Chapter 14

Evolution: How Change Occurs

Fossils, such as this fossil cycad from the Jurassic period more than 100 million years ago, provide one type of evidence for the theory of evolution.

Chapter Inquiry Classifying

1. Examine the photographs of animals and environments provided by your teacher.

2. Match each animal with its environment. What characteristics of the animal helped you determine the type of environment in which you think it lives?

Connect to the Main Ideas
Over many generations, a species evolves by adapting, meaning that it changes in response to its environment. When examining the photographs of different animals and their environments, what types of adaptation can you identify?

CHAPTER PREVIEW

Main Ideas

In this chapter, you will learn about the development of evolutionary theory, including natural selection. You will also learn how genetics relates to concepts of fitness, adaptation, speciation, and rates of evolutionary change.

Reading Strategy

Analyzing Cause and Effect Before reading this chapter, construct a chart with a column labeled "Cause" and another column labeled "Effect." After reading the chapter, give possible reasons for change over time in a species in the "Cause" column. In the "Effect" column, write the effect of such a change next to each cause.

Journal Activity

Biology and Your World Few people, it seems, actually understand what evolutionary theory is. Nevertheless, many people have strong opinions about it. In your journal, write down as much as you know about evolutionary theory and the controversy surrounding it. When you have finished this chapter, reread your journal entry. What aspects of evolutionary theory did you know pretty well? What misconceptions did you have?

14–1 Developing a Theory of Evolution

Guide For Reading

- What is evolutionary theory, and why is it important?
- What were the problems with Lamarck's theory of evolution?
- How was Darwin's thinking about evolution influenced by the ideas of others?

Evolution theory is the foundation on which the rest of biological science is built. In fact, the biologist Theodor Dobzhansky once wrote that nothing in biology makes sense except in the light of evolution. Much research in genetics, ecology, and medicine is based on evolutionary theory.

Is evolution a fact or a theory? We could say that it is both. It is a fact, for example, that living organisms have changed over time. These changes, which include the evolution of major groups of animals and plants, are documented in the fossil record and were recognized by Darwin and other scientists. In recent times, new fossil discoveries have provided even more facts that show the process of evolutionary change.

Darwin provided a convincing theory as to how these changes occurred. Many aspects of his original theory have been revised and brought up to date in the years since the publication of *On the Origin of Species.* **In this respect, evolution is indeed a theory—a collection of carefully reasoned and tested hypotheses about how evolutionary change occurs.**

By way of comparison, consider that even today physicists do not completely understand gravity, although there is no doubt in anyone's mind that gravity exists. There are at least two competing modern theories that explain how gravity works. Both theories make important useful predictions of natural events. For example, there is no question that if you jump into the air, you will end up on the ground below. It makes no difference whether you understand—or even believe in—gravity. What goes up must come down. Just as definitely, life on Earth evolves, or changes over time. Explaining the fine points of evolutionary change will continue to be one of the great challenges of biology.

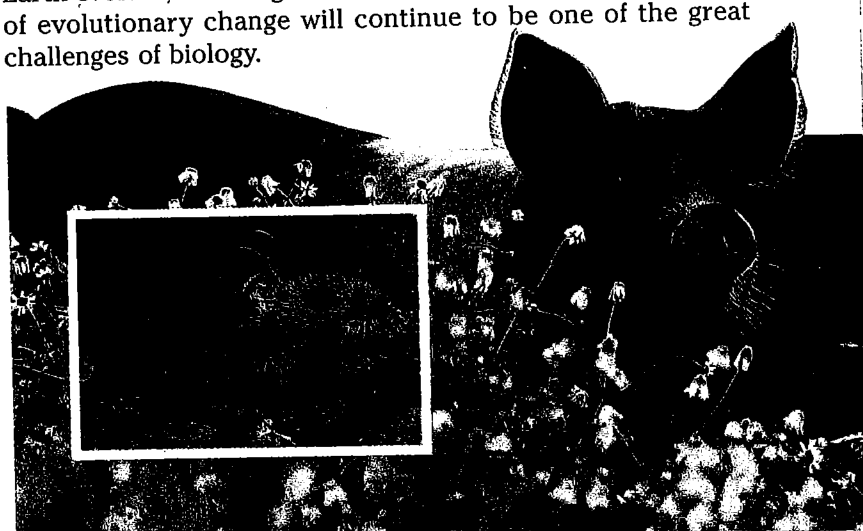


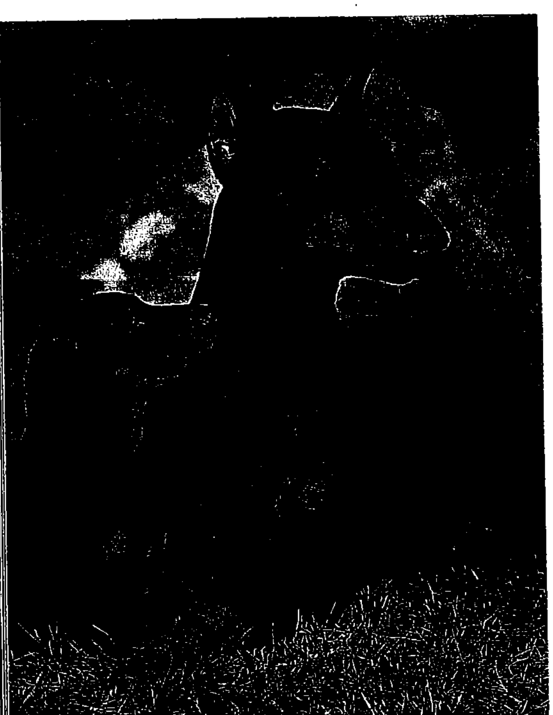
Figure 14–1 Although the mouse and the pig do not look at all alike, an analysis of their DNA shows that these two animals are more closely related than appearances would indicate.

An Early Explanation for Evolutionary Change

Jean Baptiste de Lamarck (1744–1829) was among the first scientists to recognize that living things changed over time. And long before Darwin, Lamarck also realized that organisms were somehow adapted to their environments. In explaining how adaptation occurred, however, Lamarck relied on three assumptions we now know to be incorrect.

A DESIRE TO CHANGE Lamarck thought that organisms change because they have an inborn urge to better themselves and become more fit for their environments. In Lamarck's view, for instance, the ancestors of birds acquired an urge to fly. Over many generations, birds' constant efforts to become airborne led to the development of wings. What a pity for the Wright Brothers that this element of Lamarck's theory proved not to be true!

Figure 14–2 *When this adult Doberman pinscher was still a young puppy, her ears were clipped so that they would stand up on her head. The operation occurred long before she bore the puppy resting beside her. Yet the puppy's ears look just like his mother's did when she was born. This is one of the many forms of evidence that traits acquired during an organism's lifetime are not passed on to the next generation.*



USE AND DISUSE Lamarck also believed that change occurred because organisms could alter their shape by using their bodies in new ways. Organs could increase in size or change in shape depending on the needs of the organism. For example, by trying to use their front limbs for flying, birds could eventually transform those limbs into wings. In the opposite way, Lamarck believed that if an animal did not use a particular part of its body, that body part would decrease in size and might finally disappear.

PASSING ON ACQUIRED TRAITS Included in Lamarck's reasoning was the belief, shared by many biologists of that time, that acquired characteristics were inherited. He thought that if an animal acquired a body structure (such as long arms or feathers) during its lifetime, it could pass that change on to its offspring. By the same reasoning, structures that became smaller from disuse would eventually disappear.

Although later discoveries showed that Lamarck's explanation of evolution was incorrect, he is still credited with being one of the first people to devise a theory of evolution and adaptation. He is also credited with bringing the concept of evolution to the attention of scientists. Thus Lamarck paved the way for Darwin's theory of evolution.

Lamarck's ideas may seem strange to you now, yet his theory was consistent with knowledge of that time. It was not until a century after Lamarck proposed his theory that an improved understanding of genetics and the principles of heredity showed that the mechanisms he proposed would not work.

Lamarck, you see, knew nothing about genes. As you know now, only genes and changes in genes—not alterations in body structure—are passed from parents to offspring. There is no evidence that experience during its life can cause specific changes in an organism's genes. Years of proper exercise and diet, for example, can turn a weakling into a champion weight lifter. But that weight lifter's children cannot benefit genetically from the parent's pumping iron. If the children do not exercise and eat a proper diet, they will not develop large muscles, even if their parents were world champions!

Ideas That Shaped Darwin's Theory of Evolution

Personal experience on the *Beagle*'s voyage awakened Darwin's interest in explaining the diversity and fitness of life on Earth. But both during his trip and after his return, Darwin's thinking was also influenced by the books he read and by discussions with geologists, farmers, and others.

THE INFLUENCE OF GEOLOGY: LYELL'S IDEAS As you will remember from Chapter 13, the geologist Charles Lyell demonstrated that the Earth was very old and that it had changed over time. After reading Lyell's book *Principles of Geology,* Darwin became convinced that the Earth was much older than most people of his time believed. This was an important idea for Darwin. For in order to explain evolution—to even recognize that evolution had occurred—it was essential for Darwin to realize that the Earth was very old. The long periods of time it would have taken for millions of species to have evolved from a common ancestor could be accounted for only if the Earth was very old.

Figure 14–3 *Volcanoes can alter the Earth's face. This volcano, emerging from beneath the ocean, resulted in the formation of a new island. Within a short period of time, living organisms will discover this newly formed island and begin to exploit the opportunities that exist there. A volcanic eruption can produce a completely opposite effect, destroying an area of land and all its inhabitants.*

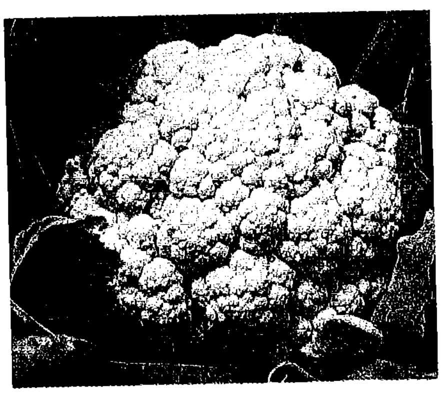


Figure 14–4 *The cabbage (top), Brussels sprouts (center), and cauliflower (bottom) are all varieties of the same plant species that have been "selected" over time to produce familiar food crops.*

Lyell's writing also caused Darwin to appreciate the geological phenomena he observed on his journey. In Chile, Darwin saw a spectacular volcanic eruption. Shortly thereafter, he observed that an earthquake had lifted a stretch of shoreline three meters higher than it had been before. With Lyell's writings fresh in his mind, Darwin came to realize that geological phenomena such as the ones he had observed could transform the face of the Earth over time. And if the Earth itself could change over time, so too could life on the Earth.

THE INFLUENCE OF FARMERS: ARTIFICIAL SELECTION While assembling his thoughts back in England, Darwin spoke extensively with plant and animal breeders. He learned that farmers altered and improved their crops and livestock through breeding programs. But how, Darwin wondered, did such programs work?

Farmers told Darwin that domesticated animals and plants vary a great deal. For example, in every corn field, some plants are larger than average; others are smaller than average. Certain cows produce a large amount of milk; other cows produce a small amount of milk. Here and there among a flock of white chickens, a gray or black chicken appears. The farmers convinced Darwin that many of these variations were often passed on to the animals' offspring. In other words, these were inheritable variations.

Darwin realized that farmers could not cause variation to occur. Variation either happened naturally or it did not. But once farmers encountered variation, they could use it to their advantage. They noted the variations they found and decided which organisms to use as breeding stock. Individuals with undesirable variations—scrawny bulls or cows that produced little milk, for example—were not allowed to mate. Superior animals—husky bulls or cows that produced much milk—would be mated as often as possible.

This process, which Darwin called **artificial selection**, allowed only the individuals who suited the farmers' needs to produce offspring. Over the years, breeders have used artificial selection to produce plants and animals that are much more

Figure 14–5 *Variation in a species is quite common in nature. These ladybug beetles show different markings.*

suited to human needs than—and often dramatically different in appearance from—their original parent stock. **In artificial selection, the intervention of humans ensures that only individuals with the more desirable traits produce offspring.**

Darwin became convinced that a process similar to artificial selection must be at work in nature. This process would allow only those organisms best suited to their environment to survive and reproduce. But in nature there is no human intervention; so how, Darwin wondered, could such a process operate?

THE INFLUENCE OF MALTHUS: POPULATION CONTROLS An important influence on Darwin was the work of the economist Thomas Malthus (1766–1834). Malthus observed that babies were being born at a faster rate than people were dying. If the human population continued to increase in that way, Malthus reasoned, sooner or later there wouldn't be enough living space and food. The only conditions that would prevent the endless growth of human populations, Malthus observed, were famine, disease, and war. In time, these unpleasant observations were called the Malthusian Doctrine.

Darwin realized that the Malthusian Doctrine applied even more to animals and plants than to humans, for most other species produce far more offspring than we do. For example, every summer each mature maple tree produces thousands of seeds. Marine animals, such as the common mussel, produce millions of eggs each time they spawn. If all the offspring of just one of these maple trees or mussels survived, they would overcrowd the area in which they lived. If each offspring then produced as many offspring as its parents, and if all those offspring reproduced, there would soon be so many maple trees or mussels that they would cover the Earth or fill the oceans!

Obviously, the oceans are not filled with mussels and the continents are not covered with maple trees. Most baby mussels die during their first year of life. Most maple seeds never grow into mature trees. Thousands upon thousands of individuals of each species die, and only a few survive. Even fewer successfully raise offspring. That much is clear. But what determines which individuals survive and reproduce?

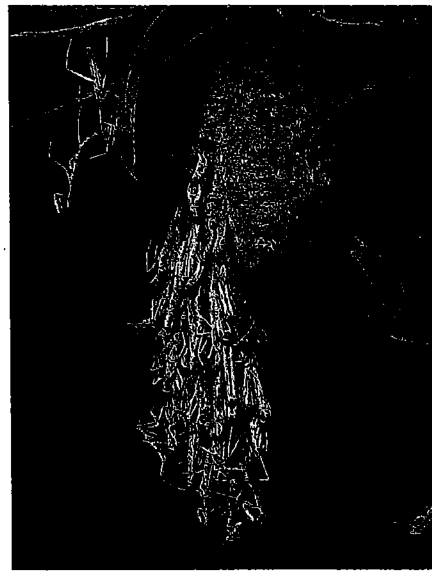


Figure 14–6 *Some animals and plants produce enormous numbers of offspring. Eggs in this praying mantis egg case have begun to hatch (top). If all the young survived to reproduce, you can imagine how the number of mantises in the world would be affected. Each sunflower in this field is capable of producing hundreds of seeds (bottom). If each seed survived and reproduced, there would be uncountable numbers of sunflowers.*

14–1 SECTION REVIEW

1. What is the importance of evolutionary theory?
2. How did Lamarck explain evolution? What are the major problems with his explanation?
3. What is artificial selection? How did this concept influence Darwin's thinking?
4. **Critical Thinking—Identifying Relationships** Would Darwin have developed his theory of evolution if he had not read the works of Lyell and Malthus? Explain.

Guide For Reading

- What is the driving force of evolution according to Darwin's theory?
- How does natural selection work?

14–2 Evolution by Natural Selection

Ultimately, Darwin recognized in nature a process that operates in a manner similar to the way artificial selection worked on farms and in fields. Darwin called this process **natural selection** and explained its action in terms of several important observations.

Darwin observed that wild animals and plants showed variations just as domesticated animals and plants did. His field notebooks were filled with records of height, weight, color, claw size, tail length, and other characteristics among members of the same species. Darwin did not understand the reasons for these variations, but he realized that many of them were inherited.

Darwin observed that high birthrates and a shortage of life's necessities forced organisms into a constant "struggle for existence," both against the environment and against each other. Plant stems grow tall in search of sunlight; plant roots grow deep into the soil in search of water and nutrients. Animals compete for food and space in which to build nests and raise young. But who among all the contenders wins the struggle for existence?

Figure 14–7 *The struggle to survive takes many forms. This smaller lizard has just become part of the gecko's food supply, but the outcome of a contest like this one does not necessarily mean that the smaller lizard's genes have lost out in evolution. The ultimate winners in natural selection are those organisms that are the most successful in leaving offspring in the next generation.*

Darwin knew that each individual differs from all the other members of its species. Sometimes the differences are easy to observe; sometimes the differences are subtle. **Individuals whose characteristics are well-suited to their environment survive. Individuals whose characteristics are not well-suited to their environment either die or leave fewer offspring.** This principle Darwin called **survival of the fittest.**

Natural selection thus operates in much the same way as artificial selection, but over much longer periods of time and without control or direction. On a farm, cows that give more milk and corn plants with bigger ears are intentionally selected to be parents to the next generation. In nature, the struggle for existence permits only those individuals well-suited to their environment to survive and reproduce. The fact that less-fit individuals of a species do not survive helps keep the species from covering the Earth.

Peppered Moths: Natural Selection in Action

England's peppered moth provides an example of natural selection in action. It also offers us a chance to study the sorts of experiments that can be used to test evolutionary theory. The story is as follows. The peppered moth spends much of the daytime resting on the bark of oak trees. In the beginning of the nineteenth century, the trunks of most oak trees in England were light brown speckled with green. Most of the peppered moths of that time were mottled light brown too. There were always a few dark-colored moths around, but light-colored moths were always the most common.

Then the Industrial Revolution began in England. Pollution (mostly soot from burning coal) stained London's tree trunks dark brown. At about the same time, biologists noticed that more and more moths with dark coloration were appearing. Why was the population changing color in this way?

The evolutionary hypothesis suggested by observation was straightforward. Birds are the major predators of peppered moths. It is much harder for birds to see, catch, and eat moths that blend in with the color of the tree bark than it is for them to spot moths whose color makes a strong contrast with the tree trunks. The moths that blend in with their background are said to be camouflaged.

As the tree trunks darkened, the rarer, dark-colored moths were better camouflaged and harder for birds to spot. Being harder to spot, the darker individuals were now better able to survive. The darker forms had greater fitness than the lighter forms. More of the darker moths survived and reproduced, passing on the genes for dark color to their offspring, and the moth population evolved darker coloration.

But a hypothesis that looks good is not enough. Scientific hypotheses must be tested by experiment whenever possible.

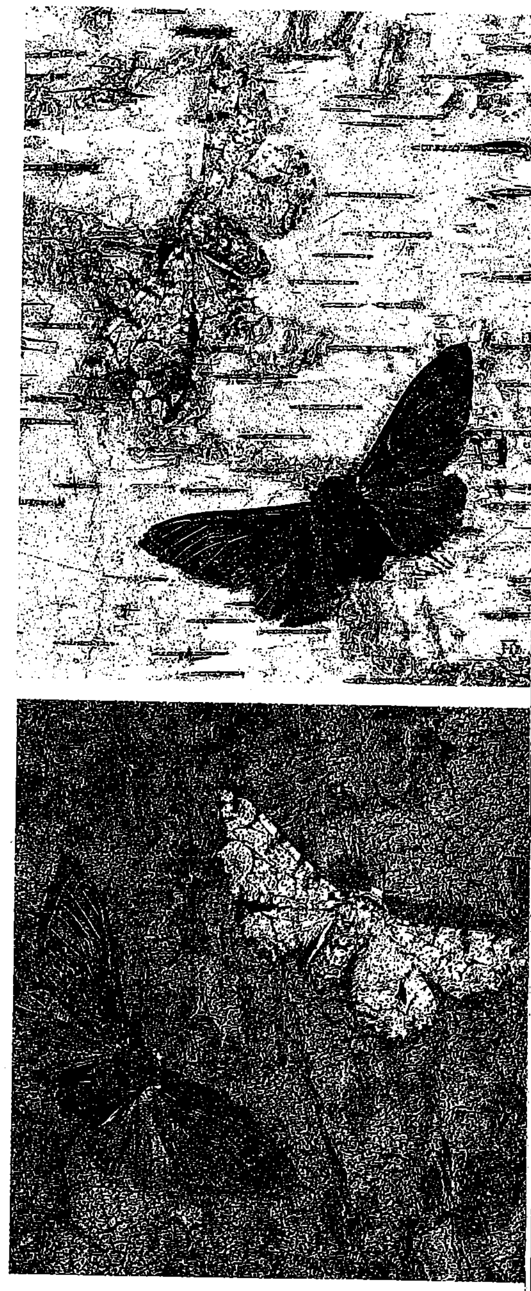


Figure 14–8 *Before the Industrial Revolution, soot was rare in the English countryside. A light-colored moth was difficult to see against the clean tree bark (top). After several years, during which the bark was darkened by the soot of burning coal, a light-colored moth stood out against the darkened tree bark (bottom). In each photograph, which moth would most likely be noticed by a hungry bird?*

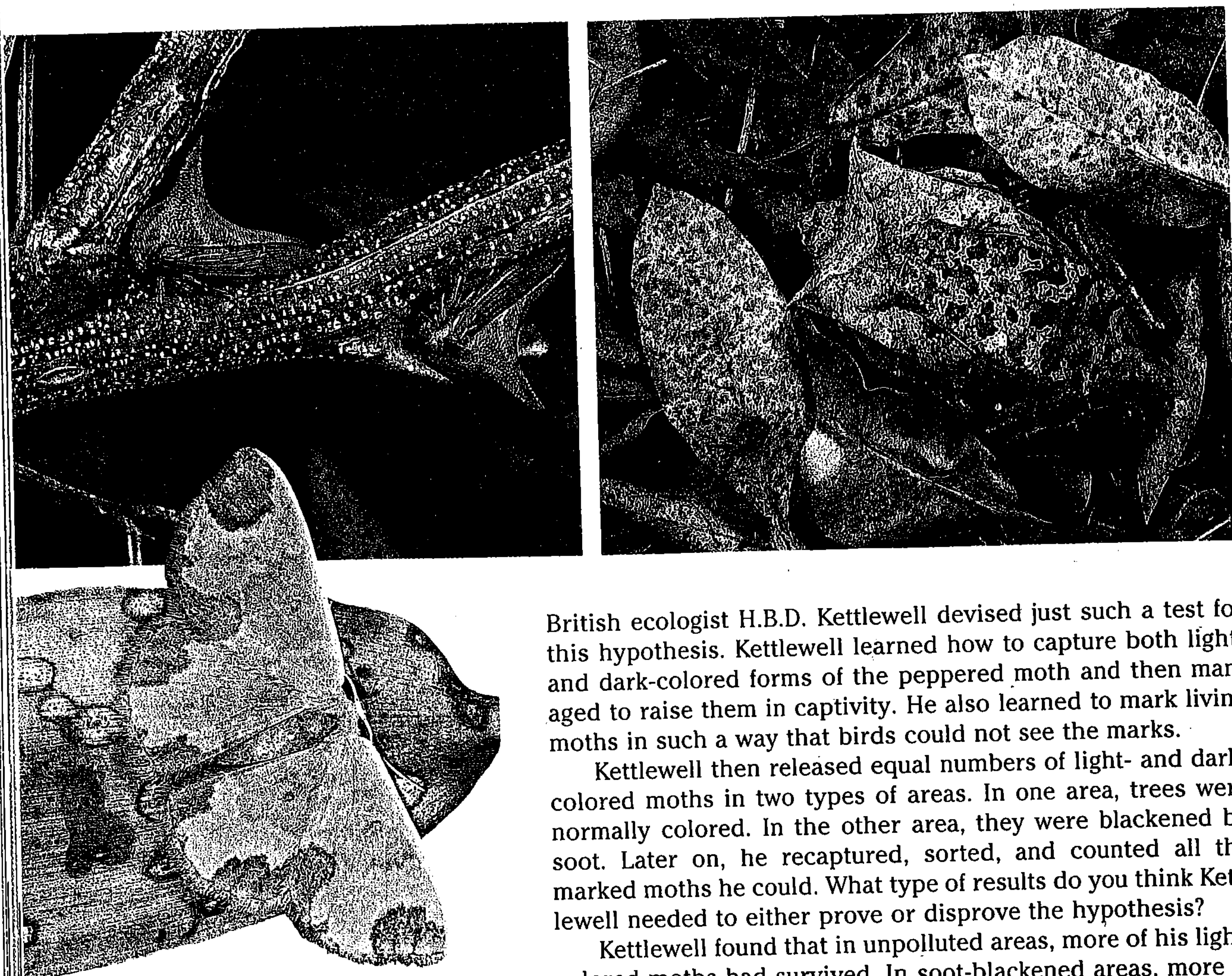


Figure 14–9 *Looking like something it's not can be helpful to an organism. It is difficult to spot the insect disguised as a thorn (top, left), the toad that resembles a fallen leaf (top, right), and the moth that looks like a plant leaf complete with diseased areas (bottom).*

British ecologist H.B.D. Kettlewell devised just such a test for this hypothesis. Kettlewell learned how to capture both light- and dark-colored forms of the peppered moth and then managed to raise them in captivity. He also learned to mark living moths in such a way that birds could not see the marks.

Kettlewell then released equal numbers of light- and dark-colored moths in two types of areas. In one area, trees were normally colored. In the other area, they were blackened by soot. Later on, he recaptured, sorted, and counted all the marked moths he could. What type of results do you think Kettlewell needed to either prove or disprove the hypothesis?

Kettlewell found that in unpolluted areas, more of his light-colored moths had survived. In soot-blackened areas, more of his dark-colored moths had survived. Thus Kettlewell showed that in each environment the moths that were better camouflaged had the higher survival rate. It was logical to conclude that when soot darkened the tree trunks in an area, natural selection caused the dark-colored moths to become more common. Today Kettlewell's work is considered to be a classic demonstration of natural selection in action.

14–2 SECTION REVIEW

1. What is natural selection? What observations led Darwin to develop this concept?
2. Define survival of the fittest. How are the concepts of natural selection and survival of the fittest related?
3. **Critical Thinking—Relating Cause and Effect** Explain how natural selection might produce a modern giraffe from short-necked ancestors.