17

The endangered Siberian tiger

Conservation

Conservation biology usually invokes thoughts of rare and endangered species like the beautiful Siberian tiger on this page. Certainly over the last half century, the industrialized world has become more concerned with its role in accelerating species extinction. As a result, international cooperation has developed to limit the harvesting of whales, and for some whale species, to prevent it completely; to stop the trade of animal products like ivory from elephants and rhinoceros; and to encourage less developed countries to set aside land for the protection of endangered species and rain forests.

Conservation biology attempts to develop a solid scientific understanding of the forces affecting the long-term maintenance of biological populations and genetic variation within populations. As we will see in this chapter, this understanding often comes from the principles we have already explored in ecology and evolution. Endangered species are not the only focus of conservation biology. Many natural populations are important economic resources. However, we need an understanding of how human harvesting from these natural populations will affect their long-term survival. Simple economic forces cannot always properly weigh the future impact of species extinction. Developing rules for harvesting natural resources is complicated by the different currencies we choose in valuing these resources.

Human activity does not always result in extinction. Humans have transported species to new habitats, where they have done exceptionally well—in some cases too well. Introduced species may become pests and can become the agents of extinction for native species. Another aspect of conservation biology, then, will be to examine how we can control recently introduced species that may change the nature of the ecosystems they have invaded.

Basics of Conservation

17.1 Conservation biology requires an understanding of the genetics, ecology, and physiology of managed populations

Biodiversity The variety of plant and animal species on Earth, the genetic variability that exists within each of these species is referred to as **biodiversity**, and the variation in communities and ecosystems. In this book we have reviewed many processes that affect genetic variation within species. These processes include genetic drift, inbreeding, and natural selection. We have also learned about ecological factors that affect the numbers of species in a community or ecosystem. Some of these processes are competition, predation, environmental variation, and energy flow. **Conservation biology** is the scientific study of biodiversity and its management for human welfare. As an applied science, conservation biology relies on theories and principles from many other disciplines. We have already noted the importance of ecology, genetics, and physiology to understanding biodiversity. However, other applied fields—like fisheries biology, forestry, and range management—have similar concerns.

> *Our understanding of biodiversity is partially due to our understanding of basic principles of ecology and genetics.*

The successful application of conservation biology often requires a detailed understanding of the ecology of endangered populations and their community. As an example, we review the decline of the large blue butterfly in England. Creating protected areas for this butterfly was not sufficient to prevent its extinction. A more detailed understanding of the butterfly's ecology was ultimately required.

Maculinea arion The large blue butterfly (Figure 17.1A) was common in Southern England in the late 1880s, but its decline was already being forecast. The number of colonies underwent a continual decline for the next 100 years. By 1974 there were only two known colonies and perhaps about 250 butterflies. Two successive droughts caused the extinction of the last colonies in Britain in 1979. Although protected areas had been established in the 1930s for this butterfly, they did not prevent the large blue's ultimate extinction. Detailed studies of the ecology of the large blue ultimately provided the clues needed to design an effective recovery program.

Caterpillars of the large blue feed on thyme plants, but gain little weight. The caterpillar ultimately leaves the thyme and travels a short distance to an ant colony. The caterpillar offers the ant some sugar, and through a variety of tactile and smell signals, cons the ant into bringing the caterpillar back to the ant colony. Once there, the caterpillar feeds on ant larvae. The species of ant that large blue does best with is *Myrmica sabuleti*. These ants prefer close-cropped turf. When the turf is not grazed or burned down, the *M. sabuleti* colonies are replaced with another species of ant, *M. scabrinodes*, which results in a 2 percent decline in the survival of the large blue caterpillar.

Many of the **reserves** set off for this butterfly excluded humans and small mammals that might graze on the grass. Thus the butterfly continued to do poorly because its preferred food resource, *M. sabuleti*, was driven from the habitat.

FIGURE 17.1A ***Maculinea arion*, the Large Blue Butterfly**

Samples of the large blue caterpillar from Northern Europe have now been successfully reintroduced into England.

The idea of setting aside tracts of land has grown and is now applied to large areas with the goal of preserving many species—not just one, like the large blue butterfly. These types of reserves have become necessary as more forest land is lost to agriculture, deserts, and other human activities. In the next modules we provide more detail on the negative consequences of habitat loss and fragmentation.

In the course of creating these ecological reserves, many practical questions arise concerning the size and number and connectedness of the reserves. Some of these questions can be addressed with knowledge we have gained from studies of species loss on islands. We will review some of these ideas from the theory of island biogeography.

Harvesting

Conservation biology also deals with the conservation of species that are currently not endangered, but might be due to human activity. Many species are hunted or harvested by humans for their economic value. Marine fisheries are an example of this. These fish are valuable food, but due to their ecology they cannot be easily raised in human captivity, so we rely on natural populations to provide the fish we need. There are a number of difficulties concerning these natural resources. In the case of ocean fish populations, there is no single owner of these fish—and thus no easily recognized authority to determine how many should be harvested at any time. It is also difficult to determine the number of fish in these populations, so the impact of human removal of fish may not be evident until it is too late. Simple ecological theory can be used to begin our analysis of this problem and provide some insights about how we should limit our harvesting efforts.

Risk Analysis

Another important component of conservation biology is the study and preservation of endangered species. One aspect of the study of endangered species is **risk analysis**, the development of quantitative estimates of the likelihood of extinction. This may often require many pieces of information, like the variability of the environment, the reproductive biology of the endangered species, and the dynamics of other species that provide food for the endangered species or feed on the endangered species. For instance, in Figure 17.1B we show information that has been developed to predict the dynamics of a population of red kangaroos in Australia. These animals feed on grasses and forbs that fluctuate widely in available biomass due to highly variable rainfall. The fluctuations in available food level have led to fluctuations in births and deaths that ultimately affect the numbers of kangaroos. The model in Figure 17.1B can be used to determine the chances of the extinction over fixed periods of time. Different scenarios of weather and total available land are used when making these predictions. Together, this information will provide concrete estimates of the vulnerability of kangaroos to extinction.

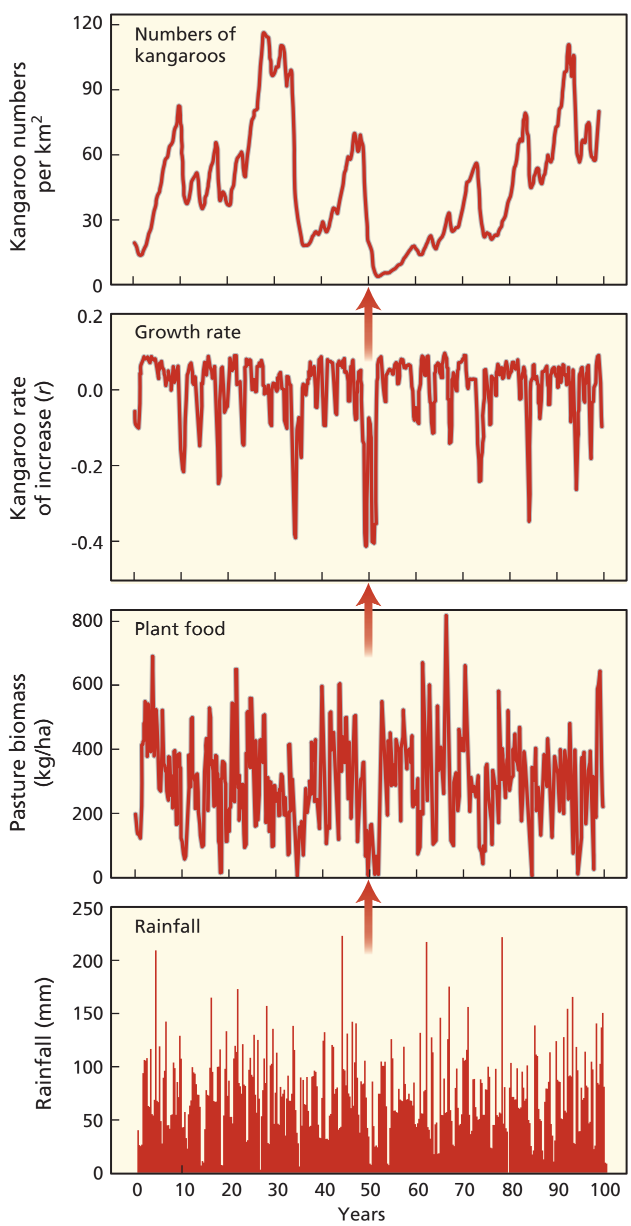


FIGURE 17.1B Predicting Population Fluctuations of Red Kangaroos

17.2 Ecological principles can be used to design reserves

There is an ever-increasing concern for the long-term fate of many plant and animal species, as well as of certain rare ecosystems. In most cases these organisms are threatened due to the negative impact of human activities on their habitat. In an effort to combat these trends, many countries are protecting areas of land or marine habitat as ecological reserves. A reserve may aim for at least three important goals: (1) The reserve may aim at preserving an entire ecosystem with all its important services. For instance, the area that constitutes a watershed may be preserved for the important needs of flood control and water recharge. (2) The reserve may have the general goal of preserving biodiversity. Some reserves might encompass regions in the tropics that are especially rich in the number of different species living there. Other areas may be converted to reserves because they contain many endemic species, that is, species found only in that area. Finally, the reserve may represent a particularly unusual environment that will be lost without protection. (3) Reserves may be set up to protect particular species. Many reserves have as a goal the preservation of particularly conspicuous species that are threatened with extinction—like rhinoceroses, pandas, and tigers.

The numbers of species on an island will stop changing when extinctions exactly equal immigrations.

One branch of ecology, called island biogeography, offers important theoretical concepts that can guide in the design of refuges. **Island biogeography** is concerned with understanding the number of species that are found on isolated habitats or islands. Obviously, an ecological preserve is similar to an island, since it may often be surrounded by inhospitable territory for the organisms within the preserve (Figure 17.2A). One general observation of the species composition of islands has been that the larger the island, the more species are typically found (Figure 17.2B, part i). While the data presented in Figure 17.2B are for birds, similar trends are seen for many different taxa of plants and animals. A guiding principal for understanding these species-area relationships is that, at any time, the numbers of species on an island represent a balance between extinctions and immigration events. We consider these in more detail next.

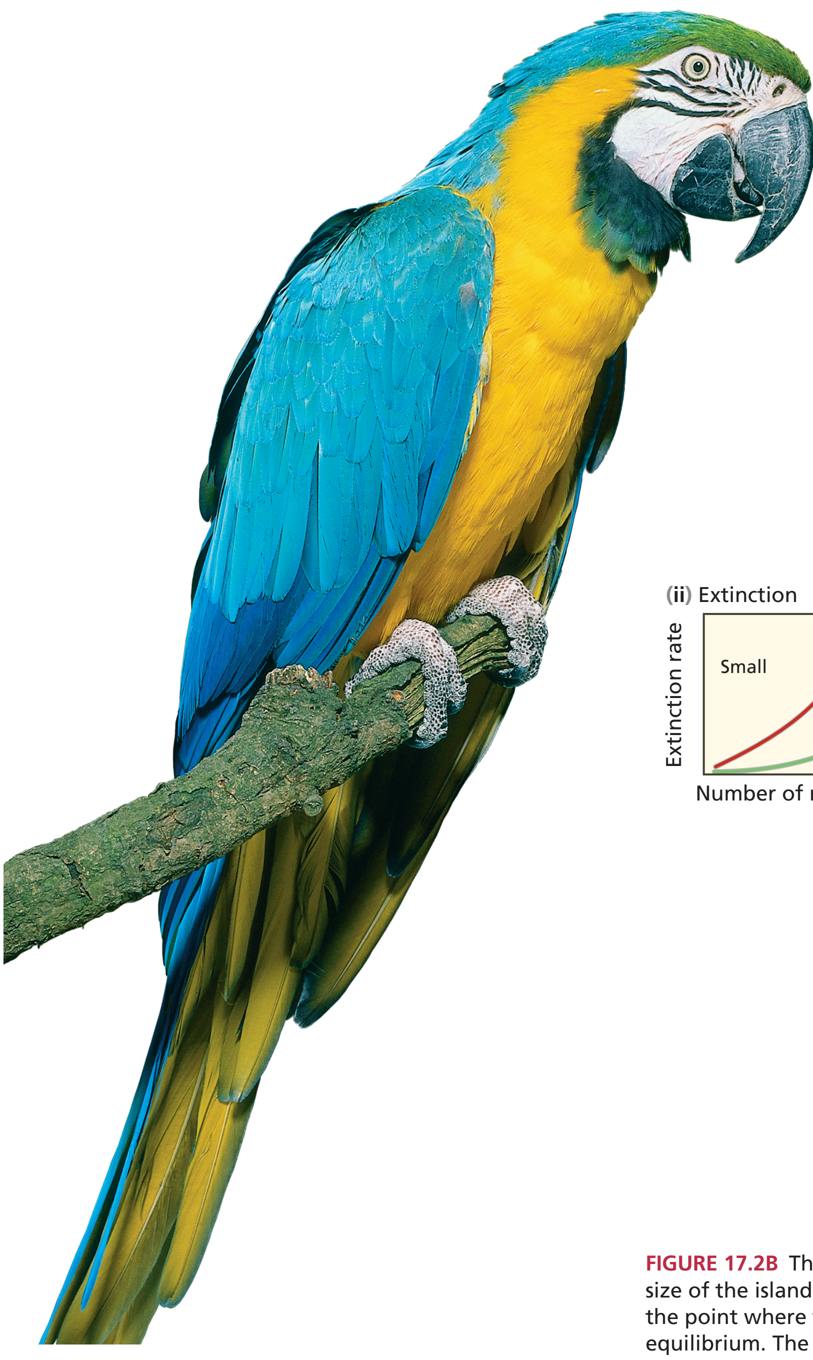
On any island, we expect that the number of species extinctions per unit of time will increase when there are more species on the island. This follows from the obvious fact that with increasing species, there are more possibilities of an extinction event. However, we also expect that for any fixed number of species, extinction is more likely on a small island than it is on a large island (Figure 17.2B, part ii). This is because all things being equal, large islands will typically have more habitat and resources for any single species, making extinction less likely. On small islands, populations will typically be smaller and more prone to extinction as we detail in Module 17.6.

Immigration is typically from a large source population, like a mainland continent, over inhospitable territory to an island. If everything happens as expected, a migrating plant or animal from the mainland is more likely to hit a nearby island than a distant island. If the island already had many species on it, there is less chance that a migrant represents a new species. Thus rates of immigration decline with increasing numbers of resident species.

FIGURE 17.2A The clear-cut hill in the foreground overlooks the Gifford Pinchot National Forest in Washington. On the right is private land clear-cut by a logging company. The idea of refuges as islands is visually supported by this picture.

The numbers of species on an island will stop changing when extinctions exactly equal immigrations. We can determine the equilibrium number of species on any island by combining the extinction and immigration curves and finding their point of intersection (Figure 17.2B, part iii). We see from this that the expected number of species is much greater on the near island than on the distant island.

At the very least, then, we can conclude that a refuge that aims to prevent extinction of species should be as large as possible. Another problem that is more difficult to answer is, What is better—one large refuge, or several small ones that add up to the same size as the large one? The answer will depend on how much higher the extinction rates are in the small reserves. Suppose their extinction rates were essentially the same as those in the single large refuge. Then it would be much better to have several small refuges because, if a species went extinct in one, you could always recolonize it with the same species from one of the other refuges. On the other hand, if extinction rates were so high in the small refuges that all species would be expected to go extinct in a single generation, then it would be much better to have a single large refuge.



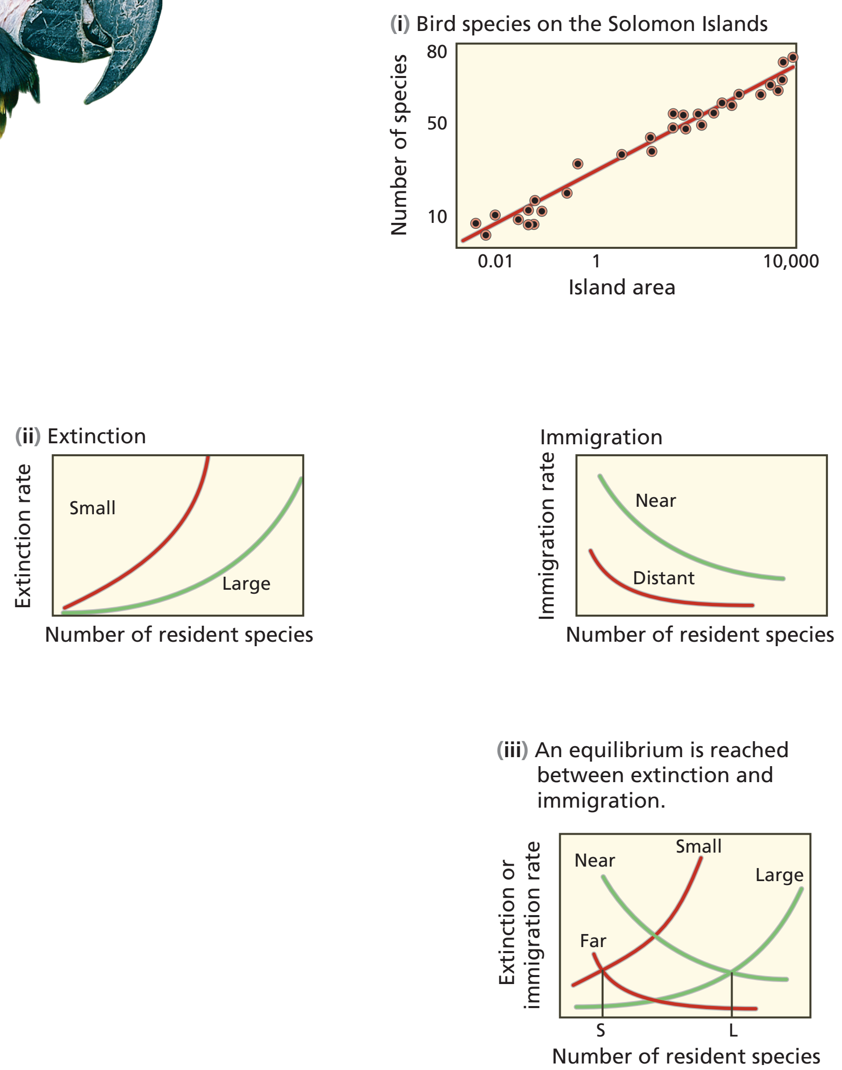


FIGURE 17.2B The number of bird species on the Solomon Islands increases with the size of the island. An equilibrium is reached between extinction and immigration—the point where the extinction and immigration curves cross represent an equilibrium. The equilibrium number of species on the small, far island (S) is less than the equilibrium number (L) on near islands.

17.3 The loss of habitat and habitat fragmentation leads to species extinctions

Many natural processes may lead to a break in the continuity of a habitat or **fragmentation**. Some of these breaks may create small gaps. For instance, a tree may fall in a forest and knock down several other trees. This will create a small gap in the forest that is no longer shaded and receives direct sunlight. A storm at sea may wash up large pieces of driftwood that smash against a dense covering of sea anemones and mussels in the intertidal zone. This creates a small opening of space in an otherwise densely packed community. Humans also create gaps in habitats; sometimes these can be quite large. The settlement of humans in forested areas of this country was followed by clearing of trees and initiation of agriculture. At first this created small gaps in the forest habitat (Figure 17.3A); but with time these gaps grew, until only small patches of forest remain. The forest had now become fragmented.

Sometimes we may not even recognize that populations are fragmented in smaller populations. Paul Ehrlich and his colleagues have studied populations of the checkerspot butterfly, *Ephydryas editha bayensis*, near the campus of Stanford University for the last 40 years (Figure 17.3B). The total numbers of butterflies at the Jasper Ridge site appears to be high over a 25-year period of observations (Figure 17.3C). However, the Jasper Ridge site is made up of several small populations—called C, G, and H—whose numbers show very different changes. In fact the smallest population, G, has gone extinct twice during the census period and has once been apparently recolonized (see Figure 17.3C). Thus, fragmentation may create small populations that are simply more vulnerable to extinction. If the fragmentation is severe, there may be no close neighbors to recolonize an extinct population.

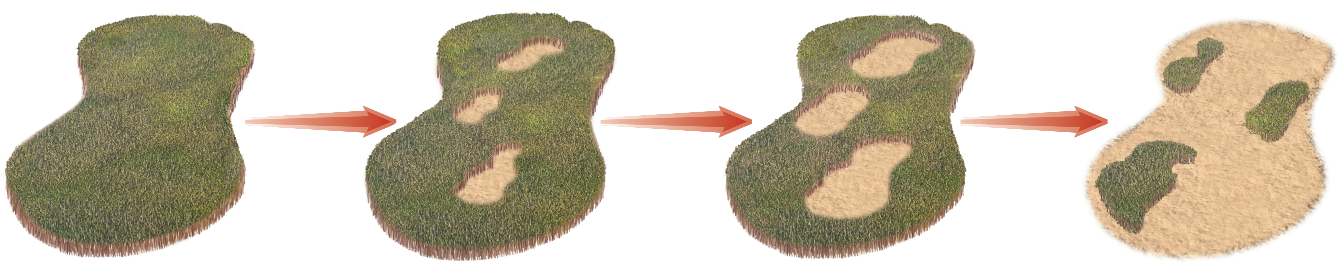


FIGURE 17.3A The Formation of Habitat Fragments

FIGURE 17.3B Euphydryas editha bayensis These butterflies are the subject of the study in Figure 17.3C and is an endangered species known to occur in only a few localities in California.

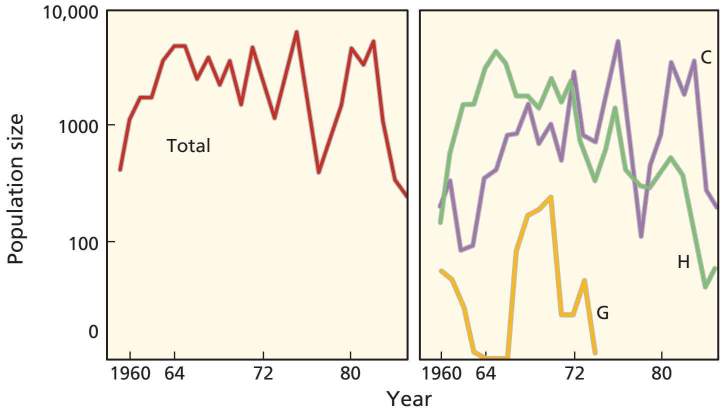


FIGURE 17.3C **Populations of Checkerspot Butterflies at Jasper Ridge, California**

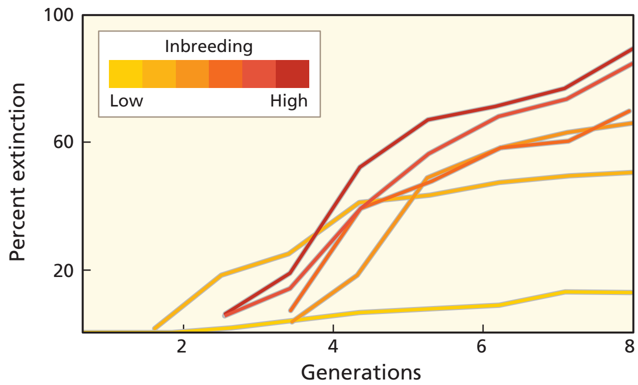


FIGURE 17.3D **Extinction of Laboratory Populations of Fruit Flies Inbred to Different Levels (low to high)**

Fragmentation of habitats may also facilitate species extinction because suitable habitat is destroyed for species with narrow distributions and specialized habitat requirements. Other species may perish because fragmentation is accompanied by barriers to essential movement. Some animals may need to move regularly from one geographic location to another to find new food resources or breeding sites. Some barriers created by humans may be quite subtle. For instance, many small mammals will not cross open roads. Others that try to cross these roads—like the endangered Florida panther—may be hit by cars so often that this becomes a major source of mortality.

Even if small populations persist, they become inbred due to their small size. For organisms that do not typically inbreed, mating with relatives can have devastating consequences. Biologists have suggested for a long time that inbreeding should make populations more vulnerable to extinction, but experimental evidence has only recently been collected. Kuke Bijlsma and his colleagues (2000) studied populations of the fruit fly, *Drosophila melanogaster*, that had been inbred to various degrees. They then made many small populations for each of the inbreeding treatments and kept track of how many populations went extinct over time. The results show that inbreeding demonstrably increased the chance of population extinction (Figure 17.3D). This effect was even more pronounced in stressful environments. The results in Figure 17.3D are for populations exposed to ethanol vapors.

17.4 The last century has been marked by the loss of terrestrial forests and the acceleration of species extinctions

There may be anywhere from 10 to 50 million species on the planet today. About 90 percent of these are terrestrial, and about 80 percent of the terrestrial species live in the tropics. It is not surprising, then, that there is heightened concern about the loss of natural habitats in tropical regions. Although many species go extinct without notice, there are also well-documented cases of extinctions. The Rift Valley in East Africa is home to three lakes—Victoria, Tanganyika, and Malawi—that have about 1000 different species of cichlid fish. Most of these species are endemic to these lakes. Lake Victoria has already lost about 200 of its 300 cichlid species. Many of these extinctions were a direct consequence of the introduction of the Nile perch to these Lakes (Figure 17.4A). As humans have become more mobile due to technical advances in travel, they have made it easier for weedy species of plants and animals to move large distances. Some of these transplanted species can seriously disrupt the local communities and in the worst case, like the Nile perch, lead to the outright extinction of resident species.

The major tropical forests of the world are found in Central and South America, Asia, and Africa. The forested regions of these continents have been declining at an alarming high rate recently (Figure 17.4B). For instance, in Central America forest cover has vanished at a rate of nearly 2 percent per year. At this rate, by the year 2019 the forests in Central America and Mexico will be half the size they were in 1981. Much of this loss of forest has been due to the conversion of land to agricultural uses (Figure 17.4C). The result has been a tremendous loss of species.

The best estimates today are that the world loses about 27,000 species per year, mostly as a consequence of the human activities just reviewed. Historically, this rate of species extinction is unprecedented. Prior to the arrival of modern humans on Earth, data from the fossil record suggests that species were disappearing at a rate of about 0.25 per year. The current rate of extinction is thus about 100,000 times higher than the historical levels. The extinction of a species is not the only negative outcome of habitat loss. Many organisms that suffer reductions in available habitat will, prior to extinction, lose genetic variation, subspecies, and many local populations. Consequently, the genetic variability of endangered organisms is often severely reduced even if they are not driven to extinction.

What are the negative outcomes of species extinctions? Even if we focus on only the direct consequences to humans, the loss of species can be great. Many important agricultural

FIGURE 17.4A After its introduction, the Nile perch eliminated many endemic species of cichlids from Lake Victoria.

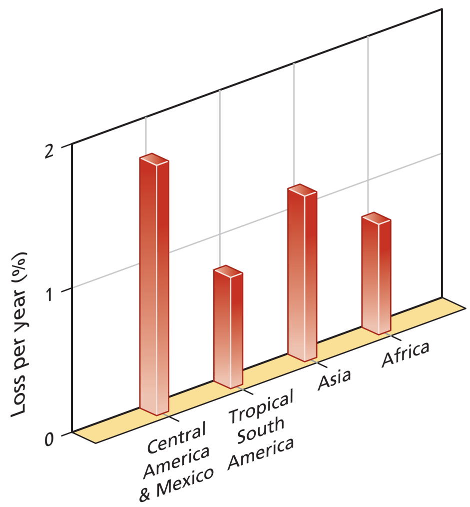


FIGURE 17.4B Annual Rates of Deforestation in Tropical Regions from 1981 to 1990

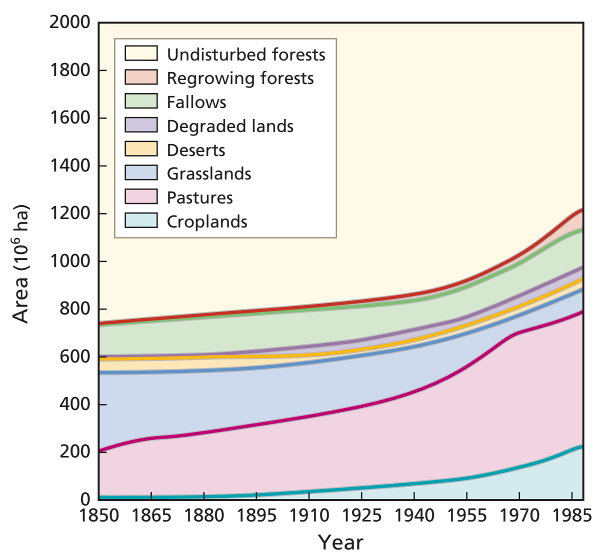


FIGURE 17.4C Land Use in Central America between 1850 and 1985 There is a general loss of undisturbed forests due to increases in pastures and croplands.

species of plants have been bred for specific characteristics and today appear quite different from their ancestral species. However, we find that agricultural species are constantly challenged with new diseases and insect pests. Having access to the genetic variation of the ancestral species of these crop plants provides opportunities to meet these new challenges by selective breeding or even through recombinant DNA technologies. The loss of these reservoirs of genetic information puts the future of agriculture at risk and makes it more difficult to respond to new challenges.

In the past we have found that plants and animal species harbor important chemical compounds that can be used for important biomedical advances. Clearly, the loss of species at the rates we are now witnessing will ultimately translate into lost opportunities for advances in medical research. Because these discoveries will never be made, we can only guess about their number and possible significance. ❖

17.5 Ecological theory can be used to guide harvesting from natural populations

It comes as no surprise that many species of plants and animals are economically quite valuable. The agricultural industry is an indication of how important these organisms are. However, the focus of modern agriculture is primarily on plant and animal species that can be easily cultivated or domesticated for human use. There are some economically valuable species, mostly animals that cannot be easily raised for human consumption. These species are then **harvested** from natural populations for human consumption. Examples include many species of fish, whales, marine mollusks, and marine crustaceans. These animals are not easily domesticated, because they need too much space, grow too slowly, or must be raised under conditions that are difficult to replicate outside of the natural environment. Often the exact numbers of animals in these natural populations is unknown. However, humans can be very effective harvesters and can cause natural populations to go extinct if they are not careful.

For instance, consider a population with a carrying capacity of 100,000 animals that grows according to the logistic equation. If a constant number of animals are removed from the population every year for human consumption, what will be the effect on the numbers of these animals? In Figure 17.5A we show several curves predicting the outcome of several levels of harvesting on this population. If the harvesting is not severe (removal of 7500, 10,000, or 12,500 animals), the population size declines; but it eventually reaches a stable point where new births equals natural deaths plus harvesting. However, if too many animals are removed (15,000 or 17,500 animals), the population will go extinct fairly rapidly.

Population density affects both birthrates and death rates. If we examine the total number of births in a population, we expect that birthrate will increase as population size increases, but that its rate of increase will slow down—and may even decrease—at very high densities due to resource limitations and their effects on female fertility (Figure 17.5B). Meanwhile, we expect the total number of deaths to increase at an accelerating rate with total density (Figure 17.5B) due to all the increased sources of mortality at high density. When these two curves meet, the population is at its carrying capacity (K): Total births equal total deaths. At densities below the carrying capacity, there is an excess of births over deaths, and some or all of these excess births may be harvested and not cause the population to decline (Figure 17.5B). The **maximum sustained yield** is the density that yields the greatest number of excess births. For populations that follow logistic growth, the maximum sustained yield occurs at $K/2$ (Figure 17.5C).

An interesting prediction for populations growing logistically is that there are two densities that will produce the same yield (see Figure 17.5C). However, the practical effects of harvesting at these two densities may be quite different. For instance, because density N_1 is less than N_2 (see Figure 17.5C), we would expect the animals to be less concentrated if we harvest at density N_1. This means that all things being equal, it will require more effort to harvest the same number of animals at density N_1 compared with density N_2. From an economic perspective, this means it will be more costly to harvest animals at N_1 compared with N_2. However, since the animals are less crowded at N_1, they should have more resources; this may mean they will be larger, and hence more valuable, than animals harvested at N_2. The details depend on the biology of the particular organisms in question and their

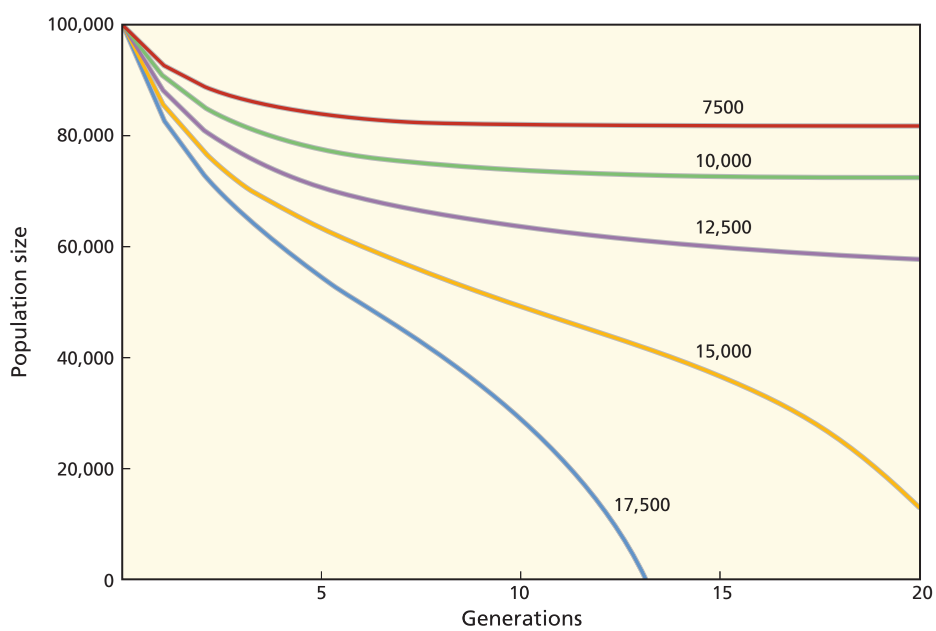


FIGURE 17.5A Population size decreases with increasing harvesting level.

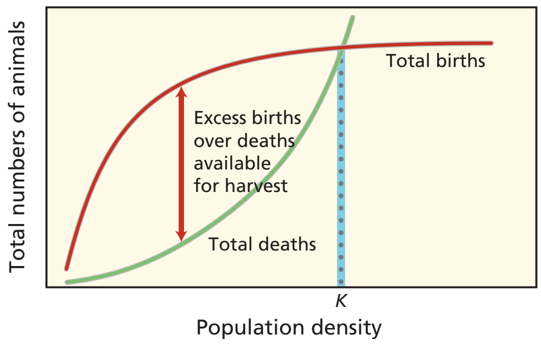


FIGURE 17.5B What density yields the greatest harvest potential?

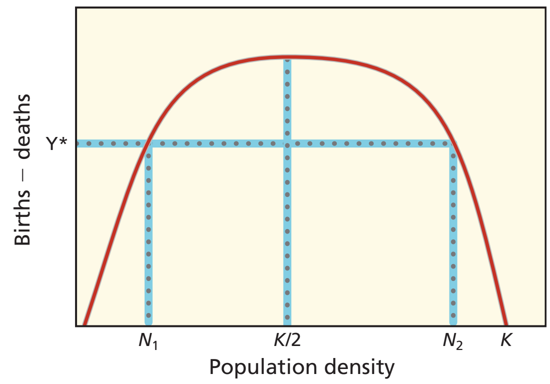


FIGURE 17.5C Logistic population growth produces the same yield at different densities. Harvesting all excess births at N_1 or N_2 will produce the same yield (Y^*) because the excess number of births over deaths is the same.

response to different levels of crowding. The practical application of maximum sustained yield methods requires accurate information about the species of interest. Unfortunately this information is not available for many species of economic interest.

It is important to realize that the maximum sustained yield may not be the most profitable yield. In fact the most profitable course of action might be to harvest all the animals at once, even if it means extinction of the population. For this reason, many scientists believe that several factors must be used in determining the allowable harvesting levels of vulnerable biological populations. In addition to immediate economic forces, the importance of preserving biological populations for future use must also be considered.

17.6 Risk assessment

How do species go extinct? Although we have abundant evidence from the fossil record of extinctions, it is difficult to determine the actual dynamics of the populations just prior to extinction. Unfortunately, we have well-documented examples of species extinctions over the last few hundred years. Some of these examples are discussed in the next module. Here we simply note that most species typically have their ranges severely restricted prior to extinction. Additionally, the species lives for some period of time at extremely low numbers before vanishing completely. When populations are very small, it stands to reason that all members of the population may fail to reproduce due to some sudden environmental catastrophe. So a virulent disease may kill the few remaining members of a population. Or unusual weather, like a drought or severe winter chill, could wipe out a small population. However, even in the absence of these types of unusual environmental scenarios, populations may go extinct due to natural variation in reproductive success.

Earlier in this book we have treated members of a population as equivalent units, all producing exactly the same number of offspring. In a population with equal numbers of males and females where every female produces 2.2 offspring, we would expect this population to sustain positive growth rates. Although the average number of offspring (λ) is 2.2, the actual number of offspring produced by each female may look more like the data shown in Figure 17.6A. An individual female may produce 0, 1, 2, or more offspring—even though the average is 2.2. Consequently, it is certainly possible that a small number of females may produce no offspring, by chance alone. This type of variability in offspring numbers is called **demographic stochasticity**. A small group of semelparous organisms will go extinct if all females fail to produce any offspring. Even though the chances of this happening in any one generation may be small, the chances over longer periods of time may be substantial. For instance, for small populations we can estimate from Figure 17.6A the chances of at least one year out of 10 with no offspring production, and hence extinction. For very small populations, 1–4 females, these probabilities can be substantial even when the average number of offspring is greater than 2. If some years are characterized by bad environments that substantially reduce the average number of offspring, to 0.5 for instance, then the chances of extinction over any group of 10 years can be quite high (Figure 17.6A).

To assess the risk of a population going extinct, we need to construct a model that incorporates the information about demographic stochasticity, density-dependent survival and fertility, and effects of environmental variation on survival and fertility. However, before doing this we must decide how

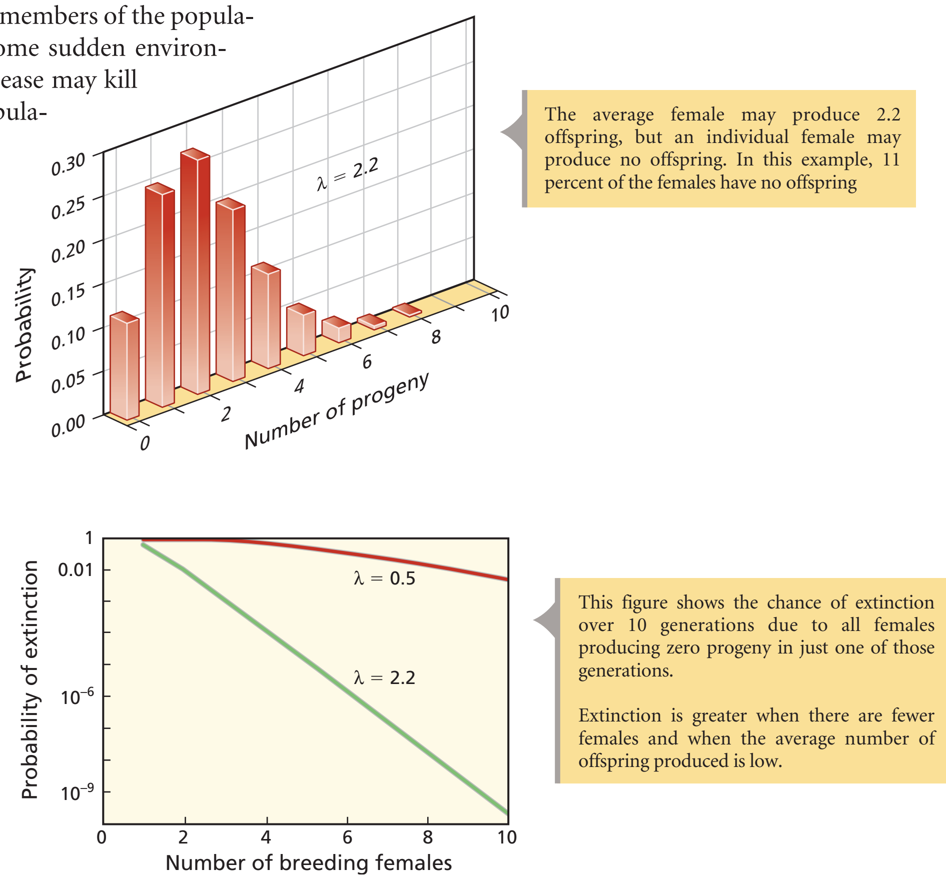


FIGURE 17.6A Demographic Stochasticity

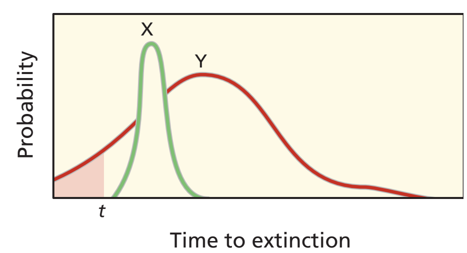


FIGURE 17.6B Time to Extinction In this figure the mean time to extinction is greater in population Y than in population X. However, the chance of extinction at time *t* or earlier is greater in population Y. This is due to the large variance in population Y.

we will characterize the risk of extinction. One value that could be estimated is the average time to extinction. Obviously, populations with short average chances of extinction over any group of ten years can be quite high. In Figure 17.6B the possible times to extinction are shown as bell-shaped curves. Because the time to extinction depends on random events, we will not know its value exactly; but we can fix certain probabilities that it will have a particular value. In Figure 17.6B, population X has a lower average time to extinction than does population Y. However, it might not be the population at greatest risk. If we ask what the chances are that the population will go extinct soon (e.g., before time *t*), we see the answer is essentially zero for population X, but it is equal to the fraction of the Y bell curve that is shaded in red. Population Y is at greater risk of going extinct in the short term because there is a much higher variance in the random factors that affect it—meaning that if all things went really badly, population Y might go extinct quite rapidly. Such rapid extinction cannot happen in population X.

The factors we considered in Figure 17.6B suggest that another way to assess the risk of a population would be to estimate the chance that a population will go extinct before a fixed time period. This can be a useful statistic for managing populations because the ability to sustain certain policy decisions for extended periods of time is limited. If policy decisions like setting aside land or banning agriculture from certain areas are believed to be sustainable for a period of 50 years, then it makes sense to focus such efforts on those species most likely to go extinct in the next 50 years. This might mean that for our example in Figure 17.6B, population Y would be deemed at greater risk than population X and thus deserving of first priority in conservation efforts. ❖

APPLICATIONS

17.7 Applications of conservation biology include designing reserves, reducing species extinctions, and managing exotic populations

Relative to other fields of ecology conservation biology is still in its infancy. Nevertheless, many practical conservation problems require immediate attention. We do not have the luxury of waiting until the science of conservation biology acquires a more rigorous empirical foundation. We next provide an overview of some of these problems. In the modules that follow we pursue these problems in more detail.

Reserves An important application of conservation biology is the design of reserves to protect endangered species and ecosystems. The use of reserves has in fact predated the development of conservation biology as an academic discipline. One of the earliest reserves also serves as an endorsement of the utility of reserves for preserving endangered species. A French missionary, Pere Armand David, discovered deer living in a walled game park just outside of Beijing, China, in the 1860s (Figure 17.7A). Bones of relatives of these deer can be found in China, and the natural populations appear to have been extinct for 2000–3000 years. It is not known how the captive population in China was established.

An important application of conservation biology is the design of reserves to protect endangered species and ecosystems.

Pere David arranged to have a pair of deer shipped to an English park in 1898. At about the same time, the remaining deer in China had escaped from the park and did not survive the social disorder of the Boxer Rebellion. Thus by 1918 there were only 50 remaining Pere David's deer in an English park. These deer were descendants of the original pair shipped to England and some others gathered from around Europe. These deer have been maintained in England. The deer have now been reintroduced in a reserve near Shanghai, China, and appear to be doing well. Without the hunting reserve in China, the species probably would have gone extinct 2000 years ago. Without the establishment of the protected population in England at the turn of the twentieth century, the species would be extinct today. The establishment of several vigorous populations of Pere David's deer around the world should reduce the chances that all populations will go extinct.

As we will see, not all species have been as fortunate as Pere David's deer. Human activity over the last 400 years has been directly implicated in the extinction of many species of plants and animals. Although we are now aware of the fragile nature of many species, that knowledge has not prevented new species from becoming endangered. Many endangered species are located in poor countries that often lack the resources to devote to effective maintenance of reserves. An example of this is the Tsavo Parks in Kenya.

In 1948 the Tsavo National Parks were established in Kenya, with elephants as a primary benefactor of these reserves (Figure 17.7B). However, to create these reserves, many of the native people living in this area were moved out to the borders of the park. From 1957 to 1958, the Kenyan government carried out an intensive antipoaching campaign that was so effective it allowed the park to rely on a

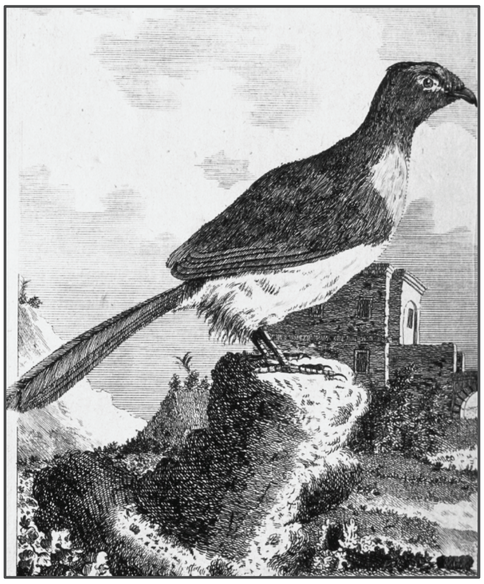
FIGURE 17.7A **Pere David's Deer**

FIGURE 17.7B **African Elephants**

very small security force to cover the park's enormous area—21,800 km^2. The elephant population increased in numbers to about 50,000 just before a severe drought in 1971. Over 9000 elephants died from the drought. The people in the surrounding countryside were also adversely affected by the drought. People who had lost their crops then entered the park to search for dead elephants and ivory. The numbers of people entering the park were far beyond what the security force could contend with, and the psychological deterrent the force represented was lost. After the ivory from dead elephants was gone, poaching ensued. The elephant population dwindled and was estimated to be only 5400 in 1987. If the economic problems of the local people had been effectively dealt with, the poaching could have been prevented.

Extinction All the species shown in Figure 17.7C have shared the fate of extinction. Furthermore, the major culprit of these extinctions was human activity. In Module 17.8 we will go into more detail about some specific cases of extinction. This is a crucial topic because as we all know, extinction is forever.

Exotic Species Human trade, agriculture, and commerce may create other types of problems. In some cases plants and animals are transported by humans to novel environments, where they become serious economic pests. In Module 17.10 we review this general problem and learn what principles from conservation biology can be used to help control or eradicate these exotic species.



Snail-eating coua

Caribbean monk seal

Flying fox

FIGURE 17.7C **Extinct Species**

17.8 Human activity has led to the extinction of many species in recent history

Compared with speciation, even compared with natural selection, extinction is inherently less mysterious than other evolutionary processes. Extinction occurs when species can no longer sustain themselves, which in turn means there are not enough individuals to continue the production of offspring at levels high enough to prevent the loss of all individuals of the species. Sometimes the exact moment of final extinction, when the last member of a species dies, is known.

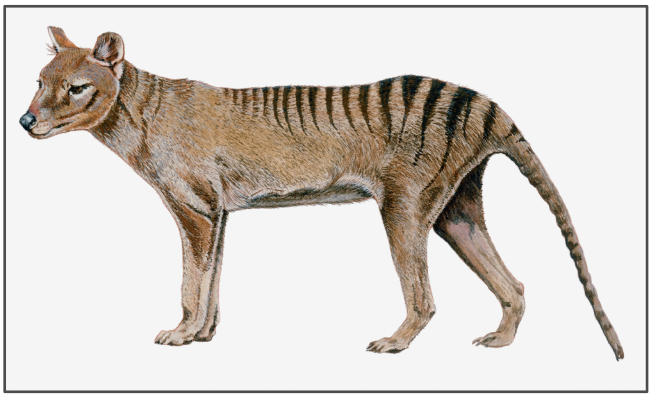
Many cases of extinction caused by human activity are well documented. Take, for example, the dodo (Figure 17.8A). The dodo was a member of the same group of birds as the common pigeon. It was gray, like many pigeons, but its body was radically different—30 to 50 pounds in weight, with small wings of no value for flight and a large beak. The dodo was a single species found only on Mauritius, an isolated island in the Indian Ocean, east of Africa. Portuguese sailors first came upon the dodo in the sixteenth century. It is thought that the name for the dodo is related to the Portuguese slang for *stupid*. The dodos were completely tame and did little to evade capture and slaughter. This is not as paradoxical as it might seem, because the island of Mauritius had no large predators on it before humans arrived, so there would have been little selection for fear of predation in dodos. Although it might be supposed that all the dodos were simply killed and eaten by sailors, two other factors were probably also important. First, humans cut down the trees making up the wooded habitat that the dodo inhabited. Second, dogs and pigs introduced by humans also hunted and ate the dodo. The pigs also competed with dodos for similar food and destroyed their nests. No living dodos have been sighted since 1681. A few museums have preserved pieces of dodos, but no complete specimens remain. The entire extinction process took only about a century.

This one example could be amplified many times over. It is perhaps relatively notable because it was one of the first cases where humans knew that they were responsible for the extinction of an entire species. The expression "dead as a dodo," which was once commonplace, bespoke an awareness of the irretrievable loss that extinction represents—its finality.

The extinction of the dodo might be considered unsurprising, given that it was a single, docile species isolated on a unique island. One step up from the dodo might be the Tasmanian tiger (See Figure 17.8A), or thylacine, a striped marsupial that had a

Dodo

Passenger pigeon



Tasmanian tiger

Recorded extinctions since 1600

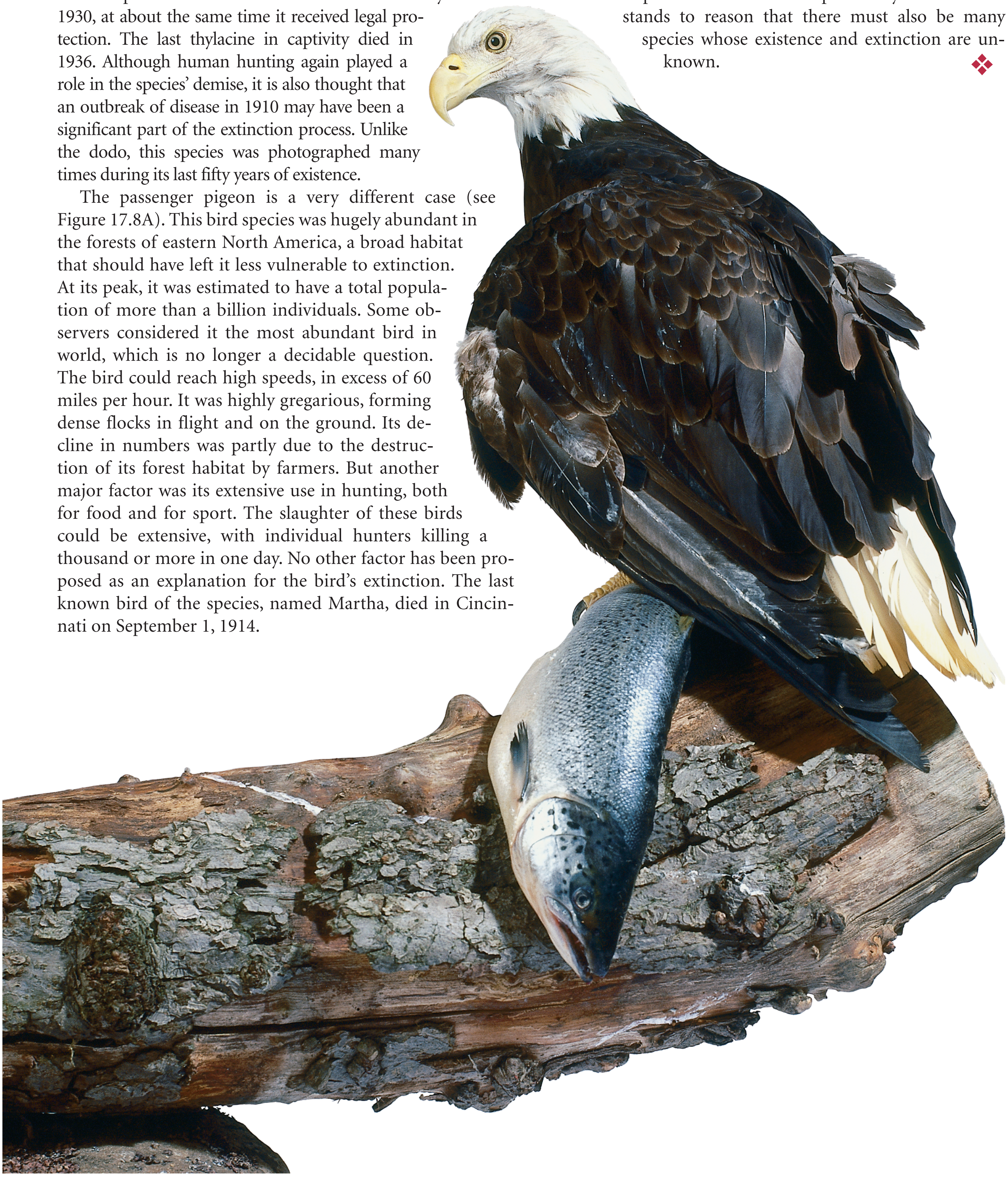
Taxa	Continental	Island	Oceanic	Total
Mammals	30	51	2	83
Birds	21	90	2	113
Reptiles	1	20	0	21
Amphibians	2	0	0	2
Fish	22	1	0	23
Invertebrates	40	48	1	98
Vascular plants	245	139	0	384

FIGURE 17.8A Gone but Not Forgotten

morphology and an ecological role generally similar to those of a wolf or coyote. This was a less docile animal than the dodo, with a wider distribution. Europeans were first made aware of its existence by reports published in 1805. It was not long before the animal was classified as a danger to livestock, with a bounty placed on each pelt. It was hunted to virtual extinction by 1930, at about the same time it received legal protection. The last thylacine in captivity died in 1936. Although human hunting again played a role in the species' demise, it is also thought that an outbreak of disease in 1910 may have been a significant part of the extinction process. Unlike the dodo, this species was photographed many times during its last fifty years of existence.

The passenger pigeon is a very different case (see Figure 17.8A). This bird species was hugely abundant in the forests of eastern North America, a broad habitat that should have left it less vulnerable to extinction. At its peak, it was estimated to have a total population of more than a billion individuals. Some observers considered it the most abundant bird in world, which is no longer a decidable question. The bird could reach high speeds, in excess of 60 miles per hour. It was highly gregarious, forming dense flocks in flight and on the ground. Its decline in numbers was partly due to the destruction of its forest habitat by farmers. But another major factor was its extensive use in hunting, both for food and for sport. The slaughter of these birds could be extensive, with individual hunters killing a thousand or more in one day. No other factor has been proposed as an explanation for the bird's extinction. The last known bird of the species, named Martha, died in Cincinnati on September 1, 1914.

This is but a small list of the known extinctions. The total number of known extinctions in recent history is in the hundreds of species (see Figure 17.8A). These numbers must also be viewed as very conservative, because we are probably unaware of many extinctions. Even today we continue to find new species that have been previously unknown. It stands to reason that there must also be many species whose existence and extinction are unknown. ❖



17.9 Some of the most prominent endangered species live in terrestrial ecosystems

Many species are currently facing the fate of passenger pigeons and dodos. Often the organisms recognized as being in danger of extinction are large, prominent, terrestrial organisms. This does not mean that there are no marine organisms facing possible extinction, nor that small insects aren't also in danger, because they almost certainly are. However, it is much more difficult to study these species, especially if they are rare and hard to find. Although the list of endangered species is large, we review a few specific examples here to illustrate the ecological and economic forces involved.

The northern spotted owl lives in old-growth forests in the Pacific Northwest of the United States. Old-growth forests are mature forests that have a relatively stable plant composition, and the dominant trees are often very large and growing little. Old-growth forests are dwindling due to economic pressures to harvest their valuable wood. The area of old-growth forest in Oregon, for instance, is very small and declining (Figure 17.9A). Only about 17 percent of the original old-growth forest in the Northwest remains. In 1987–1989 the total population of spotted owls was estimated to be 2500–3000 pairs. A pair of these birds needs an area of 800–2000 hectares (ha) to find sufficient food (flying squirrels) to survive. However, 800 hectares may contain lumber worth $8 million. Thus, setting aside sufficient land for 500 pairs of owls is a $4 billion decision. How do you weigh the immediate economic effect due to losses in the lumber industry with the consequences of extinction of an animal that has no immediate economic benefit? This is a difficult question. Of course, the lumber is still in the forest and will be available to harvest for many years to come, but extinction is an irreversible process. Undoubtedly, setting aside these old-growth forests will protect species other than just the spotted owls.

The fate of several species of rhinoceroses is affected by similar pressures—dwindling habitat and economic pressures. The area occupied by several African populations of rhinoceroses is shown in Figure 17.9A along with their former ranges. The growth of human populations, accompanied by the conversion of land to agriculture and harvesting trees from forests, has contributed to the long and continuous decline in the numbers of rhinoceroses. The horns of rhinos are also highly valued as a powdered aphrodisiac, as medicines, and as a ceremonial knife handle. In the early 1990s the wholesale price for Indian rhinoceros horn was $62,400 per kilogram, and $8000 per kilogram for African horns. Thus, even though many rhinos live in protected areas, there are frequent occurrences of poaching. Between 1984 and 1990 an estimated 782 rhinos were killed in Zimbabwe. In Northeast India between 1985 and 1989, poachers killed 243 rhinos. The current estimates of rhino populations are shown in Table 17.9A.

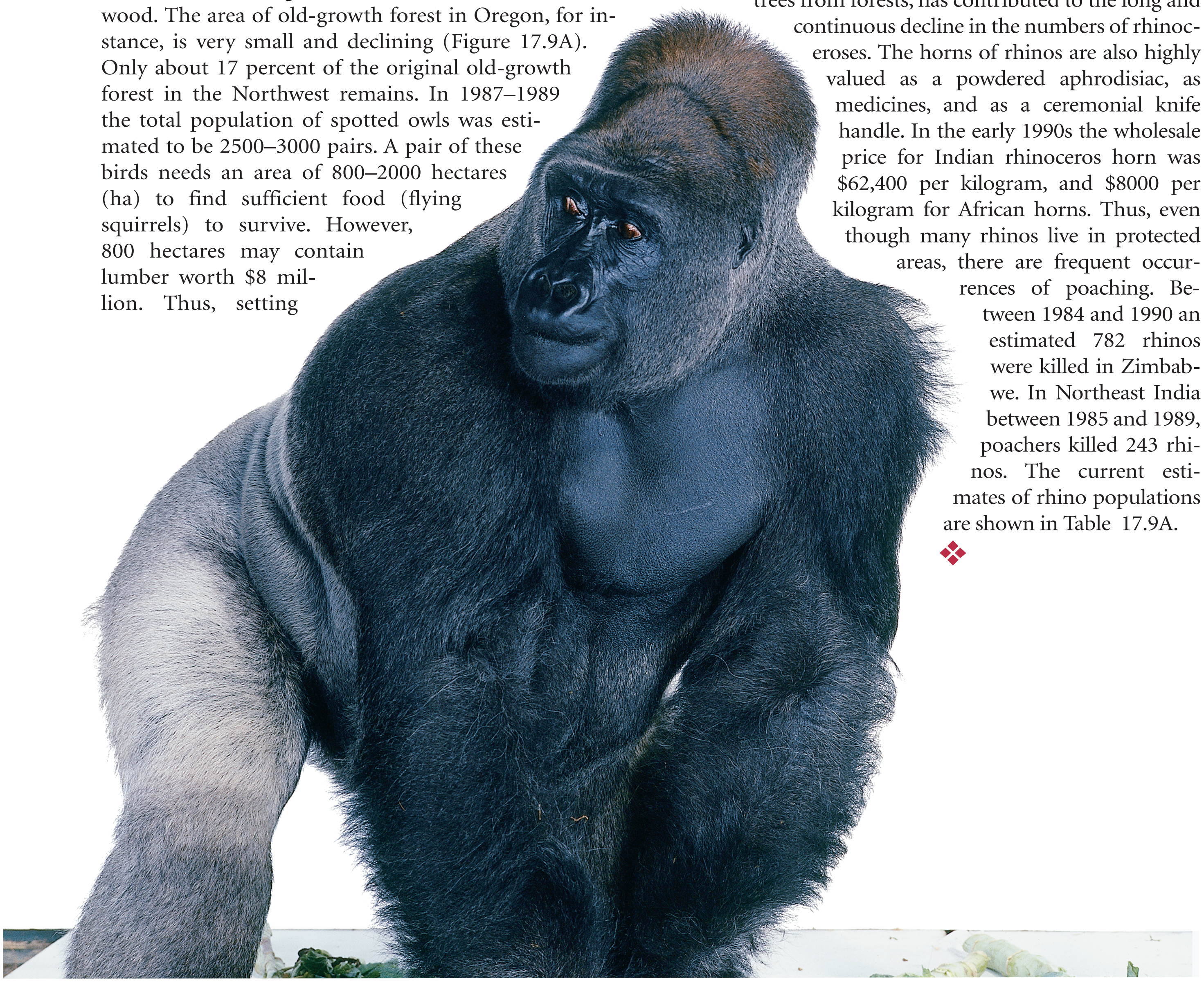


TABLE 17.9A Population Size Estimates of Wild Rhinoceroses

Species	1979	1988	1993
African black	14,875	3780	2550
African white	3841	—	6784
Indian	—	1200–1500	1900
Sumatran	—	500–900	500
Javan	—	65–70	50

Old growth forests in Oregon

Northern Spotted Owl

The distribution of rhinocerus in Africa.

Black Rhinocerus

White Rhinocerus

FIGURE 17.9A Endangered species are associated with fragmented and small habitats.

17.10 Introduced exotic species often require management

For a conservation biologist the word *exotic* does not refer to some extraordinary characteristic of color, size, or physiology of an organism. An **exotic species** is one that has recently been placed in an environment or ecosystem in which it has not evolved. So while a rabbit is certainly not exotic in the United States, it would be considered exotic in Australia. These introductions are almost always the result of purposeful or inadvertent human activity. Not all species introductions cause problems. However, there are many instances of introduced species becoming serious pests. These successful exotics may do well in their new habitat, for several reasons. They may be superior competitors to the native species. Many of the marsupial animals in Australia are inferior competitors to ecologically similar placental mammals. The introduced exotic often finds itself in an environment without natural predators or diseases. This has of course led biologists to introduce predators and diseases in an attempt to control introduced exotics (see Module 14.5). A small sampling of exotic species pests are shown in Figure 17.10A.

Historically it is now clear that the unchecked introduction of exotic species can cause serious damage to agriculture and the environment. There are several ways to prevent introductions and to minimize their potential damage (Figure 17.10B). One obvious method is to prevent their introduction in the first place. Anyone who has traveled overseas may recall that upon returning to the United States, you are required to answer questions concerning any agricultural products you are bringing back with you. This is a direct attempt to prevent the inadvertent introduction of pests from foreign countries. Sensitive ecosystems and species may be protected by setting aside habitats for them. This management approach is also useful to guard against encroaching human development and activity, like logging.

Despite these efforts, exotics may still gain entry into a new habitat and require additional attention. There may be several different approaches to attempting to eradicate or severely reduce the population of exotics. Controlling exotic insect species may involve the use of pesticides. For animals like rabbits, the introduction of biological disease agents has been tried. Biologists can attempt to limit the spread of exotics even if their numbers cannot be regulated. In 1980 in Northern California, small numbers of Mediterranean fruit flies were discovered in local citrus trees. These introduced pests have the potential to cause tremendous damage to the citrus crops in California. As a result several control methods were utilized, including aerial spraying with the pesticide malathion to reduce or eradicate the established populations. Roadblocks were also set up on the major highways leaving Northern California, and passengers in all vehicles were asked if they had any homegrown fruit in their car. If they did, they were required to dispose of it. These efforts were aimed at limiting the spread of the Mediterranean fruit flies. ❖

European rabbits introduced to Australia grew to tremendous numbers, and the species became a serious pest.

The paperback or cajeput tree was introduced to Florida from Australia. It is tolerant of flooding and recovers well from fires. It is replacing the native cypress, *Taxodium ascendens.*

The South American nutria was brought to the United States for its fur, but escaped to establish wild populations. Nutrias live in marshes in the Southeast and damage the natural vegetation by grazing.

FIGURE 17.10A A Sampling of Introduced Exotics

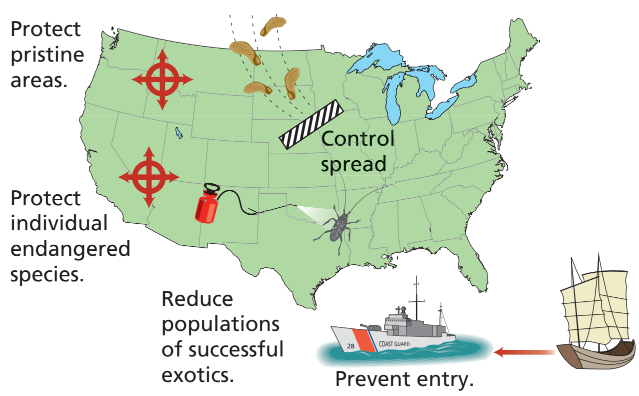


FIGURE 17.10B Methods of Controlling Exotic Species

SUMMARY

1. Small populations of endangered species share characteristics of island populations.
2. Ecological theories of island biogeography then shed light on the factors that affect the diversity of isolated populations.
   - **a.** All things being equal, larger islands or habitats should support a greater number of species.
   - **b.** Diversity will also be increased if it is easy for species to migrate onto an island.
3. Human activity has lead to the fragmentation of many habitats, thus creating the island-like structure of endangered species.
   - **a.** Habitats have not only been fragmented by human activity, but some have often been destroyed.
   - **b.** Tropical rain forests that are home to many endemic species of plants and animals are being rapidly destroyed.
4. Some natural populations are valuable economic resources.
5. Simple models of population growth can be used to determine the maximum sustainable harvest rate for a population. For populations that grow according to the logistic equation, this rate occurs at half the carrying capacity.
6. When populations become very small, they are in increased danger of extinction.
   - **a.** Animals may fail to reproduce by chance alone, and extinction can follow from this type of demographic stochasticity.
   - **b.** The ability to make predictions about chances of population extinction helps guide conservation policy efforts.
7. Extinction is more than just a theoretical concept. In recent history, there are numerous examples of species driven to extinction by human activity.
   - **a.** Just a few examples include the dodo, the passenger pigeon, and the Tasmanian tiger.
   - **b.** The known examples of human-aggravated extinctions number in the hundreds.
   - **c.** The true total number of these extinctions is almost certainly much greater.
8. An important practical problem is the identification and preservation of living species that are currently threatened by extinction—like rhinoceroses and northern spotted owls. In these two examples, we also see the complicated interaction between economic forces and species survival. The solution to these problems is often difficult.
9. Human activity has also introduced species into novel environments, where they have become pests.
   - **a.** The economic costs of these harmful exotic species can be enormous.
   - **b.** A variety of general techniques can be used to deal with exotics. The most successful solutions often require a detailed understanding of the ecology of the introduced species, so that control methods can be tailored for that particular pest.

REVIEW QUESTIONS

1. The large blue butterfly was provided a protected habitat but failed to thrive. Why?
2. How do you think the distance from an island to the mainland will affect extinction and immigration rates on the island? Consider two cases, near islands and far islands that are otherwise the same.
3. Suppose that the dynamics of a fish population are described by Figure 17.5C. Suppose the harvest policy is to catch exactly Y^* fish every year. Describe the different consequences of this policy for the fish population if the actual number of fish is around N_1 vs. N_2.
4. Review the different methods for protecting habitats against the introduction of exotic species.

KEY TERMS

biodiversity	exotic species	island biogeography	risk analysis
conservation biology	fragmentation	maximum sustained yield	reserve
demographic stochasticity	harvesting		

FURTHER READINGS

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