CHAPTER 3

Evolution and Biodiversity

The incredible variety of life on Earth is the result of evolution of species over time. This biodiversity supports ecosystems which, in turn, support human populations. Unfortunately, human impact is causing a disturbing loss of biodiversity. We can take steps to protect and preserve species, but this requires good science, adequate funding, and political will for success.

Module 3.1

Evolution and Extinction

A look at evolution by natural selection and the problems that result when drastic changes are imposed on populations that exceed their ability to adapt

Module 3.2

Biodiversity

An evaluation of the extent and importance of biodiversity, the impact of human actions on current biodiversity, and a survey of conservation approaches being pursued to protect species

Roman Lukiw Photography/Moment/Getty Images

Module 3.1 Evolution and Extinction

A WETLAND MURDER MYSTERY

Why are mammals in the Everglades disappearing?

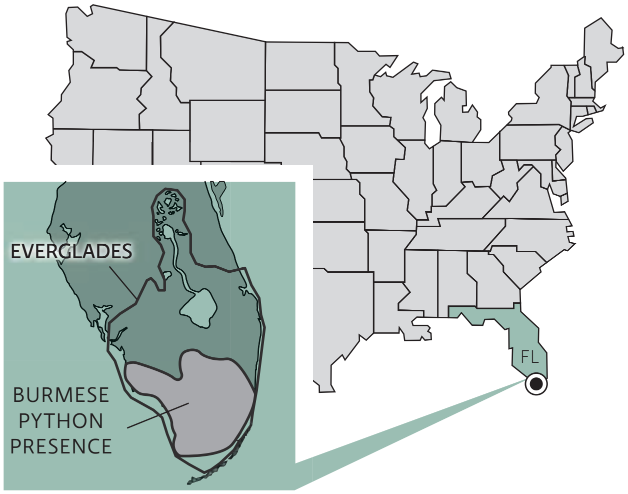
The Burmese python (*Python molurus bivittatus*) *Utopia_88/iStock/Getty Images*

After reading this module, you should be able to answer these GUIDING QUESTIONS

1. What is evolution, and how do populations adapt to changes via natural selection?
2. Why is genetic diversity important to natural selection?
3. What is coevolution, and what problems can emerge when species that did not coevolve together suddenly share a habitat?
4. How do random events influence the evolution of a population?
5. How do humans, intentionally or accidentally, affect the evolution of a population?
6. What factors affect the pace of evolution and extinction, and why are extinctions that occur quickly more of a concern than those that take a long time to unfold?
7. How do the mass extinction events of the past compare to extinctions during intervening times and today?

It was early 2012, and something odd was going on in Everglades National Park. Usually, the park was teeming with wildlife, but parts of the famous wetlands that stretch across South Florida had recently become eerily empty and signs of animal activity were scarce. University of Florida wildlife scientist Bob McCleery recalls walking through the Everglades one day looking for animal tracks and scat—usually, he saw them everywhere—and seeing nothing at all. What was going on?

WHERE ARE PYTHONS FOUND IN THE FLORIDA EVERGLADES?



One group of scientists had just published a study that tested an intriguing but, in McCleery's mind, unlikely hypothesis. In the article, Michael Dorcas and colleagues presented evidence that Burmese pythons (*Python molurus bivittatus*) were responsible for the dramatic declines in mammal populations in the Everglades. Many of these snakes, a Southeast Asian species which can exceed 20 feet in length, had been released into the Everglades over the past few decades by people who had purchased them as exotic pets and decided they didn't want them anymore. Other Burmese pythons wound up in the Everglades after escaping from a python breeding facility that was destroyed during Hurricane Andrew in 1992. But could these transported pythons really be responsible for such huge declines in local animal populations—rabbits, raccoons, opossums, deer, and foxes?

McCleery, at the time, didn't think so. "I was like, that's not possible," McCleery recalls. "I didn't believe they could do it." After all, the Everglades have been under attack from many fronts—19th-century hunting expeditions had devastated some bird populations in search of decorative feathers for ladies' hats, and more recently, urban and agricultural development had destroyed habitat, and agricultural chemicals polluted the wetlands. Surely the pythons were not responsible for the drastic declines.

Still, McCleery's curiosity was piqued, so he decided to run an experiment. In September 2012, he and his colleagues collected 95 marsh rabbits (*Sylvilagus palustris*) from the northern reaches of the Everglades and equipped them with radio transmitters so the researchers could track them. They released the rabbits into test sites within Everglades National Park where pythons were known to be residing, as well as in a part of the park that the snakes had not yet colonized.

After releasing the rabbits, McCleery watched what happened. Over the first few months, the rabbits fared reasonably well—they reproduced and their population grew. McCleery assumed the python hypothesis was incorrect. But then summer came, and suddenly, the rabbits in the python-inhabited areas started to disappear. McCleery and his team found that in control sites that lacked the python, 92% of the rabbits that were killed by a predator were taken by mammals or birds and the remaining deaths were due to native rattlesnakes, whereas

Researchers attach a radio transmitter to a marsh rabbit for McCleery's Everglades predation study.

in the test sites 77% of the rabbits that were killed by a predator succumbed to the python. (See the *Science Literacy* section of this module for more on this study.)

"Pythons came out and just gobbled up everything," McCleery recalls. "We were like, okay, well. There we have it."

1 NATURAL SELECTION AS A MECHANISM FOR EVOLUTION

Key Concept 1: Populations can evolve over time, usually in response to a change in their environment. They adapt to a changing environment when individuals, whose inherited traits make them better suited to survive or reproduce, leave more offspring with those traits on average than other less suited individuals—a process known as natural selection.

Before they started disappearing, the Everglades were home to many kinds of mammals, including bobcats, opossums, raccoons, marsh rabbits, cottontail rabbits, and foxes, each specially suited to life in the wetlands. But the pythons are threatening many of these populations and species that are found nowhere else on Earth, such as the already endangered Key Largo woodrat, find themselves at greater risk for **extinction** with the added threat of this new and very adept predator.

Populations usually contain individuals that are genetically different from one another—they possess different traits that were inherited from their parents. Traits that can be passed on to offspring are coded for by **genes**—stretches of an organism's DNA that influence everything from eye color to metabolic rate. According to the evolutionary theory first put forth, separately, by Charles Darwin and Alfred Russel Wallace, a **selective pressure** on a population—a nonrandom influence that affects who survives or reproduces—favors individuals with certain inherited traits over others (such as better camouflage, tolerance for drought, or enhanced sense of smell). These individuals leave more offspring than those who are less suited for their environment.

The process by which organisms best adapted to the environment survive to pass on their traits is **natural selection**. Evolutionary biology helps us understand the diversity of life on Earth and how populations change over time. It is one of the pillars of biological sciences and has been elevated to the level of scientific theory (see Module 1.2) by the vast amount of evidence that supports the occurrence of evolution and the mechanisms by which it happens.

For most populations, more offspring are born than can survive, since resources are limited and many species produce large numbers of young. Because only some individuals will survive, over time, the population will contain more and more of these better-adapted individuals and their offspring. Ultimately, this changes how common certain variants of genes are in the population (these variants are called **alleles**): The frequency (percentage in the population) of some alleles increases and that of others decreases from one generation to the next. When this occurs, the population has experienced **evolution**. Natural selection may be *stabilizing*, *directional*, or *disruptive*, depending on which genetic traits are favored or selected against. **INFOGRAPHIC 1**

It is important to note that *individuals* are selected but *populations* evolve; individuals do not change their own genetic makeup to produce new necessary adaptations, such as bigger size or pesticide resistance. Survivors that get the opportunity to reproduce pass on their traits to the next generation. Those that cannot tolerate environmental changes are more likely to die or fail to reproduce, and thus do not pass on their genes. Individuals may be able to adjust their behavior to accommodate environmental changes, but if a trait is not genetically controlled, and therefore is not heritable, it cannot be passed on to the next generation.

extinction The complete loss of a species from an area; may be local (gone from an area) or global (gone for good).

genes Stretches of DNA, the hereditary material of cells, that each direct the production of a molecule, usually a protein, and influence an individual's traits.

selective pressure A nonrandom influence that affects who survives or reproduces.

natural selection The process by which organisms best adapted to the environment survive to reproduce, leaving more offspring than less well-adapted individuals.

alleles Variants of genes that account for the diversity of traits seen in a population.

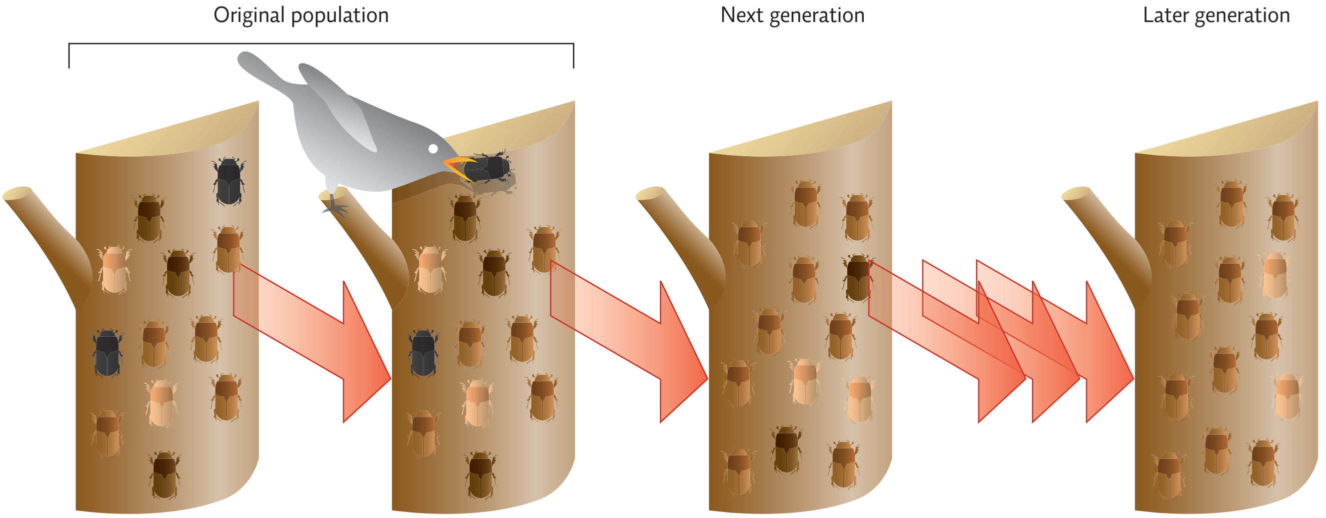
evolution Differences in the gene frequencies within a population from one generation to the next.

Bill Gozansky/Alamy

Competition with the larger non-native brown anole is pushing native green anoles in Florida higher up in the tree—a more difficult hunting ground. Directional selection is favoring green anoles with larger toepads, a trait that allows them to better grip the thinner branches higher up in the trees.

INFOGRAPHIC 1 NATURAL SELECTION AT WORK

When the environment presents a selective force (e.g., a new predator, changing temperatures, change in food supply), natural selection is the primary force by which populations adapt. The survivors are those who were lucky enough to have genetic traits that allowed them to survive in their changing environment. (Others who did not possess the trait were not as likely to survive to reproduce.) Because survivors pass on those adaptations to their offspring, the gene frequencies of the population change in the next generation, which means some traits are more common and others are less common than they used to be. When this happens, the population is said to have evolved.



Beetles resting on this tree vary in color.

Genetic variation exists in the population: Individuals possess inherited differences.

Individuals with the less favorable trait (coloration that makes them stand out on a tree trunk) are more likely to be eaten.

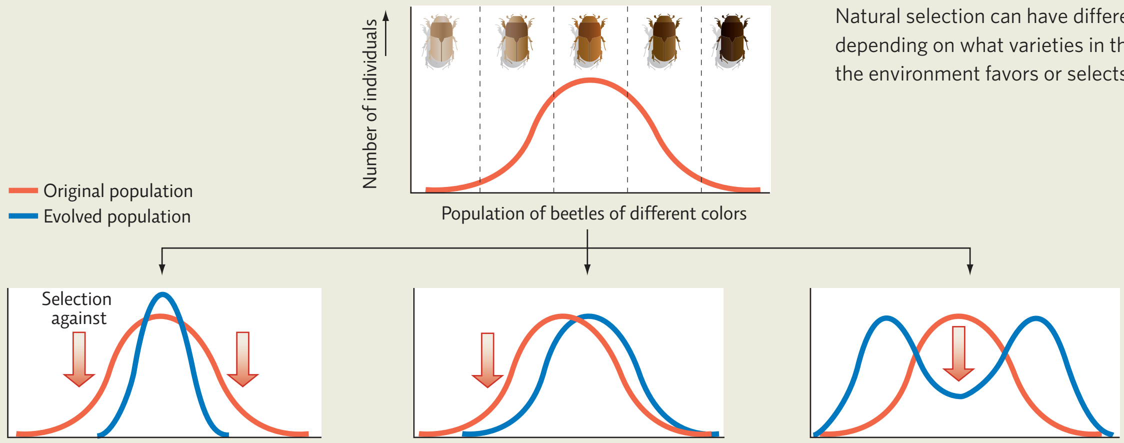
Differential reproductive success: Not everyone will survive to reproduce.

Fewer dark individuals are born (though recombination might produce some from light or tan parents).

Gene frequencies have changed: The population is evolving.

Over time, the population may be mostly or solely made up of tan individuals.

Natural selection can have different outcomes, depending on what varieties in the population the environment favors or selects against.



Stabilizing selection favors the norm and selects against extremes.

Directional selection continually favors a particular extreme of the trait (bigger, darker, etc.).

Disruptive selection favors the extremes but selects against the intermediate forms.

All trees are tan; tan beetles are favored.

In areas with trees darkened from pollution, darker beetles are favored.

In a forest with light and dark trees but no tan trees, tan beetles (the intermediate color) are not favored.

Identify the gene frequencies of the "original population" for each color morph (dark gray, dark brown, light brown, dark tan, and light tan) by counting the number of each and expressing it as a percentage of the whole. Now do the same for the "later generation." Has evolution occurred? Explain.

2 GENETIC DIVERSITY AND NATURAL SELECTION

Key Concept 2: Genetic diversity in a population is the raw material on which natural selection operates. The more diverse a population, the more likely there will be individuals present who can withstand or even thrive if environmental conditions change.

The ability of a population to adapt is a reflection of its tolerance limits to environmental factors, which largely depend on **genetic diversity**—different individuals having different alleles. A population that is highly diverse (has individuals with many inherited differences) is likely to have wider tolerance limits (see Infographic 4 in Module 2.1), which increases the population's potential to adapt to changes. This means it is more likely that some individuals will exist that can withstand (or even thrive in) the changes and that the population as a whole will survive. If a change occurs that produces a condition outside the range where any individuals can survive and reproduce (for instance, the climate becomes warmer than anyone can tolerate), the population will die out. Similarly, if a new challenge is presented, such as the introduction of a new predator or competitor, the survival of the population will depend on whether there are any individuals in the population who can effectively deal with the new species. For example, in McCleery's experiment, any marsh rabbits in the Everglades that happened to have effective python-avoidance behaviors would have a greater chance of survival. If those behaviors were based on genetic differences (e.g., a tendency to be more wary of ground predators), they could be passed on to offspring and the population would not die out.

New traits can be introduced into a population, increasing its genetic diversity via genetic *mutation* (a change in the DNA sequence) that alters a gene in the sex cells (egg or sperm) of an individual. When a mutation produces a new trait that is beneficial, this trait can quickly be passed on to the next generation, as those who possess the trait are more likely to pass on their genes than those without the trait, allowing the population to evolve to be better adapted to its environment. A second source of genetic variety occurs as eggs and sperm are made: *Genetic recombination* shuffles alleles around and sometimes produces individuals with new traits when a sperm fertilizes an egg. The production of offspring who represent unique combinations of their parents can also introduce new traits that can be favored by natural selection.

Robert Hamilton/Diomedia/Alamy

These Asian lady beetles show genetic diversity—the raw material on which natural selection works.

The value of this genetic diversity is illustrated today in the example of the rock pocket mouse of the U.S. desert Southwest. Animals of this species have coats that are either light tan or dark brown. It turns out that coat color corresponds to a population's environment: Areas of light-colored rock contain populations with mostly tan mice, whereas darker mice inhabit black lava rock regions. Research led by evolutionary biologist Hopi Hoekstra has shown that coat color is determined by a single gene that comes in two different alleles. The dominant allele is designated by the uppercase letter D; the recessive allele is designated by the lowercase letter d. All individuals have two copies of the gene, and the color of their coat is determined by which two alleles they possess. Darker mice have at least one dominant allele (DD or Dd). Tan mice possess two recessive alleles (dd).

It is likely that coat color provides camouflage and protection from visual hunters, but only if the mouse is on a background of the same color. A study on deer mice (a similar species) showed that predatory owls are more successful at capturing mice on a contrasting background. This gives support to the conclusion that coat color is adaptive as camouflage and therefore is responsive to natural selection. (See Section 3 of Module 3.2 for another example of the importance of genetic diversity—the potato famine in 19th-century Ireland.) **INFOGRAPHIC 2**

genetic diversity The heritable variation among individuals of a single population or within a species as a whole.

INFOGRAPHIC 2 EVOLUTION IN ACTION

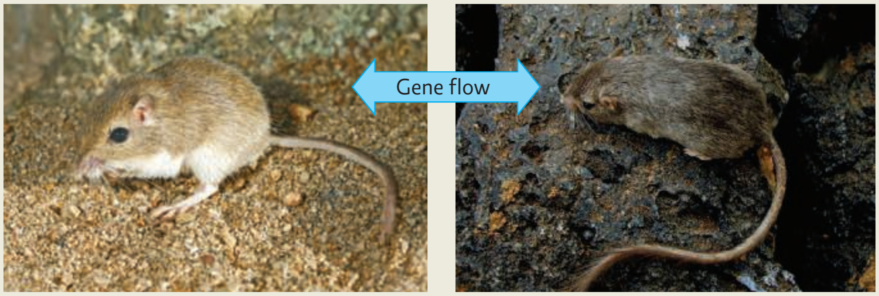
Natural selection produces populations with different gene frequencies (more or less of a particular gene variant or allele). For this to occur, there must be genetic variation (more than one allele for a given trait) and a selective pressure (a reason one variant is better than another in a given situation).

Different color morphs of the rock pocket mouse (*Chaetodipus intermedius*) are found on different-colored rocky outcroppings in the desert Southwest. An evaluation of the mice living on or near the Pinacate lava flow in southern Arizona represents the first documentation of the genetic basis (in this case, a single gene) for a naturally favored trait. The well-known peppered moth is another example in which different color variants are favored in different habitats, but the genes responsible for that trait have not yet been identified.

Even though there is gene flow between dark and light populations that are close to each other (mating between the two groups), populations on tan rock have mostly tan individuals, and populations on dark rock have mostly dark individuals, suggesting a strong selective pressure that favors one color over the other.

Predatory owls are likely the selective pressure that favors different coat colors in different habitats.

Rick & Nora Bowers/Alamy



Dr. Hopi Hoekstra

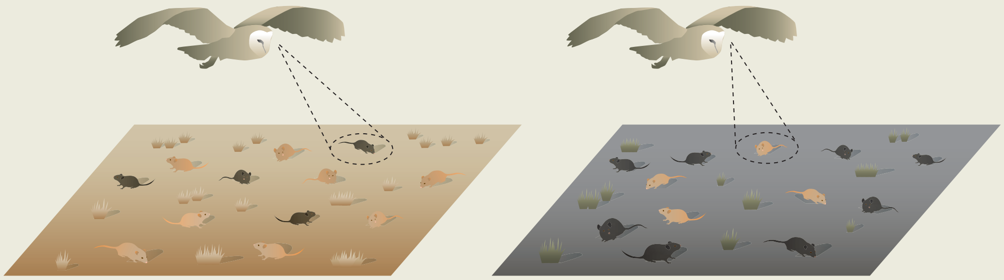
Tan mice (the recessive trait, dd) predominate in light-colored rocky outcroppings.

Darker mice (the dominant trait, DD or Dd) predominate on darker lava rocks.

Sean Locke/Getty Images

Lyn Alweis/Denver Post/Getty Images

A study done with dark and light varieties of deer mice revealed that owls caught twice as many opposite-colored mice (dark mice on a light background or tan mice on a dark background) as mice whose coloration matched their background, even in almost total darkness. Owl predation is therefore likely to be a strong selective pressure on coat color, driving directional selection that produces either light or dark populations of mice, depending on the background.



Dr. Hopi Hoekstra

Hopi Hoekstra

If this mouse population migrated to an area with a red rock habitat with visual predators like hawks or owls, what could prevent the population from evolving into one with red coats?

3 COEVOLUTION

Key Concept 3: Two species can become highly adapted to each other when each becomes the selective pressure that favors certain traits in the other, a process known as coevolution. Species that never coevolved with a particular predator or competitor may not have the traits needed to survive if that species invades their habitat.

A special type of natural selection, known as **coevolution**, occurs when two species each provide the selective pressure that determines which of the other's traits are favored by natural selection. Predator and prey species usually evolve together, each exerting selective pressures that shape the other. As predators get better at catching prey, the only prey to survive are those a little better at escaping, and it is those individuals that reproduce and populate the next generation. This game of "one-upmanship" continues generation after generation, with each species affecting the differential survival and reproductive success of the other. The result can be a predator extremely well equipped to capture prey and prey extremely well equipped to escape. **INFOGRAPHIC 3**

Non-native species that cause ecological, economic, or human health problems and are hard to eradicate, like the Burmese python, are considered **invasive species**, and they can cause significant damage in areas they invade. In fact, invasive species are one of the leading causes of species endangerment worldwide (see Module 3.2).

The reason so many mammals in the Everglades are being threatened by the invasive Burmese python is because the speed at which the eradication is happening is preventing the mammal populations from potentially coevolving survival strategies to deal with the new snake population. The python is a generalist predator, already well adapted to preying on different kinds of mammals. But the Everglades' animal populations have never faced such a predator and appear to have no natural defenses. It is an unfair fight.

coevolution A special type of natural selection in which two species each provide the selective pressure that determines which traits are favored by natural selection in the other.

invasive species A non-native species (a species outside its range) whose introduction causes or is likely to cause economic or environmental harm or harm to human health.

Many ground-nesting birds and turtles in Hawaii have no defenses against the invasive mongoose, a skilled predator that eats their eggs and hatchlings.

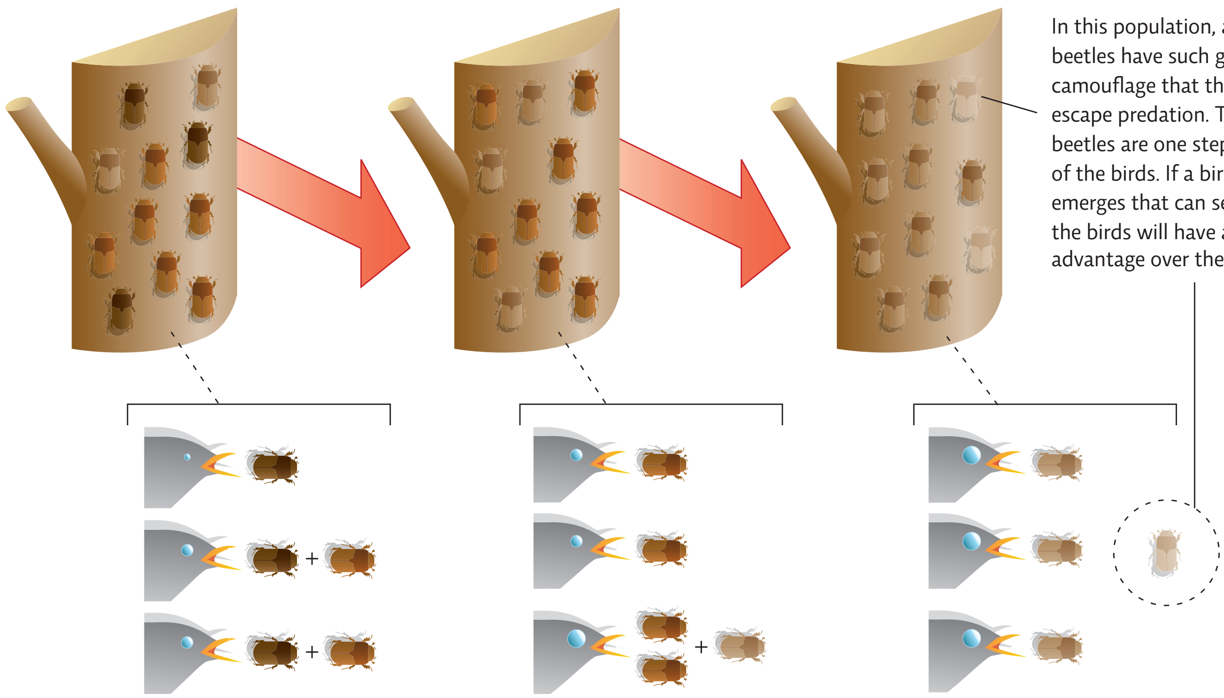
Malcolm Schuyl/Alamy

INFOGRAPHIC 3 COEVOLUTION ALLOW POPULATIONS TO ADAPT TO EACH OTHER

As selection favored beetles closest to the tree color, only birds with the keenest eyesight feed well enough to survive and reproduce.

Any beetle with an even better camouflage would be more likely to escape predation and pass on its genes.

This then favors birds with even keener eyesight that would feed well and pass on the sharp eyesight trait to their offspring.



In this population, a few beetles have such good camouflage that they escape predation. These beetles are one step ahead of the birds. If a bird emerges that can see them, the birds will have an advantage over the beetles.

Individuals with better vision, shown here as larger eyes, catch more beetles.

Most birds compete for the easy-to-see beetles, but any bird that can find the hidden ones will find more food—and thus selection will favor birds with even better eyesight.

No individual bird is present (yet) who can detect the new camouflaged beetle variant.

What do you predict would happen to the original beetle population if a species of bird with extremely keen eyesight (like those shown on the right side of the diagram) were accidentally introduced into the beetle's habitat?

A few mammal species in the Everglades have experienced **extirpation** in some areas; marsh rabbits, for instance, appear to have been eradicated by the pythons in some parts of the Everglades, but still populate northern stretches of the vast wetland as well as other coastal marshes and swamps in the Eastern and Southern United States. McCleery and his colleagues were able to conduct their 2012 experiment in part because they could bring marsh rabbits that were living elsewhere in the Everglades to areas invaded by pythons.

extirpation Locally extinct in one geographic area but still found elsewhere.

endemic Describes a species that is native to a particular area and is not naturally found elsewhere.

The introduction of the Burmese python to the Everglades also threatens the lives of other predators that rely on mammals for food, such as the Florida panther, a subspecies of the North American cougar that has been endangered for decades and is **endemic** to the area, meaning that it is found nowhere else. As the pythons gobble up the region's rabbits, raccoons, and foxes, they take away much of the panthers' prey, edging them even closer to extinction.

4 RANDOM EVENTS AND EVOLUTION

Key Concept 4: Along with natural selection, random events such as genetic drift, the bottleneck effect, and the founder effect also influence the evolution of a population.

The evolution of species in response to selective pressures may alter a population and even produce new species (*speciation*) if some members of a population are no longer reproductively compatible or rarely meet, as may happen when individuals spend their time in different parts of their habitat. However, not all evolution is driven in this manner. Random events play a role, too.

In **genetic drift**, some traits (alleles) are passed on or lost by random chance, not because they were selected for (or against), as with natural selection. How could this happen? Even with natural selection at work, in each generation, some individuals may leave more offspring than others, not because they were better adapted to their environment but because they "got lucky"—perhaps due to favorable external factors they mated more, had more offspring, or had more offspring survive. Others might be "unlucky"—they might be in the wrong place at the wrong time (e.g., killed by a mudslide) before having a chance to mate. Just because natural selection would favor certain traits over others, doesn't mean every "better" individual will leave more progeny than all the less well-adapted individuals; the best traits might increase one's chances of survival or reproduction, but no trait guarantees it.

Small populations are much more likely to experience genetic drift than large ones because the offspring of a few "lucky" individuals will have a greater impact on the gene frequencies of the next generation in a small population than a few "lucky" individuals in a large population. In large populations, the influence of random events will likely be masked by all the better-adapted individuals who are favored by natural selection and successfully reproduce. Because of this, genetic drift is more likely to happen if a population has experienced a reduction in size. For example, the **bottleneck effect** can occur when a random, catastrophic event, such as a flood or other natural disaster, causes a large portion of the population to die. The survivors then produce a new generation, and any alleles that were found only in the deceased individuals are lost from the population forever. Severe population declines of the Florida panther (*Puma concolor coryi*), a species nearly eradicated in the early 20^{th} century, created a bottleneck so extreme that subsequent individuals were likely descended from a single female until additional females of a Texas subspecies (*Puma concolor stanleyana*) were introduced, which boosted the genetic diversity of the population.

Rolf Richardson/Alamy

From ancestors that might have arrived at the isolated Galápagos Islands on floating vegetation, two giant tortoise distinct populations have evolved. Dome-shelled tortoises live in areas with abundant food and lack the notch in the shell above the neck seen in this saddle-backed tortoise, a species adapted to arid regions with less food; its shell allows the animal to stretch its neck higher in search of food.

Genetic drift can also occur via the **founder effect**. Consider the situation in which a small subset of a population colonizes a new area—for example, birds blown off course that arrive at a remote island previously uncolonized by that species. If this subset (the founding population) happens to be less genetically diverse than the original and if the subset becomes completely isolated from the original group such that there is no mixing of the two populations (and no chance to reintroduce those missing alleles), the founding population will produce a population that has different gene frequencies than the original population. Many populations on the Hawaiian Islands and other remote areas were established in this way, evolving into distinct species once they separated from their ancestral populations.

Today human impact increases instances of both the founder effect and the bottleneck effect. Much of what we do isolates populations into smaller groups, forcing them into these situations. **INFOGRAPHIC 4**

genetic drift The change in gene frequencies of a population over time due to random mating that results in the loss of some gene variants.

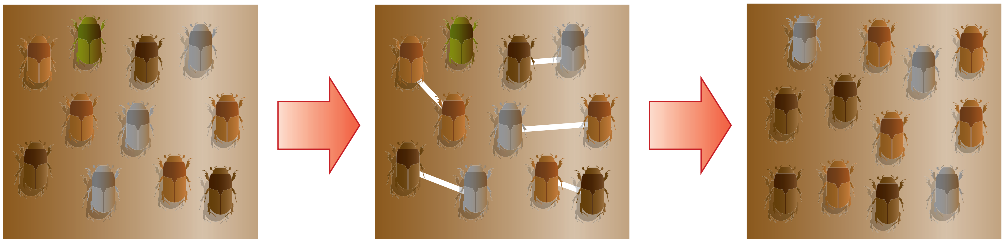
bottleneck effect The situation that occurs when population size is drastically reduced, leading to the loss of some genetic variants and resulting in a less diverse population.

founder effect The situation that occurs when a small group with only a subset of the larger population's genetic diversity becomes isolated and evolves into a different population, missing some of the traits of the original group.

INFOGRAPHIC 4 RANDOM EVENTS CAN ALTER POPULATIONS THROUGH GENETIC DRIFT

RANDOM SURVIVAL OR MATING

Genetic drift occurs when random events eliminate some gene variants (alleles) from a population. This happens because, in addition to natural selection, chance also influences who survives or reproduces. Genetic drift is more likely to accumulate and have major effects in small populations.



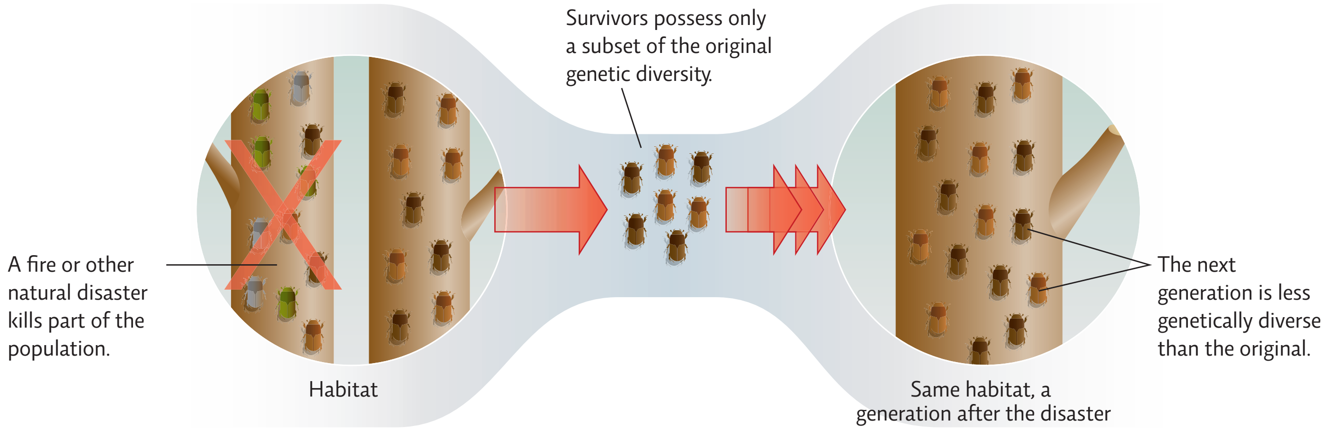
A population contains a variety of individuals, but some gene variants are more common than others.

Random mating occurs, but some unlucky individuals don't find mates.

Subsequent generations may have different gene frequencies.

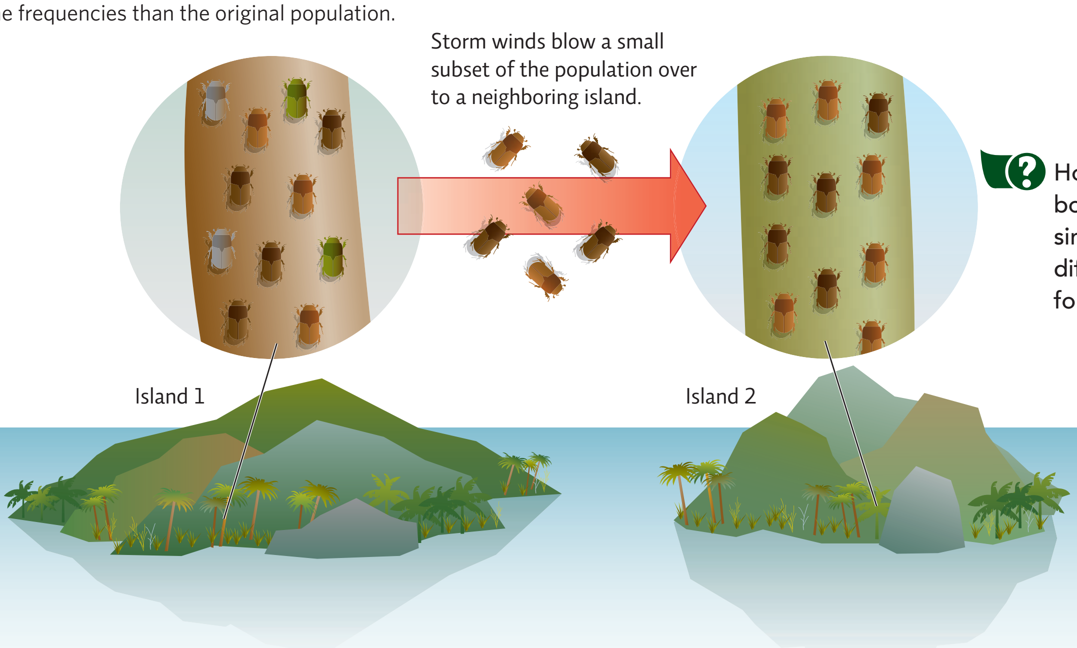
BOTTLENECK

If something causes a large part of the population to die, leaving the survivors with only a portion of the original genetic diversity, the population may recover in size but will not be as genetically diverse as the original population.



FOUNDER EFFECT

If a small subset of a population that possesses only a fraction of the genetic variability of the original population colonizes a new area and the subset becomes completely isolated from the original group, the new population will likely produce descendant populations that have different gene frequencies than the original population.



How is the bottleneck effect similar to and different from the founder effect?

5 ARTIFICIAL SELECTION

Key Concept 5: In artificial selection, humans choose which traits to keep and which to eliminate from a population through selective breeding. Our actions have also inadvertently led to the evolution of antibiotic- or pesticide-resistant populations.

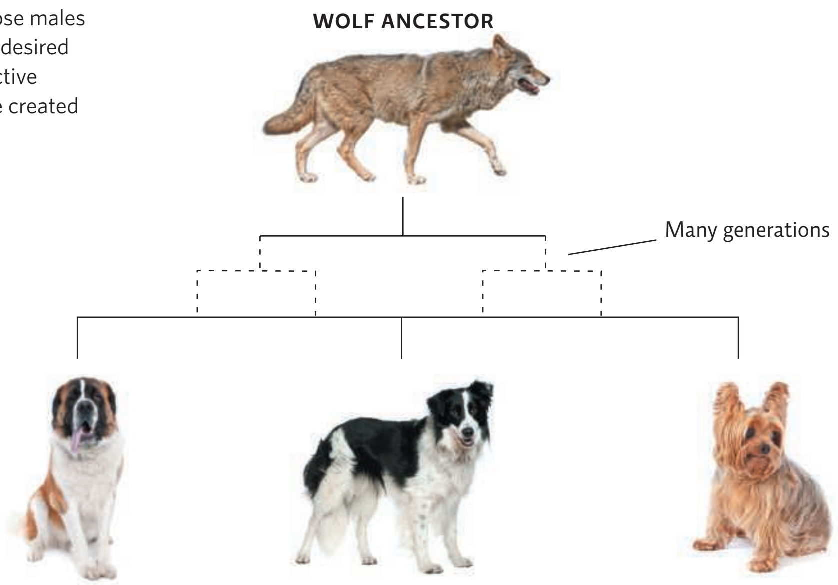
The introduction of the Burmese python to the Florida Everglades was not part of an intentional effort to alter the community and the species that lived there—it was an unfortunate accident perpetrated by misinformed pet owners and a devastating storm. But humans also directly affect the evolution of a population through **artificial selection**. Artificial selection works the same way as natural selection, but the difference is that the selective pressure is us (humans). For many animal and plant species, humans choose who breeds with whom in an attempt to produce new individuals with desired traits. By doing this over many generations, people have accentuated certain plant and animal traits, sometimes to extremes. For instance, the domestic dog is descended from the wolf; through artificial selection, breeders have created a wide variety of dog breeds by breeding dogs with certain traits (such as herding ability or protective tendencies). **INFOGRAPHIC 5**

But evolution is ever at work. Pesticide- and antibiotic-resistant populations can emerge from inadvertent human-influenced selection. When we apply a chemical that kills a pest or pathogen, some individuals survive because they were already resistant to the chemical even if they had never encountered it before. These survivors are then the only individuals who reproduce, producing the next generation that is also pesticide- or antibiotic-resistant, and ultimately changing the frequency of resistant genes in the population (see Infographic 5 in Module 8.1).

artificial selection A process in which humans decide which individuals breed and which do not in an attempt to produce a population of plants or animals with desired traits.

INFOGRAPHIC 5 HUMANS USE ARTIFICIAL SELECTION TO PRODUCE PLANTS OR ANIMALS WITH DESIRED TRAITS

All dogs (*Canis lupus familiaris*) are descendants of the wolf (*Canis lupus*). By only breeding those males and females with the traits desired (size, herding ability, protective instinct, etc.), humans have created more than 170 dog breeds.



St. Bernards were bred as mountain rescue dogs.

Border collies were selected for their herding (but not capturing) behaviors.

Yorkshire terriers are companion animals, originally bred to catch rats in clothing factories.

Wolf: DaddyBit/Getty Images; St. Bernard: GlobalP/iStock/Getty Images; Border collie: GlobalP/iStock/Getty Images; Yorkshire terrier: jimmyjamesbond/iStock/Getty Images

Why can we say that artificial selection is goal-directed but natural selection is not?

6 THE PACE OF EVOLUTION AND EXTINCTION

Key Concept 6: The pace of evolution and extinction is generally slow and is affected by population size and genetic diversity, reproductive rate, generation time, and the strength of the selective pressures at play. When extinctions unfold over long periods of time, better-adapted species tend to replace their predecessors and the niche remains filled; rapid extinction events may eliminate well-adapted species and break important community connections.

The pace of evolution by natural selection is not constant or the same for all species, but in general, it is slow—changes accumulate over generations, and speciation events can take thousands or millions of years. Evolution's pace is affected by a variety of factors, including population characteristics such as the genetic diversity and size of the population, aspects of the species' biology such as its biotic potential (maximum reproductive rate) and generation time (average time from birth to reproductive maturity), and the strength of the selective pressure a population is facing.

As mentioned earlier, genetic diversity is important because it provides options for natural selection to favor or select against. If a new selective pressure favors a less common trait in the population or if a new favorable trait arises, it can displace other variants in subsequent generations, resulting in evolution of the population. If this results in a speciation event, it can eliminate an ancestral species. However, if this happens—if a new species replaces an ancestral one—the outcome is unlikely to negatively impact the ecosystem because the niche is still filled.

The size of the population also makes a difference in how quickly natural selection can produce a change in a population: Beneficial traits can spread more quickly in smaller populations simply because it is more likely that the individuals with the trait will find each other and mate (as long as it is not a population that is widely dispersed). Of course, as mentioned earlier, smaller populations can also be at a higher risk of extinction because they likely contain less genetic diversity.

Reproductive rate and generation time also influence how quickly a population can adapt to changes. Populations of *r*-selected species (those with high reproductive rates and fast generation times) decimated by a disturbance or a depleted resource can quickly bounce back and repopulate the area because the remaining individuals can produce so many offspring in a single breeding cycle. One such example in the Everglades is the cotton rat, a small rodent that is one of the few mammals that has managed to continue to thrive after the Burmese python was introduced. As McCleery and his colleagues noted in a 2021 paper, the cotton rat probably did not get hit as hard as other mammals because it could inhabit a wide variety of habitats, reproduced quickly, and benefited from the fact that the pythons had eaten many of its other mammalian predators.

Many *endangered species* (species in high danger of becoming extinct; see Module 3.2), on the other hand, are *K*-selected species, with slower reproductive rates and longer generation times; therefore, they take longer to recover if population numbers fall. Selective pressures that change over the course of just a few years can eliminate a species with a generation time of many years—there is simply not enough time for those able to withstand the stressor to grow up and produce progeny who can also withstand the stressor. (For more on *r*- and *K*-selected species, see Module 2.2.)

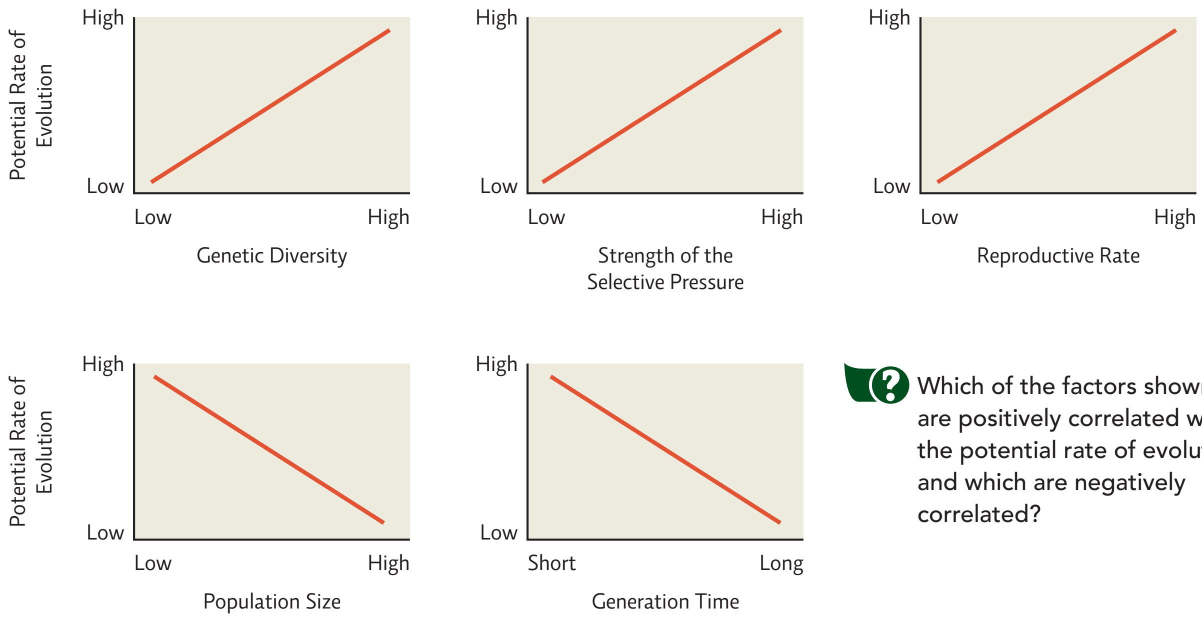
The strength of the selective pressure also affects how quickly natural selection might produce a change in a population. One of the biggest concerns with the loss of Everglades species due to python predation is that it happened so quickly. The hunting skill of the snake and the lack of suitable antipredator behaviors in the native species have made this new predator a strong selective pressure; a less proficient predator or one whose hunting style was familiar to the rabbits, opossums, and other Everglades mammals would be a weaker selective pressure, one that the native species might be able to adapt to, given enough time. **INFOGRAPHIC 6**

Martin Harvey/The Image Bank/Getty Images

K-selected species, like the Florida panther, are more vulnerable to declines in their population because they are slow to mature and have fewer offspring in their lifetime.

INFOGRAPHIC 6 THE PACE OF EVOLUTION

The speed at which evolution can occur is influenced by a variety of factors. While the relationships below are not guaranteed to affect the rate of evolution as shown (e.g., even a population with high genetic diversity would not be able to evolve [or survive] if *no one* in the population could withstand the environmental disturbance experienced), in general, the following correlations are seen.



Which of the factors shown are positively correlated with the potential rate of evolution, and which are negatively correlated?

Indeed, one lesson of the python invasion, one echoed in other invasions, is that while speciation typically occurs at a slow pace, extinction can occur much more quickly if the rate of change exceeds the ability of the population to adapt. These rapid extinction events are also a concern because they can break community connections and leave unfilled niches, negatively impacting other species. This is, in fact, already occurring. (See the *Global Case Studies* map at the end of this module for a look at other examples of invasive species threatening native populations.)

7 MASS EXTINCTIONS: PAST AND PRESENT

Key Concept 7: Extinction rates were much higher during mass extinction events than at other times. Past mass extinctions are linked to natural causes; today human impact appears to be causing another mass extinction.

Extinction is nothing new on Earth. By most estimates, more than 99% of all species that ever lived on the planet have gone extinct. Based on a critical analysis of the fossil record, scientists agree that there have been five *mass extinction events*—when species have gone extinct at much greater rates than during intervening times, each event leading to the loss of 75% or more of the species present on Earth. The most infamous of these was the extinction event that occurred at the transition from the Cretaceous period to the Tertiary period, 65 million years ago. Most scientists agree this event was set off by an asteroid impact in the Gulf of Mexico; more than 75% of all species, including the dinosaurs, were exterminated. **INFOGRAPHIC 7A**

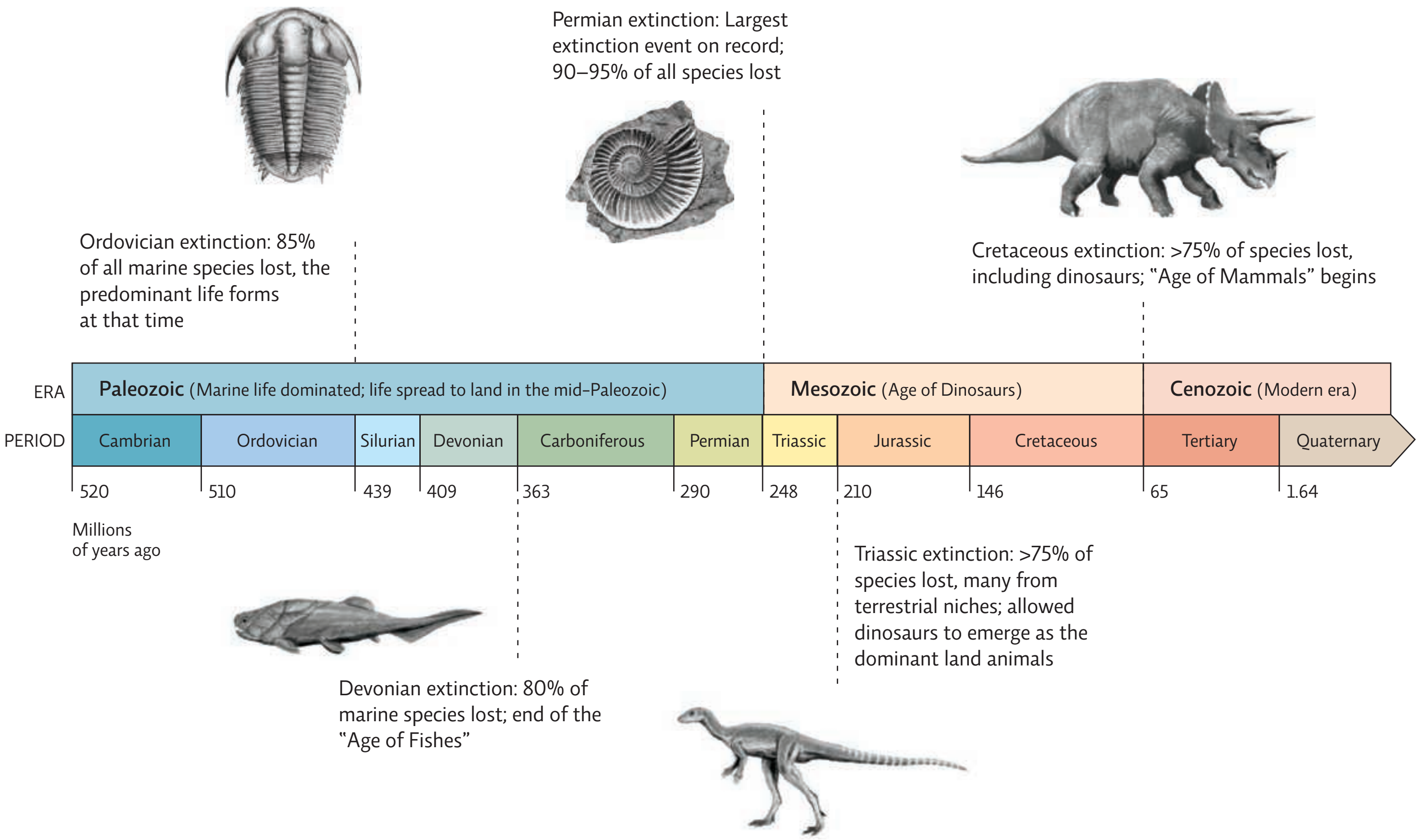
Earth's past mass extinctions were due to catastrophic events or physical changes to the atmosphere or oceans, which altered the environment faster than species' ability to adapt. Though most species loss didn't occur overnight, taking from hundreds to millions of years to unfold, these kinds of events eventually led to the emergence of new species as surviving populations adapted to the available niches (a process that took millions of years). Cycles of extinction and evolution ultimately gave rise to the diversity of life we see on Earth today—estimates range from 3 to 100 million species.

Throughout most of Earth's history, the **background rate of extinction**—the average rate of extinction that occurs between mass extinction events—has been

background rate of extinction The average rate of extinction that occurred before the appearance of humans or that occurs between mass extinction events.

INFOGRAPHIC 7A EARTH'S MASS EXTINCTIONS

There have been five mass extinctions in Earth's history, defined as extinction events that eliminated a large number of species in a short period of time (geologically speaking). Each is believed to have been caused by major environmental changes such as the meteor that struck Earth at the end of the Cretaceous period.



Why do we see mass extinction events occurring at transitions from one geologic time period to the next?

slow. The fossil record tells us that, on average, 1 or 2 species out of every 1 million species go extinct each year. In a world with 3 million species, this would be 3 to 6 species per year; if Earth is home to 100 million species, that would be 100 to 200 species per year. The current rate of extinction is estimated to be 100 to 1,000 times higher than this background rate.

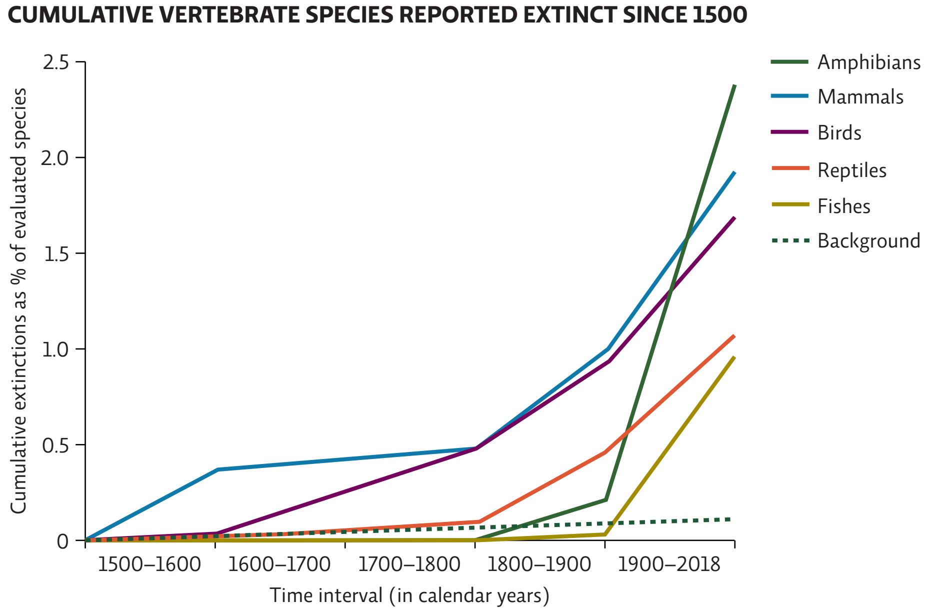
A 2015 study led by Gerardo Ceballos compared the number of vertebrate species extinctions that have been documented since the year 1500 to what would have been expected if extinction had occurred at a background rate that was determined by an extensive examination of the mammalian fossil record. The data revealed a sharp increase in the number of extinctions beginning about 200 years ago. At background rates, Earth should have seen 9 vertebrate extinctions since 1900; 477 have occurred—that's 53 times higher than expected. And things are just getting worse. Based on the number of vertebrate species on the brink of extinction, a 2020 analysis by Ceballos concludes that extinction rates are likely increasing. **INFOGRAPHIC 7B**

Unfortunately, it's not just vertebrates that are in trouble—many invertebrate groups appear to be declining at precipitous rates, too. Scientists are particularly concerned about the decline of insect species. Insects, the largest species group by far, are crucial to ecosystem function, providing services such as pollination, matter recycling, and population control. "What we're losing is not just the *diversity* part of biodiversity, but the *bio* part: life in sheer quantity," wrote Brooke Jarvis in a 2018 *New York Times* article.

In the most comprehensive evaluation of biodiversity ever completed, a 2019 global assessment by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services estimates 25% of evaluated plant and animal species are threatened, and some face imminent extinction without immediate action.

INFOGRAPHIC 7B THE RATE OF EXTINCTION IS ACCELERATING

Recent rates of species extinctions are well above that expected based on the background rate, a trend attributed to human impact such as habitat destruction, the introduction of invasive species, and climate change. This graph, based on analysis techniques developed by Ceballos, shows an estimate of extinctions since the year 1500 for vertebrates in comparison to the background rate of extinction. Accelerated extinction rates are seen for vertebrates, especially since the 19th century.



We have more data on bird and mammal extinctions than for fish, amphibians, and reptiles. Why do you think this is true? Do you think more data would reveal higher or lower rates of extinction for these groups?

Extrapolating from this to include all groups, the authors estimate that 1 million species are at risk.

Most scientists agree that the accelerated extinctions we are witnessing can be considered a sixth major extinction event, and that it is largely driven by human actions (see Module 3.2). As our use of resources increases, driven by population growth and affluence, our impact is becoming much more devastating for other species. We remove the resources they need to survive, minimize their habitat ranges, harvest them at unsustainable rates, introduce new predators or competitors, and strip them of their genetic diversity, all of which slowly eliminate them. British researchers Ian Owens and Peter Bennett analyzed the extinction risk for 1,012 bird species that were at risk for becoming endangered and found that habitat destruction was cited as a risk factor in 70% of the cases. (Similar results have been found for other terrestrial vertebrates.) Other human interventions, such as the introduction of non-native species or overharvesting, were implicated in 35% of the cases.

Some might wonder why scientists are so concerned about species extinctions—after all, extinction is a natural event. But it's the pace of extinctions that is concerning. Our changes to the environment can be so rapid or so great that natural selection simply cannot keep up—perhaps because a new needed trait is not present in the population, or it cannot spread quickly enough to prevent a population collapse. Module 3.2 will examine the value of biodiversity and why its loss can threaten us all. Indeed, an understanding of how populations evolve, and how we can affect that process, can help us avoid actions that create problems such as the emergence of antibiotic-resistant bacteria or untimely species extinctions.

In the Everglades, the deaths of so many mammals so quickly may have other surprising and worrying consequences. The Everglades virus—a virus borne by mosquitoes that can infect people—may become more common due to the introduction of the Burmese python. Now that so many mammals have died in the region, Everglades mosquitoes are more frequently feeding on cotton rats, which are natural reservoirs of this virus. As more mosquitoes in the Everglades feed on cotton rats, more may start carrying the virus and inadvertently infect humans the mosquitoes later bite. Usually, people infected by the Everglades virus have mild symptoms, but in rare instances the infection can cause dangerous brain inflammation.

Efforts to control Burmese pythons in the Everglades are ongoing and aggressive. Python hunters are paid to capture snakes, and annual snake round-up competitions bring in professional and amateur snake hunters—the 2022 Florida Python Challenge® attracted close to 1,000 participants. In an effort to more effectively control the snakes, local government organizations are using many methods, including radio signals, GPS transmitters, scent-tracking dogs, and motion trackers, to learn where the pythons live and breed, and where and how far they move. Some researchers have caught snakes, inserted radio transmitters into them, released them, and then followed these unwitting snake "spies" during breeding season in order to find other pythons so they can be removed.

So far, more than 17,000 pythons have been removed from the Everglades and in some areas, snake hunters say they are once again seeing rabbits, opossums, and deer, suggesting that the snake hunts may be taking some of the pressure off local wildlife, but they still have a long, long way to go—an estimated 100,000 pythons may now be living in the Everglades.

"There's just a lot of them," McCleery says, matter-of-factly. And unfortunately, when it comes to getting rid of the pythons, "there's been nothing even close to a silver bullet," he added. But he, and others, will continue to devise creative new strategies in the hopes of controlling the population of this destructive invader—hopefully giving mammalian life in the Everglades a chance to flourish once again.

Select References

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Python hunters participate in the annual Florida Python Challenge® to help remove the snakes from the designated areas within the Everglades. Cash prizes are awarded in three categories: the longest, heaviest, and most snakes captured. Participants undergo training and all captured snakes are humanely killed.

Sun Sentinel/ZUMA Press Inc/Alamy

GLOBAL CASE STUDIES — INVASIVE SPECIES

Non-native species that find their way to other ecosystems can wreak havoc on native species unprepared to deal with them. Here are a few notable invasive species that are taking their toll on U.S. ecosystems.

BRING IT HOME

PERSONAL CHOICES THAT HELP

The astonishing variety of life found on Earth is a result of natural selection favoring those individuals within populations that are best able to survive in their particular environment. Given enough time, some populations may be able to adapt to environmental changes. However, human activities may disrupt natural ecosystems so that organisms cannot adapt fast enough to survive, and those populations may go extinct. Conservation actions can help protect vulnerable organisms and ecosystems.

Individual Steps

- If you are thinking about buying a home, consider an older established area of your community or a location close to work. Suburban sprawl reduces habitat for wildlife, and reliance on cars causes greenhouse gas emissions that contribute to species-threatening climate change.
- Create a personal blog that includes photographs of wildlife, facts about current threats to plants and animals, and articles about conservation.
- Avoid buying exotic animals as pets; if you own a non-native animal, do not release it into the wild.

Group Action

- Throw a party in support of wildlife conservation. Take donations at the door and send the money to an organization that supports conservation.
- "Adopt an Organism." The U.S. Fish and Wildlife Service maintains a database of endangered plants and animals in every state. Research this database to find wildlife that interests you. Determine what agency, conservation group, or legislator you could contact and then start your own protection campaign. See what meetings, petitions, and legislation could impact your organism and get involved.


JOEL SARTORE/National Geographic Creative

REVISIT THE CONCEPTS

- Evolutionary biology helps us understand the diversity of life on Earth and how populations change over time. In response to selective pressures that favor the survival or reproductive success of some individuals over others due to inherited traits that better equip them to handle the challenge at hand, populations can adapt to a changing environment — a process known as natural selection.

- Genetic diversity in a population is the raw material on which natural selection operates. A population is said to have evolved if the frequency of genes in a descendant population is different from that in its ancestral population.

- Species can become highly adapted to each other when each is the selective pressure for the other (coevolution). Problems can emerge when species that did not coevolve together meet. For example, a non-native predator may be well adapted to prey on native species in its new habitat, but if those native species never coevolved with a similar predator, they may not be able to survive predation.

- Along with natural selection, random events, such as the bottleneck effect and the founder effect, can lead to genetic drift and influence the evolution of a population.

- Humans, too, can direct the evolution of a population via artificial selection by breeding individuals with the traits we desire, as in the development of animal breeds or plant varieties.

- In general, the pace of evolution is slow. When extinctions unfold over long periods of time, community connections are not broken because better-adapted species replace their predecessors and the niche remains filled; rapid extinction events may eliminate well-adapted species and break important community connections.

- There have been five mass extinction events in Earth's past, which were caused by natural events; today we are experiencing a sixth mass extinction, which is caused by human impact, that could have devastating consequences for ecosystems and the people who depend on them.

ENVIRONMENTAL LITERACY Understanding the Issue

1 What is evolution, and how do populations adapt to changes via natural selection?

1. A butterfly population adapts to a warming environment — explain how this could happen via natural selection.
2. Use the example of a bird population that feeds mainly on medium-sized insects to explain how its population would be maintained via *stabilizing selection*; present scenarios where it could be altered by *directional* or *disruptive selection*.
3. Explain this statement: Individuals are selected but populations evolve.

2 Why is genetic diversity important to natural selection?

4. As the amount of genetic diversity in a population increases, how does this affect the likelihood that the population will be able to adapt to environmental changes?
5. Does the presence of genetic diversity in a population guarantee it will be able to adapt to changes? Explain.
6. Using the example of the rock pocket mouse, explain the importance of genetic diversity to a population.

3 What is coevolution, and what problems can emerge when species that did not coevolve together suddenly share a habitat?

7. Use the concept of coevolution to explain why the Burmese python is a much more devastating predator in the Everglades than it is in its native habitat.
8. Suppose some Everglades marsh rabbits possess evasive behaviors that allow them to avoid the Burmese python. Describe a potential coevolution scenario that might allow this adaptation to eventually predominate in the population.

4 How do random events influence the evolution of a population?

9. Why is genetic drift considered random whereas natural selection is considered nonrandom?
10. Why might a population that has undergone a bottleneck or has been isolated by the founder effect be more vulnerable to extinction than the original population from which it came?

5 How do humans, intentionally or accidentally, affect the evolution of a population?

11. Give some examples of artificial selection by humans that have been beneficial to human society.
12. Explain how pesticide resistance might evolve in an insect pest.
13. Suppose you wanted to use artificial selection to produce a breed of hairless dogs for people who are allergic to dog hair. How would you go about doing this?

6 What factors affect the pace of evolution and extinction, and why are extinctions that occur quickly more of a concern than those that take a long time to unfold?

14. What factors influence the pace of evolution in the absence of a mass extinction event?
15. Why are *K*-selected species more vulnerable to extinction than *r*-selected species?

7 How do the mass extinction events of the past compare to extinctions during intervening times and today?

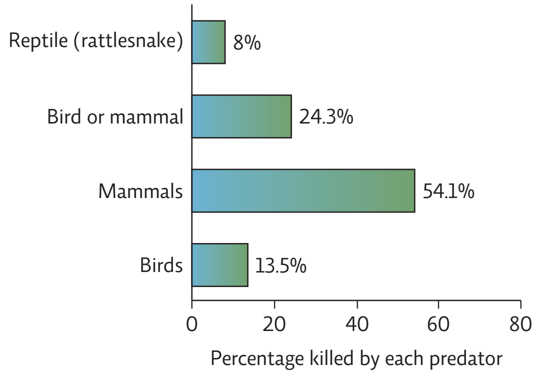
16. Why do most scientists think that we are in the midst of a sixth mass extinction?
17. Why are the changes being imposed by humans difficult for species to adjust to?

SCIENCE LITERACY Working with Data

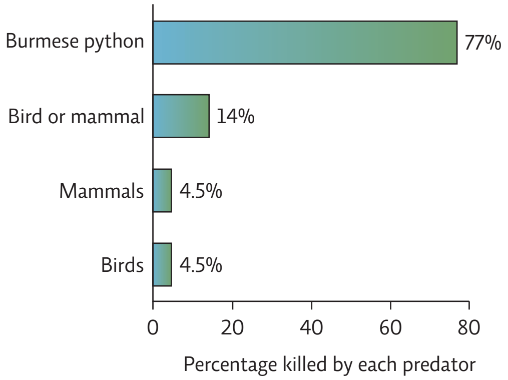
Bob McCleery's research group radio tagged 95 marsh rabbits and released them in Everglades locations with and without pythons. They were later able to identify the predator responsible for killing 59 of the rabbits. Mammal or bird predation was determined by evidence left behind, such as tracks or carcass clues of characteristic feeding patterns; since reptiles swallow their prey whole, reptile predation was confirmed by tracking the reptile that swallowed the transmitter. The following graphs depict cause-specific predation for marsh rabbits in this study.

SOURCES OF MORTALITY BY PREDATOR:

A: CONTROL SITE



B: TEST SITES



Interpretation

1. Which predator presented the greatest risk to rabbits at each study site?
2. Which study site — control or test — showed the most variation in the success rate of rabbit predators? Explain.
3. For each graph, what was the total percentage of rabbits taken by birds and mammals?

Advance Your Thinking

4. Compared to the native bird, mammal, and rattlesnake predators, how effective are pythons at taking rabbits in the test site? Use data to support your answer.
5. Offer two possible hypotheses that could explain why the percentage of rabbits killed by mammals and birds dropped so much at the test sites compared to the control site. For one of those hypotheses, propose an experiment that could test it.

DIGITAL INFORMATION LITERACY Evaluating Information

Life on Earth as we know it is the result of millions of years of evolution. By most accounts, we are currently witnessing a mass extinction event at our own hands, one that will result in changes in biodiversity, which will necessarily affect life on Earth, including humans.

Investigate This Problem

1. Visit the website of the Center for Biological Diversity at www.biologicaldiversity.org. Select the "Publications" tab and choose the link for "The Revelator." Read a few articles and then select one article to evaluate. Identify it (title, author and date, and URL) and then answer the questions that follow.

Evaluate the Article

2. In your own words, summarize the main point(s) or position of the article you are evaluating.
   a. Identify three claims made in the article. (If there are not three claims in the article you chose, choose a different one to evaluate.)
   b. Identify the evidence presented to back up each claim and evaluate that evidence. Is it sufficient? (If no evidence is given, where might you go to find that evidence?)
   c. Are references given for the evidence?

Evaluate the Organization

3. Determine if this a reliable information source:
   a. Does the organization have a clear and transparent agenda? Explain.
   b. Who runs this website? Do the credentials of the staff make this source reliable/unreliable? Explain.

Dig Deeper

4. Go to the International Union for Conservation of Nature (IUCN) website (www.iucnredlist.org).
   a. Choose five species at random that are identified as vulnerable, endangered, or critically endangered. Read about each species and list the threats each faces.
   b. Create one master list of all the threats you encountered for your five species and categorize them as either human caused or caused by natural events. Which list is longer?

Draw Conclusions

5. Based on your research, does human impact play a role in the endangerment of species? What actions would be most useful to address these threats? Do you think these actions should be pursued? Support your conclusions with evidence from your research.

Additional study questions are available at Achieve.macmillanlearning.com. Achieve

Module 3.2 Biodiversity

OIL PALM PLANTATIONS THREATEN TROPICAL FORESTS

Indonesia's forests shrink as the global demand for palm oil rises

Oil palm plantation at the forest edge. *Rich Carey/Shutterstock*

After reading this module, you should be able to answer these GUIDING QUESTIONS

1. What is biodiversity?
2. Why is biodiversity important?
3. How do genetic, species, and ecological diversity each contribute to ecosystem function and services?
4. What are the causes and consequences of biodiversity loss?
5. What is the goal of conservation biology and how do conservation status designations help achieve that goal?
6. What methods are used to address species endangerment and how effective are these approaches?
7. What legal protections are in place for threatened species?
8. How can local communities and consumers contribute to the protection of biodiversity?

Even before his plane landed on the Indonesian island of Sumatra, Laurel Sutherlin could tell the scene awaiting him would be worse than expected. They were still high above the Java Sea, and already a thick haze of yellow smoke seemed to be enveloping the aircraft. The naturalist and environmental educator who works for the Rainforest Action Network, a nonprofit that advocates for rainforest protection, had traveled all the way from California to see firsthand the impact the burgeoning palm oil industry was having on this South Pacific island.

WHERE IS SUMATRA?

Palm oil rose to prominence as a dietary replacement for *trans fats*, a type of fat linked to heart disease and other health problems. The oil comes from the waxy orange fruits that sprout from oil palm trees and makes up roughly half of the planet's edible oil production. (The tree is called an *oil palm*; the oil derived from it is called *palm oil*.) An incredibly versatile product, it has made its way into a long list of consumer products—foods like chocolate, peanut butter, and baked goods as well as cosmetics, shampoo, and toilet cleaner. Roughly half of all U.S. packaged food and household products contain palm oil. Almost all that palm oil comes from Southeast Asia.

Like other areas where oil palm plantations are established, the Indonesian island of Sumatra, where Sutherlin's plane was now landing, suffers from high rates of deforestation. His eyes and nose were assaulted with smoke the instant he stepped off the plane. "I actually had to suppress an initial panic that I would suffocate from the smoke," he would later recall. Through his studies, Sutherlin knew quite a bit about devastation wrought by deforestation. But he was not prepared for what he was about to see.

A young worker collects palm fruit clusters at an oil palm plantation in Sumatra. Oil can be extracted from both the flesh and the seed of the fruit.

Dimas Ardian/Bloomberg/Getty Images

1 BIODIVERSITY: THE VARIETY OF LIFE

Key Concept 1: We have identified only a fraction of the species that make up the tremendous variety of life (biodiversity) on Earth. We know much more about smaller groups such as plants and vertebrates than more diverse groups like invertebrates.

Rainforests, including those being cleared in Indonesia, contain the greatest concentration and variety of plant and animal terrestrial life-forms on Earth. This variety is called **biodiversity**, and it is the most unique and extraordinary feature of our planet. So great is the diversity of life on Earth that it is impossible to know just how many species exist; in fact, many believe that the vast majority of all living species have yet to be discovered or identified by humans.

So far, science has identified around 1.5 million species, and common estimates for the total number of species on Earth range from 3 to 11 million. A highly regarded study by biologist Camilo Mora estimated the total number of species (excluding bacteria) to be 8.7 million. A 2017 study by Brendan Larsen and colleagues that estimates a much larger number of invertebrate species (>150 million) and includes an estimate of bacterial species (1.75 billion species) raises the total number of species to an astonishing 2 billion. The sheer number of bacteria on Earth is hard to comprehend—microbiologist Thomas Curtis estimates that there are more bacterial cells in a ton of soil than there are stars in our galaxy.

"The numbers are mind boggling," says Jim Miller, a scientist at the Missouri Botanical Garden in St. Louis. "It's almost unfathomable." What we do know is that some life-forms are far more diverse than others; there are far more insects than there are vertebrates, for example, and there are relatively few mammals (fewer than 5,500 species) overall. **INFOGRAPHIC 1**

biodiversity The variety of life on Earth; it includes species, genetic, and ecological diversity.

© Roger Le Guen/Biosphoto

Researchers collect insects to identify which species are present, data that can help them estimate the total number of insect species found living in an area.

We also know that some regions of the world contain far greater concentrations of biodiversity than other regions. Indonesia is one such region; it has more species of parrots and swallowtail butterflies than any other country on the planet. It also hosts more mammal species than any other nation and is one of the last strongholds of the highly endangered orangutan as well as the only place on Earth where tigers, rhinos, and elephants still coexist in the wild. Plant diversity is even higher. Roughly 10% of all flowering plant species are found there.

Indeed, tropical forests (and tropical coral reef ecosystems) are the most biodiverse in the world. Ecologist John Terborgh of Duke University reports that a 2.5-acre research plot in an Amazonian rainforest contained more than 200 tree species. Compare this to the tree species diversity of the boreal forest that spans all of northern Canada, which has about 20 species. But habitat destruction and other pressures are threatening this biodiversity on a global scale.

While some forests, like those in some parts of North America and Europe, have increased in size, rapid deforestation affects many others, especially in the tropics. Since 1950, more than 650 million acres of tropical forestland have been cleared—that's an area larger than Alaska and California combined. Indonesia alone lost roughly 25 million forested acres between 2000 and 2020. Much of this deforestation has been to make way for oil palm plantations. (See Module 7.2 for a closer look at forest resources.) Clearing land for agriculture is, in fact, the leading cause of deforestation.

The environmental costs of the clearing of tropical forests are expected to be far-reaching. For one thing, such expansive loss of rainforest contributes to regional and global climate change and is almost certain to accelerate global warming. (For much of 2015, Indonesia's greenhouse gas emissions exceeded those of the United States due to the massive forest clearing and fires.) For another, forest loss contributes to soil erosion, water pollution, and flooding—not to mention a scarcity of resources on which local human communities depend.

INFOGRAPHIC 1 BIODIVERSITY ON EARTH

We have identified about 1.5 million species so far, but our knowledge of Earth's total biodiversity is scant. Even our accounting of "known species" — those described in the scientific literature — is an estimate, because some may be erroneously identified as separate species while others go unrecognized as distinct species. Of the species we have identified, insects far outnumber any other group of organisms; beetles alone account for about 25% of all known species — more than all known or estimated plant species. Vertebrates (the group to which humans belong) likely make up only 1% of all organisms on Earth.

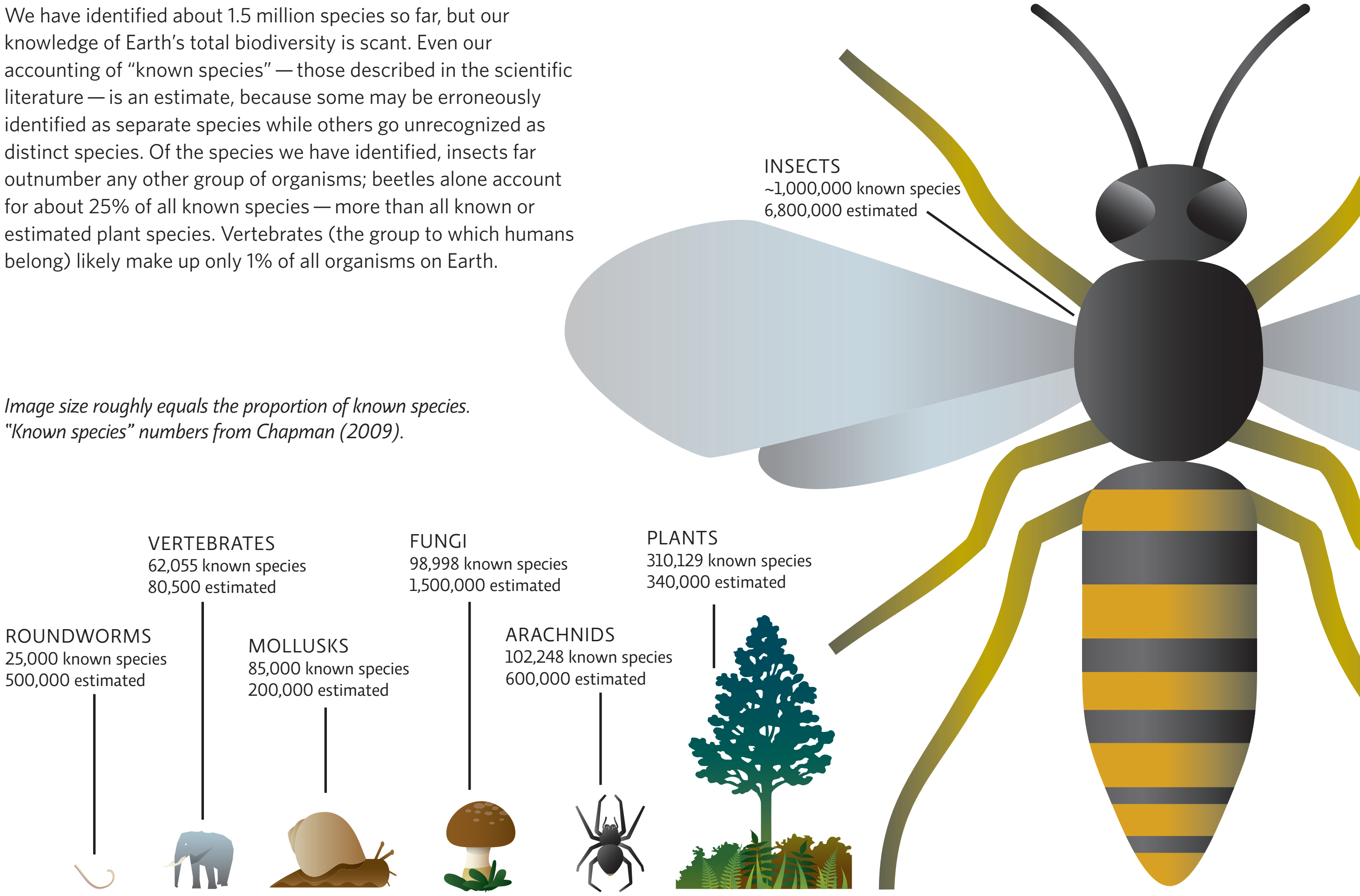


Image size roughly equals the proportion of known species. "Known species" numbers from Chapman (2009).

? How important do you think it is to get an accurate accounting of the number of species on Earth?

Rampant air pollution from forest clearing also poses a significant threat to human health in the region.

But the most immediate consequences will be visited upon the region's wildlife. Fewer than 50% of the species normally found in the natural forest are found in oil palm plantations. Mammals, in particular, tend to avoid the plantations; only about 10% of the original mammalian fauna are typically present. The habitat loss also impacts countless bird, reptile, insect, and plant species, many of which fail to thrive or even return at all because other species on which they depend are gone.

"When you look at a candy bar or package of crackers in a grocery store, or a jar of peanut butter in your kitchen, it's difficult to imagine that it has anything to do with orangutans going extinct," Sutherlin says. "But the link is actually quite direct."

Vier Pfoten/Four Paws/Rhoi/Shutterstock

Rescue workers from the animal charity Four Paws found this orangutan female holding her offspring tightly as the pair was being surrounded by a group of young men paid to hunt and kill orangutans in the area. The orangutans were rescued by the charity workers and relocated to a remote area in the rainforest.

2 THE VALUE OF BIODIVERSITY

Key Concept 2: Biodiversity contributes to the health and wellbeing of ecosystems, which in turn benefits human populations by providing ecosystem resources and services as well as cultural and health benefits.

Biodiversity is responsible for much more than the majesty of nature. As described in Chapter 2, it provides a wide array of **ecosystem services**—important to all species, including humans. For starters, it provides the key connections between individual species and between species and their environment. These connections help regulate the ecosystem as a whole. For example, photosynthetic organisms bring in energy, produce oxygen, and sequester carbon. Other organisms capture and pass along important nutrients. Still others help purify the air and water, and all species eventually become food for other creatures. Water also cycles through living things; in a forest, thousands of gallons of water a year are captured and passed along by each tree, releasing enough water vapor into the atmosphere to affect local rainfall in heavily forested areas. Life-giving soil forms as organisms decompose, and that soil supports plant life whose roots, in turn, hold it in place, keeping it from being washed away in rains or floods. Meanwhile, predators and competitors keep each other in check so that no single species grows too populous or gobbles up too many needed resources.

Pollination is another important ecosystem service that is enhanced with higher species diversity. A study by behavioral ecologist Natalie Lemanski of Rutgers University found that successful pollination of crops depended on the presence of several species of bees, since different species were present at different times of the year and even from year to year. In years when one species was present in low numbers, other species were present that could provide the critical pollination service needed for crop productivity.

Disease burden can also be reduced through increased biodiversity. A study by ecologist Kathleen LoGiudice found that the incidence of Lyme disease, for example, is often lower in areas with higher biodiversity (especially areas with squirrels and opossums, two species that if bitten by a tick are less likely to be infected and become a reservoir for the pathogen). Likewise, conservation biologist John Swaddle found that fewer human cases of West Nile virus occur in U.S. counties with higher bird biodiversity, possibly because some species are less effective at transmitting the virus than others; the more these species are present, the less likely the virus will be transmitted to humans.

Ecosystems that are biodiverse have economic value as well. Forests provide not only food, fuel, and building materials but also pharmaceuticals. Roughly half of all modern medicines—including medicine cabinet staples like aspirin and codeine, as well as most hypertension drugs and some cancer-fighting superstars—were originally derived from plants, many of them traditional remedies used for centuries. Over generations, rural forest-based communities in Sumatra have perfected a sophisticated management of forest resources that produces hillsides of coffee; groves of cinnamon trees; acres of terraced rice paddies; and a healthy mixture of fruit trees, vegetables, and tobacco, along with other useful edible, commercial, and medicinal plants.

ecosystem services
Essential ecological processes that make life on Earth possible.

Biodiversity supplies cultural benefits, too—whether it is a societal tradition rooted in nature, or the enjoyment of a natural area for recreation or aesthetic appreciation. For example, nature-based recreation is a multibillion-dollar business worldwide. Whale watching brings in $2 billion annually. The U.S. Department of Fish and Wildlife Service estimated the economic value of hunting, fishing, and wildlife viewing in 2016 to be more than $157 billion.

Both cultural and economic benefits of biodiversity are ultimately tied to ecological benefits—ecosystem regulation and support services that a rich community of species provides. Without the many species that keep ecosystems functioning, our ability to extract resources or enjoy nature would be much reduced.

Ron Boardman/Life Science Image/FLPA/Science Source

One ecosystem service of biodiversity is the provision of food, both through the food we eat and the other species that help that food grow, such as pollinators and soil decomposers.

In 1997, economist Robert Costanza published a breakthrough study that quantified the monetary worth of these services, and the most recent estimate puts that value at $125 trillion—an amount roughly equal to the annual gross domestic product (GDP) of the entire world. (For more on valuing ecosystem services, see Module 5.1.)

Unfortunately, the ability of nature to provide these services and meet human needs (and wants) is declining in almost all of the ecosystem service categories evaluated—only agricultural resources (food, fiber, and biofuels) have increased in recent decades, but these gains may be lost with further ecosystem damage.

Of course, many people feel that the value of any given species goes beyond these *instrumental values* (i.e., the ecological, cultural, and economic benefits it brings). Many say that a species like the orangutan has *intrinsic value* (an inherent right to exist) and is therefore worth preserving, regardless of what benefits it might provide. **INFOGRAPHIC 2**

INFOGRAPHIC 2 ECOSYSTEM SERVICES

We depend on genetically diverse, species-rich communities to provide the goods and services we use every day. When biodiversity declines in an ecosystem, its ability to meet the needs of humans and other species is diminished.

1. HUMAN PROVISIONS
- Food
- Fiber products, such as cotton and wool
- Fuel
- Pharmaceuticals

2. CULTURAL BENEFITS
- Aesthetic
- Spiritual
- Educational
- Recreational

Ecological benefits help regulate and support ecosystems which, in turn, make the services of human provisions and cultural benefits possible.

3. ECOLOGICAL BENEFITS
- Nutrient cycling
- Pollination
- Seed dispersal
- Pest control
- Flood control
- Climate regulation
- Wildlife habitat
- Genetic resources
- Waste treatment
- Soil formation/erosion prevention
- Air/water purification
- Decreased disease transmission

Danita Delimont/Gallo Images/Getty Images

In terms of reasons to value biodiversity, which of the beneficial ecosystem services listed here are the most important to you personally? Which ones do you think might be the most influential on society?

3 TYPES OF BIODIVERSITY: GENETIC, SPECIES, AND ECOLOGICAL

Key Concept 3: Genetic, species, and ecological diversity all enhance the ability of an ecosystem to function and of its members to adapt to changing conditions.

Biodiversity can be broken down into three types of diversity that really represent three different levels of diversity, from population up to ecosystem. Individuals in a population (or within the species as a whole) are often different from one another — they possess different inherited traits. This is a reflection of the population's **genetic diversity**, the heritable variation among individuals. The greater the genetic diversity within a population, the wider its *tolerance limits* (see Module 2.1) and the greater the chance its population can adapt to environmental changes. Without genetic diversity, even the most well-adapted species could be in danger of facing extinction if conditions change (see Module 3.1).

genetic diversity The heritable variation among individuals of a single population or within the species as a whole.

species diversity The variety of species, including how many are present (richness) and their abundance relative to each other (evenness).

ecological diversity The variety within an ecosystem's structure, including many communities, habitats, niches, and trophic levels.

The importance of genetic diversity was tragically illustrated in 19th-century Ireland. At the time, potatoes were the main food source for one-third or more of the population. Potatoes grew well in the Irish climate, despite the plant not being native to Ireland — it hails from South America. On the slopes of the Andes Mountains, thousands of different genetic varieties of potato plants grew, each adapted to the slightly different niche found at different latitudes and elevations, traits that were selected for by nature and later enhanced with artificial selection by hundreds of generations of Andean farmers. But only a few varieties of potatoes were imported to Ireland, and by the 1840s, one type was predominately planted — the "lumper." This variety grew well and fed millions until a fungus that attacked potatoes arrived in the mid-1800s. In the Andes, this fungus damaged some crops, but because all the potato varieties were so different, even though some plants died, others survived. But in Ireland, without genetic diversity in the potato "population," what killed one, killed them all. The vulnerable lumper succumbed to the fungus, and the potato crop was wiped out for several years. Between 1845 and 1851, more than 1 million people died of starvation and 1 million more emigrated (many to the United States).

Tetyana Dotsenko/Shutterstock

The Moray ruins in Peru are believed to be where ancient Incan farmers developed thousands of varieties of potatoes from native plants, representing tremendous genetic diversity. Unfortunately, only one main variety was planted in Ireland, and this lack of genetic diversity led to the loss of the potato crop to a fungus and caused widespread famine in 19th-century Ireland.

We can also find biodiversity at the community level — that is, **species diversity**. This is an accounting of the number of species living in an area (richness) and their relative abundance (evenness) (see Module 2.3).

Some ecosystems naturally have higher species diversity than others. Areas with high species diversity often owe that variety to their **ecological diversity** — the variety of habitats, niches, and ecological communities in an ecosystem. Rainforests contain a wide variety of habitats and considerable physical complexity, creating many niches. Each of the many species living in a tropical rainforest occupies an individual niche, and they all contribute to the functioning of the ecosystem (including vital services like energy capture, nutrient cycling, and decomposition). For example, a wide variety of plant species occupy every level of the rainforest, from the forest floor to the canopy, each adapted to capture the sunlight available in the forest level where they are found. This large producer base supports many trophic levels and many species within those trophic levels, increasing the efficient capture, use, and transfer of nutrients in the ecosystem. Few matter resources go unused.

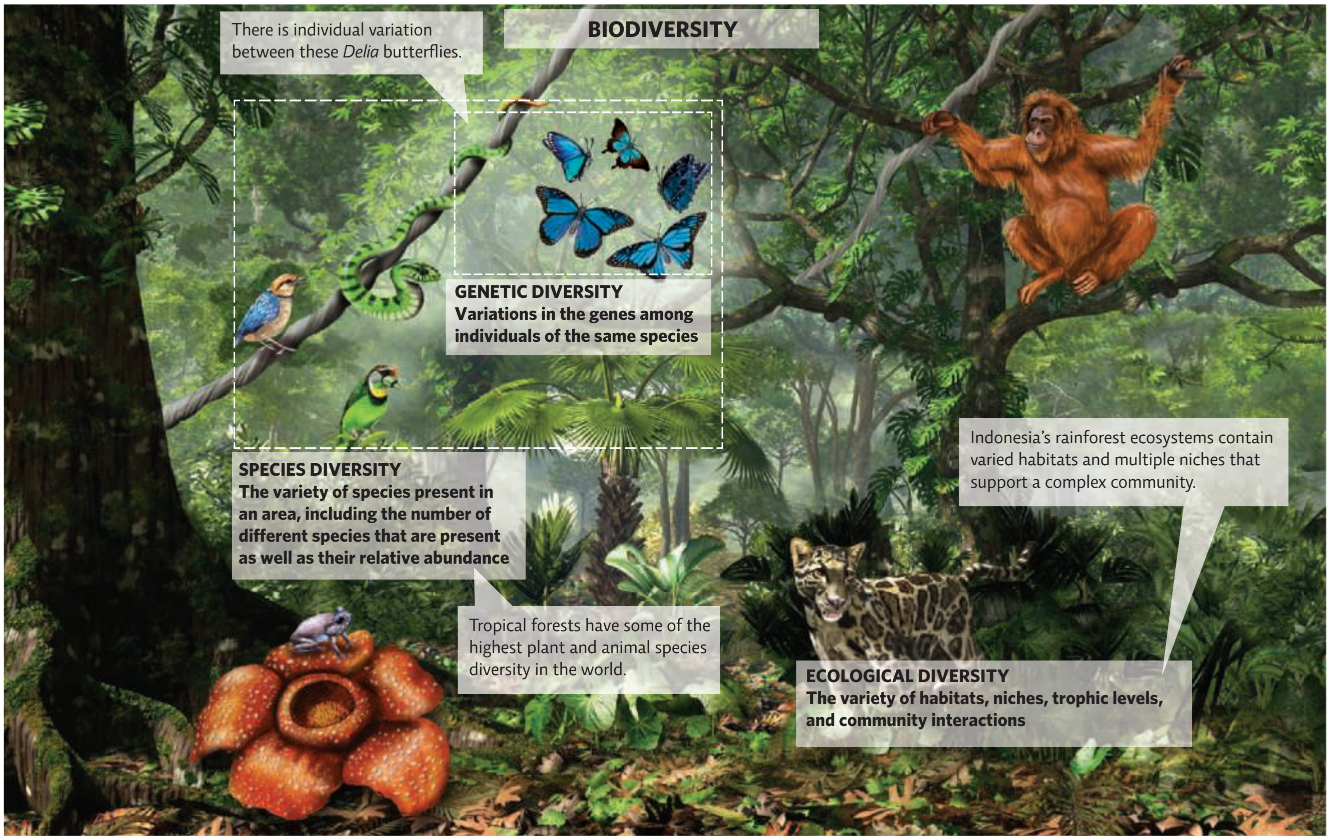
Since areas with high ecological diversity offer so many unique habitats and niches, they often have a large number of **endemic** species that are specially adapted to that locale and naturally found nowhere else on Earth. The loss of species (extinction) in an ecosystem removes contributing members from that ecosystem, potentially impacting other species and the ability of that ecosystem to function and provide ecosystem services. **INFOGRAPHIC 3**

Tropical forests tend to be particularly flush with both ecological and species diversity, thanks largely to the abundant sunlight and climatic conditions conducive to plant growth. The forests of Indonesia are no exception—the region ranks high in all three measures of biodiversity. It is home, for example, to the endemic Sumatran tiger. The pygmy elephant is likewise endemic to the nearby island of Borneo. And the orangutan is endemic to the region, with different types of orangutan found on the islands of Sumatra and Borneo. Indonesian forests also contain an amazing diversity of bird and beetle species, all supported by an impressive variety of plant species at every level of the forest.

"The truth is, no one has any idea how many species used to live here," Sutherlin says. "Half the species in these forests have yet to be described to science." Unfortunately, many of these species are being threatened by our pursuit of palm oil.

endemic A species that is native to a particular area and is not naturally found elsewhere.

INFOGRAPHIC 3 **BIODIVERSITY INCLUDES GENETIC, SPECIES, AND ECOSYSTEM DIVERSITY**



Give an example of genetic diversity and an example of species diversity from the grocery store produce section.

4 THREATS TO BIODIVERSITY

Key Concept 4: The leading threats to biodiversity today come from human activities. Biodiversity loss endangers ecosystems and the species (including humans) that depend on the ecosystem services these areas provide.

It's not just species in the rainforests of Indonesia that are seriously threatened. Indeed, a recent evaluation reveals that in just the past 50 years, monitored populations of vertebrates (mammals, reptiles, birds, amphibians, and fish) worldwide have declined, on average, by a staggering 69%. Insects too are showing disturbing and rapid population declines, as are plants. The causes of these declines are varied but all have one thing in common: humans.

The five leading threats to species are overharvesting (legal and illegal), pollution, anthropogenic climate change, the introduction of invasive species (see Module 3.1 for a detailed example), and habitat destruction — the number one cause.

For some species even *habitat fragmentation* — producing habitat "islands" where before there were larger expanses of uninterrupted habitat — can be devastating. For example, deforestation that leaves small patches of forest may not be suitable for species that need large forested areas. Some species simply will not cross over the deforested patch to disperse from one side of the patch to the other, so fragmentation effectively isolates them from other parts of their population. "The remaining populations of endemic Sumatran rhinos are widely considered to be the living dead," says Sutherlin. "Their habitat is too sparse, too fragmented, and too disturbed, their numbers too few." In addition, habitat fragmentation is also making commercially valuable wildlife, such as elephants with their ivory tusks, more vulnerable than ever to human poaching by providing hunters access to what were once inaccessible regions.

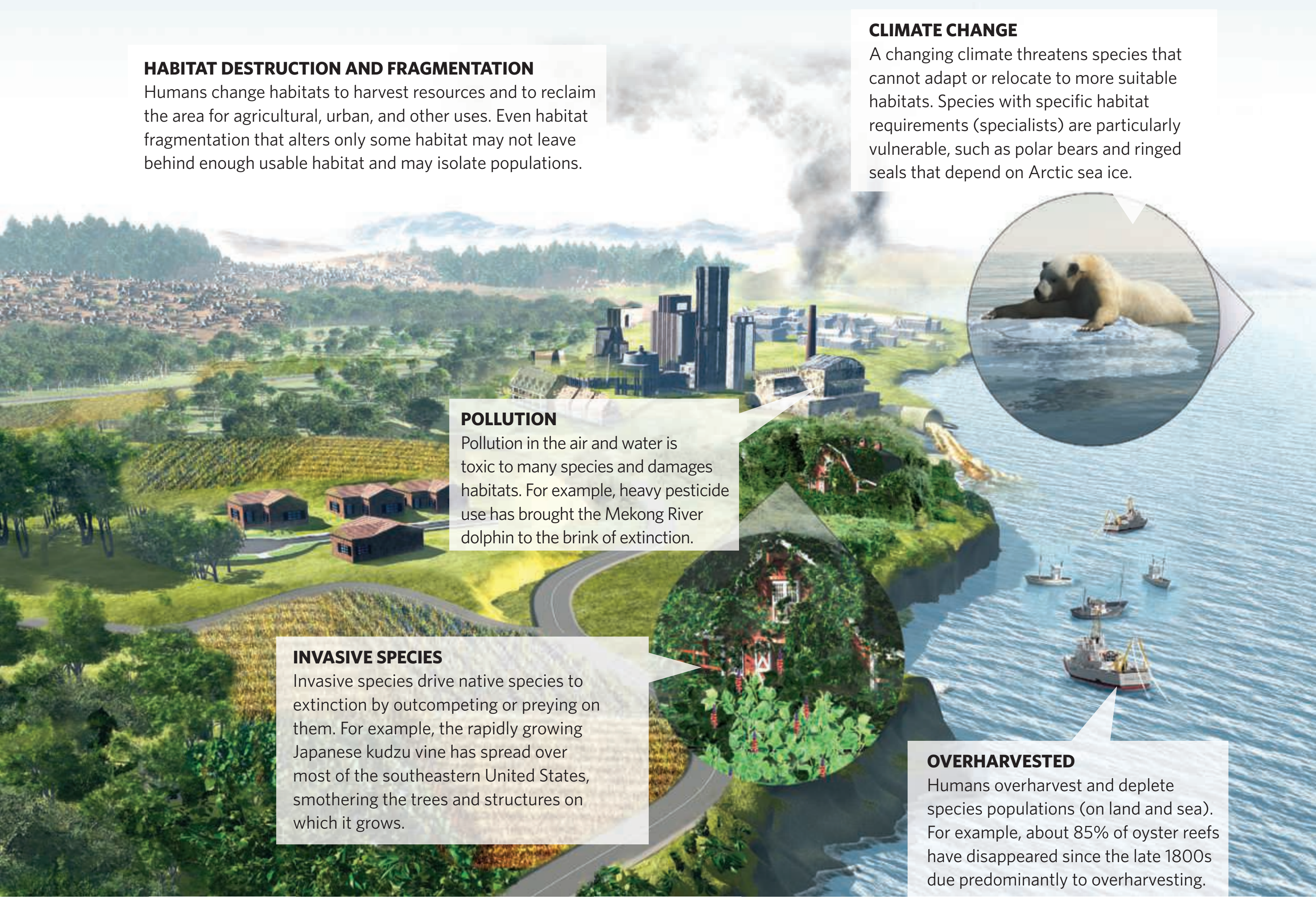
In recent decades, despite increasing international attention to the problems of biodiversity loss, each of these factors has gotten worse. Overfishing has claimed some 85% of oyster reefs and as much as 90% of the world's populations of large predatory fish like tuna and cod (see Online Module 8.4). Pesticides and mercury pollution have all but killed off the Mekong River dolphin and imperil many other species of insects, insect-eating birds, and frogs and salamanders (amphibians are a particularly vulnerable group).

Climate change has claimed the Bramble Cay melomys, a small rodent from Australia, and is threatening to bring the iconic polar bear in the Arctic Circle, not to mention many other species around the world, to disastrous ends. Meanwhile, invasive species are running amok from Alabama to Zimbabwe, thanks to intentional and accidental introductions. At their heart, all these threats are related to human overpopulation and increasing affluence, which both lead to greater resource use. **INFOGRAPHIC 4**

There is no debate that agriculture is vital to human populations — it provides us with food and fiber resources we rely on, and sustainable farming methods are increasingly bringing us those resources with a lower impact (see Chapter 8 for more on agriculture). However, globally, agriculture is the leading cause of habitat destruction, and our need for palm oil contributes significantly to that problem in the tropics.

The differences between an oil palm plantation and the natural forest it replaced are stark. Biodiversity is severely depleted — large mammals such as orangutans are excluded from the areas, but other species are also missing: Only half the bird species will be found there, and insect abundance is reduced by almost 90% in some parts of the forest. The leaf litter that normally covers the forest floor and supports a wide array of species and the nutrient cycles they facilitate is much reduced — as much as 95% of ground-dwelling ant biomass may be lost. The loss of these species, and biomass in general, negatively affects the ability of the ecosystem to perform ecosystem services. For example, without leaf litter to protect soil, flooding and soil erosion are more likely to occur, increasing the incidence of water pollution. These effects are not limited to tropical rainforests. Ecosystems across the globe — terrestrial and aquatic — become impoverished as their biodiversity declines.

INFOGRAPHIC 4 THE MAIN THREATS TO BIODIVERSITY TODAY COME FROM HUMANS



HABITAT DESTRUCTION AND FRAGMENTATION
Humans change habitats to harvest resources and to reclaim the area for agricultural, urban, and other uses. Even habitat fragmentation that alters only some habitat may not leave behind enough usable habitat and may isolate populations.

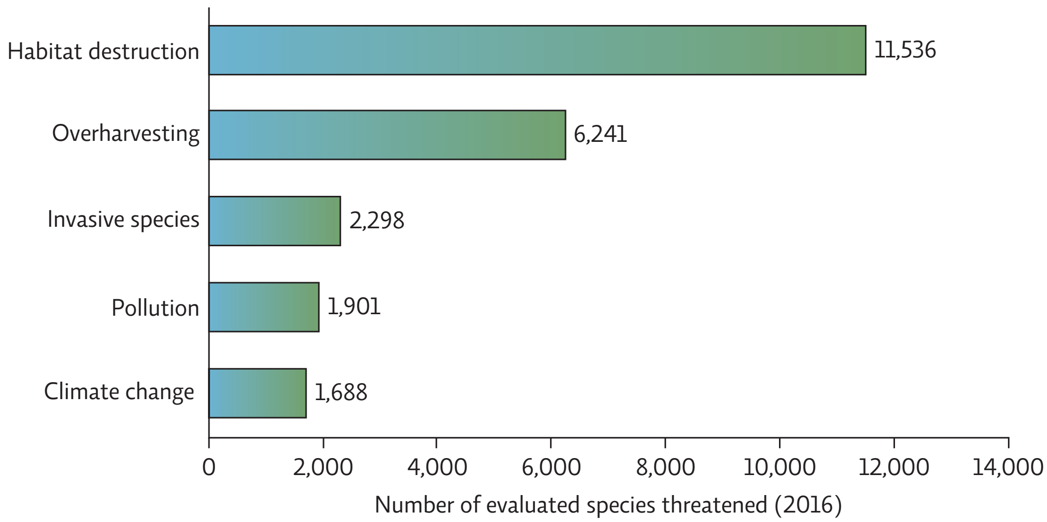
CLIMATE CHANGE
A changing climate threatens species that cannot adapt or relocate to more suitable habitats. Species with specific habitat requirements (specialists) are particularly vulnerable, such as polar bears and ringed seals that depend on Arctic sea ice.

POLLUTION
Pollution in the air and water is toxic to many species and damages habitats. For example, heavy pesticide use has brought the Mekong River dolphin to the brink of extinction.

INVASIVE SPECIES
Invasive species drive native species to extinction by outcompeting or preying on them. For example, the rapidly growing Japanese kudzu vine has spread over most of the southeastern United States, smothering the trees and structures on which it grows.

OVERHARVESTED
Humans overharvest and deplete species populations (on land and sea). For example, about 85% of oyster reefs have disappeared since the late 1800s due predominantly to overharvesting.

HUMAN ACTIVITIES THREATEN SPECIES



A 2016 evaluation of species that have been identified as threatened shows that habitat destruction leads the way in terms of anthropogenic threats.

? Species are often imperiled by more than one threat. Propose a specific example of how two or more of the threats identified here might interact to place even more pressure on a population.


blickwinkel/Sailer/Alamy

Compared to the natural forests they replace, oil palm plantations have only one species of tree, and the variety of understory plants is much diminished. This lessens ecological diversity, reducing species diversity and the ecosystem services those species might have provided.

5 CONSERVATION BIOLOGY

Key Concept 5: Conservation biology seeks to preserve biodiversity by identifying and addressing threats. Though most species have yet to be assessed, those that have been are assigned a conservation designation ranging from "least concern" to "extinct."

Conservation biology is the science of preserving biodiversity. Conservation biologists focus on protecting individual species, especially **endangered species**, and maintaining or restoring entire ecosystems. That means they also work to understand the many threats facing species and ecosystems. As has been detailed throughout this book, we humans are changing the environment with unprecedented speed—so much so that many populations cannot keep up. The details for any given species may differ, but the basic story is often the same: As more and more individuals die off, the genetic diversity of that species dwindles, and the population as a whole becomes increasingly vulnerable to extinction.

conservation biology The science concerned with preserving biodiversity.

endangered species Species at high risk of becoming extinct.

threatened species Species that are endangered or at risk of becoming endangered in the near future.

To bring attention to the problem of **threatened species**—those that are endangered or at risk for becoming endangered in the near future—the International Union for Conservation of Nature (IUCN) established the Red List of Threatened Species in 1963. The "Red List," as it is called, uses a series of *conservation status designations* to classify the seriousness of threat for those species that have been assessed. Designation criteria include things such as population size, the observed or projected percent decline in population, and the extent of its current range.

The United States as a whole, its individual states, and other countries maintain their own lists of threatened species, using the same designations. **INFOGRAPHIC 5**

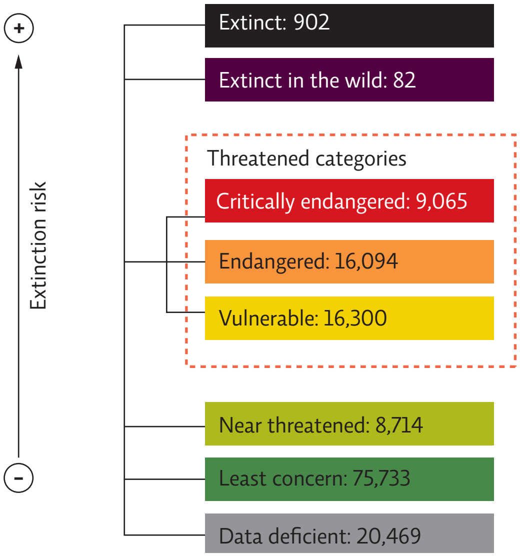
According to the extensive 2019 global assessment on biodiversity by the UN-backed Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 25% of evaluated plant and animal species are now at risk of going extinct. A more recent evaluation of vertebrate species by a group led by Neil Cox and Bruce Young found that of species that have been assessed, 40.7% of amphibians, 25.4% of mammals, 21.1% of reptiles, and 13.6% of birds are at risk of extinction. This is concerning because biodiversity contributes essential ecosystem services to us all, the report's authors point out, writing that "most of nature's contributions to people are not fully replaceable, and some are irreplaceable." This means the loss of biodiversity has major implications for the wellbeing of human societies.

Figuring out how to best preserve the biodiversity that is left might help us avert the worst of those implications. Assigning a conservation status designation to species is a good starting place—it tells us which species are in trouble and how serious the threat is, allowing conservation biologists to prioritize their efforts. In fact, this has led to many success stories from well-known species like the bald eagle and giant panda to less familiar species such as the Chatham petrel (a critically endangered seabird whose population is slowly climbing) and the Arabian oryx (a species of antelope once extinct in the wild but whose population now approaches 10,000 in the wild and in captivity).

INFOGRAPHIC 5 **CONSERVATION STATUS DESIGNATIONS**

The International Union for Conservation of Nature maintains the Red List of Threatened Species, which identifies the conservation status of assessed species worldwide, a process that helps conservationists focus efforts on the species most at risk. Status categories reflect extinction risk and range from *extinct* to *least concern*. (*Data deficient* means that there is not yet enough information to place an assessed species in one of the other categories.) Numbers shown here indicate the number of species in that category in 2022.

ALL SPECIES EVALUATED



What percentage of the 1.5 million named species have been evaluated for conservation status (include those identified as "Data Deficient")?

6 PRESERVING BIODIVERSITY

Key Concept 6: Conservation programs may focus on an individual species or on the entire ecosystem. Conservation genetics may be used to help identify endangered populations and track the illegal sale or trade of endangered species.

Scientists rely on a handful of approaches to protect areas and species that are being threatened. One approach that was used in many early conservation programs was **single-species conservation**: Scientists singled out well-known animals—known as **flagship species**—like pandas and condors, and focused on the specific threats those individual species faced. First, field conservationists worked to understand the biology of the species, including basic details such as dietary requirements and resources needed for successful mating (e.g., nesting materials or sites), as well as the factors that had caused it to become endangered.

Armed with this knowledge, conservationists then developed conservation plans tied to the needs of the species. These included actions such as habitat restoration, pollution clean-up, and the establishment of legal protections to limit or outlaw hunting.

single-species conservation A management strategy that focuses on protecting one particular species.

flagship species The focus of public awareness campaigns aimed at generating interest in conservation in general; usually an interesting or charismatic species, such as the giant panda or tiger.

Captive breeding programs aimed at reintroducing individuals to the wild are often part of the plan, although it can be hard to get animals to breed in captivity. Indonesia has had a captive breeding program in place for the Sumatran rhino since 1984, but because it took several years for zoologists to identify the proper diet and enclosure conditions (such as the correct amount of sunlight) for the animals, the first calf wasn't born until 2001.

For some species, the single-species approach has been a huge success: It has saved gray wolves, bald eagles, and brown pelicans from local extinction or complete decimation. Savanna elephants and California condors have increased in number thanks to concerted conservation efforts. And it's brought a great deal of attention and funding to conservation. Indeed, the single-species approach is still employed today. Zoos around the world participate in *Species Survival Plans* for a variety of threatened species. These plans oversee careful breeding programs aimed at increasing numbers and maximizing genetic diversity. Among other things, this includes moving reproductive animals from zoo to zoo to introduce new genes into a breeding program and to minimize inbreeding.

ecosystem conservation A management strategy that focuses on protecting an ecosystem as a whole in an effort to protect the species that live there.

surrogate species Species that collectively represent all the needs of other species in the area.

The ultimate goal of these breeding programs is to release animals back into the wild. But the tendency to focus mostly on those species that are photogenic (cute, furry, large) enough to capture the public's attention means that many species in need of help fall through the cracks—their needs and entire ecosystems overlooked. (People are more likely to donate money to "Save the panda!" than to "Save the white wartyback pearly mussel!")

As long as the main problem facing a species is low population size, reintroduction campaigns that are part of the single-species approach can be very effective, but this is insufficient if other threats—such as a degraded habitat or heavy poaching pressure—still exist. For this reason, many conservationists advocate an **ecosystem conservation** approach—working at the ecosystem level to restore habitats and other needed resources for all the species that live there. If conservationists protect the ecosystem as a whole, they protect all or most of the species in it—even the ones they didn't know were endangered.

Because many species may be threatened in an ecosystem, and it is impossible to monitor them all, conservation biologists often focus on **surrogate species**—species that collectively represent all the needs of other species in the area and the threats they face. In one approach, several surrogate species are monitored in what is known as a *landscape species suite*. The species

Mic Clark Photography/Alamy

The Grand Cayman blue iguana was once widespread on its namesake Caribbean island before habitat loss, non-native predators, and other human pressures decimated its population. A Species Survival Plan for the iguana has increased population numbers from a low of 15 to more than 1,000.

are specifically chosen to include a group that, together, uses all the vital habitats within the ecosystem. The idea behind this approach is that if you monitor these species and work to protect each of them, you will simultaneously be protecting the entire ecosystem in which they reside, including, hopefully, all the species that live around them.

For example, in Africa, forest elephants, chimpanzees, and mountain gorillas have been proposed as a landscape species suite for the northeastern forests of the Republic of Congo. Most of the other species in the ecosystem will benefit when elephants, chimpanzees, and gorillas—and their habitat—are protected, because collectively, these three species use most of the vital resources needed by other species in their ecosystem. Successfully identifying the correct surrogate species to monitor is crucial to success—and while success generally goes up as the number of species in the surrogate suite goes up, so does the cost to implement the program. (See the *Science Literacy* activity at the end of this module for more on this topic.)

Single-species and ecosystem conservation can often benefit from the desire of local communities to protect sacred landscapes—those that are important for cultural or religious regions. For example, the Indonesian island of Bali has many sacred forests (usually found near a temple or shrine) and the protection they enjoy has helped to protect the endangered Keruing tree, a valuable timber tree.

Another tool that biologists can use is **conservation genetics**, the scientific field that relies on species' genetics to inform conservation efforts. For example, through DNA analysis, managers of breeding programs can ensure that close relatives do not mate. This not only enhances the survival potential of offspring, it increases genetic diversity of the population, thus increasing the potential for the population to adapt to changing conditions. Conservation genetics also allows scientists to determine whether groups that appear to be members of the same species represent distinct populations of that species or whether they are, in fact, separate species. For example, a genetic evaluation of the Tapanuli orangutan, first discovered in 1997, recently confirmed it to be a distinct species, bringing the total number of orangutan species up to three.

Scientists can also use genetics to pinpoint poaching hotspots by identifying where animal products, such as elephant ivory or tiger skins, came from. For example, scientists have identified five genetically distinct elephant populations in Africa by analyzing DNA from samples of their dung. Law enforcement officials can use this information to identify which population a confiscated tusk came from by matching its DNA to a dung reference map, helping them track down poachers.

Another conservation approach that relies on genetics is cloning—creating an exact copy of an individual. Cloning could help increase the number of individuals in a declining population, and some researchers even hope to bring back extinct species using DNA from preserved tissue. This avenue of conservation genetics is in its infancy, and attempts to clone endangered species have met with limited success because many cloned individuals have not lived very long. But in 2020, a black-footed ferret named Elizabeth Ann was born, the clone of a female that died in 1988 and whose cells had been frozen in hopes that she could one day be cloned. Elizabeth Ann has grown to adulthood and appears healthy. If she can successfully reproduce, she will not only introduce a little more genetic diversity into the population, but she will also represent a huge step forward for cloning as a conservation approach. **INFOGRAPHIC 6**

conservation genetics
The scientific field that relies on species' genetics to inform conservation efforts.

U.S. Fish and Wildlife Service/AP Images

Elizabeth Ann, a back-footed ferret, is the first cloned endangered species in history.

INFOGRAPHIC 6 CONSERVATION APPROACHES

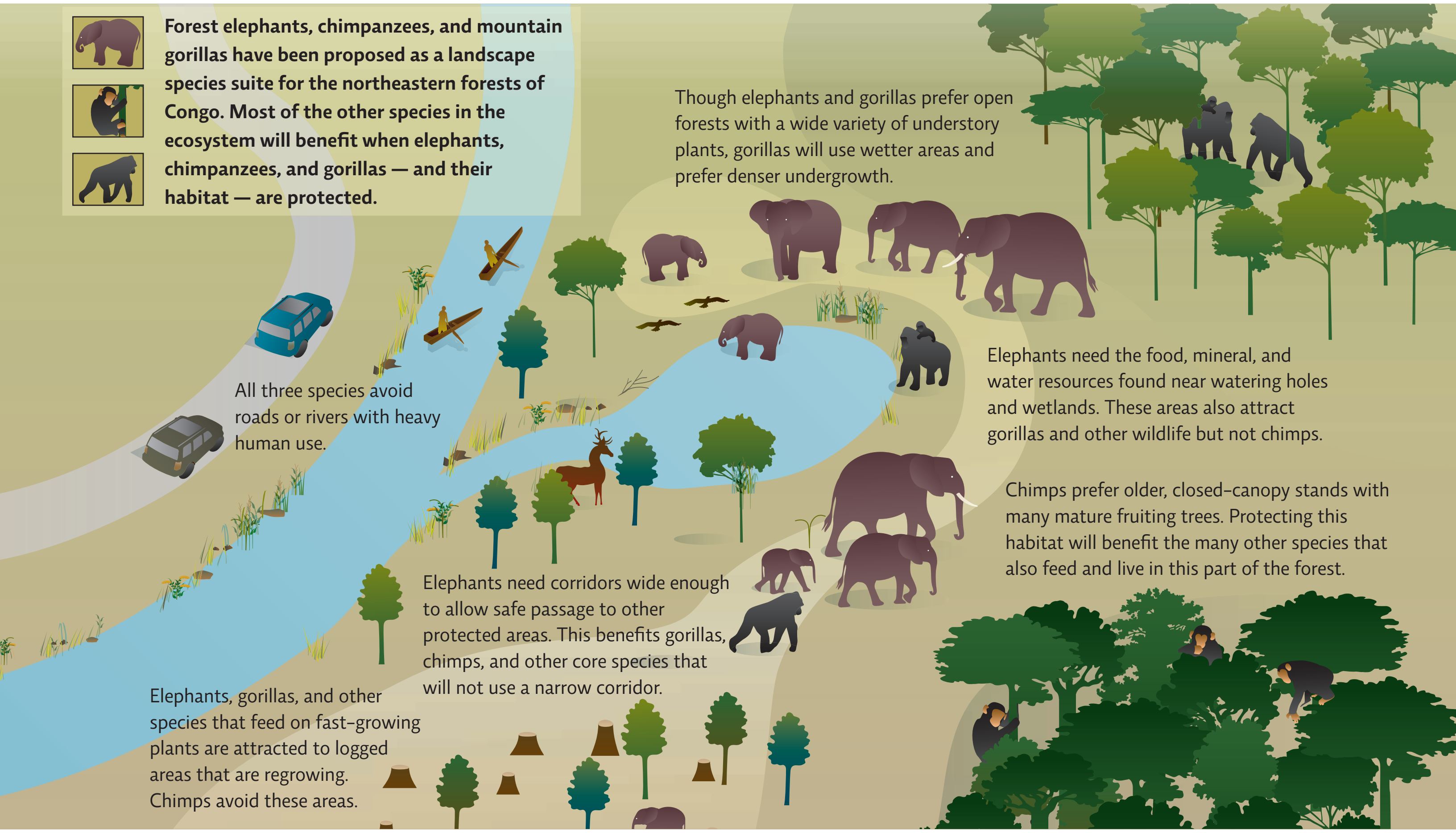
SINGLE-SPECIES CONSERVATION APPROACH

A variety of efforts seek to protect and restore endangered populations. Species Survival Plans focus on increasing the population size and genetic diversity of threatened populations. Cloning is being investigated as a method to help populations recover faster or even to bring back extinct species. Individuals are also released into the wild from captive breeding programs or relocated from wild areas with stable populations. Populations in the wild are also monitored and some are even guarded from poachers, and habitat is restored if needed.

INCREASE INDIVIDUAL NUMBERS | **FIELD CONSERVATION WORK**

ECOSYSTEM CONSERVATION APPROACH

Protecting the entire ecosystem where an endangered species lives helps protect all the species that live there — even those that conservationists didn't know were endangered. Conservationists often identify a few surrogate species (a landscape species suite) to monitor and manage — species that collectively represent the needs or threats faced by all the other species in their ecosystem.



Which single-species conservation methods might also be employed by those pursuing ecosystem conservation?

7 LEGAL PROTECTIONS

Key Concept 7: Legal protection for threatened species includes national laws and international treaties.

Laws, regulations, and treaties are also key conservation tools that can help keep species safe. The **Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)** is, for instance, an international treaty that seeks "to ensure that international trade in specimens of wild animals and plants does not threaten their survival." Today, 184 countries have signed on to the convention. When a signatory country violates the treaty, that country is offered a chance to take action to correct the violation, typically by prosecuting violators or stopping the actions. If its response is found to be unsatisfactory, other CITES nations may impose trade sanctions on the violating country. About 35,000 species are currently protected against overharvesting by CITES—such as elephants (ivory) and tigers (skin and bones). Though most regulated species are animals, CITES also protects some plant species. For example, collecting any species of cacti (popular plants for landscaping) from the wild is prohibited. CITES also protects orangutans, tropical fish and birds, and other species that live in the forests and waters of Indonesia from the illegal pet trade.

Other international treaties focus more broadly on all species, not just those that are endangered, supporting conservation and sustainable use of natural resources and biodiversity. For example, the 1971 Ramsar Convention on Wetlands, the first treaty whose focus is the protection of natural resources, is important in the conservation of waterfowl. The Convention on Biological Diversity (1992) seeks to promote sustainable use of genetic, species, and ecological biodiversity and supports ecosystem conservation approaches.

National laws also protect endangered species. In the United States, protection began with the Lacey Act of 1900, which prohibits the possession or sale of illegally obtained wildlife. The two main U.S. laws that protect threatened species are the Marine Mammal Protection Act and the better-known **Endangered Species Act (ESA)**. Passed in 1973, the ESA mandates that listed species—those that have been officially declared threatened or endangered—be protected through a range of federally funded and scientifically validated strategies. Those strategies include the conservation of natural habitats; hunting prohibitions; and the breeding, relocation, and reintroduction of animals into the wild. The law has helped bring back several species from the brink of extinction—the bald eagle and the American alligator, to name just two. But its effectiveness has also been perpetually hampered by a variety of constraints, including landowner disputes and what critics describe as significant funding shortfalls.

Protecting designated places provides another legal avenue for conservation. **Protected areas** are clearly defined geographic spaces on land or water that are managed to achieve long-term conservation of nature—especially biodiversity. Every nation in the world has protected areas. They include a range of designations. *National parks* are set aside primarily for human recreation. *Wildlife refuges* and *wilderness areas* are generally open to visitors, as well as to hunting and fishing, but are not commercially developed (i.e., they have no restaurants, hotels, or other human accommodations). *Nature* and *game reserves* are closed to hunting and fishing; their main goal is to protect wildlife. In addition to these officially recognized protected areas, there are countless other areas under the protection of Indigenous people or private entities. Similar to its Red List, the IUCN now maintains a *Green List* of areas that have been verified as having experienced conservation success for species and local human populations, with more than 60 certified sites. **INFOGRAPHIC 7**

Even though new protected areas are still being added, others are being downsized or downgraded (opened up to various levels of use). In most cases, these concessions support industrial-scale resource extraction such as oil and gas development, logging, and mining. However, when downgrading returns access rights to Indigenous populations, and local people have a say in its governance and management, both the area's biodiversity and the people who live there may benefit because the ecosystem may be maintained more sustainably.

In a review article published in *People and Nature*, a team led by anthropologist Liana Chua evaluated the intersection of ecological and societal concerns in an examination of recent orangutan conservation.

Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) An international treaty that regulates the global trade of selected species.

Endangered Species Act (ESA) The primary federal law that protects biodiversity in the United States.

protected areas Geographic spaces on land or at sea that are recognized, dedicated, and managed to achieve long-term conservation of nature.

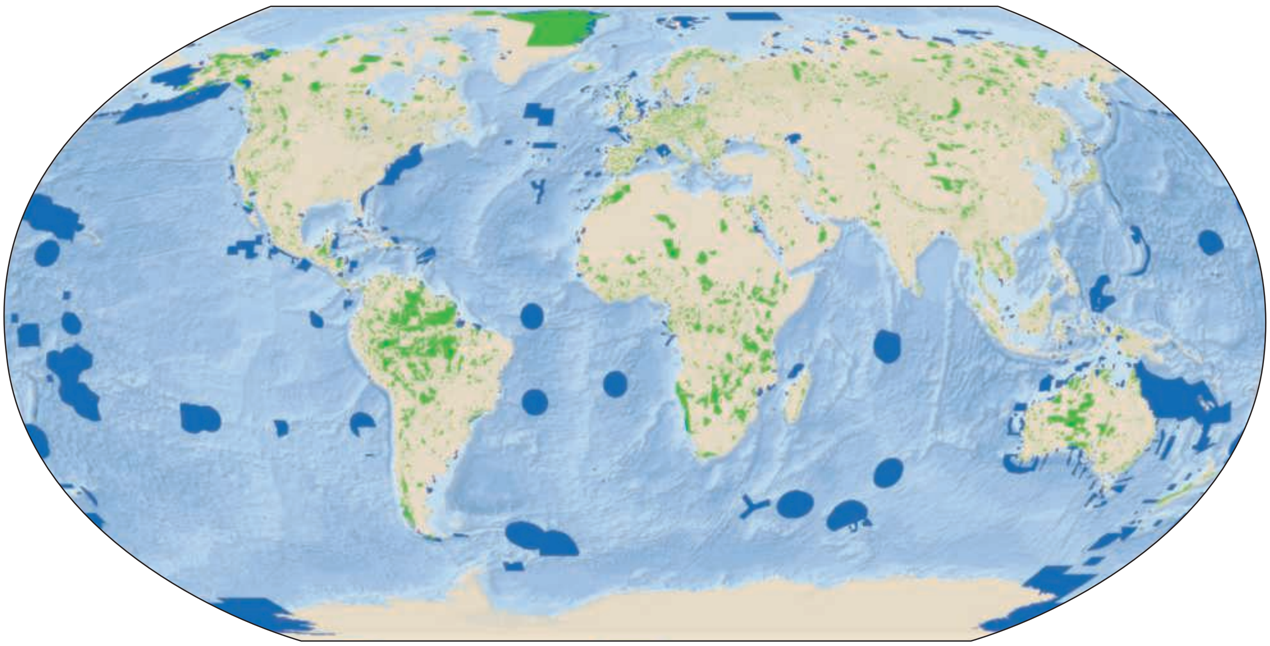
INFOGRAPHIC 7 LEGAL PROTECTION FOR SPECIES

A variety of national laws and international treaties (conventions) offer protection for species and their habitats as well as prohibit the sale of products from endangered species.

U.S. NATIONAL LAWS	
Lacey Act (1900)	The first law protecting wildlife, prohibits the sale or purchase of illegally obtained wildlife (plants or animals) and prohibits the import of non-native species into the country
Marine Mammals Protection Act (1972)	Protects all marine mammals (no killing, capture, or harassment without authorization)
Endangered Species Act (ESA) (1973)	Mandates protection for "listed" species; listing is a cumbersome process, and many species don't make it to the list due to budgetary concerns rather than need
INTERNATIONAL TREATIES	
Convention on International Trade in Endangered Species of Wild Fauna and Flora (1973)	Regulates the sale and trade of endangered or threatened species or products
Ramsar Convention (1975)	Provides a framework for the conservation and wise use of wetlands within and across national borders
Convention on Biological Diversity (1992)	Signatory nations agree to pursue goals of biodiversity conservation, sustainable use of biodiversity, and equitable sharing of genetic resources (crops and livestock)

GLOBAL PROTECTED AREAS

Protected areas come in all shapes and sizes and vary according to the level of protection the area receives (e.g., a wildlife refuge that allows hunting of some species versus a nature preserve that does not allow any hunting). See Online Modules 6.3 and 8.4 for more on marine protected areas.



Terrestrial protected areas   Marine protected areas

April 2020

UNEP-WCMC and IUCN (2020). Protected Planet: The World Database on Protected Areas (WDPA) [On-line], April 2020, Cambridge, UK: UNEP-WCMC and IUCN. Available at: www.protectedplanet.net

U.S. environmental laws like the ESA are considered "citizen laws"—citizens or citizen groups (like nonprofit organizations) can sue the federal government to enforce the law if they feel it is not doing so. The Canadian version of this law (Species at Risk Act) does not have this provision. Which law do you think is stronger (i.e., more successful at protecting species)?

Conservation programs in the 1970s, they found, tended to focus on the ecological needs of the species in question and often ignored the needs or wants of local people. These programs may not have the support of local people who fail to see the value of saving a species they do not directly benefit from, or that perhaps hurts a species they depend on for their livelihood. This disconnect is more likely to arise, Chua found, with conservation programs designed by groups from the *Global North* (e.g., wealthy nations in North America and Europe); local groups are more likely to engage the community in conservation decision making and goal setting.

Chua writes that "it is impossible to solve orangutan conservation problems without taking seriously the opinions, experiences and concerns of the people who live in, around, and near orangutans and their habitats." Therefore, strategies that help not only an endangered species, such as the orangutan, but also species that are important to local communities, such as fish (a source of food and income), or provide tangible benefits (e.g., cleaner water and air, lower fire risk to the forest) are more likely to gain support. In other words, good conservation programs do not ignore the people who share the habitat with the species those programs seek to protect.

8 COMMUNITY AND CONSUMER CONTRIBUTIONS TO CONSERVATION

Key Concept 8: Funding for conservation can come from ecotourism, debt-for-nature swaps, and programs supported by nonprofits. Consumers, too, can help protect biodiversity by making purchases that support the sustainable use of natural areas and that avoid illegal wildlife trafficking.

Another way that Indonesia is working to protect its many species is by bringing in more visitors. It turns out that **ecotourism**—low-impact travel to natural areas that contributes to the protection of the environment—is a thriving industry and a key revenue train for conservation: Tourists will pay good money to see wildlife and well-preserved wild areas, especially if they know their money is helping conservation efforts. Currently, some 35% of Indonesia's nature tourism dollars come from ecotourism, and the country is actively pursuing plans to promote ecotourism in conservation areas.

Hunting and fishing can be considered ecotourism when participants travel to destinations to hunt or fish, and these activities also bring in a lot of conservation dollars via hunting and fishing licenses. In the United States, hunting provides food to the hunters or to organizations that receive the meat as donations, and is also an important tool in regulating populations of game animals like deer and elk that might otherwise grow too numerous given that many of their natural predators are missing from their ranges. Trophy "big game" hunting in Africa and elsewhere (the animal is killed for sport rather than for food) can serve the same purpose if it aligns with conservation goals of controlling populations, but these guided hunts often draw criticism as unethical and even harmful to the animal population. Favorite hunting targets are often older males; killing them removes high-quality genes that would strengthen the population if these animals lived to pass on their genes to the next generation.

Wildlife photography tourism might seem a more ethical option and in many cases it is, but not all of these types of ecotourism experiences benefit wildlife—in fact, according to an investigative report by *National Geographic* reporter Natasha Daly, wildlife tourism that offers up-close and personal experiences or photo-ops with "wild" animals may be using animals that have been mistreated—elephants beaten into submission; tiger cubs separated from their mother so she can be bred again; wild-caught sloths that rarely live more than a few weeks in captivity. To avoid supporting these kinds of operations, tourists need to do some research to establish that the facility they are thinking of visiting treats animals humanely. Ecotourism that offers viewing safaris of animals in the wild may be the best bet for contributing to the conservation of threatened species.

Ecotourism is not the only way to support conservation. **Debt-for-nature swaps**—in which a wealthy nation forgives part of a low- or middle-income nation's debt in return for a pledge to commit an agreed-upon amount of money to conservation—are another way to appeal to the needs of those living nearest the species and ecosystems that are so embattled. So far, around $3 billion in debt has been forgiven and millions of acres of wilderness have been preserved through such programs.

Nonprofit organizations have also been major players in conserving species and their habitats by raising awareness and funding conservation projects. For example,

ecotourism Low-impact travel to natural areas that contributes to the protection of the environment and respects the local people.

debt-for-nature swap Arrangement in which a wealthy nation forgives the debt of a lower-income nation in return for a pledge to protect natural areas in that lower-income nation.

Luisa Puccini/Shutterstock

Ecotourism to view wildlife in its natural environment can contribute to conservation of these areas, benefitting wildlife and the local communities.

land trusts are nonprofit organizations set up to protect land under their care. Individual landowners can participate as well through a **conservation easement**, a legal agreement between a landowner and a land trust or government entity that permanently limits development of that land to help preserve its conservation value and support the landowner's vision for that property—the landowner retains ownership of the property and can use it in agreed upon ways (e.g., for farming but not to subdivide into a housing development).

Volunteer work is also an important part of keeping natural areas in good shape. There are a wide variety of educational, research, and wildlife/habitat management opportunities that allow individuals to contribute to conservation work, including *citizen science* projects that recruit citizens to assist in research projects. **INFOGRAPHIC 8**

Consumers also play a major role. The first step is to become informed about the threats to species and how consumer choices impact biodiversity. For example, some actions harm endangered species (such as buying wild-caught tropical birds or fish), whereas other choices support the sustainable use of natural areas, like buying sustainably grown coffee and palm oil products or sustainably harvested fish (see Online Module 8.4). Buying or using fewer resources (from gasoline to sunglasses to sneakers) means less impact on the natural areas (and their resident species) from which the resources are extracted or made. Finally, reducing one's contribution to climate change will reduce this threat to Earth's biodiversity (see Module 10.2). Environmental groups like Sutherlin's Rainforest Action Network that work to find and share information about corporate actions (e.g., which corporations are sourcing palm oil sustainably and which are not) are vital for helping consumers (and others such as potential financiers) make informed decisions about which companies to support with their spending dollars or investments.

land trust A nonprofit organization set up to protect land under its care.

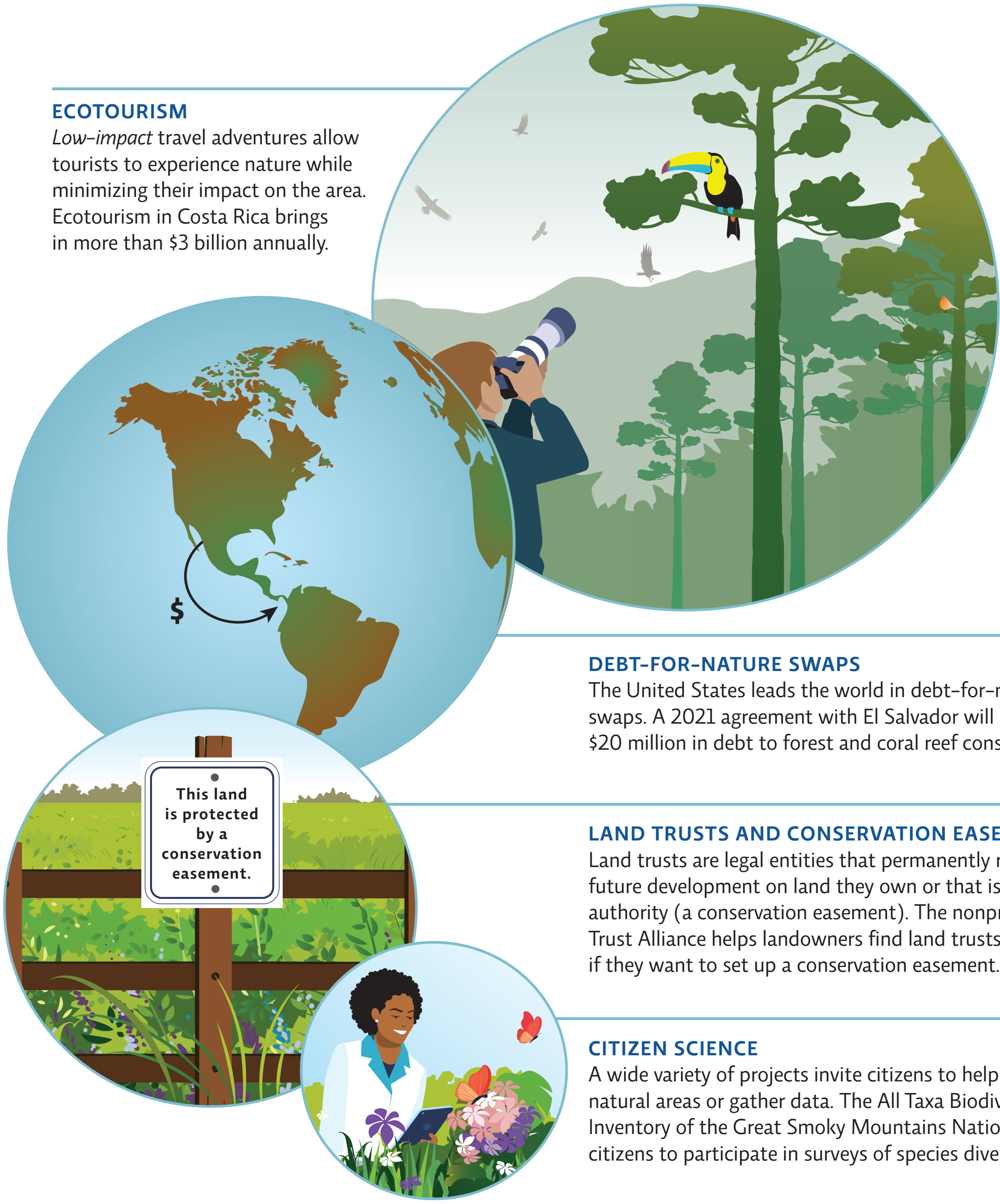
conservation easement Legal agreement that restricts the way land can be used to achieve conservation goals.

In Indonesia and elsewhere in Southeast Asia, the solution to protecting biodiversity will have to involve palm oil production. It's the most productive oil-bearing crop at our disposal, producing around 1.6 tons of oil per acre. Soybeans, by comparison, produce only 0.17 ton per acre. "To get the same amount of soybean oil, you would have to use ten times as much land," geneticist Raviga Sambanthamurthi explains. In an effort to increase palm oil productivity even more, Sambanthamurthi has developed a seed-screening technique that allows farmers to identify the most productive strains of oil palm for planting—more palm oil per tree means fewer trees need to be planted. It was the dream of improving oil palm cultivation that brought Sambanthamurthi back to her native Malaysia, another country that produces palm oil, after completing her PhD in genetics at the University College of London. "I knew if I was going to make a difference, it would be in palm oil," she said. "Sustainable palm is the key to protecting our biodiversity, and our heritage."

INFOGRAPHIC 8 MANY ROUTES TO CONSERVATION

Because the causes and consequences of biodiversity loss are numerous and varied, the conservation of biodiversity requires many approaches. In addition to regulations, laws, and treaties, other effective approaches include some that are market driven (i.e., there is a financial incentive to pursuing them) and others that rely on individuals to voluntarily give of their time or money.

ECOTOURISM
Low-impact travel adventures allow tourists to experience nature while minimizing their impact on the area. Ecotourism in Costa Rica brings in more than $3 billion annually.



DEBT-FOR-NATURE SWAPS
The United States leads the world in debt-for-nature swaps. A 2021 agreement with El Salvador will redirect $20 million in debt to forest and coral reef conservation.

LAND TRUSTS AND CONSERVATION EASEMENTS
Land trusts are legal entities that permanently restrict future development on land they own or that is under their authority (a conservation easement). The nonprofit Land Trust Alliance helps landowners find land trusts near them if they want to set up a conservation easement.

CITIZEN SCIENCE
A wide variety of projects invite citizens to help manage natural areas or gather data. The All Taxa Biodiversity Inventory of the Great Smoky Mountains National Park recruits citizens to participate in surveys of species diversity in the park.

? Would you be willing to participate in citizen science projects? If so, what kind of activities would appeal to you?

In addition to increased productivity, there are other ways to reduce the impact of growing oil palms. To be certified sustainable by the nonprofit group Roundtable on Sustainable Palm Oil (RSPO), palm oil producers must adhere to practices that minimize the use of fire and pesticides, and they must take steps to prevent soil erosion and water pollution. The rights of workers (fair wages and good working conditions) are a high priority, and the local community is given an opportunity to weigh in on proposed oil palm plantations. In addition, growers cannot clear old-growth forests or those with high biodiversity or cultural value for conversion to plantations.

Sustainable supplies of palm oil began to increase steadily around 2008. In 2022, about 19% of the global supply was sustainably grown—up from only 6% in 2013. However, sustainable production plateaued around 2015, even as the use of palm oil continues to increase. By 2050, demand is expected to quadruple. Reducing demand and growing oil palms more sustainably will be critical if we want to protect these forests and their species.

One thing is certain: There is still much value in saving these forests. Orangutans still swing freely through the canopies, and new species of lizards and birds continue to be discovered. Despite the destruction plaguing Indonesia's forests, all hope is not yet lost.

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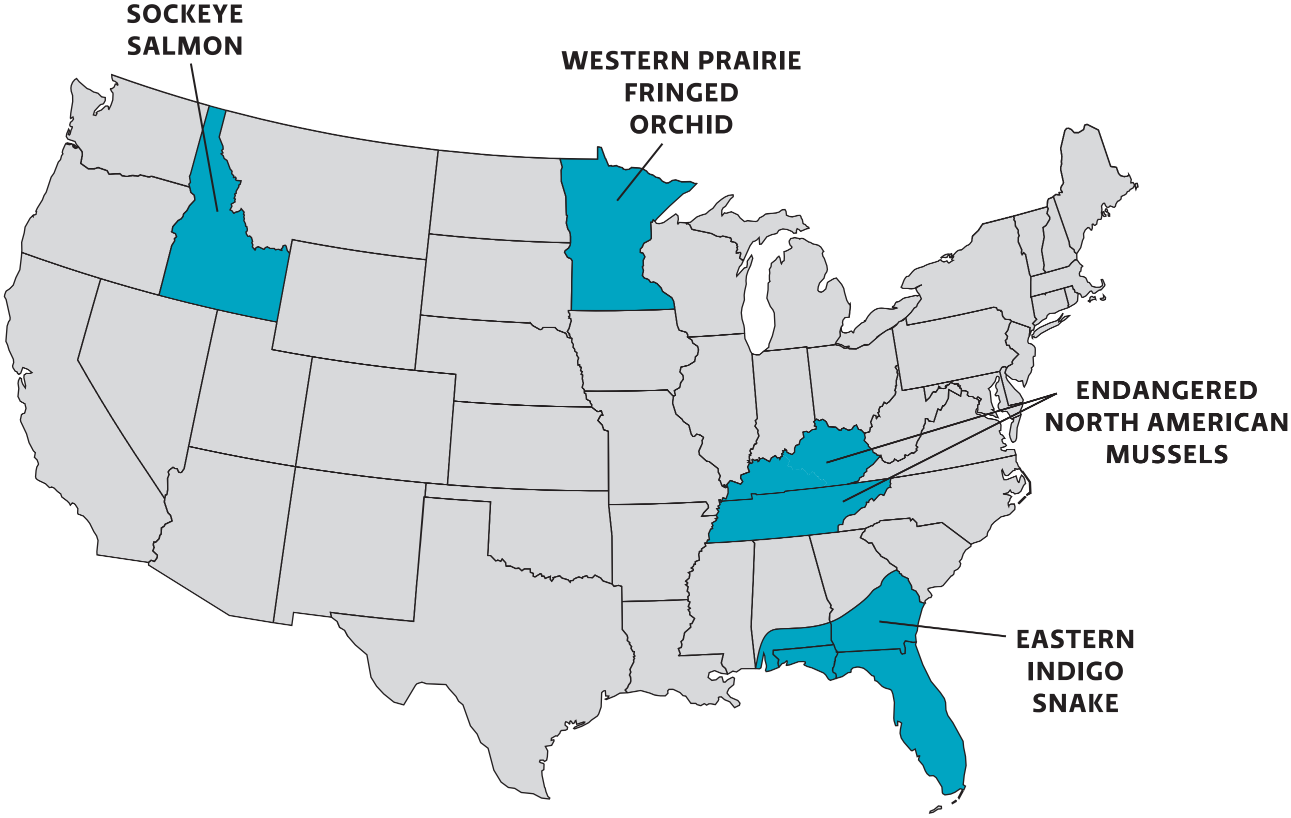
The tropical forests of Indonesia are the last place on Earth where tigers, elephants, and rhinos exist together in the wild. Protecting places like these highly biodiverse forests is a good conservation investment that has the potential to save many endangered species.

Edo Schmidt/Alamy

GLOBAL CASE STUDIES ENDANGERED SPECIES

Species all over the world face threats, and many are endangered. Here are profiles of some lesser-known endangered and threatened species of the United States.



BRING IT HOME

PERSONAL CHOICES THAT HELP

Species and habitats provide numerous benefits to people, including water and air purification, food sources, recreation, and medicine. Unfortunately, many species are facing threats at ever-increasing levels. The good news is that we as a society have a direct impact on these threats and can make changes to ensure the survival of many at-risk species.

Individual Steps

- Don't buy products made from wild animal parts such as horns, fur, shells, or bones. Only buy captive-bred tropical aquarium fish, not wild-caught fish.
- Read labels on food and personal care products you use to identify those that contain palm oil and look for alternative products that are more sustainably produced.
- Reduce your consumption of consumer goods in general and opt for responsibly harvested forest products such as fair trade coffee and cocoa, if possible. Look for labels on products that identify the palm oil it contains as "Certified Organic" or "Certified Sustainable Palm Oil RSPO" with its trademarked logo, a globe-shaped palm.
- Make your backyard friendly to wildlife, using suggestions from the National Wildlife Federation (www.nwf.org).

Group Action

- Join a citizen science program monitoring wildlife. Many regional conservation groups have monitoring opportunities and provide training. For national programs, visit https://scistarter.org/ and www.societyforscience.org.
- Go to www.fws.gov/program/endangered-species to discover which endangered species live in your state. Make flyers and posters with images and information about these species and their habitats. Share them around your school or community.

REVISIT THE CONCEPTS

- The variety of life (biodiversity) on Earth is tremendous, but we have identified only a fraction of existing species, and we know much more about smaller groups such as plants and vertebrates than more diverse groups like invertebrates.

- Biodiversity contributes to the health and wellbeing of ecosystems, which in turn benefits human populations by providing ecosystem resources and services as well as cultural and health benefits.

- Three types of biodiversity are genetic, species, and ecological diversity. Each of these enhance the ability of an ecosystem to function and its members to adapt to changing conditions.

- Unfortunately, Earth's biodiversity is declining rapidly. Many species are endangered, and others have already been lost to extinction. The leading threats to biodiversity today come from human activities. They include habitat destruction (the leading threat), overharvesting, climate change, pollution, and the introduction of invasive species.

- Biodiversity loss endangers ecosystems and the species (including humans) that depend on the ecosystem services these areas provide. Conservation biology seeks to preserve biodiversity by identifying and addressing threats. There are a variety of ways to pursue conservation of species.

- The single-species conservation approach addresses threats to an individual species, whereas the ecosystem approach takes a bigger view, protecting habitat as a way to protect all the species that live in a given area. Surrogate species that collectively represent all the needs of other species in the area and the threats they face are often selected as the focus of ecosystem conservation efforts.

- Legal protections include state and national laws as well as international treaties that identify actions to be taken to protect species.

- Collective actions that reduce our impact include ecotourism, debt-for-nature swaps, and privately funded conservation. Individually, we can avoid actions that contribute to the endangerment of species (e.g., don't buy ivory or other products that directly endanger species). But we should also reduce the amount of consumer goods we buy and use in general to reduce the impact on the natural areas from which the resources are extracted to make these goods.

ENVIRONMENTAL LITERACY Understanding the Issue

1 What is biodiversity?

1. How many species are estimated to live on Earth, and which group contains the most species (other than bacteria)?
2. Why do you suppose we know more about smaller species groups such as vertebrates and plants than larger groups like arthropods and worms?

2 Why is biodiversity important?

3. Identify the three categories of ecosystem services and give examples of each.
4. How might biodiversity loss impact the ecosystem service of human provisions?

3 How do genetic, species, and ecological diversity each contribute to ecosystem function and services?

5. How does the amount of ecological diversity affect species diversity?
6. Explain why genetic diversity is considered a population concept, whereas species diversity is a community concept.
7. Define genetic diversity and use the example of the potato blight in Ireland to explain the importance of genetic diversity to a population.

4 What are the causes and consequences of biodiversity loss?

8. Identify the five leading causes of species endangerment. Which is the leading threat?
9. How can the loss of even part of a region's habitat (habitat fragmentation) be as problematic as complete destruction of a habitat for some species?

5 What is the goal of conservation biology and how do conservation status designations help achieve that goal?

10. What does it mean to be a threatened species?
11. Identify the conservation status designations from least to most serious. How might these designations be useful?

6 What methods are used to address species endangerment and how effective are these approaches?

12. Distinguish between single-species conservation and ecosystem conservation. What are the pros and cons of each?
13. What are surrogate species and what criteria are commonly used to select a landscape species suite?
14. What is conservation genetics and how can it contribute to the conservation of species?

7 What legal protections are in place for threatened species?

15. Evaluate the Endangered Species Act in terms of its scope, effectiveness, and weaknesses.
16. How can CITES protect endangered species if it only regulates international trade? Do you think this is enough to protect endangered species? Explain.

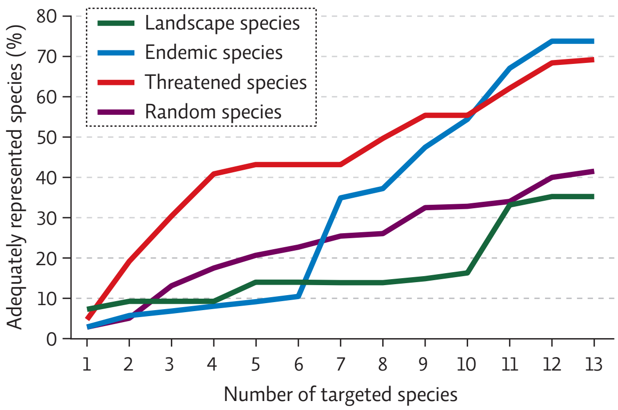
8 How can local communities and consumers contribute to the protection of biodiversity?

17. What is ecotourism, and how does it benefit wildlife and local human communities?
18. Identify some actions you could personally take that would contribute to conservation of species.

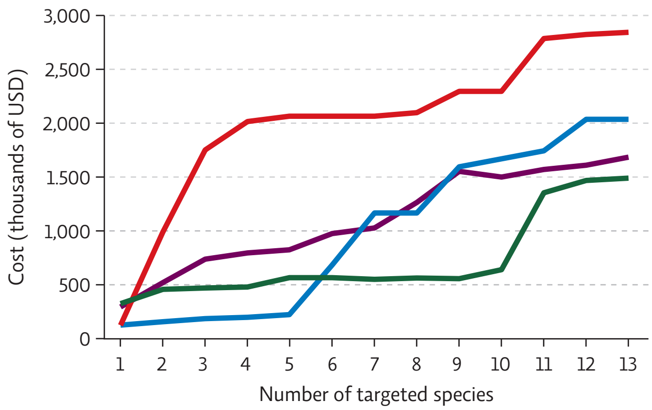
SCIENCE LITERACY Working with Data

Selecting the surrogate species that best represent the rest of the ecological community is key to the success of ecosystem conservation. Surrogate species are usually chosen based on habitat needs, whereas focusing on endemic or threatened species might also identify and address other threats. These data compare the effectiveness and cost (in U.S. dollars) of focusing conservation actions on three different surrogate species groups. The study examined species suites made up of 1 to 13 species and evaluated effectiveness in terms of the percentage of species present that are adequately represented by the surrogates. (See Section 6 for an introduction to *surrogate species*.)

A: SURROGATE SUCCESS FOR VARIOUS GROUPS



B: COSTS TO IMPLEMENT CONSERVATION



Interpretation

1. In general, how does the percentage of species that are represented change as the number of targeted species in the species suite increases in graph A?
2. Which group best represents other species in the community?
3. How many targeted species are needed in the endemic or threatened species suites to match the success of the 13-member landscape species suite?
4. If your goal is to represent at least 50% of species present, how many targeted species would need to be in each species suite? Which suite does not meet this goal?

Advance Your Thinking

5. Using graph B, identify the most cost-effective method that adequately represents 50% of species.
6. Why did the study authors also test species suites of randomly selected species? How did the three test groups compare to the success achieved with the random group?
7. In the elephant/gorilla/chimpanzee case study described in Section 6 of this module, the species chosen for the landscape suite were endemic and threatened. How do you think the success of that program might compare to that of the landscape species suite in this study?

DIGITAL INFORMATION LITERACY Evaluating Information

Everyone has limited time and money, and choosing how to invest that time and money to support biodiversity issues can be complex. Should you fund an organization that protects individual species or ecosystems? Does the organization spend no more than the recommended amount of money (30% to 35%) on administration and fundraising? What conservation focus do you prefer?

Evaluate the following websites and work with the information.

1. Visit the World Wildlife Fund (WWF) website (www.worldwildlife.org) and the Nature Conservancy website (www.nature.org). For each, answer the following questions:
   a. What is the mission of the organization?
   b. Is the website up to date? Does it appear to be accurate? Reliable? Explain.
   c. Does the organization use a single-species conservation approach, an ecosystem approach, or both? Support your answer.
   d. What does the organization claim about the percentage of its operating budget it spends on programs versus on other costs? What evidence does it provide to support this claim? Is the evidence sufficient?
   e. How long has the organization been operating? What are some of the successes it claims?
2. Go to Charity Navigator (www.charitynavigator.org).
   a. Search for World Wildlife Fund. Does the information on the percentage of the operating budget spent on programs, fundraising, and administration match the claims of the WWF website? If there is a discrepancy, why might that be? Which source would you trust, and why?
   b. Search for Nature Conservancy. How does the budget information on the Charity Navigator site compare to that on the Nature Conservancy site?
   c. How does the Nature Conservancy compare to WWF in terms of money spent on programs versus on fundraising and administration? Be specific.
   d. Would these differences lead you to choose to donate to one organization over the other? Why or why not? What other information would you use to make a decision about which organization to support?

Additional study questions are available at Achieve.macmillanlearning.com. Achieve