **grass herbicides** kill grasses but are safe for most other plants.

Two common herbicides with similar structures are *2,4-dichlorophenoxyacetic acid (2,4-D)* and *2,4,5-trichlorophenoxyacetic acid (2,4,5-T)*. Both were developed in the United States in the 1940s. These broad-leaf herbicides, disrupt the plants' natural growth processes; they kill plants such as dandelions but do not harm grasses. Many of the world's important crops, such as wheat, corn, and rice, are cereal grains (see Chapter 18), which are grasses. Both 2,4-D and 2,4,5-T kill weeds that compete with these crops, although 2,4,5-T is no longer used in the United States. The Environmental Protection Agency (EPA) banned most uses of 2,4,5-T in 1979 because of possible harmful side effects to humans that became apparent after its use in the Vietnam War. 2,4-D is no longer used by commercial lawn care companies due to toxicity to applicators, but it is still one of the most common ingredients in lawn weedkillers.

Glyphosate is currently a popular herbicide due to its nonselective action and its low toxicity to mammals. However, herbicides with glyphosate are highly toxic to amphibians, and extensive use of glyphosate on genetically engineered crops (like Roundup Ready® corn) has raised concerns about whether this herbicide is really as safe as herbicide company tests suggest. Glyphosate is safer than many herbicides, but "safer" is not the same as "safe."

REVIEW

1. How do narrow-spectrum pesticides differ from broad-spectrum pesticides?

Benefits and Problems with Pesticides

LEARNING OBJECTIVES

- Describe the benefits of pesticides in disease control and crop protection.
- Explain why monocultures are susceptible to pest problems.
- Summarize the problems associated with pesticide use, including genetic resistance; imbalances; persistence, bioaccumulation, and biological magnification; and mobility in the environment.
- Describe pesticide resistance and resistance management.

Each day a war is waged as farmers, struggling to produce bountiful crops, battle insects and weeds. Similarly, health officials fight their own war against the ravages of human diseases transmitted by insects.

Although pesticides have their benefits, they have several problems. First, many pest species evolve resistance after repeated exposure to pesticides. Second, pesticides affect numerous species, including beneficial ones, in addition to the target pests, generating imbalances in the ecosystem (including agricultural fields) and posing a threat to human health. Finally, the ability of some pesticides to resist degradation and to readily move around in the environment causes even more problems for humans and other organisms.

BENEFIT: DISEASE CONTROL

Insects transmit several devastating human diseases. Fleas and lice carry the microorganism that causes typhus in humans. Malaria, also caused by a microorganism, is transmitted to millions of humans each year by female *Anopheles* mosquitoes (**Figure 22.3**). According to the World Health Organization (WHO), in 2012 approximately 207 million people suffered from malaria, leading to over 620,000 deaths. Over 20% of childhood deaths in Africa are associated with malaria. Because only a few antimalarial drugs are available (mostly botanicals), the focus of controlling this disease is on reducing the mosquitoes that carry it. Important steps in mosquito control include limiting stagnant pools of water where mosquitoes reproduce and applying pesticides.

Pesticides, particularly DDT, have helped control mosquito populations, thereby reducing the incidence of malaria. Consider Sri Lanka. In the early 1950s, more than 2 million cases of malaria were reported in Sri Lanka each year. When spraying of DDT was initiated to control mosquitoes, malaria cases dropped to almost zero. When DDT spraying was discontinued in 1964, malaria reappeared almost immediately. By 1968, the country's annual incidence had increased to more than 1 million cases per year. Since then, DDT use has resumed in many places, but not in the huge amounts and broad applications that caused so much damage in the 1960s. Today, DDT-impregnated mosquito nets are used to keep the pests off people, and indoor walls are sprayed with DDT.

BENEFIT: CROP PROTECTION

Although it is difficult to make exact assessments, it is widely estimated that pests eat or destroy more than one-third of the world's crops. Interestingly, this general proportion has been true for centuries of human agriculture, despite changing practices of pest control. Given our expanding population and world hunger, many people hope that better control of agricultural pests is possible.

Pesticides reduce the amount of a crop lost through competition with weeds, consumption by insects, and diseases caused by plant **pathogens** (microorganisms, such as fungi and bacteria, that cause plant disease). Although many insect species are beneficial from a human viewpoint (two examples are honeybees, which pollinate crops, and ladybugs, which prey on crop-eating insects), many are considered pests. Of these, about 200 species have the potential to cause large economic losses in agriculture. For example, the Colorado potato beetle is one of many insects that voraciously consume the leaves of the potato plant, reducing the plant's ability to produce large tubers for harvest.

Pesticide use is usually justified economically, in that farmers save an estimated \$3 to \$5 in crops for every \$1 that they invest in pesticides. In countries where pesticides are not used in appreciable amounts and crop health is compromised by poor agricultural practices, the losses due to agricultural pests can be considerable.

Why are agricultural pests found in such great numbers in our fields? Part of the reason is that agriculture is usually a **monoculture**, in which only one variety of one crop species is grown on large tracts of land (this term was also used, in reference to tree plantations, in Chapter 6). The cultivated field represents a simple ecosystem from which humans have removed much of the "system." In contrast, forests, wetlands, and other natural ecosystems are complex and contain many different species, including predators and parasites that control pest populations and plant species that pests do not use for food. A monoculture reduces the dangers and accidents that might befall a pest as it searches for food. A Colorado potato beetle in a forest would have a hard time finding anything to eat, but a 500-acre potato field is like a big banquet table set just for the pest. It eats, prospers, and reproduces. In the absence of many natural predators and in the presence of plenty of food, the population thrives and grows, and more of the crop becomes damaged.

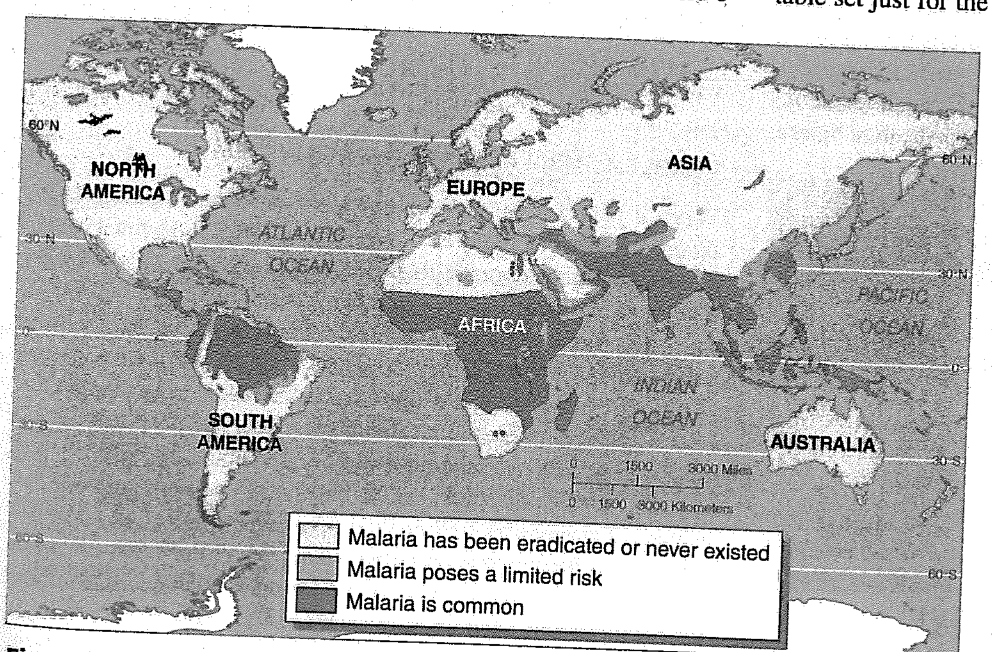

Figure 22.3 Location of malaria. Insecticides sprayed to control mosquitoes in these locations have saved millions of lives. Had insecticides not been used widely in agriculture as well, mosquitoes would also not have developed resistance to these insecticides so quickly.

PROBLEM: EVOLUTION OF GENETIC RESISTANCE

The prolonged use of a particular pesticide can cause a pest population to develop **genetic resistance** to the pesticide. In the 60 years during which pesticides have been widely used, at least 520 species of insects and mites have evolved genetic resistance to certain pesticides. Many pests are now resistant to multiple pesticides, and at least 17 species, such as diamondback moths and palm thrips, are resistant to all major classes of insecticides that farmers are legally allowed to use on them. Insects are not the only pests to evolve genetic resistance; almost 200 plant

genetic resistance Any inherited characteristic that decreases the effect of a pesticide on a pest.

ENVIRONEWS ON CAMPUS

Getting Off The Pesticide Treadmill

In the late 1990s, Bucknell University's greenhouse—a collection of plants used for research and teaching—used regular applications of pesticides to manage whitefly and mealy bug populations. Unfortunately, this meant considerable expense, and it exposed researchers and visitors to pesticide residues.

In 1999, the greenhouse manager decided to take a systems approach and manage many of the pests by fostering their natural predators—that is, by using biological control. By 2001, the facility was pesticide-free, and the greenhouse was considered a model program for greenhouse management in 2005. This does not mean that the greenhouse was pest-free but rather that the pests were kept to a small number by other insects. Balancing the system also meant managing other abiotic factors, such as temperature and humidity.

Other campus pesticide reduction programs include the following:

- Elimination of all lawn pesticides from many campuses, including Berea College in Kentucky
- The use of goats that graze on weeds in place of herbicides at the University of Colorado, Boulder
- The development of a detailed guide to campus pesticide management in Northeast schools by the Cornell University Cooperative Extension

species are known to be resistant to herbicides. Some weeds, such as annual ryegrass and canary grass, may be resistant to all available herbicides.

How does genetic resistance to pesticides occur? Every time a pesticide is applied to control a pest, some pests survive. The survivors, because of certain genes they already possess, are genetically resistant to the pesticide, and they pass on this trait to future generations. Thus, *evolution*—any cumulative genetic change in a population of organisms—occurs, and subsequent pest populations contain larger percentages of pesticide-resistant pests than before.

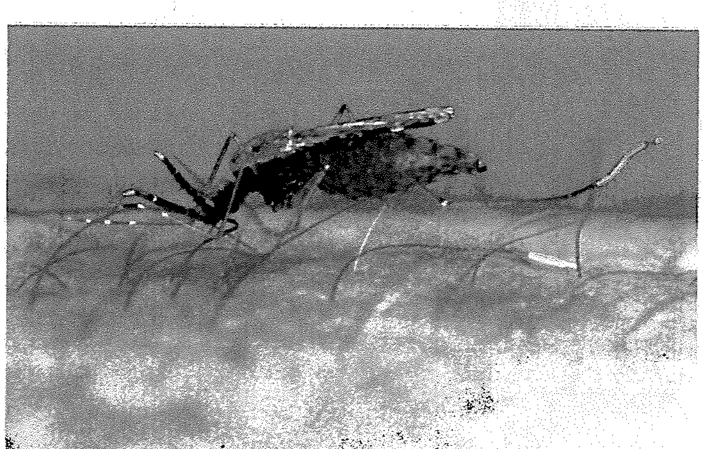

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Figure 22.4 Mosquito feeding. South American malaria vector mosquito (*Anopheles albimanus*) feeding. Mosquitoes have a short life cycle, making it possible for insecticide resistant individuals to repopulate an area quickly after pesticide application.

Insects and other pests are constantly evolving. The short generation times (the period between the birth of one generation and that of another) and large populations characteristic of most pests favor rapid evolution, which allows the pest population to quickly adapt to the pesticides used against it (**Figure 22.4**). As a result, an insecticide that kills most of an insect population becomes less effective after prolonged use because the survivors and their offspring are genetically resistant. For example, after many years of DDT applications on walls to kill mosquitoes that land, mosquitoes have genetically evolved in their behavior: some populations of mosquitoes do not land on walls before seeking their next meal.

Resistance management is a useful approach to dealing with genetic resistance. It involves efforts to delay the evolution of genetic resistance in insect pests or weeds. Strategies of resistance management vary, depending on the pest species involved.

resistance management Strategies for managing genetic resistance to maximize the period in which a pesticide is useful.

One strategy of resistance management for insect pests is to maintain a nearby "refuge" of untreated plants where the pest can avoid being exposed to the pesticide. Those insects or weeds that live and grow in the refuge remain susceptible to the pesticide. When susceptible insects migrate into the area being treated with insecticide, they mate with members of the genetically resistant population. Weeds in the refuge continue to contribute pollen to the larger weed population. This interbreeding delays the development of genetic resistance in the population as a whole.

After herbicides are applied, the field is scouted to see if any weed plants survived the herbicide application. These weeds are resistant to the herbicide, and they are removed from the field before they flower. Cultural methods that prolong the usefulness of herbicides include mechanically pulling weeds, planting seed that is certified free of weed seeds, avoiding importing manure from weedy fields onto cleaner ones, and rotating crops to keep weed populations from accumulating as easily. All of these methods can help managers avoid the pesticide treadmill, in which pesticide types and application rates must be continually increased to deal with resistant pest populations.

PROBLEM: IMBALANCES IN THE ECOSYSTEM

When a pesticide is applied, a new and powerful limiting factor enters an often delicately balanced system. Often, beneficial insects experience more damage than do pest insects. In a study of the effects of spraying the insecticide dieldrin to kill Japanese beetles, scientists found a large number of dead animals in the treated area, such as birds, rabbits, ground squirrels, cats, and beneficial insects. (Use of dieldrin in the United States has since been banned.)

Similarly, in Vermont and New York, lamprey eels attack native trout and Atlantic salmon. The U.S. Fish and Wildlife Service has approved the application of pesticides to kill lamprey larvae in 12 streams as well as Lake Champlain. However, it is not clear how effective this and other lamprey-control measures have been, and the Center for Biological Diversity claims that the pesticides do more to disrupt ecosystems than to eliminate lampreys. Pesticides do not have to kill organisms to harm them. Quite often, the stress of pesticide exposure makes an organism more vulnerable to predators, diseases, or other stressors in its environment.

Because the natural enemies of pests often starve or migrate in search of food after pesticide is sprayed in an area, pesticides are indirectly responsible for a large reduction in the populations of these natural enemies. Pesticides also kill natural enemies directly because predators consume a lot of the pesticide when consuming the pests. After a brief period, the pest population rebounds and gets larger than ever, partly because no natural predators are left to keep its numbers in check. Natural predator populations grow more slowly in numbers (see *K* selection in Chapter 5) than pest populations.

Despite a 33-fold increase in pesticide use in the United States since the 1940s, crop losses due to insects, diseases, and weeds have not changed appreciably (**Table 22.1**). Increasing genetic resistance to pesticides and the destruction of the natural enemies of pests provide a partial explanation. Changes in agricultural practices are also to blame; for example, crop rotation, a proven way of controlling certain pests, is not practiced as much today as it was several decades ago (see Chapter 14).

Creation of New Pests In some instances, use of a pesticide has resulted in a pest problem that did not exist before. Creation of new pests—that is, turning minor pest organisms into major pests—is possible because the pesticide kills most of a certain pest's natural predators, parasites, and competitors, allowing the pest's population to rebound. The use of DDT to control certain insect pests on lemon trees was documented as causing an outbreak of a scale insect (a sucking insect that attacks plants) that was not a problem before spraying (**Figure 22.5**). In a similar manner, the European red mite became an important pest on apple trees in the northeastern United States, and beet armyworms became an important pest on cotton, both after the introduction of pesticides.

PROBLEMS: PERSISTENCE, BIOACCUMULATION, AND BIOLOGICAL MAGNIFICATION

As discussed in Chapter 7, some pesticides are extremely **persistent** in the environment and may take many years to break down into less toxic forms. When a persistent pesticide is ingested, it is stored, usually in fatty tissues. Over time, the organism may accumulate high concentrations of the pesticide, a phenomenon known as **bioaccumulation.**

cumulation The up of a persistent pesticide or other c substance in an organism's body.

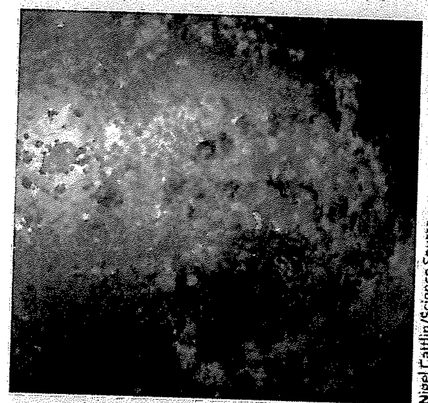
biological gnification The ed concentration c chemicals such tain pesticides in ues of organisms ier trophic levels in food webs.

Organisms at higher levels in food webs tend to have greater concentrations of bioaccumulated pesticide stored in their bodies than those lower in food webs. The increase in pesticide concentrations as the pesticide passes irough successive levels of the food web is known as **biomagnifi-ation** (**Figure 22.6**; also see Figure 7.6).

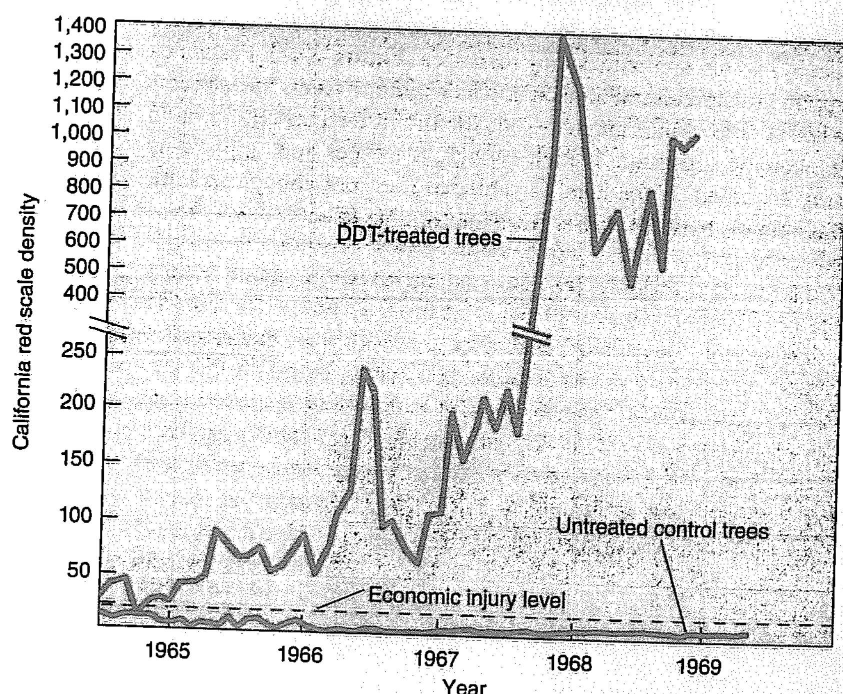
Table 22.1 Percentage of Crops Lost Annually to Pests in the United States

Period	*Insects*	*Diseases*	*Weeds*
2006	13.0	12.5	12.0
1989–1999	13.0	12.0	12.0
1974	13.0	12.0	8.0
1951–1960	12.9	12.2	8.5
1942–1951	7.1	10.5	13.8

Source: USDA Agricultural Research Service



(a) Red scale on oranges.



(b) A comparison of red scale populations on DDT-treated trees (blue line) and untreated trees under biological control (red line).

Figure 22.5 Pesticide use and new pest species. An infestation of red scale insects on lemons occurred after DDT was sprayed to control a different pest. Prior to DDT treatment, red scale did not cause significant economic injury to citrus crops.

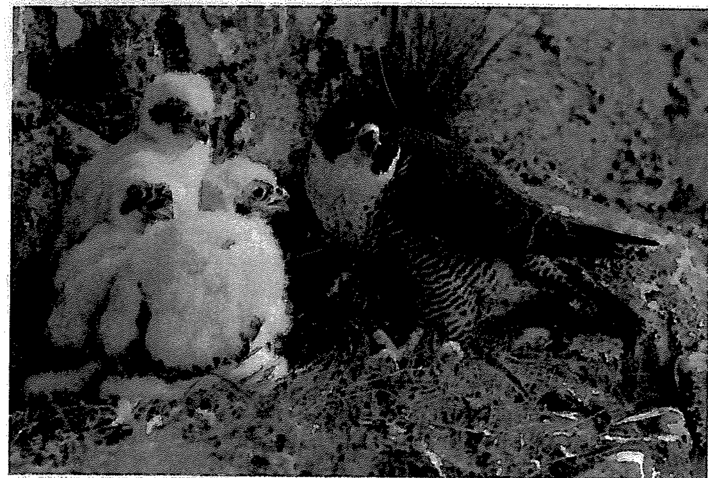

Dave Watts / Photoshot

Figure 22.6 Peregrine falcon feeding chicks. Biological magnification of DDT in the tissues of falcons and other birds of prey caused a decline in their reproductive success in the United States during the 1960s and early 1970s. DDT caused the birds to lay eggs with extremely thin, fragile shells, resulting in the chicks' deaths. (DDT use was banned in the United States in 1972.)

PROBLEM: MOBILITY IN THE ENVIRONMENT

Another problem associated with pesticides is that they do not stay where they are applied but tend to move through the soil, water, and air, sometimes long distances (**Figure 22.7**). Pesticides applied to agricultural lands or lawns wash into rivers and streams when it rains, which can harm aquatic life. If the pesticide level in the aquatic ecosystem is high enough, the fishes and amphibians may be killed. If the level is sublethal (i.e., not enough to kill), the animals may still suffer from undesirable effects such as bone degeneration. These effects may decrease the animals' fitness and increase their chances of being preyed on.

Pesticide mobility is also a problem for humans. The most recent comprehensive study by the Environmental Protection Agency and the U.S. Geological Survey reported that pesticides are found throughout the year in most of the country's surface waters. The study also found at least one pesticide above the **water quality benchmark** (the level above which aquatic organisms are threatened) in 80% of urban streams. Another study by the Environmental Working Group (EWG), a private environmental organization, revealed that more than 14 million U.S. residents drink water containing traces of five widely used herbicides (alachlor, metachlor, atrazine, cyanazine, and simazine). The study concluded that 3.5 million people living in the Midwest, where those herbicides are used on corn and soybeans, face an elevated cancer risk. Since the study, the EPA has required a decrease in the use of these herbicides.

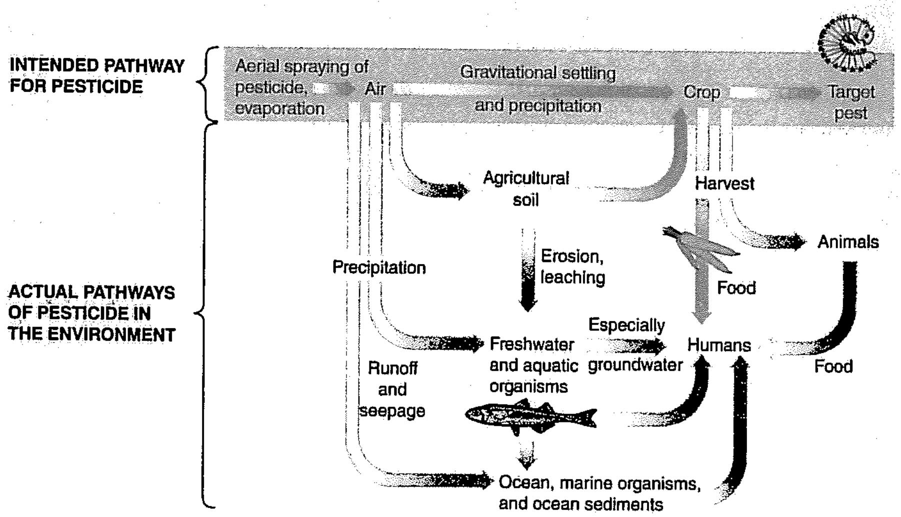
Another EWG study in California revealed how mobile pesticides can be in the atmosphere. Almost two-thirds of 100 air samples from California contained small amounts of pesticides that had drifted from farm fields. Air and water currents can carry pesticides around the world: A 2008 study sampled Antarctic krill, a keystone species in the Antarctic ecosystem (see Case in Point, Chapter 3). In each of 12 sites sampled, multiple organochlorine pesticides were found.

REVIEW

1. What are two important benefits of pesticide use?
2. Why are monocultures susceptible to pest problems?
3. What are persistence, bioaccumulation, and biomagnification?
4. Describe pesticide resistance and discuss some methods for preventing the problem.


Lawrence Migdale/Science Source

(a) A helicopter sprays pesticides on a crop—and everything else in its pathway—in California.



(b) The intended pathway of pesticides in the environment (shown at top of figure) is quite different from the actual pathways (shown at bottom).

Figure 22.7 Intended versus actual pathways of pesticides.

Risks of Pesticides to Human Health

LEARNING OBJECTIVES

- Discuss pesticide risks to human health, including short-term effects and long-term effects.
- Explain endocrine disruption.

Exposure to pesticides can damage human health. Pesticide poisoning caused by short-term exposure to high levels of pesticides can result in harm to organs and even death, whereas long-term exposure to lower levels of pesticides can cause certain types of cancer, or metabolic or reproductive problems. In addition, exposure to trace amounts of certain pesticides could disrupt the human endocrine (hormone) system. Chapter 7 discusses the elevated risk of pesticides to children (see Figure 7.10).

SHORT-TERM EFFECTS OF PESTICIDES

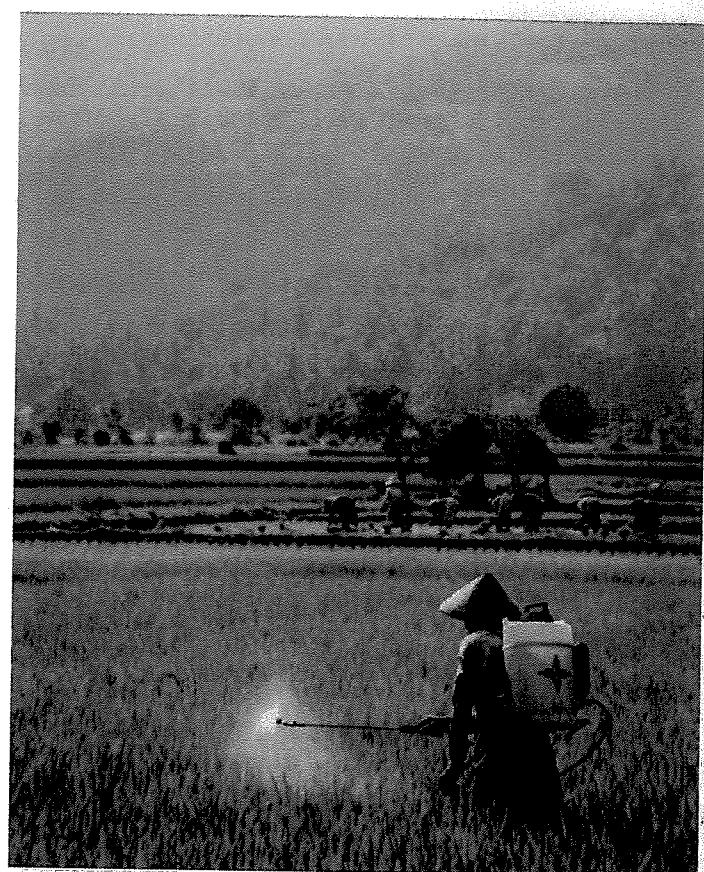
Pesticides poison tens of thousands of people in the United States each year. Most poisonings occur among farmworkers or others whose occupations involve daily contact with large quantities of pesticides. A person with a mild case of pesticide poisoning may exhibit symptoms such as nausea, vomiting, and headaches. More serious cases, particularly organophosphate poisonings, may result in permanent damage to the nervous system and other body organs. Almost any pesticide can kill a human if the dose is large enough. Fortunately, pesticide application, packaging, and distribution regulations have led to decreased poisonings since the mid-1990s.

WHO estimates that, globally, pesticides poison more than 4 million people each year; of these, at least a million require hospitalization and about 300,000 die. The incidence of pesticide poisoning is highest in countries where pesticide regulations are minimal. Pesticide users in many countries often are not trained in the safe handling and storage of pesticides, and safety regulations are generally more lax there.

LONG-TERM EFFECTS OF PESTICIDES

Many studies of farmworkers and workers in pesticide factories, many of whom are exposed to low levels of pesticides over many years, show an association between cancer and long-term exposure to pesticides (**Figure 22.8**). A type of lymphoma (a cancer of the lymph system) is associated with the herbicide 2,4-D. Other pesticides are linked to a variety of cancers, such as leukemia and cancers of the brain, lungs, and testicles. Researchers have noted a correlation between breast cancer and a high level of one or more pesticides in the breast's fatty tissue.

Long-term exposure to at least one pesticide may have resulted in sterility in thousands of farmworkers on banana and pineapple plantations. More than 26,000 workers in 12 countries sued their employers or pesticide manufacturers, and most of the defendants have paid settlements but have not admitted liability. Evidence shows that pregnant women who live near pesticide applications have higher rates of miscarriages. Other studies have indicated that the children of agricultural workers are at greater risk for birth defects, particularly stunted limbs.



Lens/Getty Images

Figure 22.8 Farmworker applying pesticide. Most people who suffer from pesticide-related illnesses are farmworkers or others whose occupations involve daily contact with pesticides.

Long-term exposure to pesticides may increase the risk of Parkinson's disease, which afflicts about 1 million people in the United States. When researchers injected rats with repeated doses of rotenone, a plant-derived pesticide, the rats developed the symptoms of Parkinson's disease, including difficulty in walking, tremors, and abnormal protein deposits in their brains. Many pesticides have chemical structures similar to rotenone, which suggests that other pesticides may increase the risk of Parkinson's disease as well. This connection between pesticide exposure and Parkinson's disease is tentative and will require additional research to prove or disprove. To date, no study has connected Parkinson's disease in humans with exposure to a specific pesticide.

PESTICIDES AS ENDOCRINE DISRUPTERS

In the 1990s, many articles were published that linked certain pesticides and other persistent toxic chemicals with reproductive problems in animals. These chemicals, known as **endocrine disrupters**, interfere with or mimic hormones in humans or other animals (**Table 22.2**; see Chapter 7 discussion on endocrine disrupters). River otters exposed to synthetic chemical pollutants were found to have abnormally small penises. Female seagulls in southern California exhibited behavioral aberrations by pairing with one another rather than with males during the mating season. In Florida, alligators exposed to a common herbicide produce eggs inside their testes. In many cases scientists have produced the

Table 22.2 Some Pesticides That Are Known Endocrine Disrupters*

Pesticide	*General Information*
Atrazine	Herbicide; still used
Chlordane	Insecticide; banned in United States in 1988
DDT (dichlorodiphenyl-trichloroethane)	Insecticide; banned in United States in 1972
Endosulfan	Insecticide; still used
Kepone	Insecticide; banned in United States in 1977
Methoxychlor	Insecticide; still used

*Based on experimental research with laboratory animals.

same abnormal symptoms in the laboratory, providing support that certain persistent chemicals cause the defects.

The suggestion in the 1996 book *Our Stolen Future*, by Theo Colborn, Dianne Dumanoski, and John Myers, that persistent toxic chemicals in the environment are disrupting human hormone systems ignited a barrage of media attention. Theo Colborn, then a senior scientist at the World Wildlife Fund, hypothesized that ubiquitous chemicals in the environment are linked to disturbing trends in human health. These include increases in breast and testicular cancer, increases in male birth defects, and decreases in sperm counts.

Many studies suggest that certain chemicals in the environment may affect human health, but direct cause-and-effect relationships between these chemicals and adverse effects on the human population have not been widely established. Some scientists think the potential danger is so great that persistent chemicals such as DDT should be internationally banned immediately. Other scientists are more cautious in their assessment of the danger, but few think the problem should be disregarded. Meanwhile, an international effort is under way to ban the production and use of nine pesticides suspected of being endocrine disrupters (see section on the global ban of persistent organic pollutants later in this chapter).

REVIEW

1. What are some of the long-term effects of pesticides on human health?
2. Why are endocrine-disrupting pesticides of particular concern?

Alternatives to Pesticides

LEARNING OBJECTIVE

- Describe alternative ways to control pests, including cultivation methods, biological controls, pheromones and hormones, reproductive controls, genetic controls, quarantine, integrated pest management, and food irradiation.

Fortunately, pesticides are not the only weapons in our arsenal against pests. Alternative ways to control pests include cultivation methods, biological controls, pheromones and hormones, reproductive controls, genetic controls, quarantine, and irradiation. A combination of these methods, often including a limited use of pesticides as a last resort, is known as *integrated pest management (IPM)*. IPM is the most effective way to control pests. (Also see Chapter 18 for a discussion of organic agriculture, in which foods are grown in the absence of pesticides and commercial fertilizers.)

USING CULTIVATION METHODS TO CONTROL PESTS

Sometimes agricultural practices are altered in such a way that a pest is adversely affected or discouraged from causing damage. Although some techniques, such as using vacuums for removing insect pests, are relatively new, other cultivation methods that discourage pests have been practiced for centuries.

One way to reduce damage from crop pests is to *intercrop* mixtures of plants, for example, by alternating rows of different plants. When corn was interplanted with sorghum in an experiment in Kenya, only about 5% of the corn crop was damaged, as compared with about 39% damage in the monoculture field of corn. Sorghum repels some insects and attracts wasps that lay their eggs inside corn borers, insects that eat through and destroy maturing corn stalks. Sorghum–corn intercropping is now common in parts of Africa.

A technique used with success in alfalfa crops is *strip cutting*, in which only one segment of the crop is harvested at a time. The unharvested portion of the crop provides an undisturbed habitat for natural predators and parasites of the pest species. The same type of benefit is derived from keeping strips of unplowed plants (i.e., wild plants, including weeds) along the margins of fields. A German study found that pest mortality was about 50% higher in oilseed rape fields with margin strips of other plants, as compared to fields without margins. The margins provided a refuge for three parasites of the pollen beetle, which is a significant pest on oilseed rape plants.

The proper timing of planting, fertilizing, and irrigating promotes healthy, vigorous plants that are more resistant to pests because they are not stressed by other environmental factors. The rotation of crops controls pests, such as corn rootworm.

BIOLOGICAL CONTROLS

As an example of a **biological control**, suppose that an insect species is accidentally introduced into a country where it was not found previously and becomes a pest. It might be possible to control this pest by going to its place of origin and looking at how the pest fit into its native ecosystem. Usually, some other organism—often a wasp or disease organism—is an exclusive predator or parasite of the pest species. That predator or parasite, if successfully introduced, may lower the population of the pest species.

biological control A method of pest control that involves the use of naturally occurring disease organisms, parasites, or predators to control pests.

The pest species typically does not evolve genetic resistance to the biological control agent in the same way it does to a pesticide, since both pest and predator are living organisms that are responsive to *natural selection*. As the pest evolves a way to resist the biological control agent, the agent in turn may evolve some sort of countermeasure against the pest. (Recall the discussion of the predator–prey "arms race" in Chapter 5; a similar arms race occurs here between the pest and its biological control agent.)

Cottony-cushion scale provides an example of successfully using one organism to control another. The cottony-cushion scale is a small insect that sucks the sap from the branches and bark of many fruit trees, including citrus trees. It is native to Australia but was accidentally introduced into the United States in the 1880s. A U.S. entomologist went to Australia and returned with several possible biological control agents. One, the vedalia beetle (**Figure 22.9**), was effective in controlling scales, which it eats voraciously and exclusively. Within two years of its introduction, the vedalia beetle had significantly reduced the cottony-cushion scale in citrus orchards. Today, both the cottony-cushion scale and the vedalia beetle are present in low numbers, and the scale is not considered an economically important pest.

More than 300 species have been introduced as biological control agents to North America. The Agricultural Research Service of the U.S. Department of Agriculture (USDA) is constantly investigating possible biological controls for insect and weed pests. Although some examples of biological control are quite spectacular, finding an effective parasite or predator is usually difficult. And just because a parasite or predator is identified does not mean it will become successfully established in a new environment. Slight variations in environmental conditions, such as temperature and moisture, can alter the effectiveness of the biological control organism in its new habitat.

Care must be taken to ensure that the introduced control agent does not attack unintended hosts and become a pest itself. To guard against this possibility when the control agent is an insect, scientists put the insects in cages with samples of important crops, ornamentals, and native plants to determine if the control agents will eat the plants when they are starving. Despite such tests, organisms introduced as biological controls sometimes cause unintended problems in their new environment, and once they are introduced, they cannot be recalled. For example, a weevil was introduced in 1968 to control the Eurasian musk thistle, a noxious weed that arrived in North America in the mid-19th century. Since then, the weevil has expanded its host range to include a North American thistle listed as a threatened species. The weevils significantly reduce seed production in the native thistles.

Figure 22.9 Vedalia beetle. Imported from Australia to reduce cottony-cushion scale infestation, the vedalia beetle is a biological control success story.

Australia, in particular, has been home to many spectacularly effective and spectacularly disastrous biological control efforts. Rabbits were introduced for meat production, but were so devastating to native plant communities that a rabbit disease, myxomatosis, was introduced to control them. Cane toads were introduced as a biological control against the sugar cane grub, yet failed entirely at controlling the pest, and cane toads themselves are now a widespread pest throughout Queensland, Australia. All introductions of non-native species should be carefully considered, especially on islands; many problems could be averted by relying on native species for agriculture and landscaping.

Biological Control Agents Insects are not the only biological control agents (indeed, cats have long been kept to control rodents). When DDT was banned in the United States, alternative solutions to mosquito problems were explored. One alternative has been to spray nematodes (microscopic worms) that attack mosquito larvae. Other nematodes are often sprayed on corn to kill corn borers. Nematodes (and bacteria, discussed later) can be used to control beetle grubs in lawns. The nematodes can be sprayed much like a chemical pesticide, but with the advantage that the nematode is usually specific to a single pest and harmless to other animals. Some nematodes are also effective against a range of pests, including weevils, grasshoppers, and locusts.

Another noninsect biological control agent targets desert locusts: a fungal spore known as the Green Muscle. Locusts periodically increase in number and swarm across the African Sahel, threatening crops across 12 million hectares (30 million acres) (see Figure 4.22 for a map showing the Sahel). During a major swarm in 1988, African farmers spent $300 million to spray massive quantities of pesticides into the environment to bring the locust population under control. Many people were concerned about the adverse ecological and health effects of using such large quantities of pesticides. The use of Green Muscle in Tanzania averted much of the threat from a 2009 locust infestation that could have impacted crops that feed as many as 15 million people.

Bacteria and viruses that harm insect pests are also used successfully as biological controls. *Bacillus popilliae*, which causes milky spore disease in insects, is applied as a dust on the ground to control the larval (immature) stage of Japanese beetles. The common soil bacterium *Bacillus thuringiensis*, or *Bt*, produces a natural pesticide toxic to some insects, such as the cabbage looper, a green caterpillar that damages many vegetable crops, and the corn earworm. When eaten by insect larvae, *Bt* toxin damages the intestinal tract, killing the young insect. The toxin does not persist in the environment and is not known to harm mammals, birds, or other noninsect species.

PHEROMONES AND HORMONES

Pheromones are commonly called sexual attractants because they are often produced to attract members of the opposite sex for mating. Each insect species produces its own specific pheromone, so once the chemical structure is known, it is possible to make use of pheromones to control individual

pheromone A natural substance produced by animals to stimulate a response in other members of the same species.

pest species. Pheromones lure insects such as Japanese beetles to traps, where they are killed. Alternatively, pheromones are released into the atmosphere to confuse insects so that they cannot locate mates.

Insect hormones are natural chemicals produced by insects to regulate their own growth and metamorphosis, which is the process in which an insect's body changes through several stages to an adult. Specific hormones must be present at certain times in the life cycle of the insect; if they are present at the wrong time, the insect develops abnormally and dies. Many such insect hormones are known, and synthetic hormones with similar structures have been made. Entomologists are actively pursuing the possibility of using these substances to control insect pests.

A synthetic version of the insect hormone *ecdysone*, which causes molting, was the first hormone approved for use. Known as MIMIC, the hormone triggers abnormal molting in insect larvae (caterpillars) of moths and butterflies. Since MIMIC affects some beneficial insects, its use has risks.

REPRODUCTIVE CONTROLS

Like biological controls, reproductive controls of pests involve the use of organisms. Instead of using another species to reduce the pest population, reproductive control strategies suppress a pest population by sterilizing some of its members. In the **sterile male technique**, large numbers of males are sterilized in a laboratory, usually with radiation or chemicals. Males are sterilized rather than females because male insects of species selected for this type of control mate several to many times, but females of that species mate only once. Thus, releasing a single sterile male may prevent successful reproduction by several females, whereas releasing a single sterile female would prevent successful reproduction by only that female.

The sterilized males are released into the wild, where they reduce the reproductive potential of the pest population by mating with normal females, which then lay eggs that never hatch. As a result, the population of the next generation is much smaller.

One disadvantage of the sterile male technique is that to be effective it must be carried out continually. If sterilization is discontinued, the pest population rebounds to a high level in a few short generations. The procedure is expensive because a production facility must rear and sterilize large numbers of insects. During the 1990 Mediterranean fruit fly (medfly) outbreak in California, as many as 400 million sterile male medflies were released each week. The medfly, which lays eggs on 250 different fruits and vegetables, is a particularly destructive pest.

The standard way to sterilize male insects is to irradiate them. However, this approach does not work on at least one major human health threat: mosquitoes. An Oxford University researcher has developed a way to genetically modify mosquitoes such that their offspring die off in the larval stage. This is a promising technique, but it is too new to be certain how effective it is and how broadly it can be applied. With their short life cycles and widespread distribution in nonagricultural areas (where pest control is difficult), mosquitoes will continue to challenge our pest-control abilities.

GENETIC CONTROLS

Traditional selective breeding has been used to develop many varieties of crops that are genetically resistant to disease organisms or insects. Traditional breeding of crop plants typically involves identifying individual plants that are present in an area where the pest is common but that are not damaged by the pest. These individuals are then crossed with standard crop varieties in an effort to produce a pest-resistant version. It may take as long as 10 to 20 years to develop a resistant crop variety, but the benefits are usually worth the time and expense.

Although traditional selective breeding has resulted in many disease-resistant crops and has enabled decreased use of pesticides, there are potential problems. Fungi, bacteria, and other plant pathogens evolve rapidly and quickly adapt to the disease-resistant host plant—meaning that the new pathogen strains can cause disease in the formerly disease-resistant plant variety. Plant breeders are in a continual race to keep one step ahead of plant pathogens.

Genetic engineering offers promise in breeding pest-resistant plants more quickly (see Chapter 18). For example, a gene from the soil bacterium *Bt* (already discussed in the section on biological controls) has been introduced into several plants, such as corn and cotton. Caterpillars that eat cotton leaves from these **genetically modified (GM)** plants die or exhibit stunted growth. On the other hand, when *Bt* toxin is present in plants on a large scale, caterpillars are more likely to evolve resistance to the toxin.

CASE IN POINT

Bt, ITS POTENTIAL AND PROBLEMS

Bt has been marketed since the 1950s, but it was not sold on a large scale until recent decades, mainly because many different varieties of the *Bt* bacterium occur and each variety produces a slightly different protein toxin. Each is toxic to only a small group of insects. The *Bt* variety that works against corn borers, for example, would not be effective against potato beetles. As a result, *Bt* is not economically competitive compared to chemical pesticides, each of which could kill many different kinds of pests on many different crops.

Genetic engineers have greatly increased the potential of *Bt*'s toxin as a natural pesticide by modifying the gene coding for the toxin so that it affects a wider range of insect pests. They then inserted the *Bt* gene that codes for the toxin into at least 18 crop species, including corn, potato, and cotton. *Bt* corn, one of the first GM crops, was engineered to produce a continuous supply of toxin, which provides a natural defense against insects such as the European corn borer. Similarly, *Bt* tomato and *Bt* cotton are more resistant to pests such as the tomato pinworm and the cotton bollworm. Early ecological risk assessment studies, performed before the EPA approved their use, indicated that GM crops are essentially like their more conventional counterparts that are produced by selective breeding. Genetically modified crops do not become invasive pests or persist in the environment longer than crops that are not genetically modified. Significantly fewer pesticide applications are needed for GM crops with the *Bt* gene.

The future of the *Bt* toxin as an effective substitute for chemical pesticides is not completely secure, however. Beginning in the late 1980s, farmers began to notice that chemically applied *Bt* was not working as well against the diamondback moth as it had in the past. All farmers who reported this reduction in effectiveness had used *Bt* frequently and in large amounts. In 1996, many farmers growing *Bt* cotton reported that their crop succumbed to the cotton bollworm, which *Bt* is supposed to kill. It appears that certain insects, such as the diamondback moth and possibly the cotton bollworm, may have evolved resistance to this natural toxin. If *Bt* is used in greater and greater amounts, it is likely that more insect pests will develop genetic resistance to it, greatly reducing *Bt*'s potential as a natural pesticide. Scientists are developing resistance management strategies to slow the evolution of pest resistance to genetically engineered crops that make *Bt*.

GM crops with the *Bt* gene create situations where the *Bt* toxin is present in more places. John Losey, a Cornell entomologist, demonstrated in 1998 that *Bt* corn pollen, blown by wind onto milkweed plants (a common corn weed), could make the milkweed leaves deadly to monarch butterfly larvae. This research demonstrated the potential for *Bt* toxin to become a kind of environmental pollutant through pollen spread from *Bt* crops. ■

QUARANTINE

Governments attempt to prevent the importation of foreign pests and diseases by practicing **quarantine**, or restriction of the importation of exotic plant and animal material that might harbor pests. If a foreign pest is accidentally introduced, quarantine of the area where it is detected helps prevent its spread. If a foreign pest is detected on a farm, the farmer may be required to destroy the entire crop.

Quarantine is an effective, though not foolproof, means of control. The USDA has blocked the accidental importation of medflies on more than 100 separate occasions. On the few occasions when quarantine failed and these insects successfully passed into the United States, millions of dollars of crop damage were incurred in addition to the millions spent to eradicate the pests. Eradication efforts include the use of helicopters to spray the insecticide malathion over hundreds of square kilometers and the rearing and releasing of millions of sterile males to breed the medfly out of existence.

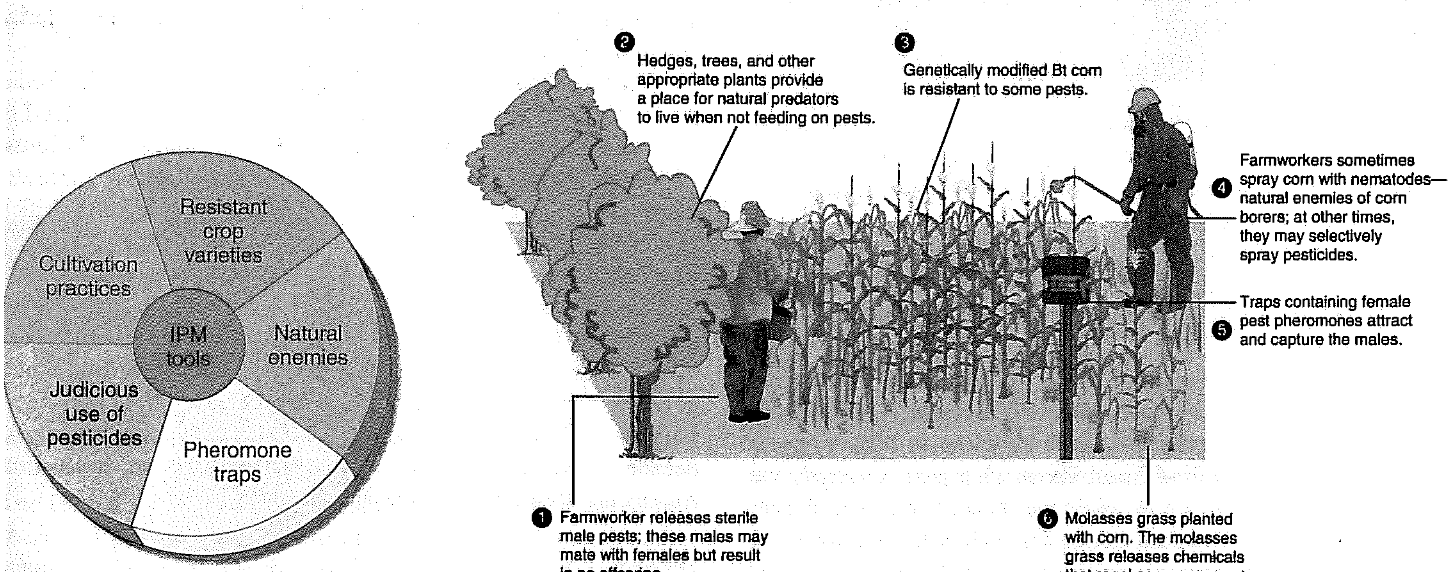
Experts were once concerned that repeated finds of medflies in California indicated that, rather than being accidentally introduced each year, the medfly had become established in the state. Other countries could stop importing California produce or require expensive inspections and treatments of every shipment to prevent the importation of the medfly into their countries. However, by 2008, the medfly had been eliminated, so quarantine remains an important strategy to minimize future medfly infestations.

THE SYSTEMS APPROACH: INTEGRATED PEST MANAGEMENT

Many pests are not controlled effectively with a single technique; rather, a combination of control methods is often more effective. **Integrated pest management (IPM)** combines a variety of biological, cultivation, and pesticide controls tailored to the conditions and crops of an individual farm, school, campus, city, or greenhouse. **Figure 22.10** provides an illustrated example of some ways in which IPM can control corn pests.

integrated pest management (IPM) A combination of pest control methods that, if used in the proper order and at the proper times, keep the size of a pest population low enough that it does not cause substantial economic loss.

Biological and cultural controls, including pest-resistant GM crops, are used as much as possible, and conventional pesticides are used sparingly and only when other methods fail (see You Can Make a Difference: Avoiding Pesticides at Home). When pesticides are



(a) IPM takes a systems approach to management of pests, providing interventions that impact various parts of pests' life cycles.

(b) Examples of IPM strategies to control corn borers and other corn pests.

Figure 22.10 Tools of integrated pest management (IPM).

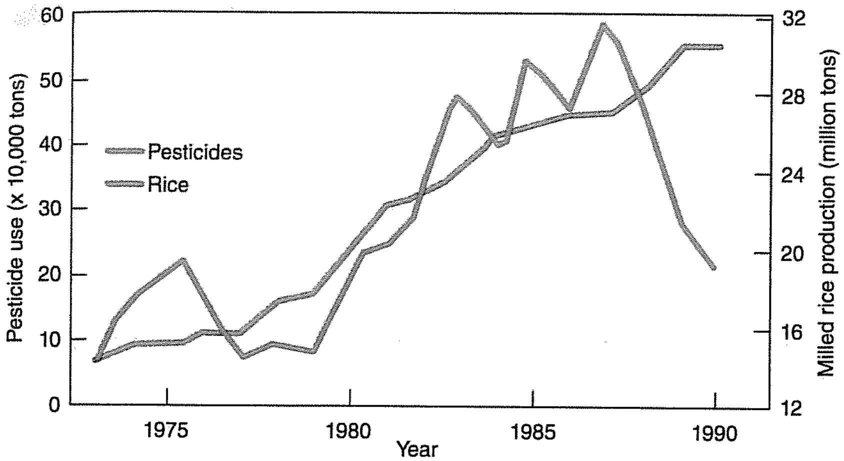


Figure 22.11 Rice production and pesticide use in Indonesia, 1972–1990. The decline in pesticide use in the late 1980s and early 1990s did not cause a decrease in rice yields. Instead, rice production increased during the four years following the new policy. Indonesia was the first Asian country to widely embrace integrated pest management. It phased out pesticide subsidies, banned the use of dozens of pesticides on rice, and trained more than 200,000 farmers in IPM techniques.

required, the least toxic pesticides are applied in the lowest possible quantities and at carefully scheduled times. Thus, IPM allows the farmer to control pests with a minimum of environmental disturbance and often at a minimal cost.

To be effective, IPM requires a thorough knowledge of the system, including life cycles, feeding habits, travel, and nesting habits of the pests as well as all their interactions with their hosts and other organisms. The timing of planting, cultivation, and treatments with biological controls is critical and is determined by carefully monitoring the concentration of pests. Integrated pest management optimizes natural controls by using agricultural techniques that discourage pests. Integrated pest management is an important part of sustainable agriculture (see Chapter 18).

Two fundamental premises are associated with IPM. First, IPM is the management rather than the eradication of pests. Farmers who have adopted the principles of IPM tolerate a low level of pests in their fields and accept a certain amount of economic damage from the pests. These farmers do not spray pesticides at the first sign of a pest. Instead, they periodically sample the pest population in the field to determine when it reaches an economic injury threshold, at which point the benefit of taking action (such as the judicious use of pesticides) exceeds the cost of that action.

Second, IPM requires that farmers be educated so that they know what strategies will work best in their particular situations (**Figure 22.11**). Managing pests is more complex than trying to eradicate them. The farmer must know what pests to expect on each crop and what to do to minimize their effects. The farmer must also know what beneficial species will assist in controlling the pests and how to encourage these beneficial species.

Cotton, which is attacked by many insect pests, has responded well to IPM. Cotton has the heaviest insecticide application of any crop: Although only about 1% of agricultural land in the United States is used for this crop, cotton accounts for almost 50% of all the insecticides used in agriculture! Applying simple techniques, such as planting a strip of alfalfa adjacent to the cotton field, lessens the need for chemical pesticides. Lygus bugs, a significant pest of cotton, move from the cotton field to the strip of alfalfa, which they prefer as a food. Thus, less damage is done to the cotton plants.

IPM is commonly used on school campuses. Pennsylvania, for example, mandates that state schools use IPM methods to control pests in and around school grounds. IPM helps reduce children's exposure to pesticides, and also helps reduce risk to school employees, especially cleaning staff.

U.S. farmers have increasingly adopted IPM since the 1960s, but the overall proportion of farmers using IPM is still small. IPM is not more widespread in part because the knowledge needed to use IPM is more sophisticated than that required to use pesticides. Also, marketing IPM crops is challenging, because no guarantees are given to consumers that the produce lacks pesticide residues.

IRRADIATING FOODS

It is possible to prevent insects and other pests from damaging harvested food without using pesticides. The food is harvested and then exposed to ionizing radiation, which kills many microorganisms, such as salmonella, a bacterium that causes food poisoning. This is called **food irradiation** or **cold pasteurization**. Numerous countries, such as Canada, much of Western Europe, Japan, Russia, and Israel, extend the shelf lives of foods with irradiation. The U.S. Food and Drug Administration (FDA) approved this process for fruits and vegetables as well as fresh poultry in 1986, and the first irradiated food was sold in the United States in 1992. In 2000, the USDA approved the irradiation of additional raw meats, such as ground beef, steaks, and pork chops, to eliminate bacterial contamination.

The irradiation of foods is somewhat controversial. Some consumers are concerned because they fear that irradiated food is radioactive; it is not. Critics of irradiation are concerned because irradiation forms traces of certain chemicals called *free radicals*, some of which are carcinogenic in laboratory animals. Critics also point out that we do not know the long-term effects of eating irradiated foods. Others are concerned about the potential security risk from misuse of the radiation source, usually cobalt-60 or cesium-137. Proponents of irradiation argue that free radicals normally occur in food and are produced by cooking methods such as frying and broiling. They assert that more than 1000 investigations of irradiated foods, conducted worldwide for more than three decades, have demonstrated it is safe. Furthermore, irradiation lessens the need for pesticides and food additives.

REVIEW

1. What is an example of using cultivation methods to control pests? Of using pheromones and hormones?
2. What is integrated pest management? Why is IPM considered a systems approach?

YOU CAN MAKE A DIFFERENCE

Avoiding Pesticides at Home

Animals, plants, and diseases are not just pests that affect agriculture and people in developing countries; they can be a constant challenge in most homes. Ants, moths, cockroaches, and rodents can damage property and spread disease. Weeds can overrun gardens, lawns, and houseplants. Mold and mildew can damage property and spoil food. While sprays and chemical traps can be quick and easy solutions, they are also household hazards—and they don't deal with the underlying causes of infestations.

Alternatives are available to homeowners to manage many pests. Consider mice, for example. Mice not only damage property by chewing through wood, furniture, and appliances; they can also carry disease. While mouse and cockroach droppings are an inhalation hazard even when they do not carry disease, the hantavirus, which is rare but often fatal, is transferred to humans through the urine and feces of deermice. One way to eliminate mice and rats is to put out poison—but rat poison causes tens of thousands of human and pet poisonings in the United States each year.

Consider the following set of control options (household integrated pest management) for mice:

- Remove the carrying capacity for mice to live in the home by keeping foods sealed and stored when not in use.
- Reduce potential entrances for mice by closing up holes in walls and carefully but thoroughly cleaning out any place where mice have built nests.
- Add a cat—a form of biological control that has been practiced for millennia.
- Set mousetraps in places where mice are known to travel.

Mildew thrives in warm, humid places and can be controlled by anti-mildew chemical sprays, but there are other options:

- The best solutions are preventative: Clean and dry mildew-prone areas regularly.
- Try to increase airflow to areas with mildew, and consider a dehumidifier or desiccant (a chemical that absorbs water from the air) for extreme cases.
- A mixture of lemon juice and salt can eliminate mildew from fabrics, but be sure to test for color-fastness. Other options include baking soda pastes and white vinegar.
- Bleach is a powerful mildew-control agent but must be used cautiously since it is also hazardous to humans and can damage materials.

Nonpesticide control measures are effective against a range of other household pests:

- Store food carefully, and clean up spills promptly. This includes pet food! This is the best way to reduce cockroach, ant, and housefly infestations.
- Many plants that are considered lawn weeds are edible or beautiful (see photograph). Fostering a healthy lawn with proper mowing and reseeding can help reduce the worst weed problems.
- Mosquitoes need standing water to lay their eggs, so if you find they are a problem, check your yard and surrounding areas for water in old tires, flowerpots, unused pools, and other containers that might catch rainwater.
- The best way to control spiders is to eliminate their prey—typically flies and other small insects. Also, get to know spiders, since those that are not dangerous to humans, like the orb weaver spider, can help control pests.

Nancy Gift

Yellow wood sorrel (*Oxalis stricta*), an edible lawn weed.

Laws Controlling Pesticide Use

LEARNING OBJECTIVE

- Briefly summarize the three U.S. laws that regulate pesticides: the Food, Drug, and Cosmetics Act; the Federal Insecticide, Fungicide, and Rodenticide Act; and the Food Quality Protection Act.

The federal government has passed several laws to regulate pesticides in the interest of protecting human health and the environment. These include the Food, Drug, and Cosmetics Act; the Federal Insecticide, Fungicide, and Rodenticide Act; and the Food Quality Protection Act. The EPA and, to a lesser extent, the FDA and the USDA, oversee the implementation of these laws. In addition, the EPA has some responsibility to regulate pesticides if they lead to violations of the Endangered Species Act.

FOOD, DRUG, AND COSMETICS ACT

The **Food, Drug, and Cosmetics Act (FDCA)**, passed in 1938, recognized the need to regulate pesticides found in food but did not provide a means of regulation. The FDCA was made more effective in 1954 with passage of the **Pesticide Chemicals Amendment**. This amendment, also called the *Miller Amendment*, required the establishment of acceptable and unacceptable levels of pesticides in food.

An amended FDCA, passed in 1958, contained an important section, the **Delaney Clause**, which stated that no substance capable of causing cancer in test animals or in humans would be permitted in processed food. Processed foods are prepared in some way—such as frozen, canned, dehydrated, or preserved—before being sold. The Delaney Clause recognized that pesticides tend to concentrate in condensed processed foods, such as tomato paste and applesauce.

The Delaney Clause, though commendable for its intent, contained two inconsistencies. First, it did not cover pesticides on raw foods such as fresh fruits and vegetables, milk, meats, fish, and poultry. As an example of this double standard, residues of a particular pesticide might be permitted on fresh tomatoes but not in tomato ketchup. Second, because the EPA lacked sufficient data on the cancer-causing risks of pesticides used for a long time, the Delaney Clause applied only to pesticides registered after strict tests were put into effect in 1978. This situation gave rise to one of the paradoxes of the Delaney Clause. There were cases in which a newer pesticide that posed minimal risk was banned because of the Delaney Clause, but an older pesticide, which the newer one was to have replaced, was still used even though it was many times more dangerous.

When the Delaney Clause was passed, the technologies for detecting pesticide residues could reveal only high levels of contamination. Modern scientific techniques are so sensitive that it is almost impossible for any processed food to meet the Delaney standard. As a result, the EPA found it difficult to enforce the strict standard required by the Delaney Clause. In 1988 the EPA began granting exceptions that permitted a "negligible risk" of one case of cancer in 70 years for every 1 million people. However, the EPA was taken to court because of its failure to follow the Delaney Clause as written, and the U.S. courts decided in 1994 that no exceptions could be granted unless Congress modified the Delaney Clause. (One of the key provisions of the 1996 Food Quality Protection Act, discussed shortly, did just that.)

Although the FDCA has not been amended since 2004, the EPA continues to update its regulations in response to new pesticides and newly recognized risks. For example, while many rules focus on cancer, birth defects, or acute effects, concern about *endocrine disrupters* is more recent. The EPA has identified 73 chemicals that it will review as possible endocrine disrupters.

FEDERAL INSECTICIDE, FUNGICIDE, AND RODENTICIDE ACT

The **Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)** was originally passed in 1947 to regulate the effectiveness of pesticides—that is, to prevent people from buying pesticides that did not work. FIFRA has been amended over the years to require testing and registration of the active ingredients of pesticides. Any pesticide that does not meet the tolerance standards established by the FDCA must be denied registration by FIFRA.

In 1972 the EPA was given the authority to regulate pesticide use under the terms of the FDCA and FIFRA. Since that time, the EPA has banned or restricted the use of many chlorinated hydrocarbons. In 1972 the EPA banned DDT for almost all uses. Aldrin and dieldrin were outlawed in 1974 after more than 80% of all dairy products, fish, meat, poultry, and fruits were found to contain residues of these insecticides. The banning of kepone occurred in 1977 and of chlordane and heptachlor in 1988.

FIFRA was amended in 1988 to require reregistration of older pesticides, which subjected them to the same toxicity tests that new pesticides face. Although the 1988 amendment is stricter than previous legislation, it represented a compromise between agricultural interests, including pesticide manufacturers, and those opposed to all uses of pesticides. The new law did not address an important issue, the contamination of groundwater by pesticides. Nor did the law address the establishment of standards for pesticide residues on foods and the safety of farmworkers who are exposed to high levels of pesticides (the Occupational Safety and Health Administration regulates workplace pesticide exposures).

FIFRA also did not require pesticide companies to disclose the inert ingredients in their formulations. Many pesticide products contain as much as 99% inert ingredients, which are not supposed to have active properties. The National Coalition for Alternatives to Pesticides determined that 394 of the more than 2500 chemicals listed as "inert" were once listed as active ingredients. Many inert ingredients are generally recognized as safe (including pine oil, ethanol, silicone, and water). Others are known toxins (including asbestos, benzene, formaldehyde, lead, and cadmium). Inert ingredients in some herbicides are particularly toxic to amphibians. More than 200 inert ingredients are classified as hazardous air and water pollutants, and 21 are known or suspected to cause cancer.

FOOD QUALITY PROTECTION ACT

The **Food Quality Protection Act** of 1996 amended both the FDCA and FIFRA. It revised the Delaney Clause by establishing identical pesticide residue limits—those that pose a negligible risk—for both raw produce and processed foods. The law requires that the increased susceptibility of infants and children to pesticides be considered when establishing pesticide residue limits for some 9700 pesticide uses on specific crops. The pesticide limits are established for all health risks, not just cancer. For example, the EPA must develop a program to test pesticides for endocrine-disrupting properties. Another key provision of the Food Quality Protection Act is that it reduces the time it takes to ban a pesticide considered dangerous, from 10 years to 14 months.

REVIEW

1. What three laws regulate pesticides in the United States?

The Manufacture and Use of Banned Pesticides

LEARNING OBJECTIVE

- Define *persistent organic pollutant* and describe the purpose of the Stockholm Convention on Persistent Organic Pollutants.

Many pesticides have been identified as too hazardous to permit for any use and thus are banned in the United States and other highly developed countries. The UN Food and Agriculture Organization (FAO) is attempting to help developing countries become more aware of dangerous pesticides. It established a "red alert" list of more than 50 pesticides banned in five or more countries. The FAO further requires that the manufacturers of these pesticides inform importing countries about why such pesticides are banned. The United States supports these international guidelines and exports banned pesticides only with the informed consent of the importing country. However, this information often does not trickle down to the local level, and many farmers worldwide never receive any guidelines or training on the safe handling and application of pesticides.

Another concern is that unwanted stockpiles of leftover, deteriorated pesticides are accumulating, particularly in developing countries. A 2008 UN estimate found that more than 500,000 tons of these obsolete pesticides are stockpiled worldwide, with 120,000 tons in Africa alone. They are often stored in drums at waste sites in the countryside because developing countries have few or no hazardous waste disposal facilities. Over time, chemicals leach from such waste sites into the soil and groundwater (see Chapter 23).

IMPORTATION OF FOOD TAINTED WITH BANNED PESTICIDES

The fact that many dangerous pesticides are no longer being used in the United States is no guarantee that traces of those pesticides are not in our food. Although many pesticides are restricted or banned in the United States, they are widely used in other parts of the world. Much of our food—some 1.2 million shipments annually—is imported from other countries, particularly in Latin America. Some produce contains traces of banned pesticides such as DDT, dieldrin, chlordane, and heptachlor. The 2007 discovery of contaminated pet food and toothpaste from China highlighted the risk of imported foods.

The FDA monitors toxic residues on incoming fruits and vegetables, but it inspects only about 1% of the food shipments that enter the United States each year. In addition, the General Accounting Office reports that some food importers continue to sell tainted food after the FDA finds the company is in violation of the law. When caught, these companies face fines that are not severe enough to discourage such practice.

GLOBAL BAN ON PERSISTENT ORGANIC POLLUTANTS

The **Stockholm Convention on Persistent Organic Pollutants**, which went into effect in 2004, is an important international treaty. As last amended in 2014 (with some exemptions), it seeks to protect human health and the environment from the 23 most toxic chemicals, classified as **persistent organic pollutants (POPs)** (**Table 22.3**; also see the discussion of long-distance transport of air pollution in Chapter 19). Nine of these POPs are pesticides. Some POPs disrupt the endocrine system, others cause cancer, and still others adversely affect the developmental processes of organisms.

persistent organic pollutants (POPs) A group of persistent, ...ic chemicals that bio-...umulate in organisms ... can travel thousands ...ilometers through air ...nd water to contami-...ate sites far removed from their source.

The Stockholm Convention requires that countries develop plans to eliminate the production and use of intentionally produced POPs. A notable exception to this requirement is that DDT can still be produced and used to control mosquitoes that carry the malaria pathogen in countries where no affordable alternatives exist. (DDT is inexpensive, and many of these countries cannot afford safer alternatives.)

Table 22.3 Persistent Organic Pollutants: The "Dirty Dozen"

Persistent Organic Pollutants Regulated Under the Stockholm Convention (2014)

Aldrin Pesticide	Hexabromobiphenyl* Industrial chemical
Chlordane Pesticide	Lindane Pesticide
Chlordecone Pesticide	Mirex Pesticide
DDT Pesticide	Pentachlorobenzene Pesticide, Industrial chemical, by-product
Dieldrin Pesticide	Perfluorooctane sulfonic acid Industrial chemical
Endrin Pesticide	Polychlorinated biphenyls Industrial chemical
Endosulfan Pesticide	Polychlorinated dibenzo-p-dioxins By-product
Heptachlor Pesticide	Polychlorinated dibenzofurans By-product
Hexachlorobenzene Pesticide	(Tetra- and penta-)bromodiphenyl ether Industrial chemical
Hexachlorocyclohexane* Pesticide, by-product	Toxaphene Pesticide

* multiple forms regulated

Although the Stockholm Convention goes a long way toward achieving the goal of a global ban on these chemicals, it applies only to the 179 countries that have ratified the treaty; as of 2014, the United States is not among them. To be more effective, the United States will have to ratify it and adhere to its rules, and countries that have ratified the treaty will have to abide by its conditions.

REVIEW

1. What is the Stockholm Convention on Persistent Organic Pollutants?

ENVIRONEWS

Pest Management in Kitchen Gardens

Pesticide use in small-scale home gardens does not affect as many acres as agricultural pesticide use. However, suburban pesticide use often exceeds agricultural use in the amount of pesticides used per acre. Furthermore, people using pesticides at home have no required training in handling or proper use of these products. Pesticides available to the public in hardware stores and garden centers are just as toxic as those available to farmers and commercial applicators. Unfortunately, many people purchasing these products assume they are safer, the same way that a pain killer at the pharmacy is typically a milder or safer version of drugs available by prescription. In 2012, over 3000 poison control center calls addressed potential pesticide poisonings, mostly by home use pesticides.

Fortunately, many organic pesticides or biological controls are now available for gardeners and homeowners, and county agricultural extension services also offer advice about IPM techniques for pest control. Parasitoid wasps, which do not sting people, can be released to control tomato hornworms, one of the pests of greatest concern in many gardens. Beer attracts slugs, which die when they consume it. Mulches and newspaper, which are impractical to use in large-scale agriculture, can serve as excellent weed control in kitchen gardens.

REVIEW OF LEARNING OBJECTIVES WITH SELECTED KEY TERMS

- **Distinguish between narrow-spectrum and broad-spectrum pesticides, and describe the various types of pesticides, such as insecticides and herbicides.**

Pesticides are toxic chemicals used to kill **pests** such as insects (**insecticides**), weeds (**herbicides**), fungi (**fungicides**), and rodents (**rodenticides**). The ideal pesticide would be a **narrow-spectrum pesticide** that kills only the target organism. Most pesticides are **broad-spectrum pesticides**, which kill a variety of organisms, including beneficial organisms, in addition to the target pest.

- **Describe the benefits of pesticides in disease control and crop protection.**

Pesticides help prevent malaria and other diseases transmitted by insects. Pesticides reduce crop losses from pests, thereby increasing agricultural productivity. Pesticides reduce competition with weeds, crop consumption by insects, and diseases caused by plant **pathogens** such as certain fungi and bacteria.

- **Explain why monocultures are more susceptible to pest problems.**

A **monoculture** is the cultivation of only one type of plant over a large area. Thus, it represents a system that is out of balance compared to what would be found without human intervention. Agricultural fields are monocultures that provide abundant food for pest organisms. Many natural predators are absent from monocultures.

- **Summarize the problems associated with pesticide use, including development of genetic resistance; creation of imbalances in the ecosystem; persistence, bioaccumulation, and biological magnification; and mobility in the environment.**

Genetic resistance is any inherited characteristic that decreases the effect of a pesticide on a pest. Pesticides affect species other than those for which they are intended, causing imbalances in ecosystems; in some instances, the use of a pesticide has resulted in a pest problem that did not exist before. A pesticide that demonstrates **persistence** takes a long time to break down into less toxic forms. **Bioaccumulation** is the buildup of a persistent pesticide or other toxic substance in an organism's body. **Biological magnification** is the increased concentration of toxic chemicals, such as certain pesticides, in the tissues of organisms at higher trophic levels in food webs. Many pesticides move through the soil, water, and air, sometimes for long distances.

- **Describe pesticide resistance and resistance management.**

The **pesticide treadmill** is a predicament faced by pesticide users, in which the cost of applying pesticides increases (because they have to be applied more frequently or in larger doses) while their effectiveness decreases (as a result of increasing genetic resistance in the target pest). **Resistance management** consists of strategies for managing genetic resistance to maximize the period in which a pesticide is useful.

- **Discuss pesticide risks to human health, including short-term effects and long-term effects.**

Humans may be poisoned by short-term exposure to a large amount of pesticide. Lower levels of many pesticides may pose a long-term threat of cancer. Certain persistent pesticides may interfere with the actions of natural hormones.

- **Explain endocrine disruption.**

Endocrine disruption occurs when a chemical interferes with or mimics a hormone associated with growth and development in humans or other animals. Endocrine disrupters include pesticides such as atrazine and DDT, and problems include abnormal physical features—such as deformed reproductive organs—and aberrant behavior.

- **Describe alternative ways to control pests, including cultivation methods, biological controls, pheromones and hormones, reproductive controls, genetic controls, quarantine, integrated pest management, and food irradiation.**

Cultivation techniques such as strip cutting, interplanting, and crop rotation are effective in controlling pests. **Biological control** uses naturally occurring disease organisms, parasites, or predators to control pests. A **pheromone** is a natural substance produced by animals to stimulate a response in other members of the same species; pheromones can be used to lure insects to traps or to confuse insects so that they cannot locate mates. Insect hormones are natural substances produced by insects to regulate their own growth and metamorphosis; a hormone present at the wrong time in an insect's life cycle disrupts its normal development. Reproductive controls include reducing the pest population by sterilizing some of its members (the **sterile male technique**) or genetically modifying some of its members so that offspring are not viable. Genetic control of pests involves producing varieties of crops and livestock animals that are genetically resistant to pests; some **genetically modified (GM)** crops contain the *Bacillus thuringiensis* (*Bt*) gene that codes for a toxin used against insect pests. **Quarantine** involves restricting the importation of exotic plant and animal material that might harbor pests; if a foreign pest is accidentally introduced, quarantine of the area where it is detected helps prevent its spread. **Integrated pest management (IPM)** is a systems approach that combines several pest control methods that, if used in the proper order and at the proper times, keep the size of a pest population low enough that it does not cause substantial economic loss. **Food irradiation** controls pests after food is harvested.

- **Briefly summarize the three U.S. laws that regulate pesticides: the Food, Drug, and Cosmetics Act; the Federal Insecticide, Fungicide, and Rodenticide Act; and the Food Quality Protection Act.**

The **Food, Drug, and Cosmetics Act (FDCA)**, as originally passed, recognized the need to regulate pesticides in food but did not provide a means of regulation. The *Miller Amendment* required the establishment of acceptable and unacceptable levels of pesticides in food, and the **Delaney**

Clause stated that no substance capable of causing cancer in laboratory animals or in humans would be permitted in processed food. The **Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)** was amended over the years to require testing and registration of the active ingredients of pesticides; the 1988 version required the reregistration of older pesticides, which subjected them to the same toxicity tests that new pesticides face. The **Food Quality Protection Act** amended both the FDCA and FIFRA and revised the Delaney Clause by establishing identical pesticide residue limits—those that pose a negligible risk—for both raw and processed foods.

- **Define *persistent organic pollutant* and describe the purpose of the Stockholm Convention on Persistent Organic Pollutants**

Persistent organic pollutants (POPs) are a group of persistent, toxic chemicals that bioaccumulate in organisms and can travel thousands of kilometers through air and water to contaminate sites far removed from their source. The **Stockholm Convention on Persistent Organic Pollutants** seeks to protect human health and the environment from the 23 most toxic chemicals on Earth. As of 2014, the United States has not ratified this treaty.

Critical Thinking and Review Questions

1. Distinguish among insecticides, herbicides, fungicides, and rodenticides.
2. Describe the general characteristics of each of the following groups of insecticides: chlorinated hydrocarbons, organophosphates, and carbamates.
3. Overall, do you think the benefits of pesticide use outweigh its disadvantages? Give at least two reasons for your answer.
4. Sometimes pesticide use increases the damage done by pests. Explain.
5. The widely used herbicide Roundup is starting to lose its effectiveness in killing certain weeds. Explain why.
6. How is the buildup of insect resistance to insecticides similar to the increase in bacterial resistance to antibiotics?
7. How does genetic change in response to biological control agents differ from genetic resistance to pesticides?
8. Biological control is often much more successful on a small island than on a continent. Offer at least one reason why this might be the case.
9. It is more effective to use the sterile male technique when an insect population is small than when it is large. Explain.
10. Define *integrated pest management (IPM)*. List five tools of IPM, and give an example of each.
11. How is IPM related to ecological concepts such as food webs and energy flow?
12. Which of the following uses of pesticides do you think are most important? Which are least important? Explain your views.
    a. Keeping roadsides free of weeds
    b. Controlling malaria
    c. Controlling crop damage
    d. Producing blemish-free fruits and vegetables
13. Why is pesticide misuse increasingly viewed as a global environmental problem?
14. Propose an integrated pest management plan to control rabbits in a garden. Your approach may include a rodenticide.
15. Climate change may lead to a greater need for pesticides to control mosquitoes. Suggest some ways in which other pesticide uses could increase or decrease as the Earth warms and precipitation patterns shift over the next century.
16. Do you think this cartoon reasonably depicts the challenge of reducing pesticide use?

"Sure it costs more. We have to squash bugs by hand."

www.CartoonStock.com

Food for Thought

Many home gardeners take pride in the fact that their produce is not only fresher than purchased produce, but that their use of organic pest control techniques can save money, reduce pesticide exposures, and finally, reduce greenhouse gas production inherent in food transport. Look into the pest management methods used where you live. Are they pesticide intensive? Are they effective? Explore some ways in which you could get equal or better pest control with fewer chemicals.