# Biology Essentials 2

# BIOLOGY ESSENTIALS 2

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# CONTENTS

## Chapter 4: Prokaryotes and Protists



## Chapter 5: Plants and Fungi



## Chapter 6: Invertebrate Animals



## Chapter 7: Vertebrate Animals

## Chapter 8: Ecology and the Biosphere



## Chapter 9: Population Ecology



## Chapter 10: Community and Ecosystem Ecology



## Chapter 11: Biodiversity and Conservation

# ACKNOWLEDGEMENTS

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# LAND ACKNOWLEDGEMENT

*We acknowledge and honour the Anishanaabe, Huadenoshaunnee, and Lanape people of Southwestern Ontario as the traditional owners and custodians of the land and waterways on which Fanshawe College is located. Further, we acknowledge the cultural diversity of all Indigenous peoples, and pay respect to the Elders, past, present, and future.*

*We celebrate the continuous living cultures of the original inhabitants of Canada, and acknowledge the important contributions Indigenous people have, and continue to make, in Canadian society. The College respects and acknowledges our Indigenous students, staff, Elders, and Indigenous visitors who come from many nations.*

–*Fanshawe College Land Acknowledgement*

As we begin our exploration of biology, it is important to recognize our relationship with the land on which we live and learn. The more we learn about the natural world, the more we come to understand how deeply disconnected many of us have become from it. I acknowledge that to truly reconnect and learn to care for our land, we must follow the lead of Indigenous peoples who have maintained a profound and respectful relationship with nature.

"Canoeing" by Tom Harman, CC BY-NC-SA 4.0

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As someone who deeply values outdoor recreation, such as hiking, mountain biking, canoeing and camping, I am continuously reminded of the beauty and significance of this land. Engaging with nature through these activities enhances my appreciation for its wonders and the need for its protection. I commit to treating nature with care and respect and hope to foster a relationship with the land that honours its original caretakers.

As we learn about life throughout this course, let's also work to understand our place within it – as members of a shared living world.

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Please see Biology Essentials 1, the first in this series.

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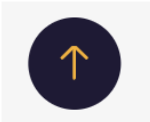

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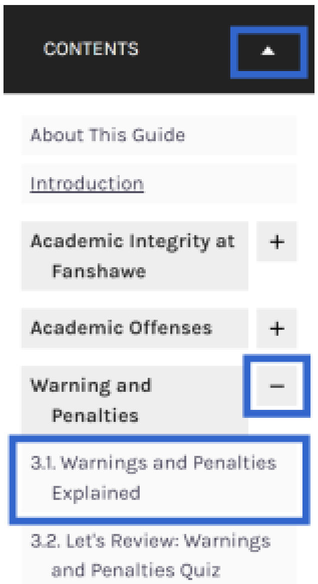


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# CHAPTER 1: EVOLUTION

## Chapter Overview

## Learning Objectives

By the end of this chapter, you will be able to:

- Explain the scientific theory of evolution and describe how it accounts for the diversity and common ancestry of life on Earth.
- Identify and interpret key fossil evidence that challenges the concept of static species and supports evolutionary change over time.
- Describe Charles Darwin's contributions to evolutionary theory, including the role of natural selection, and contrast them with earlier theories.
- Summarize the five main categories of evidence for evolution: fossils, comparative anatomy, biogeography, embryonic development, and genetic evidence.
- Differentiate between the mechanisms of evolution, including natural selection, mutation, gene flow, and genetic drift.
- Compare the different types of natural selection—stabilizing, directional, disruptive, frequency-dependent, and sexual selection.

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# 1.1 INTRODUCTION TO EVOLUTION

## What is Evolution?

All species of living organisms—from the bacteria on our skin, to the trees in our yards, to the birds outside—evolved at some point from a different species. Although it may seem that living things today stay much the same from generation to generation, that is not the case: evolution is ongoing.

**Evolution** is the process by which populations of organisms change over generations through inherited variations in traits. These changes can lead to the emergence of new species and the extinction of others. At its core, evolution explains the incredible diversity of life on Earth and how all living organisms are connected through common ancestry. It is important to understand that evolution is not a belief or a guess—it is a scientific theory, which means it is a well-supported explanation based on a large body of evidence from fields such as genetics, paleontology, comparative anatomy, and molecular biology.

## The Historical View of Static Species

Before the concept of evolution gained scientific acceptance, the prevailing belief in Western thought was that species were fixed and unchanging. This idea was rooted in both philosophical and religious traditions. Ancient Greek philosophers like Plato and Aristotle believed in a static natural world where all organisms had a fixed place, with humans at the top. This view was later reinforced by religious beliefs, which held that all species were created by God in their present form and had remained unchanged since creation. Many religious scholars also believed the Earth was only around 6000 years old. Such a worldview left little room for the idea that species could change over time.

## Early Naturalists and the Shift in Thinking

By the 18th century, observations made by naturalists and explorers began to challenge the idea of unchanging species. Naturalists were uncovering fossils of creatures that didn't resemble any known living organism.

**Mastodon** fossils in North America also suggested that species may change over time. These fossils resembled modern elephants but with distinct differences in tooth structure and skull shape that cast doubt on the belief that species remain fixed.

Figure 1.1.1 "Cohoes Mastodon, New York State Museum" by Kenneth C Zirkel, CC BY-SA 4.0

**Ammonites** have distinctive spiral shells that were once thought to be "snakestones", or serpents turned to stone, based on medieval folklore. However, these fossils were never found with heads, which puzzled early collectors and cast doubt on the legend. Ammonites were found embedded in rock layers across the globe, but didn't appear like anything that was currently living, raising the unsettling possibility of extinction.

Figure 1.1.2 "Ammonite Asteroceras" by Dlloyd, CC BY-SA 3.0

The discovery of the first **Ichthyosaurus** fossil in England was instrumental in the shift in thinking away from fixed species. The creature's dolphin-like body and reptilian features were unlike anything known, convincing naturalists that extinctions do occur.

Figure 1.1.3 "Ichthyosaurus" by Ballista, CC BY-SA 3.0

These discoveries offered compelling evidence that directly challenged the long-held belief in a static, unchanging natural world. In response, naturalists began to build on this growing body of fossil evidence and attempted to develop explanations for how life might change over time.

**Jean-Baptiste Lamarck** offered one of the first formal theories of evolution, suggesting that organisms could pass on traits acquired during their lifetimes, such as giraffes stretching their necks to reach higher leaves. In Lamarck's theory, modifications in an individual caused by its environment, or the use or disuse of a structure during its lifetime, could be inherited by its offspring and, thus, bring about change in a species. While this mechanism for evolutionary change, as described by Lamarck, was discredited, his ideas were an important influence on evolutionary thought.

**Charles Lyell,** a geologist, challenged the predominant view that the geology of the planet was a consequence of catastrophic events occurring during a relatively brief past. Lyell argued that geological processes such as erosion and sedimentation occurred gradually over long periods. Lyell's work greatly influenced Darwin's thinking about slow, gradual biological change.

## Charles Darwin and the Voyage of the HMS Beagle

**Charles Darwin**, born in 1809, revolutionized biology with his theory of natural selection—the mechanism by which evolution occurs. In 1831, Darwin embarked on a five-year voyage aboard the **HMS Beagle**. During this journey, he observed a wide variety of plants, animals, and fossils.

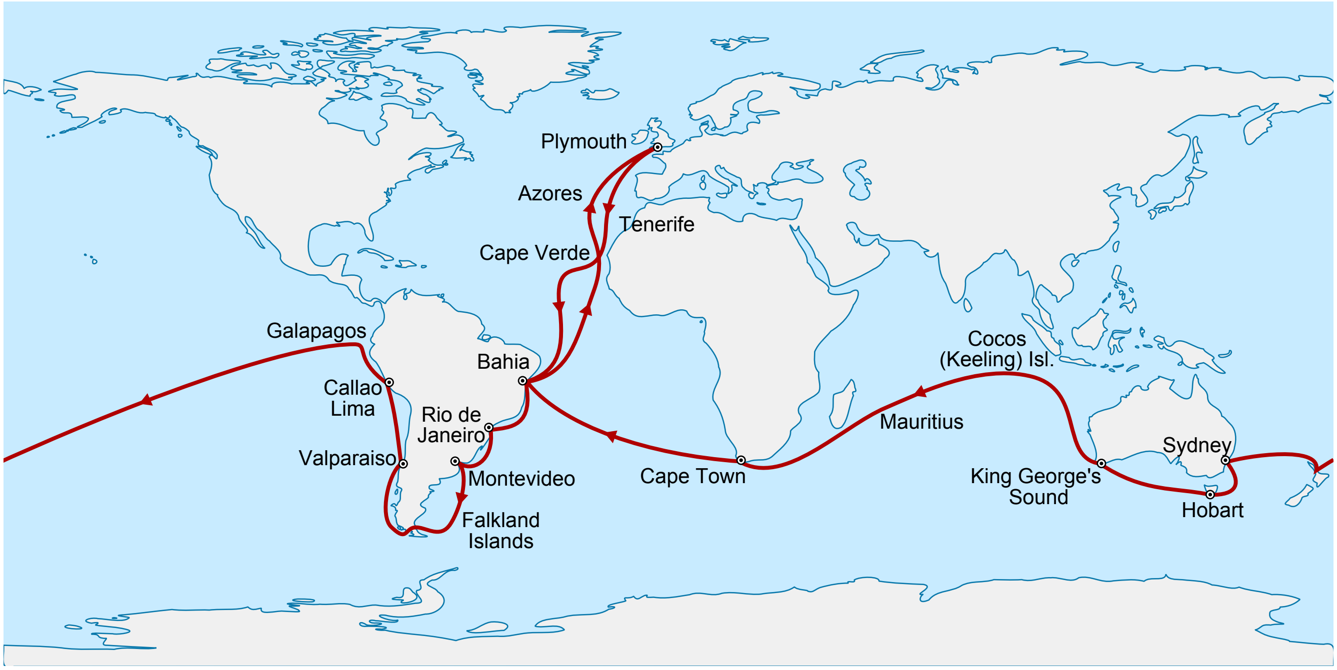


Figure 1.1.4 "Map of the Voyage of the Beagle" Sémhur, Wikimedia Commons, CC-BY-SA-4.0

Figure 1.1.4 Image Description

The image is a detailed black-and-white map illustrating the voyage of the HMS *Beagle* during Charles Darwin's famous expedition from 1831 to 1836. The map outlines the continents of South America, Africa, Australia, and parts of Europe, with a heavy emphasis on the southern hemisphere. A dotted line traces the *Beagle*'s route across the Atlantic, around the coasts of South America (including the Strait of Magellan), across the Pacific, around Australia, and back via the Indian Ocean and Cape of Good Hope. Key ports of call and notable waypoints are labelled along the path. Insets and labels indicate major geographic features, and a title at the top identifies the map as depicting the *Voyage of the Beagle*. The style has a historical, 19th-century cartographic appearance, consistent with period nautical charts.

One of the most significant stops on his voyage was the **Galápagos Islands**, off the coast of Ecuador. While exploring the islands, Darwin observed that many of the islands' species were similar to those on the South American mainland but had distinct differences that reflected their specific island environments.

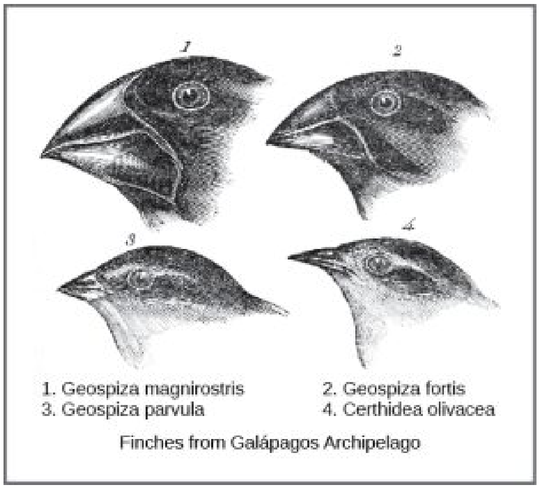


Figure 1.1.5 Image by OpenStax, CC BY 4.0

Among the most notable were the **finches**, whose beak shapes varied between the islands depending on their primary food sources, such as seeds, insects, or fruit (Figure 1.1.5).

Darwin postulated that the beak of an ancestral species had adapted over time to equip the finches to acquire different food sources. Figure 1.1.5 shows the beak shapes for four species of ground finch, each adapted to a specific diet. For example, the large ground finch (*Geospiza magnirostris*) has a very large, robust beak for cracking open hard seeds and nuts, while the small tree finch (*Geospiza parvula*) has a small, slightly curved beak better suited to foraging for insects among leaves and bark.

Darwin also studied **giant tortoises**, which had differently shaped shells and neck lengths depending on the vegetation available on each island.

Figure 1.1.6 Giant Tortoises. Top left: "Domed (porteri)" by putneymark, CC BY-SA 2.0, Bottom left: "Intermediate (chathamensis)" by mtkopone, CC BY-SA 2.0, and Right: "Saddleback (abingdoni)" by Mike Weston, CC BY 2.0

Darwin was also intrigued by the **marine iguanas** of the Galápagos Islands, which were unlike any lizards he had seen before. Although they shared many features with terrestrial iguanas from mainland South America, these Galápagos iguanas had evolved unique adaptations that allowed them to forage in the ocean, such as flattened tails for swimming, strong claws for clinging to rocks, and salt glands to expel excess salt from their bodies. Their resemblance to mainland species suggested to Darwin that they shared a common ancestor, but had diverged over time in response to their environment. In the Galápagos, where terrestrial vegetation is often sparse, the ability to feed on marine algae gave these iguanas a distinct survival advantage.

Figure 1.1.7 "Marine Iguana" by RAF-YYC, CC BY-SA 2.0

These observations supported Darwin's growing idea that species could adapt to their surroundings through natural processes, reinforcing the concept of evolution by natural selection.

## Charles Darwin and the Theory of Natural Selection

In 1859, Charles Darwin published *On the Origin of Species by Means of Natural Selection*, introducing the theory that species evolve gradually over time through a process he called **natural selection**. This mechanism explains how certain traits become more common in a population based on their impact on survival and reproduction. Natural selection relies on the idea that traits can be **inherited** (passed from parents to offspring) and that individuals within a species are not identical but show **variation** in their characteristics. Because organisms tend to produce more offspring than the environment can support (**overproduction**), this leads to competition for limited resources. In this struggle, individuals with traits that offer even slight advantages are more likely to survive and reproduce, gradually shaping the population over generations. We will cover more details on natural selection in Section 1.3.

Darwin was influenced by economist **Thomas Malthus**, who observed that human population growth often exceeds resource availability, resulting in disease, famine and war. Darwin applied this idea to other populations. He reasoned that offspring with inherited characteristics that allow them to best compete for limited resources will survive and have more offspring than those individuals with variations that are less able to compete. Because characteristics are inherited, these traits will be better represented in the next generation. This will lead to a change in populations over generations in a process that Darwin called "descent with modification."

Figure 1.1.8 (a) Charles Darwin and (b) Alfred Wallace wrote scientific papers on natural selection. [Image](#) by [OpenStax](#), [CC BY 4.0](#)

While Darwin was developing his ideas, another naturalist, **Alfred Russel Wallace**, independently arrived at a similar theory of evolution. Wallace had conducted extensive fieldwork in the Malay Archipelago and observed patterns in species distribution that led him to conclusions remarkably close to Darwin's. In 1858, Wallace sent Darwin a manuscript outlining his theory. Recognizing the significance of Wallace's work—and the overlap with his own—Darwin arranged for both of their ideas to be presented jointly at a meeting of the Linnean Society of London that same year. Presenting both works together gave the theory of natural selection a stronger foundation in the scientific community, showing that two independent naturalists had arrived at the same conclusion through different lines of evidence.

## Knowledge Check

**Text Description**

1. What is the process by which populations of organisms adapt over generations?

   a. Genetic drift
   b. Mutation
   c. Artificial selection
   d. Natural selection

2. Which of the following was a belief held by early philosophers like Plato and Aristotle regarding species?

   a. Species were fixed and unchanging
   b. Species can evolve over time
   c. Species were formed through natural selection
   d. Species were created by natural forces

3. What did the discovery of fossils like the Mastodon and Ichthyosaurus challenge?

a. The theory of natural selection
b. The belief that species remain fixed
c. The belief in extinct species
d. The idea of creationism

4. What did Charles Darwin observe about finches on the Galápagos Islands that contributed to his theory of natural selection?

a. Their beaks varied depending on their food sources
b. Their beaks were identical on all islands
c. They could only feed on seeds
d. They had wings adapted for long-distance flights

5. Who proposed one of the first formal theories of evolution, suggesting that traits acquired during an organism's lifetime could be inherited by offspring?

a. Charles Darwin
b. Thomas Malthus
c. Jean-Baptiste Lamarck
d. Alfred Russel Wallace

6. Which principle of natural selection explains why more offspring are produced than can survive?

a. Descent with modification
b. Variation
c. Overproduction
d. Heritability

7. How did Alfred Russel Wallace contribute to the theory of evolution?

a. He disproved the idea of species change
b. He worked with Lamarck on his evolutionary theory
c. He independently developed a similar theory to Darwin's
d. He discovered that organisms pass on acquired traits

8. What did the marine iguanas of the Galápagos Islands illustrate in Darwin's theory of evolution?

a. They were unchanged from their ancestors
b. They had evolved unique adaptations to survive in the ocean

c. They were an example of extinction
d. They had no relationship to mainland species

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**Answers:**

1. d. Natural selection
2. a. Species were fixed and unchanging
3. b. The belief that species remain fixed
4. a. Their beaks varied depending on their food sources
5. c. Jean-Baptiste Lamarck
6. c. Overproduction
7. c. He independently developed a similar theory to Darwin's
8. b. They had evolved unique adaptations to survive in the ocean

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# 1.2 EVIDENCE OF EVOLUTION

The evidence for evolution is compelling and extensive. Looking at every level of organization in living systems, biologists see the signature of past and present evolution. Darwin dedicated a large portion of his book, *On the Origin of Species*, to identifying patterns in nature that were consistent with evolution, and since Darwin, our understanding has become clearer and broader (Darwin, 2009).

Evidence of evolution can be divided into five main categories:

## 1. Fossils

**Fossils** are the preserved remains or traces of organisms that lived in the remote past (over 10,000 years ago). Many different types of fossils occur in various stages of completeness, collectively forming the fossil record, which provides a wealth of information about evolution (Figure 1.2.1).

A) B) C)

Figure 1.2.1 Examples of fossilized remains: Photo (a) "Caddisflies in Amber", by Anders L. Damgaard, CC BY-SA 4.0, Photo (b) a fossilized flatfish "Amphistium" by Totodu74, Public Domain, Photo (c) "Fossilized Dinosaur Footprints" by Greg Willis, CC BY-SA 2.0

Fossils provide solid evidence that organisms from the past are not the same as those found today; fossils show a progression of evolution. Scientists determine the age of fossils and categorize them all over the world to determine when the organisms lived relative to each other. The resulting fossil record tells the story of the past and shows the evolution of form over millions of years (Figure 1.2.2). For example, highly detailed fossil records have been recovered for sequences of species in the evolution of whales and modern horses.

The fossil record of horses in North America is especially rich, and many contain transition fossils: those showing intermediate anatomy between earlier and later forms. The fossil record extends back to a dog-like ancestor some 55 million years ago that gave rise to the first horse-like species 55 to 42 million years ago in the genus Eohippus. The series of fossil tracks shows the change in anatomy resulting from a gradual drying trend that changed the landscape from a forested one to a prairie. Successive fossils show the evolution of tooth shapes and foot and leg anatomy to a grazing habit, with adaptations for escaping predators, for example, in species of Mesohippus found from 40 to 30 million years ago. Later species showed gains in size, such as those of Hipparion, which existed from about 23 to 2 million years ago. The fossil record shows several adaptive radiations in the horse lineage, which is now much reduced to only one genus, Equus, with several species.

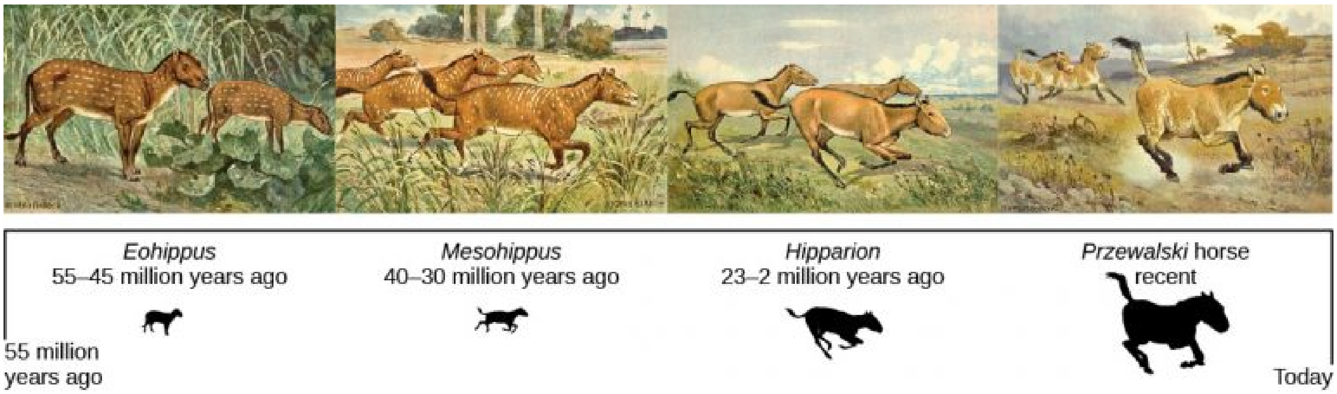


Figure 1.2.2: This illustration shows an artist's renderings of species derived from fossils of the evolutionary history of the horse and its ancestors. The species depicted are only four from a very diverse lineage that contains many branches, dead ends, and adaptive radiations. One of the trends, depicted here, is the evolutionary tracking of a drying climate and an increase in prairie versus forest habitat, reflected in forms that are more adapted to grazing and predator escape through running. Przewalski's horse is one of the few living species of horse. Image by OpenStax, 

## 2. Comparative Anatomy

Related organisms have similar bodily structures or anatomy; for example, the skeletons of humans, cats, and bats are similar, despite numerous obvious differences. There is a bone-by-bone similarity in the bodies of these three animals. Anatomical similarities are particularly evident in a comparison of the forelimbs (Figure 1.2.3). These animals live in different types of environments and use their limbs for different functions–flying, swimming, or grasping and throwing. Despite these different functions, all of these animals possess limbs with certain shared characteristics: a five-digit structure, a single large bone (humerus), two bones in the forearm (ulna and radius), and several wrist bones. These bones are homologous to each other; that is, they were inherited from a common ancestor.

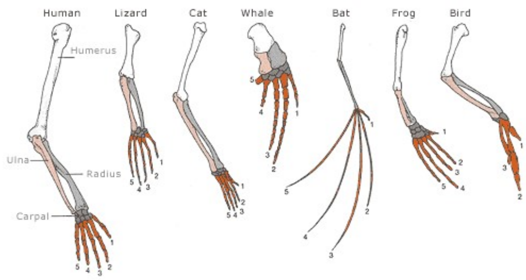


Figure 1.2.3 Homologies in vertebrate forelimbs. Image by OpenStax, CC BY 4.0

All four-limbed animals (or **tetrapods**)–amphibians, reptiles, birds, and mammals–have similar limbs. Anatomical similarities, such as those that characterize tetrapod limbs, are used as evidence for common ancestry. In other words, these similarities suggest that birds, bats, whales, and humans all share a common ancestor somewhere in their distant past. Learning about shared ancestry provides an important clue to understanding an organism's evolution.

## Homologous Structures

**Homologous structures,** or homologies, are anatomical features that different organisms share as a result of a common ancestor. The tetrapod limbs discussed above are homologous. Because they evolved from an ancestor and are currently shared by different organisms, homologies are often called shared derived traits. Cactus spines, the leaves of a maple tree, and the cup-like "pitcher" of a pitcher plant are all modified from a common structure in an ancestor shared by all leaf-bearing land plants. While these leaves look different and have evolved to serve different purposes, they are homologous structures and tell important stories about each plant's history (Figure 1.2.4). These differences are the result of **divergent evolution**, where species with a common ancestor evolve distinct traits in response to different environmental pressures.


Figure 1.2.4 Leaves as homologous structures. Cactus spines, the leaves of a maple tree, and the cup-like "pitcher" of a pitcher plant are all modified from a common structure in an ancestor shared by all leaf-bearing land plants.  a)"Red Maple", by Dcrjsr, CC BY 3.0 b) "Maihueniopsis darwinii", by Frank Vincentz, CC BY 3.0 c) "Pitcher Plant", by Drew Avery, CC BY 2.0

## Analogous Structures

**Analogous structures,** or analogies, are anatomical features that different types of organisms share, but not as a result of a shared ancestor. Instead, analogies are similar because the organisms have changed in response to similar environments. When distantly related organisms share features as a result of similar environmental pressures (and not because of common ancestry), we say that they have undergone **convergent evolution**. For example, arctic mammals such as foxes and snowshoe hares grow white fur during the winter months. White fur allows these organisms to blend into the ice and snow that characterizes their polar home and presumably protects them from predation. Foxes and snowshoe hares, however, do not share a common ancestor with white fur. Of course, they ultimately share a common ancestor, as do all mammals, but the fox lineage is full of non-white animals, as is the group to which hares belong. The winter white of arctic foxes and snowshoe hares is thus an analogous structure, resulting from convergent evolution in a white, wintry landscape.

## Vestigial Structures

Figure 1.2.5 The vestigial piloerection of humans leads to goosebumps. Photo by Ildar Sagdejev, CC BY-SA 3.0

**Vestigial structures** are anatomical features that are either no longer in use or have a use which has been greatly reduced or altered. Vestigial structures provide clues to an organism's history by suggesting what features were useful in the past, and by linking an organism to other, related organisms. For example, many mammals exhibit **piloerection**, whereby muscles constrict around the hair follicles and the animal's hair stands on end. If you've ever surprised or otherwise threatened a dog or cat, you've probably seen the results of piloerection. Humans are mammals too, but we've been reduced to a scant covering of body hair. When we are scared, we also constrict the muscles around our hair follicles, but this just gives us goosebumps (Figure 1.2.5). Goosebumps aren't very scary, but as vestigia, they link us to our mammalian relatives and tell us something about our evolutionary history.

# 3. Biogeography

**Biogeography**, the study of the distribution of living organisms, addresses several evolutionary questions: How many types of organisms exist? Why are some types of organisms (e.g. insects) more abundant than others (e.g. mammals)? Why do certain organisms live in some places and not others? Why do islands have such distinct biodiversity compared to the larger continents? Why aren't there any polar bears in Antarctica? Why aren't there any giraffes in Hawaii? And so on….

Likewise, an understanding of evolution helps us appreciate the otherwise perplexing global distribution of marsupial mammals (Figure 1.2.6). **Marsupials** are mammals in which females transport their young in distinctive pouches throughout their early infancy. In contrast, placental mammals have placental gestation and young that are born at a more developed stage. Marsupial mammals, such as kangaroos, opossums, wombats, and wallabies, occur in North and South America, Australia, and New Guinea, whereas the more numerous placental mammals dominate the rest of the world. How can we explain these odd distribution patterns?

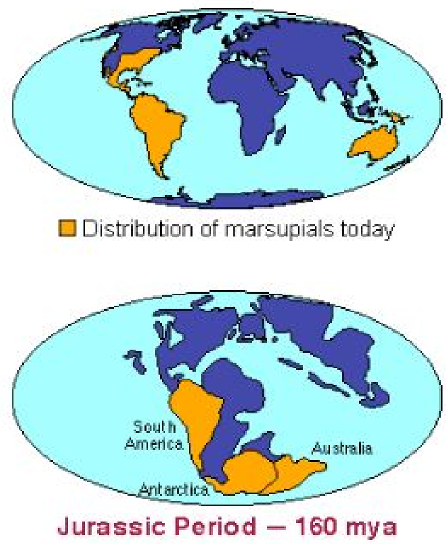


Figure 1.2.6. Distribution of marsupials today versus the Jurassic period. Image by Katherine Furniss and Sarah Hammarlund, CC BY-NC 4.0

Knowledge of Earth's history is key to biogeography and evolutionary understanding. Indeed, a consideration of **continental drift**—the movement of the continents, over geologic time, as a result of the movement of plates in Earth's crust (discussed in more depth in 3.1)—is necessary to understand marsupial biogeography (Figure 1.2.7). We also know, from fossil evidence, that marsupials originated over 150 million years ago in China, at a time when the Asian and North American landmasses were joined. Marsupials dispersed to South America, and from there to Antarctica and Australia, both of which were attached to South America. When Australia, Antarctica, and South America drifted apart, each landmass carried a population of marsupial mammals. Over time, Australia's marsupials evolved into the bandicoots, kangaroos, koalas, and other marsupials that inhabit the continent today. When Australia moved closer to Asia, about 15 million years ago, placental mammals such as rats and bats colonized the landmass.

Figure 1.2.7 Marsupial mammals. Clockwise: Kangaroo, Opossum, Long-nosed bandicoot, Monito del Monte, Tasmanian Devil. Image by LittleJerry, CC BY-SA 4.0

## 4. Comparative Embryology

Studying how embryos develop in different species can help scientists understand evolutionary relationships. Species with more similar development patterns are often more closely related.

Scientists observe how organisms grow and change after fertilization. In vertebrates, the fertilized egg divides into many cells and forms a ball. This ball continues to change shape and structure as development progresses. At early stages, embryos of different species—like mice, sea urchins, and chickens—can look very similar under a microscope. This similarity suggests they share a common ancestor.

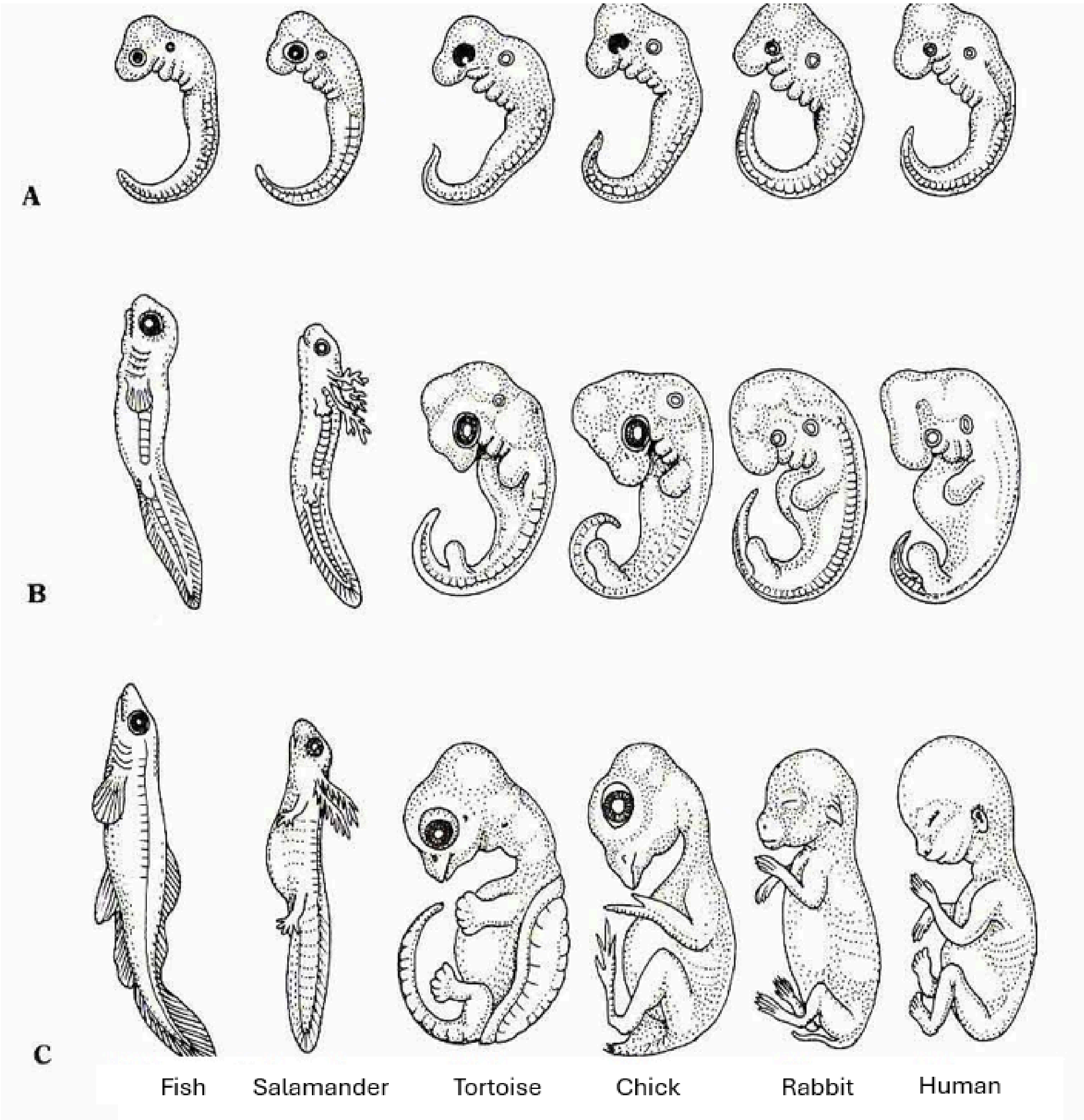


Figure 1.2.8 Comparison of embryos. Image by Starlarvae, CC BY-SA 3.0

Even though many species start with similar structures during development, these structures often take on different roles in adults. These shared features (homologous structures) point to a shared evolutionary history. For example, embryos of humans, fish, birds, and reptiles all have similar features that later develop into different parts of the body, like gills in fish and parts of the ear and throat in humans.

# 5. Genetic Evidence

All living things use DNA as their genetic material, and the way DNA is read and used is nearly the same across all life. This strongly suggests that all life shares a common ancestor. In general, the more similar the DNA of two organisms is, the more closely related they are. This matches what we would expect if all life came from a common ancestor and changed over time.

For example, as seen in Figure 1.2.8, humans share about 98.8% of their DNA with chimpanzees, making them our closest living relatives. We also share 90% with cats, 84% with dogs, and 80% with cows. Even more surprisingly, humans share about 60% of their DNA with fruit flies and bananas. These similarities show how all living things are connected through evolution, even if they look very different on the outside.

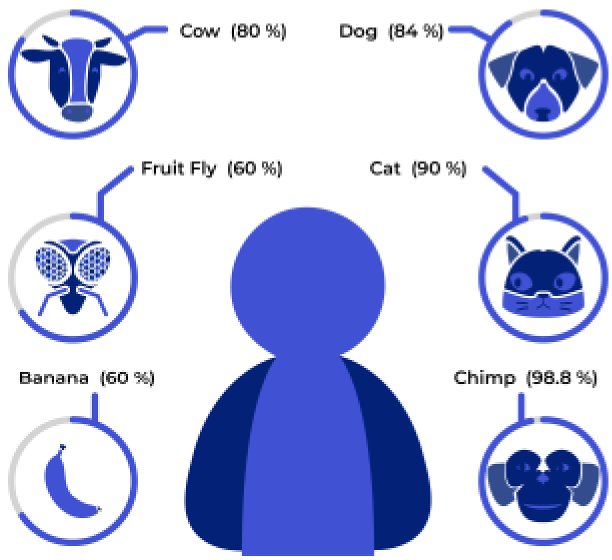


Figure 1.2.9 Percentage of DNA shared between humans and other organisms. Image by Koen Liddiard, CC BY-NC-SA 4.0

## Knowledge Check

**Text Description**

1. Which of the following is NOT one of the five main categories of evidence for evolution?

   a. Fossils
   b. Comparative anatomy
   c. Climate change
   d. Genetic evidence

2. What does the fossil record show about the evolution of horses?

   a. Horses have remained unchanged for millions of years
   b. Horses evolved from a dog-like ancestor to modern species
   c. Horses evolved from a species of fish
   d. Horses first appeared around 100 million years ago

3. What does the similarity in the forelimbs of different animals (e.g., humans, bats, and whales) suggest?

   a. These animals share a common ancestor
   b. These animals evolved through convergent evolution
   c. These animals have analogous structures
   d. These animals adapted to similar environments

4. What is an example of an analogous structure?

   a. The similar forelimb bones of humans and bats
   b. The wings of birds and insects
   c. The vertebrate skeletal structure in mammals
   d. The similar leaves of maple trees and cacti

5. Which of the following is an example of a vestigial structure in humans?

   a. Wisdom teeth
   b. Spleen

c. Bones in the forelimb
d. Hair

6. What does biogeography help explain about the distribution of marsupial mammals?

a. They originated in North America and spread globally
b. They evolved in isolation after the continents drifted apart
c. They are found only in Africa and Asia
d. They evolved after the last Ice Age

7. How does the study of embryonic development provide evidence for evolution?

a. Species with similar embryonic development patterns are likely unrelated
b. Species with similar embryos share a common ancestor
c. Embryos of all species look identical under a microscope
d. Embryonic development does not offer evidence for evolution

8. What does the genetic evidence of DNA similarities between humans and chimpanzees suggest?

a. Humans and chimpanzees are unrelated species
b. Humans and chimpanzees share a common ancestor
c. Humans evolved from chimpanzees
d. DNA evidence does not support evolutionary theory

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**Answers:**

1. c. Climate change
2. b. Horses evolved from a dog-like ancestor to modern species
3. a. These animals share a common ancestor
4. b. The wings of birds and insects
5. a. Wisdom teeth
6. b. They evolved in isolation after the continents drifted apart
7. b. Species with similar embryos share a common ancestor
8. b. Humans and chimpanzees share a common ancestor

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Create 8 multiple-choice questions using the following content

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# 1.3 MECHANISMS OF EVOLUTION

Many students mistakenly use the term “evolution” as if it means the same thing as “natural selection,” but they are not identical. Evolution refers to the overall process of change in the genetic makeup of populations over time. Natural selection is just one of the mechanisms that drive evolution. It occurs when individuals with traits better suited to their environment are more likely to survive and reproduce. It is the only way in which populations evolve adaptively.

We can see more random changes in a population through other evolutionary mechanisms, such as random mutations, genetic drift, and gene flow.

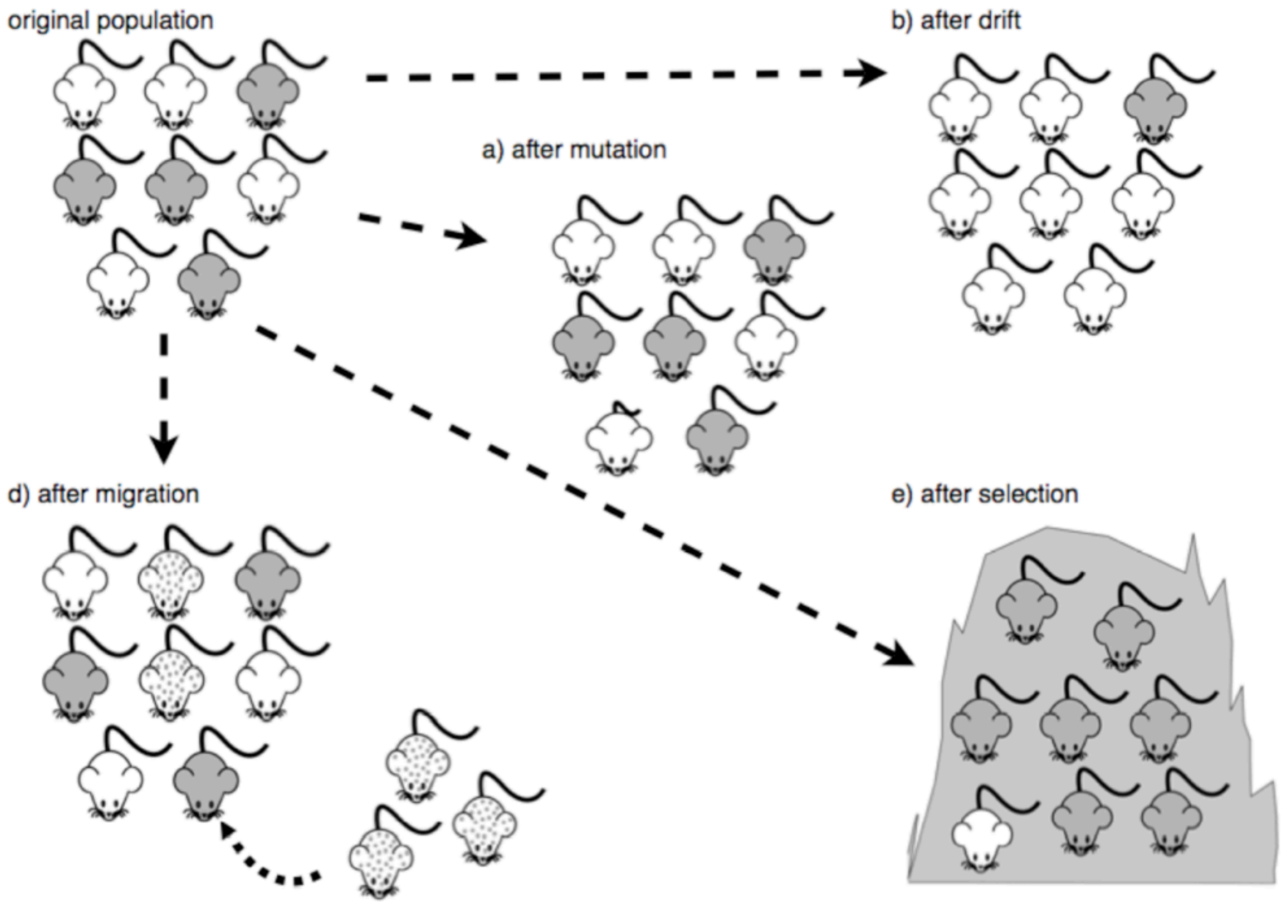


Figure 1.3.1 Populations evolve through mutation, natural selection, migration, and drift. The dashed arrows show that multiple generations have occurred, so the mice in the original population are not the same individuals as in the later populations. After mutation, one of the mice has a shorter tail, caused by one or more random changes in the mouse's DNA. After drift, the frequency of dark mice has decreased simply by random chance. After migration, spotted mice have joined the population from another population. After selection, the mice have adapted to a new environment (a darker habitat). Image by Sehoya Cotner, CC BY-NC

## Mutations

A **mutation** is a random change in the DNA sequence of an organism. Errors in DNA replication and exposure to environmental factors (like radiation or chemicals) can lead to mutations.

A population has high **genetic variation** when there are many different variants of genes within the population. Mutations contribute to this variation by creating new gene variants. In this sense, mutations are the ultimate source of genetic diversity in evolving populations and provide the raw material for natural selection to act upon.

When a novel mutation arises, the population has changed, so mutation alone is a mechanism of evolution.

However, a single random mutation is unlikely to have a major impact on its own. Other evolutionary mechanisms—such as natural selection, gene flow, and genetic drift— play a larger role in determining whether that mutation becomes widespread.

Mutations can be harmful, beneficial, or neutral, depending entirely on the environmental context. Harmful mutations may reduce an individual's chances of survival or reproductive success and are typically removed from the population through natural selection. Beneficial mutations, on the other hand, can provide an advantage in a specific environment, such as improving survival or reproduction, and are more likely to spread. These mutations are often associated with natural selection because they lead to adaptations that help organisms respond to selective pressures. Some mutations have no effect on an organism's fitness. These neutral mutations are not influenced by natural selection and instead change in frequency due to other evolutionary mechanisms like genetic drift or gene flow.

## Genetic Drift

**Genetic drift** is a random change in allele frequencies in a population, especially noticeable in small populations. Unlike natural selection, which is driven by advantages in survival or reproduction, genetic drift happens by chance. For example, if an individual dies before reproducing or fails to find a mate, their alleles may be lost from the population, not because they were harmful, but just by luck.

In small populations, losing even one individual can significantly change the gene pool. For instance, in a group of 10 individuals, one death could remove 10% of the genetic variation. In a population of 1000, that one individual represents only 0.1% of the overall gene pool; therefore, it has much less impact on the population's genetic structure and is unlikely to remove all copies of even a relatively rare allele.

Figure 1.3.2 Genetic drift in a population of beetles. Two green individuals are randomly lost because someone steps on them, not because they are green, but because those beetles randomly happen to be under the person's foot. The frequency of green beetles drops, and the degree of variation in the population therefore declines. Drift tends to decrease variation. [Image](#) by [UC Museum of Paleontology](#), [CC-BY-NC-SA 4.0](#)

There are two key types of genetic drift:

## Bottleneck Effect

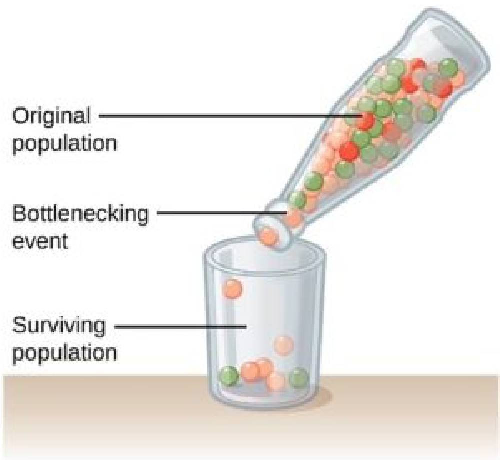


Figure 1.3.3: A chance event that dramatically reduces the population size can alter the allele frequencies in the population. "Bottleneck Effect" by OpenStax, CC BY 4.0

Natural events, such as an earthquake disaster that randomly kills a large portion of the population, can magnify the effects of genetic drift. These situations, where a large portion of the gene pool is suddenly and randomly eliminated, are called the **bottleneck effect** (Figure 1.3.2). At once, the survivors' genetic structure (i.e., allele frequencies) becomes the entire population's genetic structure, which may be very different from the pre-disaster population. Almost certainly, rare alleles are lost from the population, resulting in a decrease in the variability in the population. The survivors reproduce to create the next generation, which can have dramatically different allele frequencies compared to the population before the bottleneck event occurred. Bottleneck effects are a special case of genetic drift where the effects of drift are particularly strong because a population's size has been dramatically reduced.

## Founder Effect

- Another scenario in which populations might experience a strong influence of genetic drift is if some portion of the population leaves to start a new population in a new location. It is likely that the small number of individuals who found the new population have different allele frequencies than the entire population due to random chance. Thus, the new population can end up having very different allele frequencies than the original source population due to genetic drift – this is called the **founder effect**.

Tristan da Cunha, one of the most remote inhabited islands in the world, provides a classic example of the founder effect. In 1816, the island was settled by just a few individuals, including one man who unknowingly carried a rare allele for retinitis pigmentosa, a genetic disorder that causes progressive blindness. Due to the island's isolation and small population size, this allele was passed down through generations and became unusually common. Among roughly 240 descendants, several individuals developed blindness, and others were carriers of the condition. This high frequency of a rare genetic disorder, far above global averages, occurred not because the allele was advantageous, but purely due to chance (Berry, 1967).

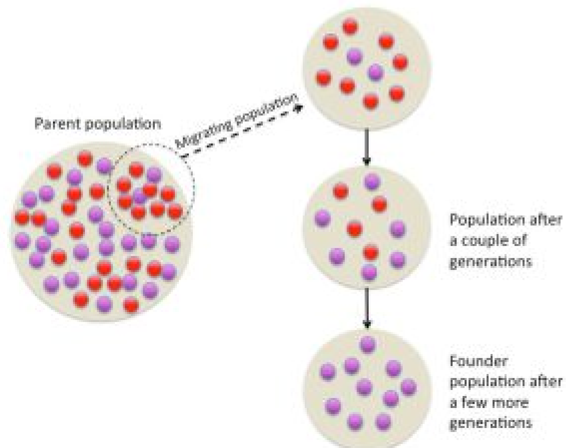


Figure 1.3.4: "Founder effect illustration" By Tsaneda, CC BY 3.0

Figure 1.3.4 Image Description

The image is a diagram illustrating the founder effect in population genetics.

- On the left, a large beige circle labelled "Parent population" contains many individuals represented by small red and purple circles mixed together.
- A smaller group of circles, highlighted within a dashed oval, is labelled "Migrating population" and shown moving to the right with a dashed arrow. This migrating group contains a higher proportion of red circles than in the original parent population.
- To the right, the migrating group forms a new, smaller beige circle representing the initial population in the new location. This group has fewer total individuals, mostly red with some purple.
- An arrow points downward to the next beige circle labelled "Population after a couple of generations", showing more mixing but still a smaller, less diverse gene pool compared to the original population.
- A final arrow leads to the bottom beige circle labelled "Founder population after a few more

generations”, which now consists almost entirely of purple circles, showing reduced genetic variation over time due to genetic drift.

The diagram visually explains how a small migrating population can lead to reduced genetic diversity and altered allele frequencies in future generations.

Genetic drift can lead to significant evolutionary changes over time, especially in small populations where random events have a larger impact.

## Gene Flow

**Gene flow** refers to the flow of alleles in and out of a population due to the migration of individuals or gametes. While some populations are fairly stable, others experience more flux. Many plants, for example, send their pollen far and wide, by wind or by a pollinator, to pollinate other populations of the same species some distance away. Even a population that may initially appear to be stable, such as a pride of lions, experiences immigration (coming into) and emigration (departing from) as developing males leave their mothers to seek out a new pride with genetically unrelated females. The flow of individuals in and out of populations changes the population’s allele frequencies. When an individual migrates into a new population, it may sometimes carry alleles that were not present in that population before, introducing new genetic variation into that population. Alternatively, if an individual emigrates from (leaves) a population where it is the only individual with a particular allele, it can result in its original population losing genetic diversity. Migration between populations causes them to become more genetically similar to each other. For example, alleles that may be present in one population but not the other can become present in both populations when a migrating individual introduces that allele to the new population.

In either case, emigration or immigration, if it changes the allele frequency of a trait, it results in evolution. For example, if the trait in question is coloration and a population of beetles has only the variation or allele of green colour, the allele frequency will change if a brown beetle immigrates into this population. Evolution has occurred (Figure 1.3.5).

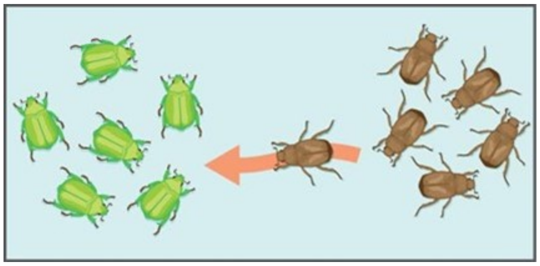

Figure 1.3.5 Gene flow occurs when an individual migrates from one population to another. This results in non-adaptive evolution. "Gene Flow" by OpenStax, CC BY 4.0

There are many examples of populations evolving through gene flow. One interesting case involves the global distribution of HIV resistance in humans. A mutation in the CCR5 gene provides resistance to certain forms of HIV, yet it is not the most common in regions with high rates of HIV and AIDS. This mutation is relatively recent—biochemical and geographic evidence suggests it originated in Northern Europe about 1,200 years ago. Interestingly, the mutation spread globally long before HIV became a threat to human health. Its distribution closely follows the migration patterns of the Vikings during the 9th to 11th centuries, suggesting they may have carried the mutation with them as they settled new territories. Why the mutation was common among Vikings is still uncertain—it may have offered a survival advantage, or it may have become widespread through the founder effect.

## Natural Selection

We've already introduced natural selection, but let's take a closer look.

**Natural selection** is the process by which individuals with traits better suited to their environment are more likely to survive and reproduce. Being better suited means they can more effectively overcome environmental challenges, known as **selective pressures**, such as predators, climate, food availability, or competition. Individuals with traits that help them cope with these pressures tend to leave more offspring, passing those beneficial traits to the next generation.

Over time, this process increases the frequency of advantageous traits in a population, leading to adaptation. An adaptation is a heritable trait that aids the survival and reproduction of an organism in its present environment. An adaptation is a "match" of the organism to the environment. Whether or not a trait is favourable depends on the environment at the time. The same traits do not always have the same relative benefit or disadvantage because environmental conditions can change. For example, finches with large bills benefited in one climate, while small bills were a disadvantage; in a different climate, the relationship reversed.

For natural selection to occur, there are three requirements:

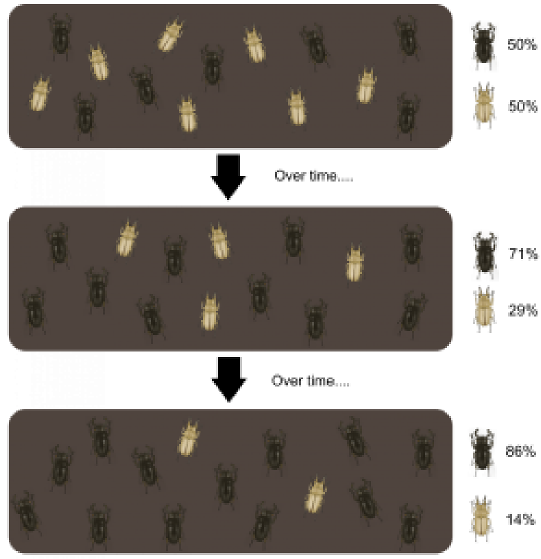


Figure 1.3.6 Evolution within a population of beetles. The dark-colored beetles increase in frequency over several generations. Image by Katherine Furniss and Sarah Hammarlund, CC BY NC

1. **Variation**. Multiple variants of genes must be present in a population for natural selection to produce any changes. Figure 1.3.6 shows a population of beetles that vary in their colour. In order for the population to evolve, the population must contain individuals with different colours. In the top panel, seven beetles are light-colored and 7 beetles are dark-colored.
2. **Heritability**. For a trait to be subject to natural selection, it must be heritable. By heritable, we mean that the trait must be passed down from parents to their offspring through their DNA sequences. In the beetle example, light-colored beetles produce light offspring, and dark-colored beetles produce dark offspring.
3. **Differential reproductive success**. An organism's ability to produce a relatively high number of offspring is its **reproductive success**. In order to evolve via natural selection, an organism's reproductive success must be directly affected by its traits. The number of offspring an individual produces in their lifetime is how scientists measure reproductive success. The more offspring, the higher the reproductive success. Some individuals will have no offspring, some a few, and some many. This is what we mean by differential reproductive success. In Figure 1.3.6, the beetles live on trees with dark-colored bark. Predators like birds can detect and kill light-colored beetles more easily than dark-colored beetles. This means that dark-colored beetles survive longer and therefore produce more offspring (have higher reproductive success than beetles with light coloration). We would say, "Dark-colored beetles are more fit", where **fitness** is a measure of an individual's relative reproductive success compared to others in the population.

There are several ways selection can affect population variation. The three general outcomes of natural selection include:

## Stabilizing Selection

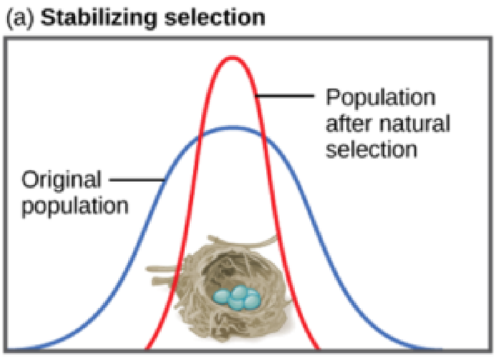


Figure 1.3.7 An average phenotype is favoured. For example, robins typically lay four eggs. Larger clutches may result in malnourished chicks, while smaller clutches may result in no viable offspring. "Types of Selection" by OpenStax, CC BY 4.0 Modified: cropped.

If natural selection favours an average phenotype, selecting against extreme variation, the population will undergo **stabilizing selection**. In a population of mice that live in the woods, for example, natural selection is likely to favour individuals that best blend in with the forest floor and are less likely to be spotted by predators. These camouflage mice are more adapted to that environment and will be more fit (reproducing more and leaving more descendants). Assuming the ground is a fairly consistent shade of brown, those mice whose fur is most closely matched to that colour will be most likely to survive and reproduce, passing on their genes for their brown coat. Mice that carry alleles that make them a bit lighter or a bit darker will stand out against the ground and be more likely to fall victim to predation. As a result of this selection, the population's genetic variance will decrease.

## Directional Selection

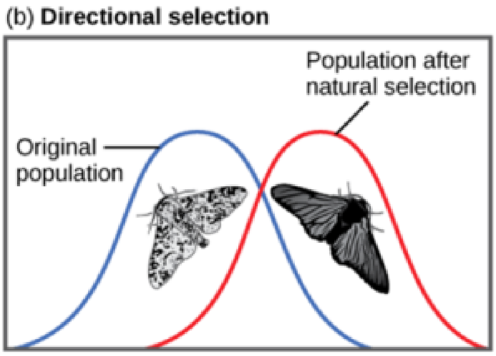


Figure 1.3.8 A change in the environment shifts the spectrum of phenotypes observed. As the Industrial Revolution progressed in 19th-century England, the colour of the moth population shifted from light to dark. "Types of Selection" by OpenStax, CC BY 4.0 Modified: cropped.

When the environment changes, populations will often undergo **directional selection**, which selects for phenotypes at one end of the spectrum of existing variation. A classic example of this type of selection is the evolution of the peppered moth in eighteenth- and nineteenth-century England. Prior to the Industrial Revolution, the moths were predominantly light in colour, which allowed them to blend in with the light-colored trees and lichens in their environment. But as soot began spewing from factories, the trees became darkened, and the light-colored moths became easier for predatory birds to spot. Over time, the frequency of the darker form of the moth increased because they had a higher survival rate in habitats affected by air pollution, as their darker coloration blended with the sooty trees. Similarly, the hypothetical mouse population may evolve to take on a different coloration if something were to cause the forest floor where they live to change colour. The result of this type of selection is a shift in the population's genetic variance toward the new, fit phenotype.

### Disruptive Selection

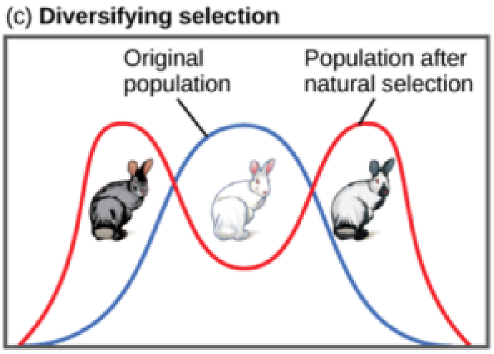


Figure 1.3.9 Two or more extreme phenotypes are selected for, while the average phenotype is selected against. "Types of Selection" by OpenStax, CC BY 4.0 Modified: cropped.

Sometimes two or more distinct phenotypes can each have their advantages and be selected for by natural selection, while the intermediate phenotypes are, on average, less fit. Known as **disruptive (or diversifying) selection**, this is seen in many populations of animals that have multiple male forms. Large, dominant alpha males obtain mates by brute force, while small males can sneak in for furtive copulations with the females in an alpha male's territory. In this case, both the alpha males and the "sneaking" males will be selected for, but medium-sized males, which can't overtake the alpha males and are too big to sneak copulations, are selected against. Diversifying selection can also occur when environmental changes favour individuals on either end of the phenotypic spectrum. Imagine a population of mice living at the beach where there is light-colored sand interspersed with patches of tall grass. In this scenario, light-colored mice that blend in with the sand would be favoured, as well as dark-colored mice that can hide in the grass. Medium-colored mice, on the other hand, would not blend in with either the grass or the sand and would thus be more likely to be eaten by predators. The result of this type of selection is increased genetic variance as the population becomes more diverse.

## Frequency-Dependent Selection

Figure 1.3.10 A yellow-throated side-blotched lizard is smaller than either the blue-throated or orange-throated males and appears a bit like the females of the species, allowing it to sneak copulations. "Lizard" by tinyfroglet, CC BY 2.0

**Frequency-dependent selection** is a type of natural selection that favours phenotypes that are either common (positive frequency-dependent selection) or rare (negative frequency-dependent selection). An interesting example of this type of selection is seen in a unique group of lizards of the Pacific Northwest. Male common side-blotched lizards come in three throat-colour patterns: orange, blue, and yellow. Each of these forms has a different reproductive strategy: orange males are the strongest and can fight other males for access to their females; blue males are medium-sized and form strong pair bonds with their mates; and yellow males (Figure 1.3.10) are the smallest, and look a bit like females, which allows them to sneak copulations. Like a game of rock-paper-scissors, orange beats blue, blue beats yellow, and yellow beats orange in the competition for females. That is, the big, strong orange males can fight off the blue males to mate with the blue's pair-bonded females, the blue males are successful at guarding their mates against yellow sneaker males, and the yellow males can sneak copulations from the potential mates of the large, orange males.

In this scenario, orange males will be favoured by natural selection when the population is dominated by blue males, blue males will thrive when the population is mostly yellow males, and yellow males will be selected for when orange males are the most populous. As a result, populations of side-blotched lizards cycle in the distribution of these phenotypes—in one generation, orange might be predominant, and then yellow males will begin to rise in frequency. Once yellow males make up a majority of the population, blue males will be selected for. Finally, when blue males become common, orange males will once again be favoured.

## Sexual Selection

**Sexual selection** is a form of natural selection that occurs when individuals with certain traits are more likely to attract mates and reproduce. These traits may not directly improve survival, but they increase reproductive success by making individuals more appealing to potential mates or more competitive in securing them.

In many species, males and females differ significantly in appearance beyond their reproductive organs—a phenomenon known as **sexual dimorphism**. Males are often larger and more elaborately adorned, like the peacock's colourful tail, while females tend to be smaller and less decorated. This difference arises because, in many animal populations, a few males achieve most of the matings, while others may get none. Since eggs are energetically costly to produce and females often invest more in raising offspring, they tend to be more selective in choosing mates. This choosiness drives males to evolve traits that increase their chances of being selected, such as larger body size, brighter colours, or elaborate displays. As a result, sexual selection creates strong pressure on males to stand out and compete for limited mating opportunities.

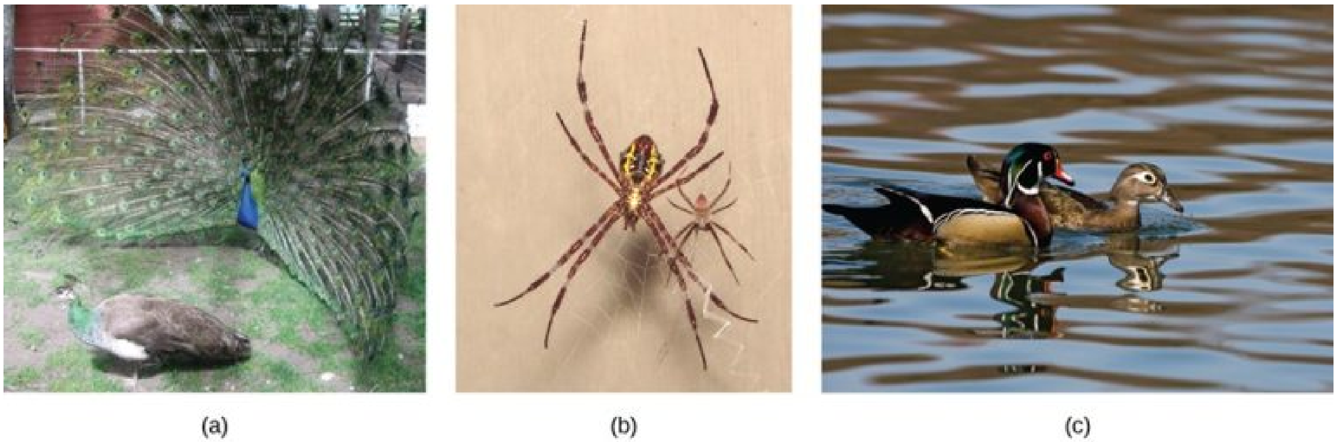


Figure 1.3.11 Sexual dimorphism is observed in (a) peacocks and peahens, (b) Argiope appensa spiders (the female spider is the large one), and in (c) wood ducks. Images by OpenStax, CC BY 4.0 Modified: cropped.

Sexual dimorphism varies widely among species, of course, and some species are even sex-role reversed. In such cases, females tend to have a greater variance in their reproductive success than males and are correspondingly selected for the bigger body size and elaborate traits usually characteristic of males.

## Knowledge Check

**Text Description**

1. What is the process by which populations of organisms change over generations?

  a. Genetic drift
  b. Artificial selection
  c. Natural selection
  d. Mutation

2. Which of the following was a belief held by early philosophers like Plato and Aristotle regarding species?

  a. Species can evolve over time
  b. Species were formed through natural selection
  c. Species were fixed and unchanging
  d. Species were created by natural forces

3. What did the discovery of fossils like the Mastodon and Ichthyosaurus challenge?

  a. The theory of natural selection
  b. The idea of creationism
  c. The belief that species could evolve over time
  d. The belief in extinct species

4. What did Charles Darwin observe about finches on the Galápagos Islands that contributed to his theory of natural selection?

  a. Their beaks were identical on all islands
  b. They had wings adapted for long-distance flights
  c. Their beaks varied depending on their food sources
  d. They could only feed on seeds

5. Who proposed one of the first formal theories of evolution, suggesting that traits acquired during an organism's lifetime could be inherited by offspring?

a. Thomas Malthus
b. Charles Darwin
c. Jean-Baptiste Lamarck
d. Alfred Russel Wallace

6. Which principle of natural selection explains why more offspring are produced than can survive?

a. Heritability
b. Variation
c. Descent with modification
d. Overproduction

7. How did Alfred Russel Wallace contribute to the theory of evolution?

a. He worked with Lamarck on his evolutionary theory
b. He independently developed a similar theory to Darwin's
c. He disproved the idea of species change
d. He discovered the process of natural selection

8. What did the marine iguanas of the Galápagos Islands illustrate in Darwin's theory of evolution?

a. They had evolved unique adaptations to survive in the ocean
b. They had no relationship to mainland species
c. They were an example of extinction
d. They were unchanged from their ancestors

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**Answers:**

1. c. Natural selection
2. c. Species were fixed and unchanging
3. c. The belief that species could evolve over time
4. c. Their beaks varied depending on their food sources
5. c. Jean-Baptiste Lamarck
6. d. Overproduction
7. b. He independently developed a similar theory to Darwin's
8. a. They had evolved unique adaptations to survive in the ocean

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Prompt: Create 8 multiple-choice questions using the following content

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# CHAPTER 1 SUMMARY

## Key Takeaways

- **Evolution Is a Scientific Theory Explaining Life's Diversity:** Evolution is the well-supported scientific theory that explains how populations change over generations through inherited traits. It accounts for the origin, diversity, and interconnectedness of all life forms via common ancestry, not as speculation, but as evidence-based science supported by genetics, fossils, anatomy, and molecular biology.
- **Fossil Discoveries Challenged the Idea of Static Species:** The belief that species were fixed was overturned by fossil evidence of extinct organisms like mastodons, ammonites, and ichthyosaurs. These findings led early naturalists to conclude that species could indeed change or disappear, laying the groundwork for theories of evolution.
- **Darwin's Observations on the HMS Beagle Led to Natural Selection:** During his voyage, Darwin observed how species like finches, tortoises, and marine iguanas had adapted to different environments. These insights, influenced by geological and economic theories, led him to propose natural selection—the process by which advantageous traits become more common over generations.
- **Multiple Lines of Evidence Support Evolution and come from:**
    - Fossils showing gradual changes in species over time
    - Comparative anatomy revealing homologous and vestigial structures
    - Biogeography demonstrating species distributions explained by plate tectonics
    - Embryonic development shows similar stages among related species
    - Genetic similarities across all life, confirming common ancestry
- **Evolution Proceeds Through Multiple Mechanisms:** Besides natural selection, evolution is driven by:
    - Mutations: Random genetic changes
    - Genetic drift: Random changes in small populations

- Gene flow: Migration of individuals/genes between populations

- **Natural Selection Shapes Populations in Diverse Ways and can result in:**
  - Stabilizing selection: Favouring average traits.
  - Directional selection: Shifting traits in one direction
  - Disruptive selection: Favouring extremes
  - Frequency-dependent selection: Favouring traits based on how common they are
  - Sexual selection: Favouring traits that improve mating success

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Prompt: Summarize the following content into six key takeaways.

## Flashcards

**Text Description**

Front of card:

1. Fossils
2. Charles Lyell
3. Diversifying or disruptive selection
4. Marsupials
5. Ichthyosaurus
6. Types of structures examined in comparative anatomy
7. Vestigial structures
8. Sexual dimorphism
9. Founder effect
10. Sexual selection
11. Alfred Russel Wallace
12. Continental drift

13. Analogous structures
14. Frequency-dependent selection
15. Giant tortoises
16. Piloerection
17. Genetic drift
18. Homologous structures
19. Charles Darwin
20. Tetrapods
21. Evidence of Evolution
22. Evolution
23. Outcomes of natural selection
24. Overproduction
25. Mastodon
26. Stabilizing selection
27. Natural selection
28. HMS Beagle
29. Adaptation
30. Requirements of natural selection
31. Types of Genetic Drift
32. Heritability
33. Marine iguanas
34. Mutation
35. Variation
36. Thomas Malthus
37. Jean-Baptiste Lamarck
38. Finches
39. Ammonites
40. Galápagos Islands
41. Directional selection
42. Biogeography
43. Mechanisms of Evolution
44. Gene flow
45. Bottleneck effect
46. Selective pressure
47. Genetic variation

Back of card:

1. Preserved remains or traces of ancient organisms provide evidence for evolution
2. A geologist who argued that the Earth changes slowly over time influenced Darwin's thinking
3. Natural selection that favours both extremes of a trait; intermediate phenotypes are often less fit
4. Mammals with pouches; their distribution supports ideas of continental drift and evolution
5. An extinct marine reptile; its fossil helped prove that extinction is real
6. Homologous structures, analogous structures, and vestigial structures
7. Body parts that have lost their original function through evolution
8. Differences in appearance between males and females of the same species, often due to sexual selection
9. Genetic drift occurs after a small number of individuals colonize a new area, leading to different allele frequencies
10. Type of natural selection that occurs when individuals with certain traits are more likely to attract mates and reproduce
11. Independently developed a theory of natural selection similar to Darwin's
12. The movement of Earth's continents explains patterns in fossil and species distribution
13. Body parts with similar function but different structure resulting from convergent evolution
14. Type of natural selection that favours phenotypes that are either common or rare
15. Galápagos animals with varied shell shapes and beak lengths; helped Darwin see adaptation to the environment
16. Hair standing up (e.g., goosebumps); a vestigial response in humans
17. A mechanism of evolution due to random changes in allele frequencies, especially in small populations
18. Body parts with similar structure but different functions show common ancestry
19. Developed the theory of evolution by natural selection
20. Four-limbed vertebrates; their forelimbs are homologous structures
21. 1) Fossils, 2) Comparative Anatomy, 3) Biogeography, 4) Embryonic Development, 5) Genetic Evidence
22. The change in the genetic makeup of populations over generations, often resulting in new species
23. Stabilizing Selection, Directional Selection, Disruptive Selection
24. More offspring are produced than can survive, leading to competition
25. An extinct relative of elephants; fossil evidence helped support the idea of extinction and

change over time

26. Natural selection that favours an average phenotype, selecting against extreme variation
27. The process by which individuals with favourable traits are more likely to survive and reproduce
28. The ship on which Darwin travelled and made observations that led to his theory of evolution
29. A heritable trait that improves an organism's ability to survive and reproduce in its environment
30. Variation, Heritability, Differential Reproductive Success
31. Bottleneck effect, Founder effect
32. The ability of a trait to be passed from one generation to the next
33. Galápagos reptiles that swim and feed in the ocean; they helped Darwin see adaptation to the environment
34. A change in DNA, the source of new genetic variation
35. Differences among individuals in a population; essential for natural selection
36. An economist who proposed that populations grow faster than resources, influenced Darwin
37. Proposed an early theory of evolution involving the inheritance of acquired traits
38. Birds from the Galápagos Islands; differences in their beaks helped Darwin develop his theory of natural selection
39. Extinct marine mollusks with spiral shells; their fossils suggested that species can go extinct
40. The location where Darwin observed unique species that influenced his ideas on evolution
41. Natural selection that selects for phenotypes at one end of the spectrum of existing variation
42. The study of where organisms live supports evolution through geographic distribution
43. Mutations, Genetic Drift, Gene Flow, Natural Selection
44. Movement of genes between populations; can introduce new traits
45. Genetic drift that occurs when a chance event causes a sharp reduction in population size, reducing genetic diversity
46. Environmental factors that influence which individuals in a population survive and reproduce; e.g. predators, climate, food availability, or competition
47. The differences in DNA sequences among individuals in a population, which lead to differences in traits, provide the raw material for natural selection to act upon

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat

Prompt: Provide definitions for all the bolded terms in the shared content and list all the terms in alphabetical order.

# CHAPTER 2: MICROEVOLUTION AND SPECIATION

## Chapter Overview

## Learning Objectives

By the end of this chapter, you will be able to:

- Explain the historical development of evolutionary theory, including the role of Mendel's work and the integration of genetics into the modern synthesis.
- Define population genetics and describe how allele frequencies are used to measure evolutionary change within a population over time.
- Identify and differentiate the sources of genetic variation—including mutation and sexual reproduction—and explain their impact on genetic diversity and fitness.
- Apply the Hardy-Weinberg principle to calculate genotype and allele frequencies.
- Interpret real-world examples of microevolution by analyzing shifts in allele frequencies and predicting genotype distributions using Hardy-Weinberg equations.
- Evaluate how genetic structure and reproductive isolation contribute to the formation of new species, emphasizing the importance of both prezygotic and postzygotic barriers.

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Provide 6 learning objectives for the shared content.

# 2.1 EVOLUTION OF POPULATIONS

Figure 2.1.1 Image by Vika_Glitter, Pixabay License

The mechanisms of inheritance, or genetics, were not understood at the time Charles Darwin and Alfred Russel Wallace were developing their idea of natural selection. This lack of understanding was a stumbling block to comprehending many aspects of evolution. In fact, the predominant (and incorrect) genetic theory of the time, **blending inheritance**, made it difficult to understand how natural selection might operate. Darwin and Wallace were unaware of the genetics paper by Gregor Mendel, called *Experiments on Plant Hybridization,* which was published in 1866, not long after the publication of Darwin's book *On the Origin of Species*. Mendel's work was rediscovered in the early twentieth century, at which time geneticists were rapidly coming to an understanding of the basics of inheritance. Over the next few decades, genetics and evolution were integrated into what became known as the **modern synthesis**—the coherent understanding of the relationship between natural selection and genetics that took shape by the 1940s and is generally accepted today. In sum, the modern synthesis describes how evolutionary processes, such as natural selection, can affect a population's genetic makeup, and, in turn, how this can result in the gradual evolution of populations and species.

## Population Genetics

A gene for a particular trait can have different versions, called **alleles**. Each individual in a population of diploid organisms carries two alleles for each gene—one from each parent. However, in the whole population, there can be many different alleles for the same gene.

Gregor Mendel studied how alleles are passed from parents to offspring (Mendel, 1866). Later, scientists in a field called **population genetics** began to study how these alleles change in a population over time.

The **allele frequency** is how common a certain allele is in a population. Until now, we've talked about evolution as changes in traits we can see. But behind those visible changes are changes in genes. In population genetics, evolution means a change in allele frequency over time.

For example, in the ABO blood type system, a study in Jordan found that the $I^{A}$ allele made up 26.1% of the population's ABO alleles. The $I^{B}$ allele was 13.4%, and $i$ was 60.5% (Hanania et al., 2007). If these numbers change over time, that's evolution. These small, gradual genetic changes are called **microevolution**.

Microevolution happens when certain alleles help individuals survive or reproduce better. These helpful alleles become more common because they get passed on more often. Over time, this changes the **gene pool**, which is the total set of alleles in a population.

## Variation and Genetic Diversity

Natural selection can only take place if there is variation, or differences, among individuals in a population. Importantly, these differences must have a genetic basis; otherwise, selection will not lead to change in the next generation. This is critical because variation among individuals can be caused by non-genetic reasons, such as an individual being taller because of better nutrition rather than different genes.

**Genetic diversity,** the total variety of genetic traits within a population, comes from two main sources: mutation and sexual reproduction. As discussed in Section 1.3, **mutations** are random changes in DNA and are the ultimate source of new alleles in a population. These new alleles introduce novel traits that may be acted upon by natural selection.

In addition to mutation, **sexual reproduction** increases genetic variation by reshuffling existing alleles. During meiosis, processes like crossing over and independent assortment create new combinations of genes. When two parents reproduce, their offspring inherit a unique mix of alleles, resulting in diverse genotypes and, consequently, a wide range of phenotypes. This genetic variation is essential for populations to adapt to changing environments over time.

## Hardy-Weinberg Principle of Equilibrium

In the early twentieth century, English mathematician Godfrey Hardy and German physician Wilhelm Weinberg stated the principle of equilibrium to describe the genetic makeup of a population. The theory, which later became known as the **Hardy-Weinberg principle of equilibrium**, states that a population's allele and genotype frequencies are inherently stable— unless some kind of evolutionary force is acting upon the population, neither the allele nor the genotypic frequencies would change. The Hardy-Weinberg principle assumes conditions with no mutations, migration, or selective pressure for or against genotype, plus an infinite population. While no population can satisfy those conditions, the principle offers a useful model against which to compare real population changes.

Working under this theory, population geneticists represent different alleles as different variables in their mathematical models. The variable $p$ represents the dominant allele in the population, while the variable $q$ represents the recessive allele. For example, when looking at Mendel's peas, the variable p represents the frequency of Y alleles that confer the colour yellow, and the variable q represents the frequency of y alleles that confer the colour green. If these are the only two possible alleles for a given locus in the population, $p + q = 1$. In other words, all the p alleles and all the q alleles make up all of the alleles for that locus that are found in the population.

However, what ultimately interests most biologists is not the frequencies of different alleles but the frequencies of the resulting **genotypes**, known as the population's genetic structure, from which scientists can surmise the distribution of **phenotypes**. If the phenotype is observed, only the genotype of the homozygous recessive alleles can be known, because the recessive trait is only expressed when both alleles are recessive (unlike dominant traits, which can be expressed in both homozygous and heterozygous individuals). The calculations then provide an estimate of the remaining genotypes in the population.

Since each individual carries two alleles per gene, if the allele frequencies (p and q) are known, predicting the frequencies of these genotypes is a simple mathematical calculation to determine the probability of getting these genotypes if two alleles are drawn at random from the gene pool. So in the above scenario, an individual pea plant could be pp (YY), and thus produce yellow peas; pq (Yy), also yellow; or qq (yy), and thus produce green peas. In other words, the frequency of pp individuals is simply $p^2$; the frequency of pq individuals is $2pq$; and the frequency of qq individuals is $q^2$. And, again, if $p$ and $q$ are the only two possible alleles for a given trait in the population, these genotype frequencies will sum to one:

$$p^2 + 2pq + q^2 = 1$$

Let us assume that there are two alleles for a particular gene in a population. The *allele frequencies* would be represented by:

$$p \text{ (frequency of the dominant allele, Y)}$$
$$q \text{ (frequency of the recessive allele, y)}$$

Then, according to the Hardy-Weinberg equation, the sum of the allele frequencies must equal 1.

i.e., $p + q = 1$

Using these allele frequencies, we can predict the *genotype frequencies* in the population with the formula:

$$p^2 + 2pq + q^2 = 1$$

where:

$p^2$ = frequency of individuals with the homozygous dominant genotype (YY)

$2pq$ = frequency of individuals with the heterozygous genotype (Yy)

$q^2$ = frequency of individuals with the homozygous recessive genotype (yy)

Suppose in a population, 80% of alleles for a certain gene are dominant (A), and 20% are recessive (a):

$p = 0.8$

$q = 0.2$

Using the Hardy-Weinberg equation:

$$p^2 = (0.8)^2 = 0.64$$

(64% are AA)

$$2pq = 2 \times 0.8 \times 0.2 = 0.32$$

(32% are Aa)

$$q^2 = (0.2)^2 = 0.04$$

(4% are aa)

This means that in this ideal population, 64% would be homozygous dominant, 32% heterozygous, and 4% homozygous recessive.

Read the following examples and try to solve them. Click on "View Solution" to check your work.

## Example #1

A population of crickets is composed of both loud chirpers and soft chirpers. This trait is determined by genes, with the loud chirping allele being dominant to the soft chirping allele. There are 48 loud chirpers and 14 soft chirpers in the population. What percentage of crickets are heterozygous for loud chirping?

View Solution

### Step 1: Start with the recessive

We need to know what % of the population are soft chirpers. 14 crickets out of a total of 62 animals. Since these are individuals and since it is a genotype we are looking at $q^2$. That means $\frac{14}{62}$ or $0.225$ are soft chirpers.

### Step 2: What is the recessive allele frequency?

Since $0.225$ is $q^2$, we can take the square root of this to get $q$. This value is $0.474$.

### Step 3: Now that we have the recessive allele frequency, determine the dominant allele frequency.

Use the equation $p + q = 1$ and rearrange to be $p = 1 - q$.

We know that $q$ is $0.474$, so plug this in:

$$p = 1 - 0.474 = 0.526$$

### Step 4: Determine what part of the equation you need to solve for and then answer the question.

We need to know what the heterozygous frequency is, so we are looking at $2pq$

We have determined $p$ and $q$ already, so we just need to plug in the values.

$$2 \times 0.526 \times 0.474 = 0.498$$

This means that $\sim 50\%$ (rounding up) of the cricket population is heterozygous for loud chirping.

## Example #2

In a population of 162 rabbits, 34 of them express a recessive trait. What is the allelic frequency for this trait? Assuming Hardy-Weinberg equilibrium, how many rabbits would you expect to have the recessive trait the following year when 250 rabbits are present?

View Solution

### Step 1: Start with the recessive and find the recessive allele frequency

34 out of 162 have the recessive genotype or trait. That means that $0.209$ or $\approx 21\%$ of the rabbits have this recessive trait. This is the $q^2$ value.

To find the allelic frequency, you need to take the square root of 0.21, which is 0.46. This is $q$.

### Step 2: Apply this frequency to determine the prediction for the following year

Remember 0.46 is $q$ (allele) and 0.21 is $q^2$ (genotype). If we have 250 rabbits, we can use the percentage and apply it.

That is, we expect ~21% of the rabbits to have the recessive trait.

So $0.21 \times 250$ rabbits $= 52.5$ or $53$ rabbits

If there is no evolution and equilibrium remains, we expect that 53 rabbits out of the 250 will be exhibiting the recessive trait.

(As a double-check, you can take 53 out of 250, and you will find a 0.21 frequency for the recessive trait. This tells us we did the problem correctly.)

## Knowledge Check

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# 2.2 WHAT IS A SPECIES?

This simple question is more difficult than it may appear. It turns out that scientists don't always agree on the definition of a species. The different ideas about what constitutes a species are referred to as species concepts. There are around twenty-six different species concepts, but we will focus on the biological species concept. The **biological species concept** states that a species is a group of organisms that interbreed and produce **fertile**, **viable** offspring. According to this definition, one species is distinguished from another when, in nature, it is not possible for matings between individuals from each species to produce fertile offspring.

Figure 2.2.1 Males of the Western Meadowlark (left) by Becky Matsubara, CC BY 2.0 and the Eastern Meadowlark (right) by USFWS Midwest Region, CC BY 2.0

The biological species concept works well for scientists studying living creatures that have regular breeding patterns, such as insects, birds or mammals. However, this definition has limitations and is not always applicable (e.g. asexual organisms, fossils).

In some cases, the biological species concept is straightforward to apply. For instance, the western meadowlark (*Sturnella neglecta*) and the eastern meadowlark (*Sturnella magna*) (Figure 2.2.1) respectively inhabit the western and eastern halves of North America. Even though their breeding ranges overlap throughout many upper midwestern states, including Michigan, Wisconsin, Illinois, Iowa, Missouri, and Minnesota, the two groups do not interbreed. The courtship songs of the males of each species are distinctly different, and females of each species respond to the songs of the males of their species, leading to strong reproductive isolation between the two groups despite a high degree of similarity in appearance.

That being said, species' appearance can be misleading in suggesting an ability or inability to mate. For example, even though domestic dogs (*Canis lupus familiaris*) display phenotypic differences, such as size, build, and coat, most dogs can interbreed and produce viable puppies that can mature and sexually reproduce (Figure 2.2.2).

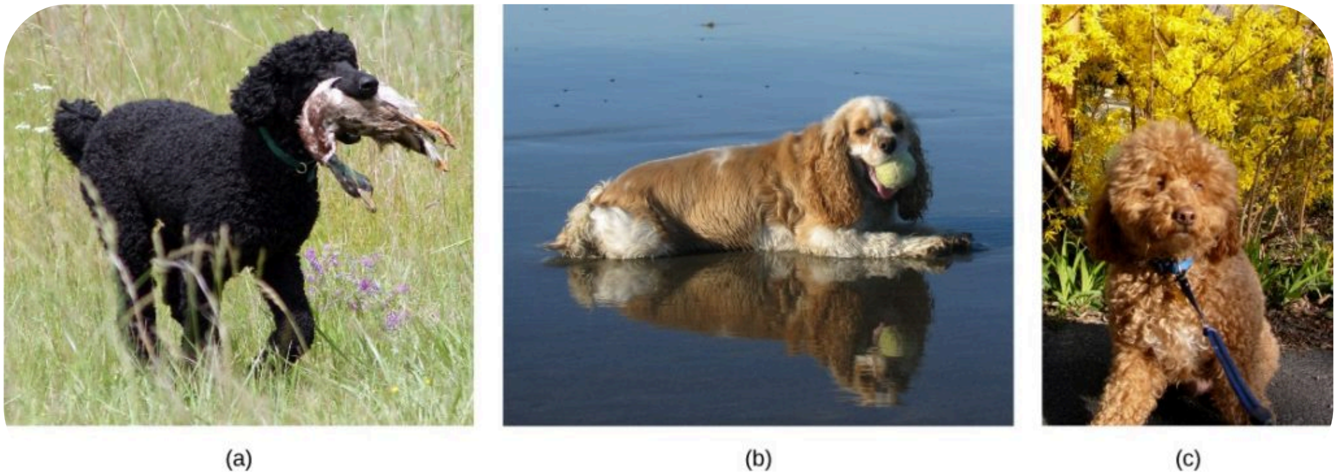


Figure 2.2.2 The (a) Poodle and (b) Cocker Spaniel can reproduce to produce a breed known as (c) the Cockapoo. Image by Open Stax, CC BY 4.0

# Reproductive Isolation

**Reproductive barriers** are any biological features or behaviours that prevent different species from interbreeding and producing fertile, viable offspring. These barriers are essential in maintaining species boundaries and are a key part of the Biological Species Concept.

Scientists organize them into two groups: prezygotic barriers and postzygotic barriers.

## Prezygotic barriers

Recall that a **zygote** is a fertilized egg: the first cell of the development of an organism that reproduces sexually. Therefore, a **prezygotic barrier** is a mechanism that blocks reproduction from taking place; this includes barriers that prevent fertilization when organisms attempt reproduction.

Temporal Isolation

Many organisms only reproduce at certain times of the year, often just annually. Differences in breeding schedules, called **temporal isolation**, can act as a form of reproductive isolation. For example, two species of frogs inhabit the same area, but one reproduces from January to March, whereas the other reproduces from March to May (Figure 2.2.3).

Figure 2.2.3. These two related frog species exhibit temporal reproductive isolation. (a) Rana aurora breeds earlier in the year than (b) Rana boylii. Image by Open Stax, CC BY 4.0

## Habitat Isolation

In some cases, populations of a species move or are moved to a new habitat and take up residence in a place that no longer overlaps with the other populations of the same species. This situation is called **habitat isolation**. Reproduction with the parent species ceases, and a new group exists that is now reproductively and genetically independent. For example, a cricket population that was divided after a flood could no longer interact with each other. Over time, the forces of natural selection, mutation, and genetic drift will likely result in the divergence of the two groups.

## Behavioural Isolation

**Behavioural isolation** occurs when the presence or absence of a specific behaviour prevents reproduction from taking place. For example, male fireflies use specific light patterns to attract females.

Various species of fireflies display their lights differently. If a male of one species tried to attract the female of another, she would not recognize the light pattern and would not mate with the male.

### Mechanical Isolation

In some cases, closely related organisms attempt to mate, but their reproductive structures simply do not fit together. This is known as **mechanical isolation**, a type of reproductive barrier that prevents successful mating due to incompatible anatomical structures. For example, damselfly males of different species have differently shaped reproductive organs. If one species tries to mate with the female of another, their body parts simply do not align properly, preventing fertilization (Figure 2.2.4).

Figure 2.2.4 The shape of the male reproductive organ varies among male damselfly species, and is only compatible with the female of that species. Reproductive organ incompatibility keeps the species reproductively isolated. Image by Open Stax, 

In plants, certain structures are aimed at attracting one type of pollinator while simultaneously preventing a different pollinator from accessing the pollen. The tunnel through which an animal must access nectar can vary widely in length and diameter, which prevents the plant from being cross-pollinated with a different species (Figure 2.2.5).

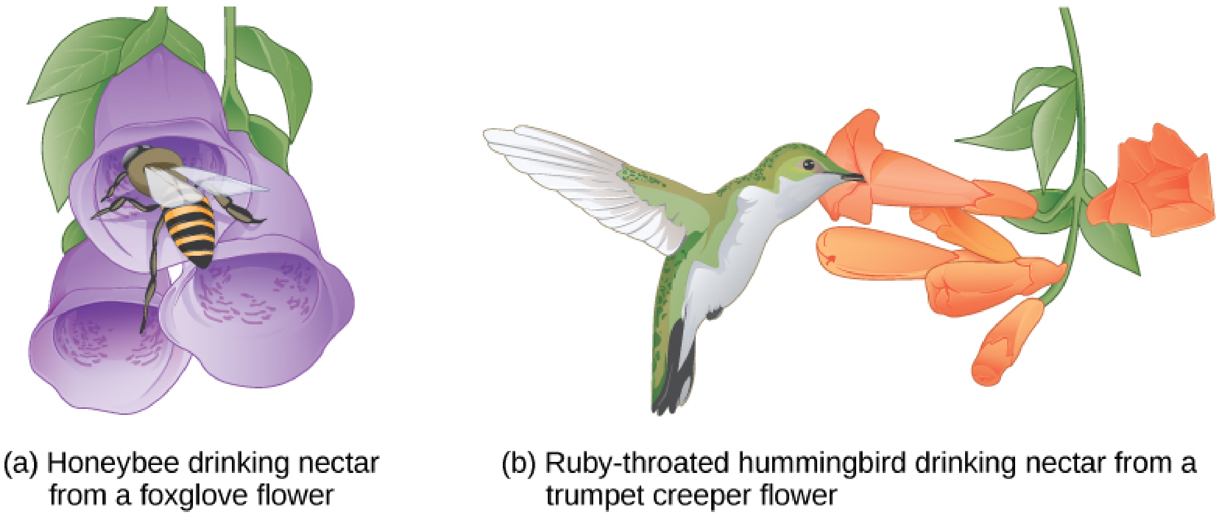


Figure 2.2.5 Some flowers have evolved to attract certain pollinators. The (a) wide foxglove flower is adapted for pollination by bees, while the (b) long, tube-shaped trumpet creeper flower is adapted for pollination by hummingbirds. Image by Open Stax, CC BY 4.0

Gametic Isolation

**Gametic isolation** is where the sperm of one species is unable to fertilize the egg of another species. This can occur due to chemical incompatibilities or differences in reproductive proteins. For example, many aquatic species (e.g. many fishes, mollusks, jellyfish, sea urchins) release their gametes into the water. Fertilization only occurs if the sperm and egg are from the same species because their surface proteins must match precisely for fusion to happen.

## Postzygotic barriers:

A **postzygotic barrier** occurs after zygote formation; this includes organisms that don't survive the embryonic stage and those that are born sterile.

### Hybrid Inviability

**Hybrid inviability** is when the hybrid offspring fails to develop properly or dies at an early stage. This is often due to genetic incompatibilities between the two parent species. For example, when certain species of frogs interbreed, the resulting embryos may not survive past early developmental stages, preventing the continuation of the hybrid line.

### Hybrid Sterility

**Hybrid sterility** is where the hybrid offspring is healthy and reaches adulthood but is sterile, meaning it is unable to reproduce. A well-known example is the mule, which is the offspring of a horse and a donkey. Although mules are strong and capable animals, they are generally sterile because of differences in the number of chromosomes between their parents, which disrupts normal gamete formation.

Figure 2.2.6 "Mules from Supai, Arizona carrying U.S. Mail containers." by Elf, CC BY-SA 3.0

### Hybrid breakdown

**Hybrid breakdown** occurs when the first-generation hybrids are fertile and viable, but their offspring are weak, sterile, or otherwise less fit. This is seen in some species of cultivated rice, where the initial hybrid plants can reproduce, but their descendants often show reduced fertility or poor growth.

## Knowledge Check

**Text Description**

1. What does the biological species concept define a species as?

   a. A group of organisms that share similar physical traits
   b. A group of organisms that can interbreed and produce fertile offspring
   c. A group of organisms that are genetically identical
   d. A group of organisms that live in the same geographical area

2. What is a limitation of the biological species concept?

   a. It only applies to plants
   b. It does not apply to asexual organisms or fossils
   c. It ignores genetic diversity within populations
   d. It assumes all organisms interbreed

3. What type of reproductive isolation occurs when two species reproduce at different times of the year?

   a. Habitat isolation
   b. Temporal isolation
   c. Behavioural isolation
   d. Mechanical isolation

4. Which of the following is an example of mechanical isolation?

   a. Male fireflies use distinct light patterns to attract females

b. Two species of frogs breed at different times of the year
c. Male damselflies of different species have differently shaped reproductive organs
d. Two species of birds do not mate because of different courtship rituals

5. What does gametic isolation prevent?

a. Hybrid sterility in offspring
b. Interbreeding between species due to incompatible mating behaviours
c. Fertilization due to chemical incompatibilities between sperm and egg
d. The formation of hybrid offspring

6. What occurs during hybrid inviability?

a. The hybrid offspring are sterile
b. The hybrid offspring do not survive past early developmental stages
c. The hybrid offspring are weaker but can reproduce
d. The hybrid offspring produce fertile descendants

7. Which of the following describes hybrid sterility?

a. The hybrid offspring fail to develop properly and die early
b. The hybrid offspring are sterile and unable to reproduce
c. The hybrid offspring are weak but still fertile
d. The hybrid offspring break down and become unfit over generations

8. What is an example of a hybrid breakdown?

a. Mules, the offspring of horses and donkeys, are fertile
b. Hybrid plants in cultivated rice are strong but cannot reproduce
c. Hybrid frogs from different species survive but have reduced fitness in future generations
d. Hybrid offspring in cichlids are viable but unable to produce offspring

---

**Answers:**

1. b. A group of organisms that can interbreed and produce fertile offspring
2. b. It does not apply to asexual organisms or fossils
3. b. Temporal isolation
4. c. Male damselflies of different species have differently shaped reproductive organs

5. c. Fertilization due to chemical incompatibilities between sperm and egg
6. b. The hybrid offspring do not survive past early developmental stages
7. b. The hybrid offspring are sterile and unable to reproduce
8. c. Hybrid frogs from different species survive but have reduced fitness in future generations

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Create 8 multiple-choice questions using the following content

# 2.3 SPECIATION

**Speciation** is the evolutionary process by which populations evolve to become distinct species. It occurs when genetic differences accumulate to the point that individuals from different populations can no longer interbreed and produce fertile offspring. Darwin envisioned this process as a branching event and diagrammed the process in *On the Origin of Species* (Figure 2.3.1a). Compare this illustration to the diagram of elephant evolution (Figure 2.3.1b), which shows that as one species changes over time, it branches to form more than one new species, repeatedly, as long as the population survives or until the organism becomes extinct.

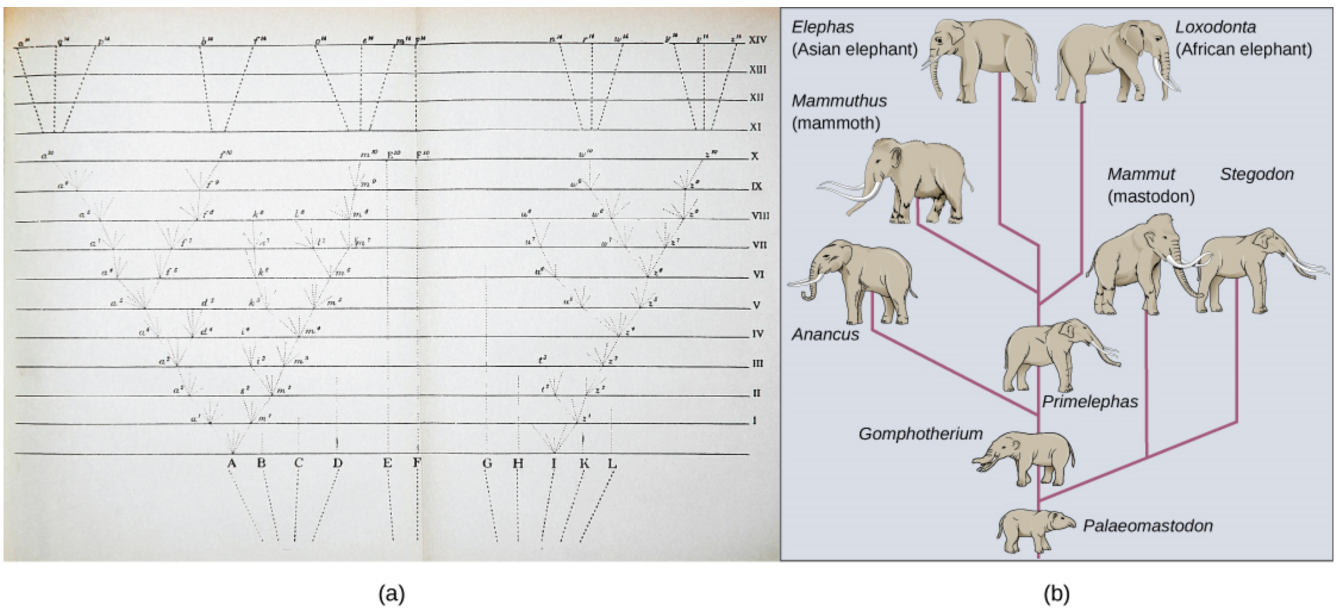


Figure 2.3.1 The only illustration in Darwin's *On the Origin of Species* is (a) a diagram showing speciation events leading to biological diversity. The diagram shows similarities to phylogenetic charts that today illustrate the relationships of species. (b) Modern elephants evolved from the Palaeomastodon, a species that lived in Egypt 35 to 50 million years ago. Image by Open Stax, 

## Types of Speciation

For speciation to occur, two new populations must form from one original population, and they must evolve in such a way that it becomes impossible for individuals from the two new populations to interbreed. Biologists have proposed mechanisms by which this could occur that fall into two broad categories:

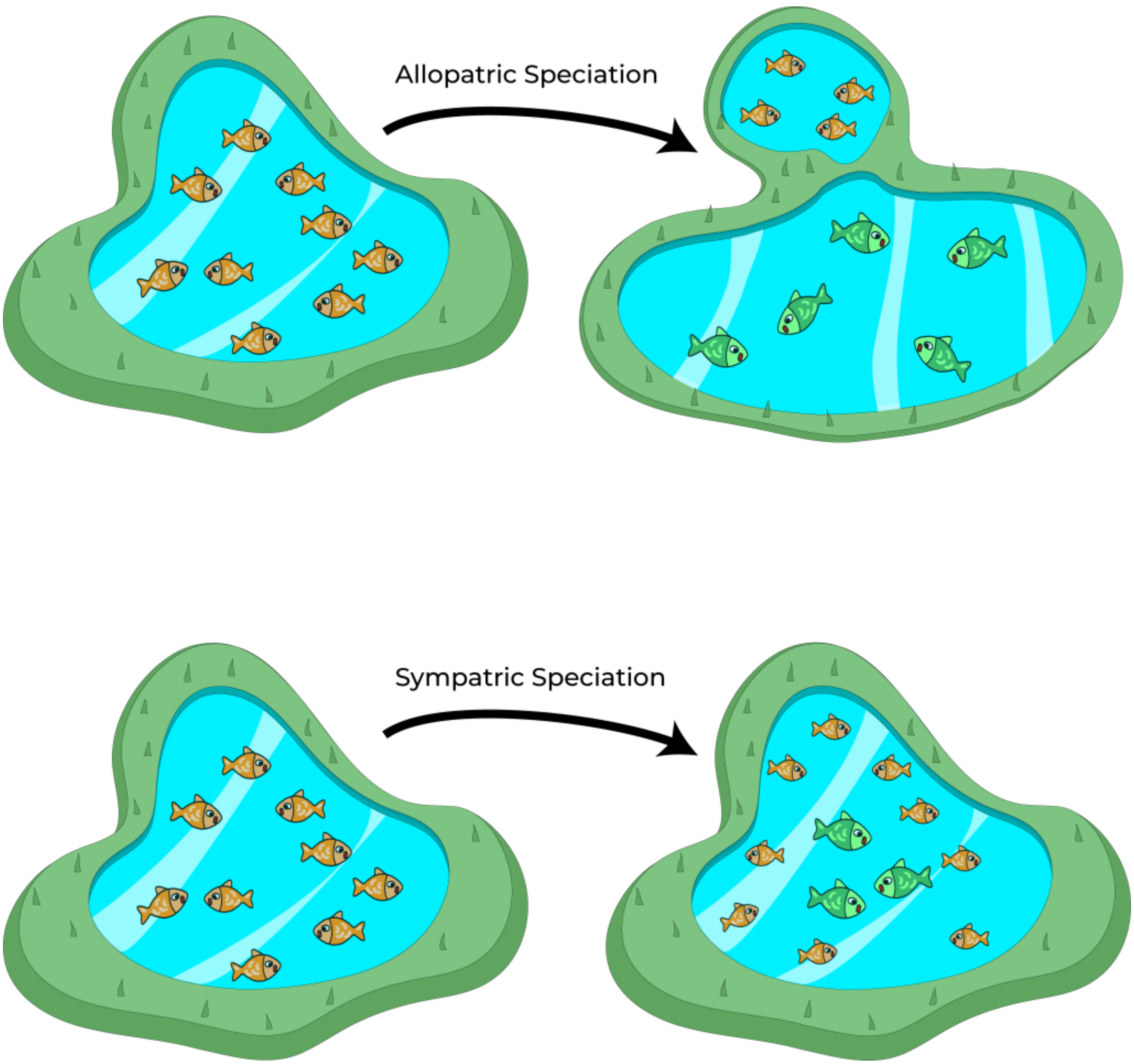


Figure 2.3.2 "Allopatric Speciation and Sympatric Speciation" by Koen Liddard, CC BY-NC-SA

**Figure 2.3.2 Image Description**

The image shows two examples of speciation using fish in ponds.

Top illustration (Allopatric Speciation): A single pond with only orange fish splits into two separate ponds. In one pond, the orange fish remain, while in the other pond, the fish evolve into green fish, showing how physical separation leads to the formation of different species.

Bottom illustration (Sympatric Speciation): A single pond with only orange fish remains undivided. Over time, some fish evolve into green fish while coexisting in the same pond, showing how new species can form without physical separation.

This image contrasts allopatric speciation (species form due to geographic isolation) and sympatric speciation (species form in the same location).

### Allopatric Speciation

**Allopatric speciation** occurs when a population is divided by a physical barrier, such as a mountain range, river, or large distance, which prevents individuals from different groups from interbreeding. Over time, these geographically isolated populations experience different environmental pressures, so they accumulate genetic differences that eventually lead to reproductive isolation. Even if the physical barrier is later removed, the populations may no longer be able to interbreed successfully, indicating that they have become distinct species.

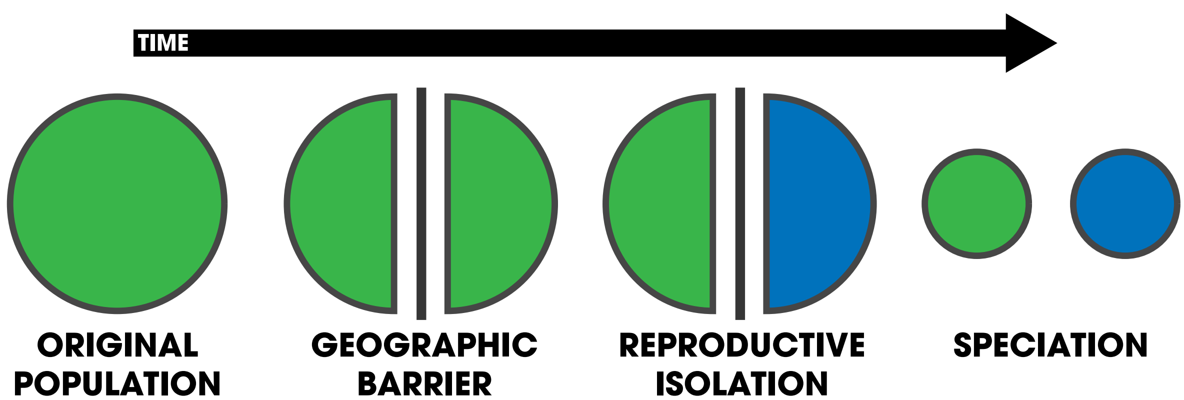


Figure 2.3.3 A population becomes separated by a geographic barrier; reproductive isolation develops, resulting in two separate species. Image by Andrew Z. Colvin, CC BY-SA 4.0

**Figure 2.3.3 Image Description**

The graphic illustrates the process of allopatric speciation over time using a sequence of circles:

- The first circle, labelled Original Population, is entirely green, representing one unified population.

- Next, the circle is split in half by a vertical line labelled Geographic Barrier, showing the population divided into two isolated groups.
- In the third stage, labelled Reproductive Isolation, the two halves diverge, with one half remaining green and the other changing to blue, symbolizing genetic differences developing between the isolated groups.
- The final stage, Speciation, shows two separate, smaller circles—one green and one blue—indicating the formation of two distinct species.
- A large arrow labelled Time runs across the top, emphasizing that this process occurs gradually.

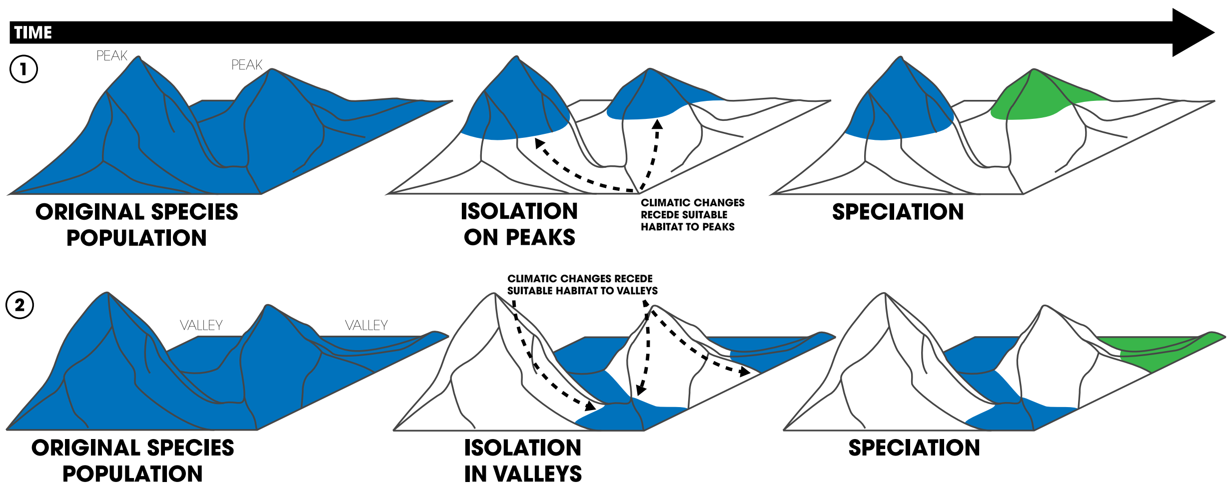


Figure 2.3.4. In allopatric speciation, a species population becomes separated by a geographic barrier, whereby reproductive isolation evolves, producing two separate species. From this, if a recently separated population comes in contact again, low fitness hybrids may form, but reinforcement acts to complete the speciation process. Image by Andrew Z. Colvin, CC BY-SA 4.0

### Figure 2.3.4 Image Description

The graphic shows two scenarios of how geographic isolation caused by climatic changes leads to speciation over time, illustrated with mountain ranges. A large arrow labelled Time runs across the top.

Isolation on Peaks (top row):

- The first image shows an original species population (in blue) spread across mountains.
- In the second image, labelled Isolation on Peaks, climatic changes restrict suitable habitat to

higher elevations, isolating populations on mountaintops.
- In the third image, labelled Speciation, the isolated groups evolve separately, shown by one peak remaining blue while another turns green, representing the emergence of a new species.

Isolation in Valleys (bottom row):

- The first image shows the original species population (in blue) across mountain ranges and valleys.
- In the second image, labelled Isolation in Valleys, climatic changes confine suitable habitat to lower valleys, isolating populations there.
- In the final stage, labelled Speciation, populations diverge, shown by some areas remaining blue while others turn green, indicating the formation of a new species.

This diagram emphasizes how environmental changes and habitat fragmentation (on peaks or in valleys) can drive speciation.

A well-known case of allopatric speciation can be seen in the Galápagos finches that Charles Darwin observed. Today, there are around 15 distinct finch species across the Galápagos Islands, each with unique physical traits and beak shapes adapted to specific food sources like seeds, insects, and flowers. These birds are believed to have evolved from a single ancestral species that initially colonized the islands. As different groups settled on separate islands, they became geographically isolated. Over time, genetic variations emerged within each group. Traits that improved survival and reproduction in each unique environment became more common, eventually leading to the development of multiple new species.

## Sympatric Speciation

**Sympatric speciation** occurs without any physical separation between populations. Instead, reproductive isolation arises within a shared habitat due to behavioural or ecological differences. For instance, individuals may begin to exploit different resources, develop distinct mating preferences, or undergo chromosomal changes that prevent successful reproduction with others in the population.

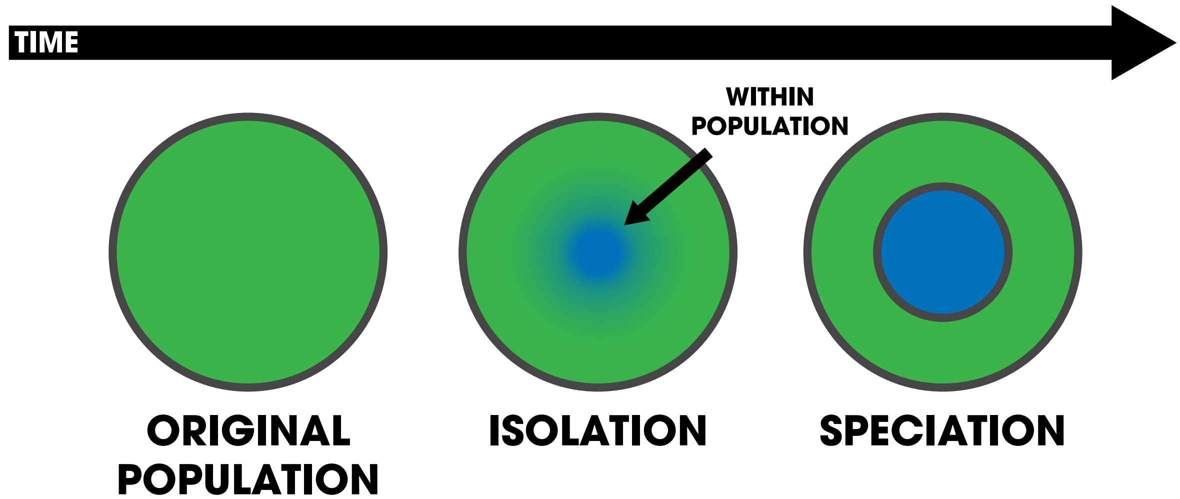


Figure 2.3.5 In sympatric speciation, reproductive isolation evolves within a population without the aid of geographic barriers. Image by Andrew Z. Colvin, CC BY-SA 4.0

**Figure 2.3.5 Image Description**

Hidden text (could be the answer to the question posed above).

For example, imagine a species of fish that lived in a lake. As the population grew, competition for food also grew. Under pressure to find food, suppose that a group of these fish had the genetic flexibility to discover and feed off another resource that was unused by the other fish. What if this new food source were found at a different depth of the lake? Over time, those feeding on the second food source would interact more with each other than with the other fish; therefore, they would breed together as well. Offspring of these fish would likely behave as their parents and feed and live in the same area, keeping them separate from the original population. If this group of fish continued to remain separate from the first population, eventually sympatric speciation might occur as more genetic differences accumulated between them.

This scenario does play out in nature. For example, Lake Victoria in Africa is famous for its sympatric speciation of cichlid fish (Figure 11.19). In this locale, two types of cichlids live in the same geographic location, but they have come to have different morphologies that allow them to eat various food sources.

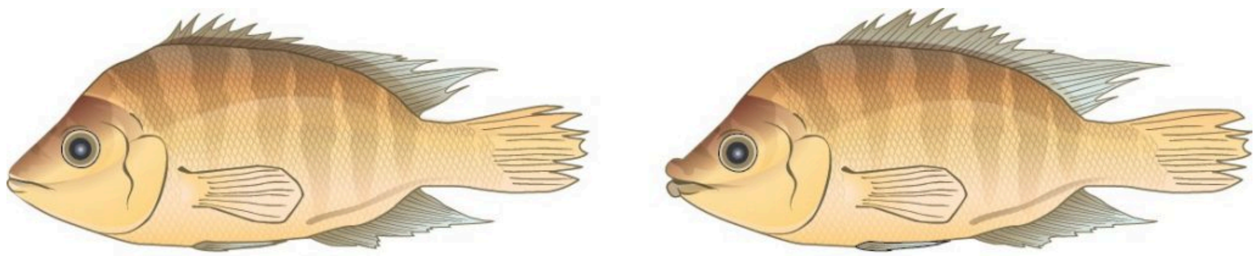


Figure 2.3.6 Cichlid fish from Lake Apoyeque, Nicaragua, show evidence of sympatric speciation. Lake Apoyeque, a crater lake, is 1800 years old, but genetic evidence indicates that the lake was populated only 100 years ago by a single population of cichlid fish. Nevertheless, two populations with distinct morphologies and diets now exist in the lake, and scientists believe these populations may be in an early stage of speciation. Image by Open Stax, CC BY 4.0

## Overview

| Feature | Allopatric Speciation | Sympatric Speciation |
|---|---|---|
| **Geographic Separation** | Yes | No |
| **Cause of Isolation** | Physical barriers | Behavioural, ecological, or genetic factors |
| **Common in** | Animals and plants | More common in plants, some animals |
| **Example** | Squirrels separated by a canyon | Fish in the same lake choose different habitats |

## Rate of Speciation

The rate of speciation can vary widely depending on environmental conditions, genetic factors, and ecological pressures. In some cases, species evolve gradually over millions of years through a slow accumulation of changes – a pattern known as **gradualism**. In contrast, other species may appear relatively suddenly in the fossil record, following long periods of little change. This pattern, called **punctuated equilibrium**, suggests that speciation can occur in rapid bursts, often triggered by environmental shifts or the colonization of new habitats.

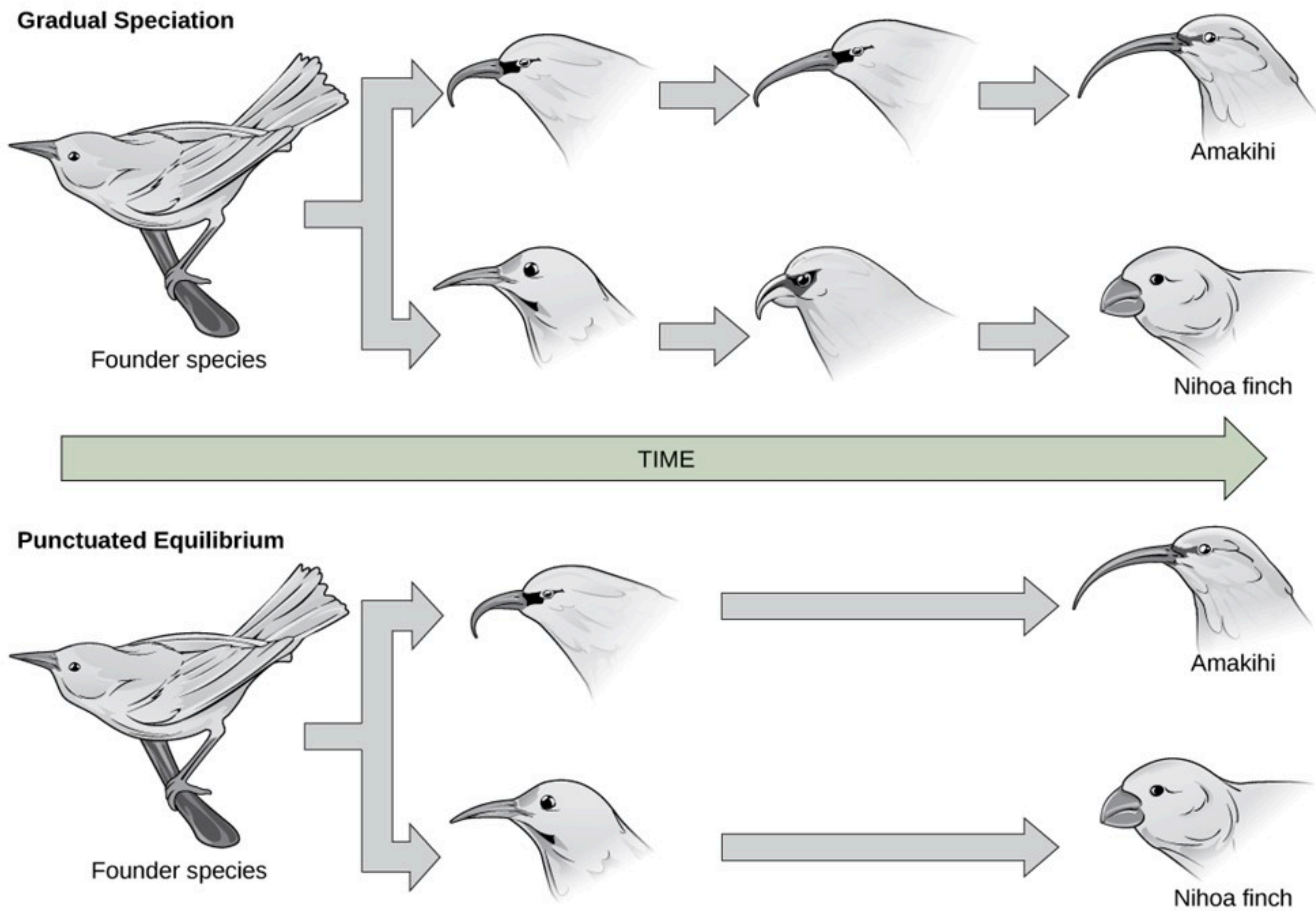


Figure 2.3.7 In gradual speciation, species diverge at a slow, steady pace as traits change incrementally. In punctuated equilibrium, species diverge quickly and then remain unchanged for long periods of time. Image by Open Stax, CC BY 4.0.

**Figure 2.3.7 Image Description**

The diagram compares Gradual Speciation and Punctuated Equilibrium using bird evolution as an example.

- Top row (Gradual Speciation):
  A founder species bird is shown on the left. Over time, it diverges gradually into different species, with intermediate forms depicted in a sequence of head illustrations. One lineage evolves into the Amakihi (shown with a long, curved beak), and another evolves into the Nihoa finch (shown with a short, thick beak). A long horizontal arrow labelled Time emphasizes that this process occurs slowly with many transitional forms.
- Bottom row (Punctuated Equilibrium):
  The same founder species bird is shown on the left. Instead of gradual change, there are long periods

with little change, followed by rapid divergence. The intermediate forms are absent, and the founder species quickly gives rise to distinct species—the Amakihi and the Nihoa finch.

The illustration highlights the difference between gradualism, where species evolve slowly through continuous changes, and punctuated equilibrium, where species remain stable for long periods with sudden bursts of evolutionary change.

## Knowledge Check

**Text Description**

1. What is the key characteristic that defines speciation?

   a. The accumulation of genetic differences between two populations
   b. The ability of populations to interbreed and produce fertile offspring
   c. The physical separation of populations
   d. The appearance of new traits within a population

2. Which of the following best describes allopatric speciation?

   a. Speciation that occurs within a shared habitat due to behavioural differences
   b. Speciation that occurs when a physical barrier separates populations
   c. Speciation due to changes in chromosome numbers within a population
   d. Speciation that occurs when environmental pressures favour specific traits

3. Which of the following is an example of sympatric speciation?

   a. Two populations of squirrels being separated by a canyon
   b. Fish in the same lake developing distinct morphologies to exploit different food sources
   c. Finches on different islands developing different beak shapes
   d. A population of frogs being separated by a river

4. What is a major difference between allopatric and sympatric speciation?

   a. Allopatric speciation occurs in the same geographic location, while sympatric speciation involves geographic separation
   b. Allopatric speciation requires physical barriers, while sympatric speciation occurs without physical barriers

c. Allopatric speciation is more common in plants, while sympatric speciation is more common in animals
d. Allopatric speciation results in hybrid inviability, while sympatric speciation leads to hybrid sterility

5. Which of the following best describes the process of punctuated equilibrium in speciation?

a. Species evolve slowly over millions of years through gradual changes
b. Speciation occurs in rapid bursts, often triggered by environmental shifts
c. Speciation occurs as populations accumulate small genetic changes over time
d. Species evolve at a constant rate over long periods of time

6. What is the primary cause of reproductive isolation in sympatric speciation?

a. Physical barriers like mountains or rivers
b. Geographical separation of populations
c. Behavioural, ecological, or genetic factors
d. Changes in environmental conditions leading to natural disasters

---

**Answers:**

1. a. The accumulation of genetic differences between two populations
2. b. Speciation that occurs when a physical barrier separates populations
3. b. Fish in the same lake developing distinct morphologies to exploit different food sources
4. b. Allopatric speciation requires physical barriers, while sympatric speciation occurs without physical barriers
5. b. Speciation occurs in rapid bursts, often triggered by environmental shifts
6. c. Behavioural, ecological, or genetic factors

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Prompt: Create 6 multiple-choice questions using the following content

# CHAPTER 2 SUMMARY

## Key Takeaways

- **Modern Synthesis and Population Genetics:** The modern synthesis combines Darwin's theory of natural selection with Mendelian genetics. Evolution is understood as a change in allele frequencies in a population over time (microevolution). Variation in alleles arises through *mutation* and *sexual reproduction*, providing the raw material for natural selection to act upon.
- **Hardy-Weinberg Principle:** The *Hardy-Weinberg equilibrium* provides a mathematical model to study genetic stability in populations. In the absence of evolutionary forces, allele and genotype frequencies remain constant. The equation $p^2 + 2pq + q^2 = 1$ allows scientists to predict genotype frequencies and assess whether evolution is occurring.
- **Biological Species Concept:** A *species* is defined as a group of organisms that can interbreed and produce fertile offspring. While useful for sexually reproducing organisms, this concept has limitations (e.g. for asexual species or fossils). Physical appearance alone does not always indicate species boundaries.
- **Reproductive Isolation:** *Reproductive barriers* prevent gene flow between species and are crucial for maintaining species boundaries. They include:
    - **Prezygotic barriers:** temporal, habitat, behavioural, mechanical, and gametic isolation.
    - **Postzygotic barriers:** hybrid inviability, hybrid sterility, hybrid breakdown.
- **Types of Speciation:** Speciation occurs when populations become reproductively isolated:
    - **Allopatric speciation:** involves geographic separation (e.g., mountains, rivers).
    - **Sympatric speciation:** happens without geographic separation, driven by behavioural, ecological, or genetic factors (e.g., habitat use within the same area).
- **Rate of Speciation:** Speciation can follow different temporal patterns:

- **Gradualism:** slow, continuous evolution over long periods.
- **Punctuated equilibrium:** rapid bursts of change followed by long periods of stability, often triggered by environmental shifts.

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Prompt: Summarize the following content into six key takeaways.

## Flashcards

**Text Description**

Front of card:

1. Allele
2. Population genetics
3. List two rates of speciation
4. p
5. List two types of speciation
6. Zygote
7. List 5 Prezygotic Barriers
8. Habitat isolation
9. Postzygotic barrier
10. Gradualism
11. 2pq
12. Microevolution
13. Prezygotic barrier
14. Hardy-Weinberg principle of equilibrium
15. p2
16. Reproductive barriers
17. q

18. Mechanical isolation
19. Biological species concept
20. Genetic diversity
21. Gametic isolation
22. Modern synthesis
23. Genotype
24. Allele frequency
25. Sexual reproduction
26. Main sources of genetic diversity
27. Reproductive isolation
28. Blending inheritance
29. Phenotype
30. Hybrid inviability
31. Allopatric speciation
32. List 3 Postzygotic Barriers
33. Gene pool
34. Temporal isolation
35. Speciation
36. Mutation
37. q2
38. Punctuated equilibrium
39. Behavioural isolation
40. Hybrid sterility
41. Sympatric speciation
42. Hardy-Weinberg equation
43. Hybrid breakdown
44. Fertile
45. Viable

Back of card:

1. A version of a gene; different alleles can produce variations in the trait controlled by the gene
2. A branch of biology that studies allele frequency changes in populations over time and the evolutionary forces that cause these changes
3. gradualism and punctuated equilibrium
4. frequency of the dominant allele, Y

5. allopatric speciation and sympatric speciation
6. The single cell formed when a sperm fertilizes an egg
7. Temporal isolation, habitat isolation, behavioural isolation, mechanical isolation, gametic isolation
8. A prezygotic reproductive barrier where species live in different habitats and thus do not meet to reproduce
9. A reproductive barrier that occurs after fertilization, resulting in non-viable or sterile offspring
10. A pattern of evolution characterized by the slow, continuous accumulation of small genetic changes over long periods of time
11. frequency of individuals with the heterozygous genotype (Yy)
12. Small-scale changes in allele frequencies within a population over time
13. A reproductive barrier that prevents fertilization from occurring
14. A principle stating that allele and genotype frequencies in a population will remain constant from generation to generation in the absence of evolutionary forces
15. frequency of individuals with the homozygous dominant genotype (YY)
16. Biological features or behaviours that prevent different species from interbreeding and producing fertile, viable offspring
17. frequency of the recessive allele, y
18. A prezygotic reproductive barrier where structural differences in reproductive organs prevent mating between species
19. A definition of species stating that a species is a group of organisms that can interbreed and produce fertile, viable offspring
20. The total variety of genetic characteristics in the genetic makeup of a population
21. A prezygotic reproductive barrier where the sperm of one species cannot fertilize the egg of another species due to incompatibilities
22. The integration of genetics with Darwin's theory of natural selection forms a unified theory of evolution that explains how evolutionary processes affect genetic variation
23. The genetic makeup of an organism determines the phenotype
24. The proportion of a specific allele among all alleles of a gene in a population
25. The process of combining genetic material from two parents to produce genetically unique offspring
26. mutation and sexual reproduction
27. A state in which two populations can no longer interbreed and produce fertile offspring, maintaining species boundaries

28. An outdated theory of inheritance where offspring were thought to be a uniform blend of parental traits, making it difficult to understand how traits persist across generations
29. The observable physical or physiological traits of an organism, determined by its genotype and environmental influences
30. A postzygotic reproductive barrier where hybrid offspring fail to develop properly or die at an early stage
31. The formation of new species due to geographic separation of populations, which prevents gene flow between them
32. Hybrid inviability, hybrid sterility, hybrid breakdown
33. The total set of alleles present in a population
34. A prezygotic reproductive barrier where species reproduce at different times, preventing mating
35. The evolutionary process by which populations evolve to become distinct species
36. A change in DNA sequence that can introduce new genetic variation into a population
37. frequency of individuals with the homozygous recessive genotype (yy)
38. A pattern of evolution where species undergo rapid changes in short periods, followed by long periods of stability
39. A prezygotic reproductive barrier where differences in behaviour, such as mating calls or courtship rituals, prevent mating between species
40. A postzygotic reproductive barrier where hybrid offspring are healthy but sterile and cannot reproduce
41. The formation of new species within a shared habitat, without geographic separation
42. $p2 + 2pq + q2 = 1$
43. A postzygotic reproductive barrier where first-generation hybrids are fertile, but their offspring are weak, sterile, or less fit
44. Able to produce offspring
45. Capable of surviving; a viable offspring can grow, develop, and potentially reproduce

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Prompt: Provide definitions for all the bolded terms in the shared content and list all the terms in alphabetical order.

# CHAPTER 3: MACROEVOLUTION

## Chapter Overview

## Learning Objectives

By the end of this chapter, you will be able to:

- Explain how large-scale evolutionary changes, such as the emergence of new traits and mass extinctions, are recorded in the fossil record and interpreted using the geologic time scale.
- Identify the four major divisions of the Geologic Time Scale—Precambrian, Paleozoic, Mesozoic, and Cenozoic
- Explain how continental drift and plate tectonics influence evolution by shaping global climates, ecosystems, and contributing to mass extinctions and the diversification of species.
- Describe the major mechanisms of macroevolution, including gene duplication, homeotic gene changes, paedomorphosis, co-option, and advantageous intermediates.
- Differentiate between taxonomy and phylogenetics.
- Interpret phylogenetic trees to trace evolutionary relationships and explain the significance of branch points, common ancestors, and sister taxa in understanding the diversification of life.

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Prompt: Provide 6 learning objectives for the shared content.

# 3.1 MACROEVOLUTION AND THE GEOLOGIC TIME SCALE

**Macroevolution** refers to large-scale evolutionary changes above the species level that occur over long periods of time. Macroevolution includes events such as mass extinctions and the evolution of major new traits like wings or flowers.

The **fossil record** offers a chronological archive of macroevolution. Fossils preserve the remains or traces of organisms from the past, allowing scientists to observe how life has changed over millions of years. By studying the fossil record, researchers can identify transitional forms, track the emergence of new species, and document large-scale evolutionary trends.

## The Geologic Time Scale

The **geologic time scale** provides the framework for interpreting the fossil record. This scale organizes Earth's 4.6-billion-year history into eons, eras, periods, and epochs.

The following link includes the symbols for each geologic period or era: Geologic Time Scale

By placing fossils within this timeline, scientists can correlate evolutionary changes with global events such as mass extinctions, climate shifts, and continental drift. This context helps explain how and when major evolutionary transitions occurred.

**Mass extinctions** are events in Earth's history when a significant, global loss of biodiversity occurs in a relatively short geological time frame. These events often mark the boundaries between major divisions in the Geologic Time Scale, such as the ends of eras or periods. Scientists recognize five major mass extinctions in the fossil record, each dramatically reshaping the course of evolution by eliminating dominant species and allowing new groups to rise. Today, many scientists believe we are entering, or already experiencing, a sixth mass extinction, driven largely by human activities such as habitat destruction, climate change, pollution, and overexploitation of species.

**Continental drift** is the slow movement of Earth's continents over time. This movement happens because the rigid outer layer of the Earth (lithosphere) is broken into large pieces known as **tectonic plates.** These plates move slowly (5 to 10 cm/year) over a hot, semi-liquid rock layer beneath them (mantle).


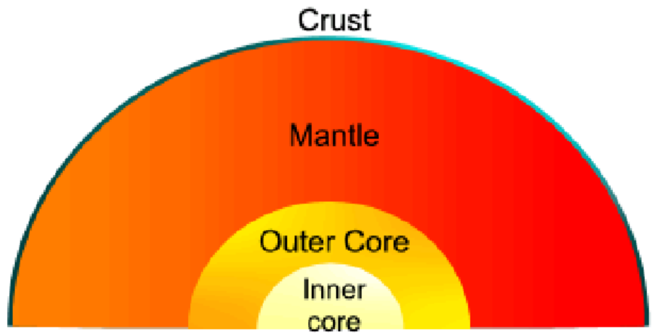


Figure 3.1.1 "Tectonic Plates" by M.Bitton, CC BY-SA 3.0, "Inside the Earth" by Theresa knott, CC BY-SA 3.0

As these plates shift, they interact at their boundaries – sometimes colliding, pulling apart, or sliding past one another. These interactions are responsible for much of Earth's geological activity, including earthquakes, volcanic eruptions, mountain formation, and even the creation of oceans. Because continents are embedded in these plates, they drift along with them, gradually reshaping Earth's surface over millions of years.

This movement has had a major impact on Earth's history. When continents merge or split, it can trigger significant changes in climate and ecosystems, which often leads to mass extinctions. Large-scale continental drift events help explain some divisions in the Geologic Time Scale because they caused dramatic shifts in life on Earth.

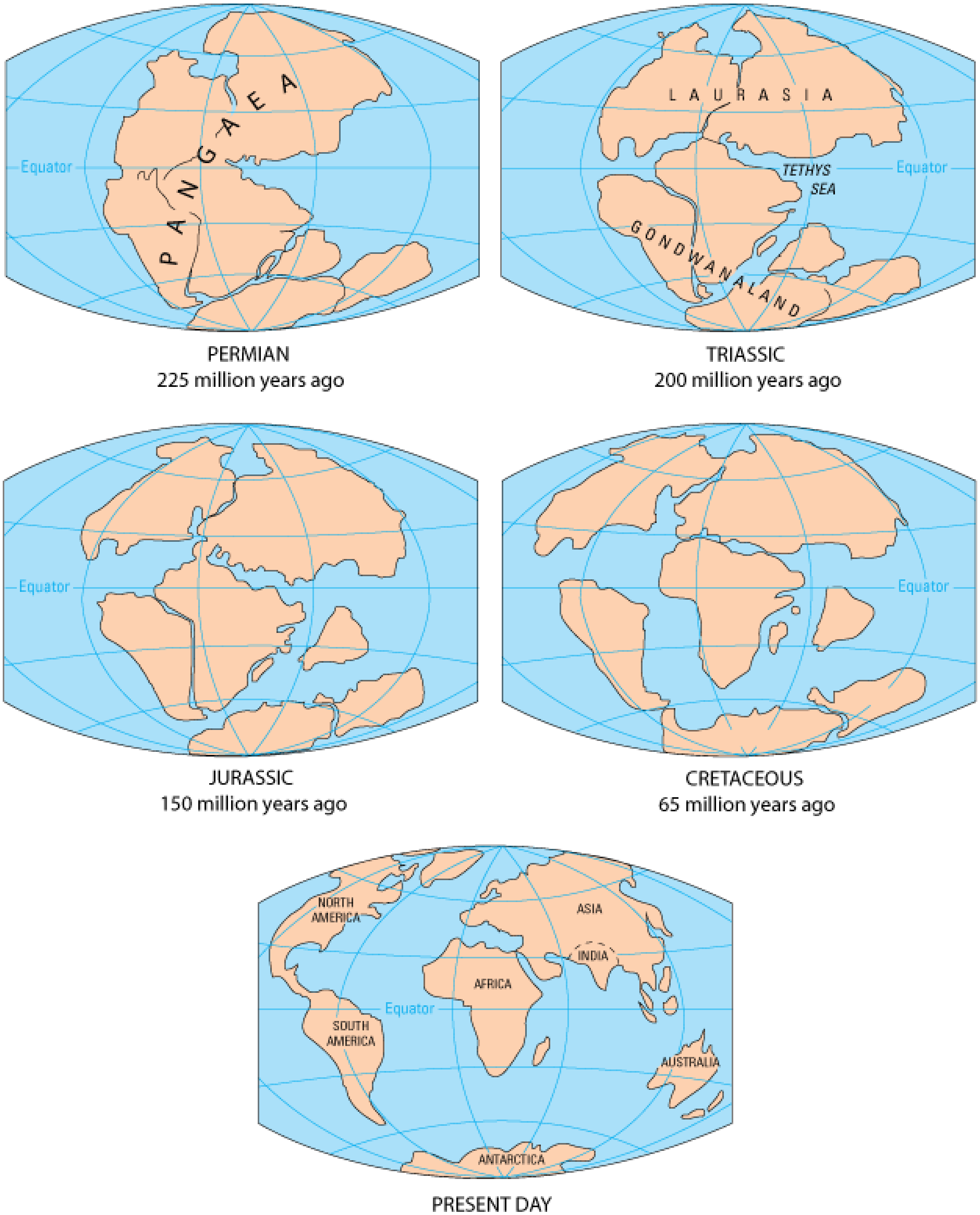


Figure 3.1.2 The breakup of Pangaea and the motion of its continents to their present-day positions. Permian (225 million years ago), Triassic (200 million years ago), Jurassic (150 million years ago), Cretaceous (65 million years) ago to Present day. Image, by USGS, Public Domain

## Divisions in the Geologic Time Scale

The time scale is divided into four main divisions: Precambrian (a super eon), followed by the Paleozoic, Mesozoic, and Cenozoic eras.

### Precambrian (4.6 billion to 541 million years ago)

The **Precambrian** spans the vast majority of Earth's history and marks the origin of the planet, the formation of the first oceans, and the emergence of life. During this time, life was mostly microscopic, consisting of single-celled organisms like bacteria and archaea. Later in the era, simple multicellular organisms and soft-bodied animals began to appear. Oxygen began to accumulate in the atmosphere due to photosynthetic microbes, leading to major environmental changes. The Precambrian ended with the rise of more complex life forms, setting the stage for the explosion of biodiversity in the Paleozoic.

### Paleozoic Era (541 to 252 million years ago)

The **Paleozoic Era** began with the **Cambrian Explosion** around 541 million years ago – a relatively brief period marked by a remarkable and rapid diversification of life. During this time, most of the major animal groups (or phyla) that exist today first appeared in the fossil record. This evolutionary burst was likely driven by a combination of factors that created ideal conditions for rapid change. One major factor was the increase in oxygen, which allowed animals to grow larger and develop more complex body structures. Additionally, the emergence of predator-prey relationships may have triggered an evolutionary arms race, encouraging the development of hard shells, mobility, and defensive adaptations.

One of the most iconic organisms of this era was the **trilobite**, a marine arthropod that thrived in early oceans but ultimately went extinct. Throughout the Paleozoic, life expanded from water to land, with the evolution of fish, land plants, insects, amphibians, and early reptiles.

In the later part of the era, Earth's landmasses gradually merged to form the supercontinent **Pangaea**, which significantly altered global climates and ocean circulation. These environmental shifts, combined with massive volcanic activity, likely contributed to the **Permian-Triassic extinction** – the most severe mass extinction in Earth's history, which wiped out about 90% of marine species and 70% of terrestrial species.

### Mesozoic Era (252 to 66 million years ago)

The **Mesozoic Era,** often called the **Age of Reptiles**, was dominated by dinosaurs on land, along with marine reptiles and flying pterosaurs. This era also saw the emergence of the first birds and mammals, as well as the spread of flowering plants. The continents began to drift apart, reshaping Earth's geography. The Mesozoic ended with the **Cretaceous-Paleogene (K-Pg) extinction**, likely triggered by a massive asteroid impact, which led to the extinction of the non-avian dinosaurs and many marine species.

### Cenozoic Era (66 million years ago to Present)

The **Cenozoic Era**, known as the **Age of Mammals**, began after the extinction of the dinosaurs. Mammals rapidly diversified and became the dominant land animals. Birds, flowering plants, and insects also flourished. During this era, the Earth's climate gradually cooled, leading to the formation of polar ice caps and repeated ice ages. This era includes the rise of primates and eventually humans. The Cenozoic continues today, marked by rapid environmental changes and significant human impact on ecosystems and climate.

## Knowledge Check

**Text Description**

1. What does macroevolution refer to?

    a. Small-scale genetic changes within a population over short periods
    b. Large-scale evolutionary changes above the species level occuring over long periods of time
    c. The development of new species through asexual reproduction
    d. The process of natural selection within a species

2. Which of the following is a major feature of the geologic time scale?

    a. It organizes Earth's history into eons, eras, periods, and epochs.
    b. It only applies to the last 100 million years of Earth's history.
    c. It tracks the fossil record but does not correlate with evolutionary changes.
    d. It focuses solely on the Mesozoic Era.

3. What event is associated with the end of the Paleozoic Era?

    a. The rise of mammals
    b. The Cambrian Explosion
    c. The Permian-Triassic extinction event
    d. The appearance of birds

4. Which process describes the slow movement of Earth's continents over time?

    a. Fossilization
    b. Continental drift
    c. Tectonic shift
    d. Mass extinction

5. During which era did dinosaurs dominate the Earth?

    a. Cenozoic Era
    b. Mesozoic Era
    c. Paleozoic Era
    d. Precambrian Era

6. Which of the following was a major cause of the Cretaceous-Paleogene (K-Pg) extinction event?

a. Climate change due to volcanic activity
b. An asteroid impact
c. The rise of mammalian predators
d. The formation of the supercontinent Pangaea

7. What key event marks the transition from the Mesozoic to the Cenozoic Era?

a. The rise of flowering plants
b. The extinction of the dinosaurs
c. The appearance of the first birds
d. The diversification of mammals

8. Which era is known as the "Age of Mammals"?

a. Mesozoic Era
b. Paleozoic Era
c. Cenozoic Era
d. Precambrian Era

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Answers:

1. b. Large-scale evolutionary changes above the species level occurring over long periods of time
2. a. It organizes Earth's history into eons, eras, periods, and epochs.
3. c. The Permian-Triassic extinction event
4. b. Continental drift
5. b. Mesozoic Era
6. b. An asteroid impact
7. b. The extinction of the dinosaurs
8. c. Cenozoic Era

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Prompt: Create 8 multiple-choice questions using the following content

# 3.2 MECHANISMS OF MACROEVOLUTION

The Geologic Time Scale shows large-scale changes in life forms at different points in Earth's history. These significant shifts raise an important question: *How do entirely new traits and body plans evolve over time?*

We've already explored several mechanisms of evolution, including mutation, genetic drift, gene flow, and natural selection, which explain the genetic changes associated with microevolution. While these small changes can accumulate over time and lead to noticeable differences, they don't fully explain the origin of major evolutionary innovations. To understand these large-scale changes, we turn to the mechanisms of macroevolution. In this section, we'll examine several key mechanisms that help explain how new features arise, including changes in developmental genes, the repurposing of existing traits, and the gradual evolution of complex structures through beneficial intermediate stages.

## 1. Evolutionary Developmental Biology (Evo-Devo)

One of the most powerful ways to understand how major evolutionary changes occur is through the field of **evolutionary developmental biology**, or **evo-devo**. This area of study explores how small changes in the genes that control development can lead to large-scale differences in body structure and function. By examining how organisms grow and develop, scientists have discovered that altering when, where, or how certain genes are expressed can result in entirely new traits. Below are three key mechanisms within evo-devo that help explain how complex features evolve.

## Gene Duplication and Divergence

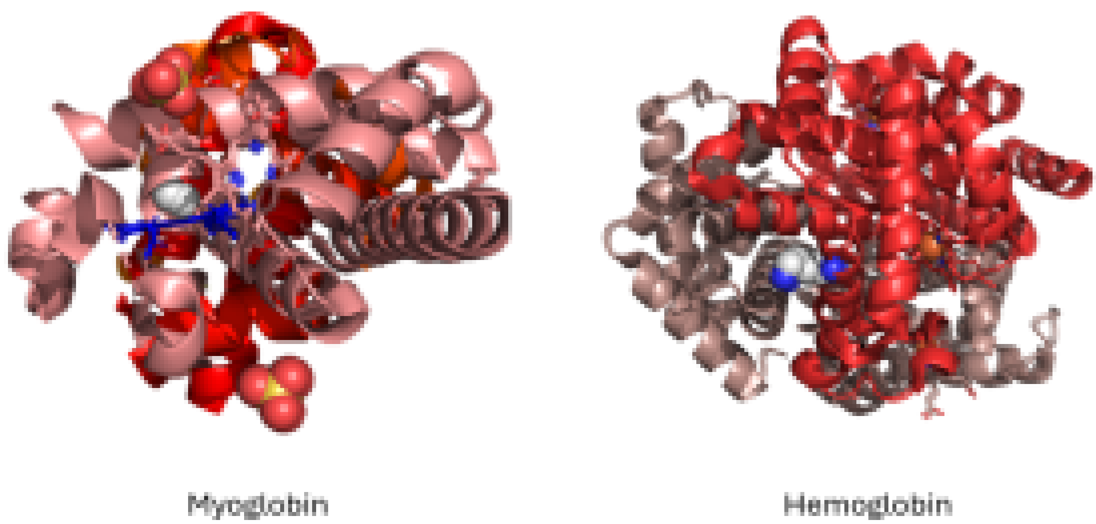



Figure 3.2.1 Myoglobin by Veronica Stafford, CC BY SA 4.0, Mods: cropped; and Hemoglobin by A2-33, CC BY SA 4.0.

**Gene duplication** occurs when a gene is accidentally copied during DNA replication. This creates an extra copy of the gene, which is free to accumulate mutations without affecting the original gene's function. Over time, the duplicated gene may evolve a new role, which can allow for the development of new traits. For example, in vertebrates, gene duplication events have led to the evolution of different types of globin proteins, which are essential for transporting oxygen in the blood. These proteins, such as hemoglobin in red blood cells and myoglobin in muscles, originated from a common ancestral gene that was duplicated and then specialized through evolutionary changes.

## Homeotic Genes and Body Plan Modifications

**Homeotic genes** are a group of regulatory genes that control the basic layout of an organism's body during early development. They help determine where key body parts like limbs, wings, or antennae will form. These genes are remarkably similar across many different species, even those that are only distantly related. This high level of similarity suggests that homeotic genes play a critical role in development, and that even small changes in how or when they are expressed can lead to major differences in body structure. For example, changes in homeotic gene activity are thought to have contributed to the evolution of **tetrapods** (four-limbed vertebrates) from their fish ancestors. In this transition, shifts in the expression of these genes helped modify fin structures into limbs with digits, which allowed the movement from water to land.

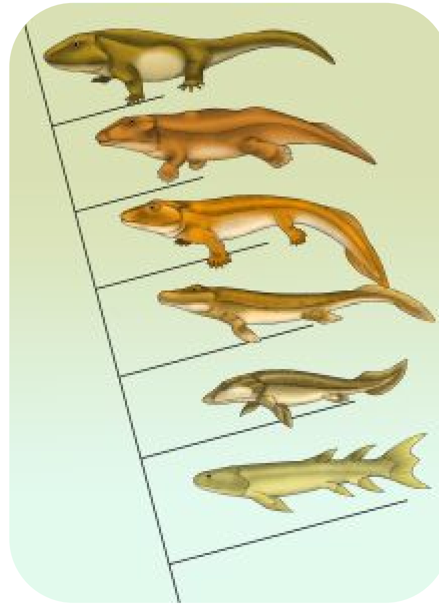


Figure 3.2.2 Image by Eurwentala, CC BY-SA 3.0

## Paedomorphosis and the Retention of Juvenile Traits

Figure 3.2.3 "AxolotlBE" by th1098, CC BY-SA 3.0

**Paedomorphosis** is a process in which adults of a species retain traits that were previously seen only in juveniles. This happens through changes in the timing of development. By slowing down or halting certain developmental processes, organisms can preserve youthful features into adulthood. A well-known example is the axolotl, a type of salamander that retains its gills and aquatic lifestyle throughout its life, unlike most other amphibians that undergo metamorphosis. Paedomorphosis can lead to new evolutionary pathways by allowing traits that were once temporary to become lifelong (permanent) and potentially advantageous.

## 2. Co-option (Exaptation)

**Co-option**, also known as **exaptation**, occurs when a structure or gene that originally evolved for one function is repurposed for a new use. Rather than developing entirely new traits from scratch, evolution often works with what is already available by modifying existing features to serve new roles. This process operates through the *remodelling* of existing structures or genes, allowing them to take on new functions. In this way, complex traits can emerge from the raw materials already present in an organism's genome or anatomy.

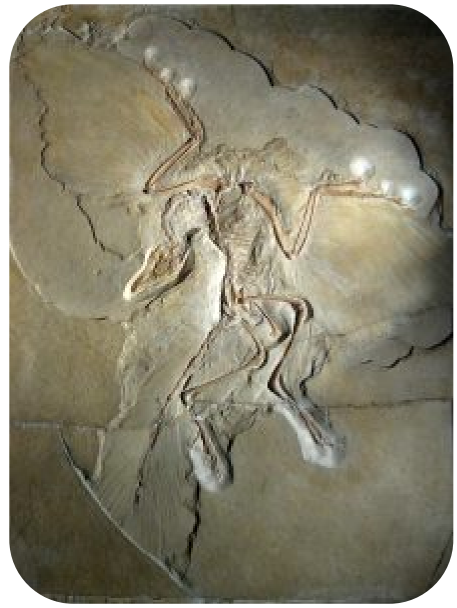


Figure 3.2.4 Specimen displayed at the *Museum für Naturkunde* in Berlin of an Archaeopteryx (bird-like dinosaur). Photo by Vesta, CC BY-SA 3.0

One of the most famous examples of co-option is the evolution of feathers. Feathers are thought to have originally evolved in theropod dinosaurs for purposes such as insulation or display, not for flight. Over time, these feathers were modified and refined, eventually becoming essential for flight in birds.

Co-option is not limited to physical structures but also applies to genes. For instance, genes involved in the development of limbs in vertebrates have been co-opted in other animals to help form entirely different structures, such as the wings of insects or the appendages of cephalopods. These examples show how evolution can creatively reuse existing genetic "toolkits" to create new features.

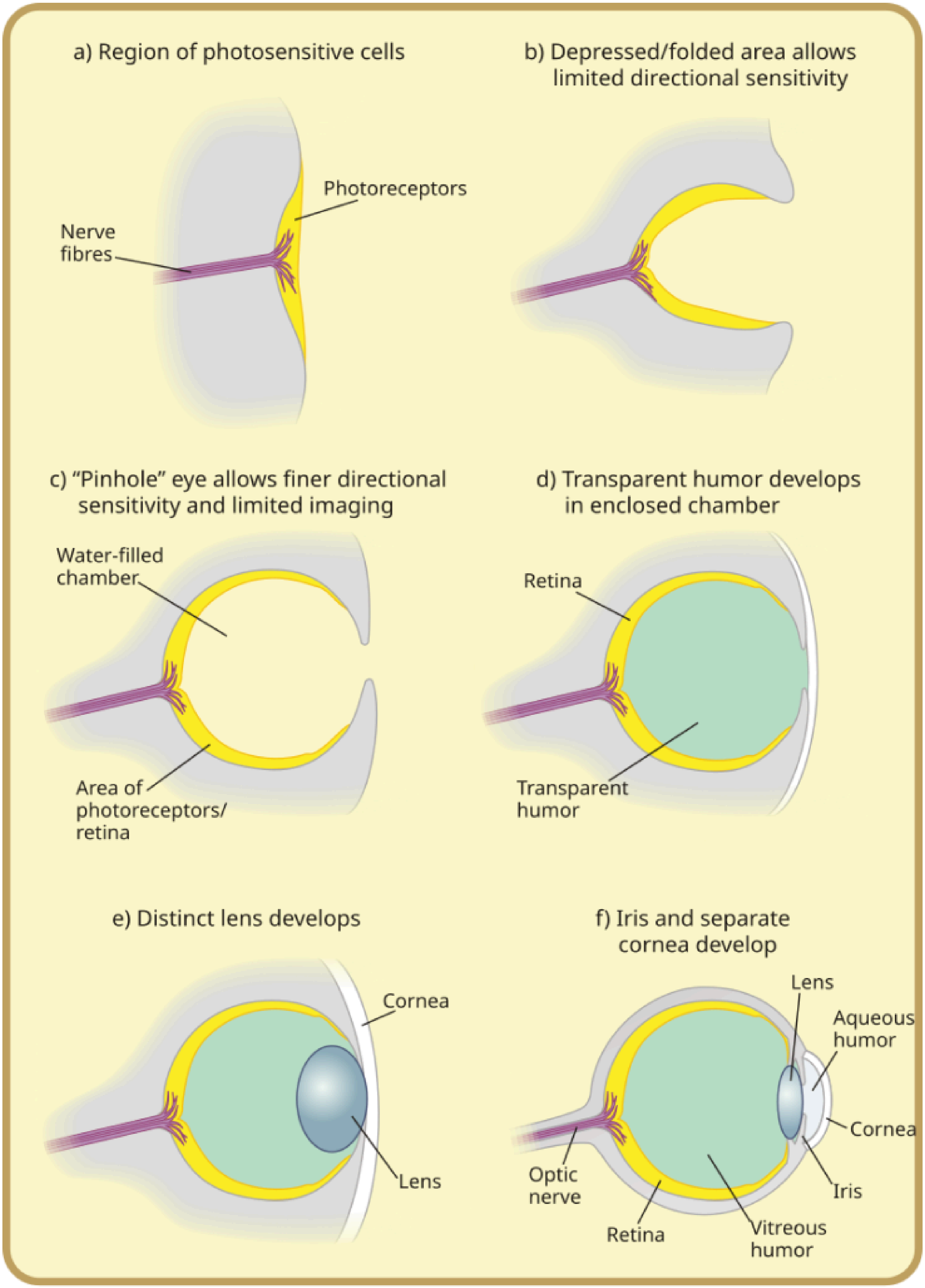
## 3. Advantageous Intermediates

Complex traits often evolve through a series of small, functional steps, with each stage offering some benefit to the organism. These **advantageous intermediates** help explain how intricate structures can arise gradually over time.

A classic example is the evolution of the eye. It likely began with simple light-sensitive cells that could detect changes in brightness, which could have helped early organisms respond to their environment.

Over time, these cells became more specialized, forming a curved surface to detect direction, then a pit to focus light, and eventually a lens to sharpen images. At each stage, the intermediate form was better at performing the specific function, so it would have been more likely to be favoured by natural selection. Advantageous intermediates operate through refinement, where a structure keeps the same function but becomes more effective over time.

Figure 3.2.5 Flatworms have eyespots, which are simple light-sensitive patches that only distinguish light from dark."Dugesia subtentaculata" by Eduard Solà, CC BY-SA 3.0



a) Region of photosensitive cells
Photoreceptors
Nerve fibres
b) Depressed/folded area allows limited directional sensitivity
c) "Pinhole" eye allows finer directional sensitivity and limited imaging
Water-filled chamber
Area of photoreceptors/ retina
d) Transparent humor develops in enclosed chamber
Retina
Transparent humor
e) Distinct lens develops
Cornea
Lens
f) Iris and separate cornea develop
Lens
Aqueous humor
Cornea
Iris
Optic nerve
Retina
Vitreous humor

Figure 3.2.6 Major stages of the evolution of the eye in vertebrates. Image by Matticus78, CC BY-SA 3.0

**Fig 3.2.6 Image Description**

The image illustrates the evolutionary stages of the eye through six labelled diagrams, showing increasing complexity from simple photosensitive cells to a fully developed eye.

- (a) Region of photosensitive cells: A simple patch of photoreceptors connected to nerve fibres that detect light.
- (b) Depressed/folded area: The photoreceptor patch begins to fold inward, allowing limited directional sensitivity.
- (c) "Pinhole" eye: The inward fold deepens into a water-filled chamber, providing finer directional sensitivity and limited image formation.
- (d) Transparent humour in enclosed chamber: The chamber fills with transparent humour, improving light transmission, with the retina lining the back.
- (e) Distinct lens develops: A lens forms at the front, behind the cornea, focusing light more effectively onto the retina.
- (f) Iris and separate cornea develop: The eye becomes fully structured, with a cornea, lens, aqueous humour, vitreous humour, iris, retina, and optic nerve, enabling sharp image formation and controlled light entry.

This sequence demonstrates the gradual evolution from simple light-sensitive cells to a complex, image-forming eye.

It is important to note that the mechanisms of macroevolution often work together to produce evolutionary innovations. For example, all of these mechanisms played a role in the evolution of bird flight. Shifts in homeotic gene expression helped shape the forelimbs into wings. Feathers, which originally evolved for insulation or display, were co-opted for aerodynamic purposes. Then, each intermediate stage, such as gliding or controlled flapping, offered incremental advantages which allowed natural selection to refine the structure and function of wings over time. This interplay of developmental changes, remodelling, and refinement shows how evolution can lead to complex, new features over time.

## Knowledge Check

**Text Description**

This is a drag-and-drop activity

Match the mechanism of evolution with the appropriate definition.

1. _____A process where a structure or gene originally evolved for one function is repurposed for a new use.
2. _____ A field that studies how changes in development influence evolutionary changes in body form and structure.
3. _____ Genes that control the body plan of an organism and determine where body parts develop.
4. _____ A developmental change where juvenile traits are retained in the adult form of a descendant species.
5. _____ A mechanism where a duplicated gene evolves a new function
6. _____ The idea that intermediate forms of a trait can still provide a functional advantage, even if the final form is more complex.

Possible answers:

- Gene Duplication and Divergence
- Advantageous Intermediates
- Paedomorphosis
- Co-option (Exaptation)
- Evolutionary Developmental Biology (Evo-Devo)
- Homeotic Genes

**Answers:**

1. ***Co-option (Exaptation):*** A process where a structure or gene originally evolved for one function is repurposed for a new use.
2. ***Evolutionary Developmental Biology (Evo-Devo):*** A field that studies how changes in development influence evolutionary changes in body form and structure.
3. ***Homeotic Genes:*** Genes that control the body plan of an organism and determine where body parts develop.
4. ***Paedomorphosis:*** A developmental change where juvenile traits are retained in the adult

form of a descendant species.

5. ***Gene Duplication and Divergence:*** A mechanism where a duplicated gene evolves a new function
6. ***Advantageous Intermediates:*** The idea that intermediate forms of a trait can still provide a functional advantage, even if the final form is more complex.

# 3.3 ORGANIZING LIFE ON EARTH

**Systematics** is the scientific study of the diversity of organisms and their evolutionary relationships. It involves identifying, naming, classifying, and determining the evolutionary connections among species.

Systematics includes two main branches: taxonomy and phylogenetics.

## Taxonomy

**Taxonomy** (which literally means "arrangement law") is the science of naming and grouping species to construct an internationally shared classification system. The taxonomic classification system (also called the Linnaean system after its inventor, Carl Linnaeus, a Swedish naturalist) uses a hierarchical model. A hierarchical system has levels, and each group at one of the levels includes groups at the next lowest level, so that at the lowest level, each member belongs to a series of nested groups. For example, in the most inclusive grouping, scientists divide organisms into three domains: Bacteria, Archaea, and Eukarya. Within each domain is a second level called a kingdom. Each domain contains several kingdoms. Within kingdoms, the subsequent categories of increasing specificity are: phylum, class, order, family, genus, and species.

As an example, the classification levels for the domestic dog are shown in Figure 3.3.1. The group at each level is called a taxon (plural: taxa). In other words, for the dog, Carnivora is the taxon at the order level, Canidae is the taxon at the family level, and so forth. Organisms also have a common name that people typically use, such as a domestic dog or a wolf. Each taxon name is capitalized except for species, and the genus and species names are italicized. Scientists refer to an organism by its genus and species names together, commonly called a scientific name, or Latin name. This two-name system is called **binomial nomenclature**. The scientific name of the wolf is therefore Canis lupus. A recent study of the DNA of domestic dogs and wolves suggests that the domestic dog is a subspecies of the wolf, not its own species. Thus, it is given an extra name to indicate its subspecies status, *Canis lupus familiaris*.

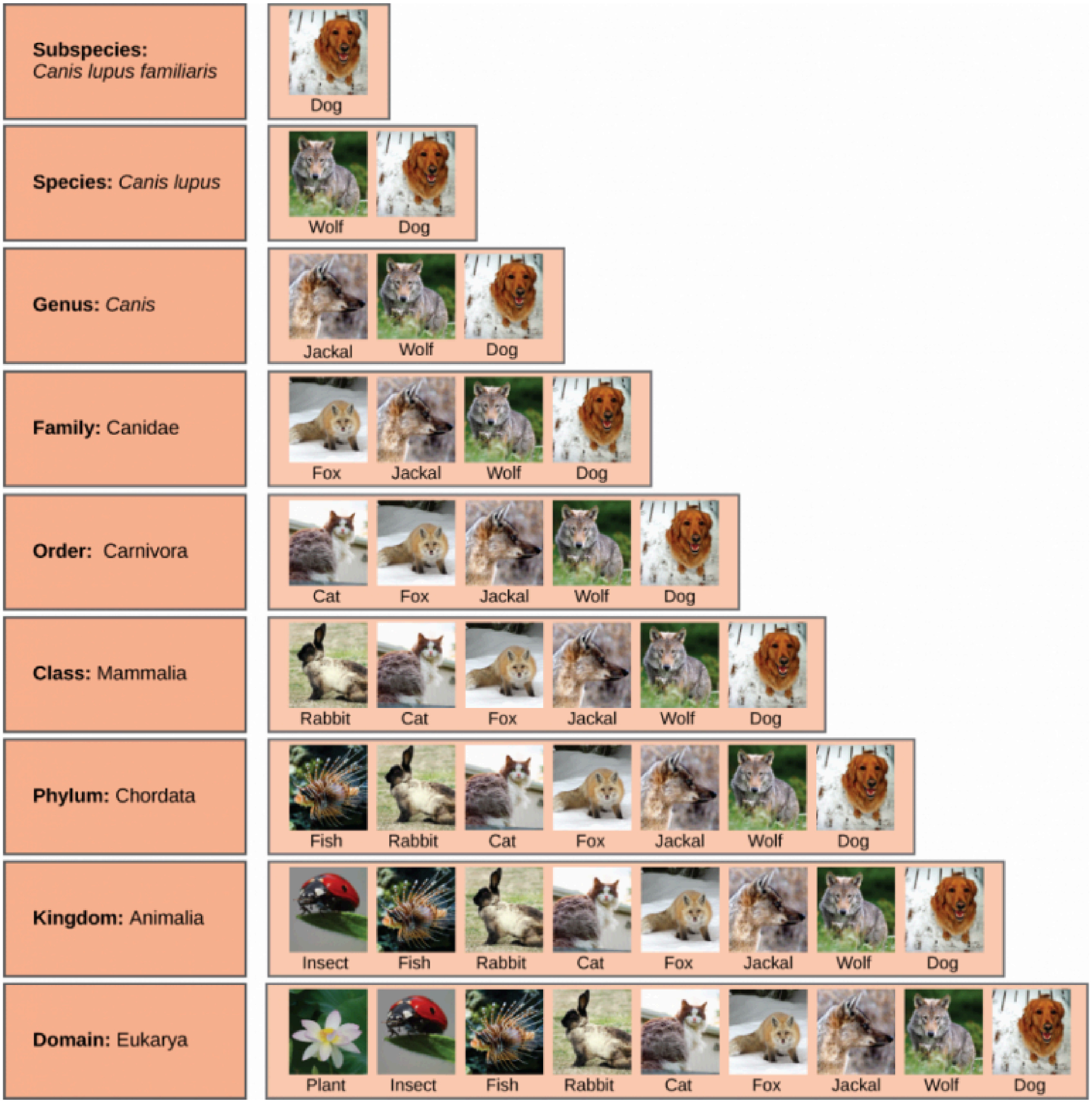



Figure 3.3.1 Collage by OpenStax, CC BY 4.0

### Figure 3.3.1 Image Description

The diagram shows the taxonomic classification of the domestic dog (Canis lupus familiaris), illustrated with images of different animals at each level. The hierarchy expands step by step from subspecies to domain:

1. Subspecies: Canis lupus familiaris – Dog
2. Species: Canis lupus – Wolf, Dog

3. Genus: Canis – Jackal, Wolf, Dog
4. Family: Canidae – Fox, Jackal, Wolf, Dog
5. Order: Carnivora – Cat, Fox, Jackal, Wolf, Dog
6. Class: Mammalia – Rabbit, Cat, Fox, Jackal, Wolf, Dog
7. Phylum: Chordata – Fish, Rabbit, Cat, Fox, Jackal, Wolf, Dog
8. Kingdom: Animalia – Insect, Fish, Rabbit, Cat, Fox, Jackal, Wolf, Dog
9. Domain: Eukarya – Plant, Insect, Fish, Rabbit, Cat, Fox, Jackal, Wolf, Dog

Figure 3.3.1 also shows how taxonomic levels move toward specificity. Notice how, within the domain, we find the dog grouped with the widest diversity of organisms. These include plants and other organisms not pictured, such as fungi and protists. At each sublevel, the organisms become more similar because they are more closely related. Before Darwin's theory of evolution was developed, naturalists sometimes classified organisms using arbitrary similarities, but since the theory of evolution was proposed in the 19th century, biologists have worked to make the classification system reflect evolutionary relationships. This means that all of the members of a taxon should have a common ancestor and be more closely related to each other than to members of other taxa.

## Knowledge Check

Text Description
At what Taxonomic levels are cats and dogs considered to be part of the same group? Select all that apply.

- Order: Carnivora
- Kingdom: Animalia
- Species: Canis lupus
- Genus: Canis
- Subspecies: Canis Lupus familiaris
- Phylum: Chordata
- Class: Mammalia
- Domain: Eukarya
- Family: Canidae

---

Anwers:

- Order: Carnivora
- Kingdom: Animalia
- Phylum: Chordata
- Class: Mammalia
- Domain: Eukarya

# Phylogenetics

Recent genetic analyses have revealed that some traditional taxonomic classifications do not accurately reflect evolutionary relationships. As a result, classifications are continually revised as new discoveries are made. A notable example of this is the reclassification of prokaryotes. Until the 1970s, all prokaryotic organisms were grouped under Bacteria. However, molecular studies uncovered significant genetic differences, leading to the division of prokaryotes into two distinct domains: **Bacteria** and **Archaea**, now recognized as two of the three fundamental branches of life.

Understanding these evolutionary relationships is the focus of **phylogenetics**—the study of the evolutionary history and connections among organisms. Scientists use **phylogenetic trees** to visually represent these relationships. A phylogenetic tree is a branching diagram that reflects how species or groups of organisms have evolved from common ancestors. As species evolve and diverge over time, they form distinct lineages, which are depicted as branches on the tree.

By analyzing inherited traits and other historical evidence, biologists can reconstruct evolutionary pathways. These trees allow us to trace the lineage of a species back to its common ancestors and identify how closely related different organisms are. The branching patterns illustrate how evolution has shaped the diversity of life through descent with modification.

## A Phylogenetic Tree for Vertebrates

**Text Description**

The image is a phylogenetic tree (cladogram) showing evolutionary relationships among different groups of vertebrates. From left to right, the diagram depicts sharks, ray-finned fish, amphibians, primates, rodents & rabbits, crocodiles, and dinosaurs & birds. Each branching point represents the evolution of a new trait.

Pop-up text on hotspots:

- Notice that the species are at the ends of the branches.
- The evolutionary relationships among these species is identified by the nodes (i.e., the branching points).
- Each node can be considered the common ancestor of the species that descend from that node. Notice that there are no images at the nodes. A limitation of phylogenetic trees is that these models do not indicate what the ancestor looked like- just that there is a common ancestor.
- The base of the tree is the common ancestor of all of the above species.
- Characteristics are listed with hashmarks along the tree. This indicates when the characteristic first evolved. In this case, primates, rabbits, rodents, crocodiles, dinosaurs, and birds all have amniotic eggs.

All life on Earth evolved from a common ancestor, so the phylogenetic tree starts with a single point and then branches into the three domains of Archaea, Bacteria, and Eukarya. Each domain then diverges and branches repeatedly. The small branch that plants and animals (including humans) occupy in this diagram shows how recently these groups had their origin compared with other groups.

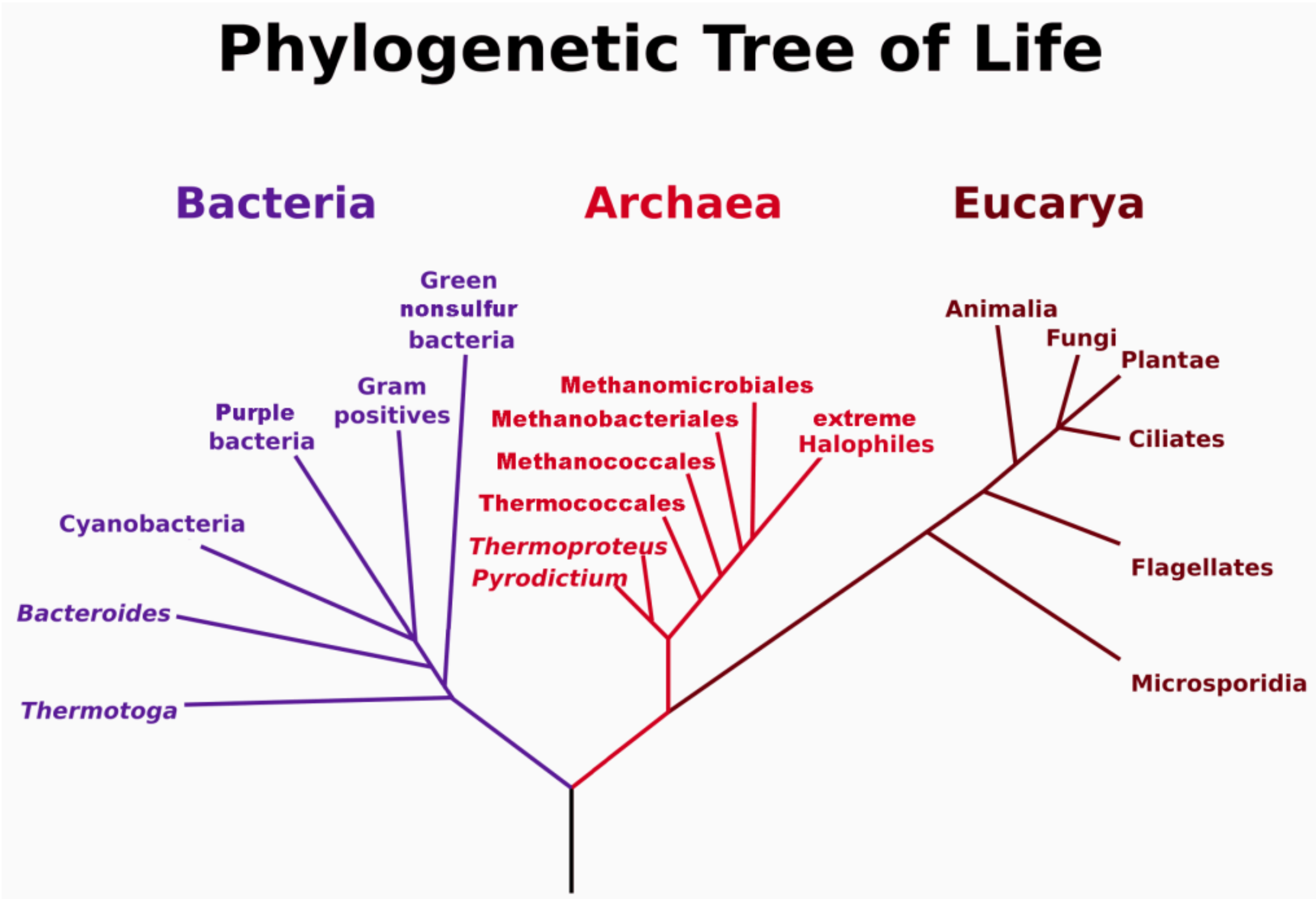



Figure 3.3.2 Phylogenetic tree of Bacteria, Archaea, and Eukarya. The vertical line at the bottom represents the last universal common ancestor. Image by Maulucioni, CC BY-SA 3.0

**Figure 3.3.2 Image Description**

The image shows a phylogenetic tree of life, illustrating the evolutionary relationships among the three domains: Bacteria, Archaea, and Eucarya.

- Bacteria (left, in purple) includes groups such as Thermotoga, Bacteroides, Cyanobacteria, Purple bacteria, Gram positives, and Green nonsulfur bacteria.
- Archaea (center, in red) branches into lineages such as Methanomicrobiales, Methanobacteriales, Methanococcales, Thermococcales, Thermoproteus, Pyrodictium, and extreme halophiles.
- Eucarya (right, in dark red) contains major eukaryotic groups, including Animalia, Fungi, Plantae, Ciliates, Flagellates, and Microsporidia.

Each domain is colour-coded: purple for Bacteria, red for Archaea, and dark red for Eucarya. The tree emphasizes the common origin point at the root, showing how all life diverged into these three main domains.

The tree is supported by many lines of evidence, but it is probably not flawless. Scientists constantly re-evaluate hypotheses and compare them to new evidence. As scientists gather even more data, they may revise these particular hypotheses, rearranging some of the branches on the tree. For example, evidence discovered in the last 50 years suggests that birds are dinosaurs, which required an adjustment to several "vertebrate twigs."

## Understanding Phylogenetic Trees

The point where a split occurs in a tree, called a branch point, represents where a single lineage evolved into distinct new ones. Many phylogenetic trees have a single branch point at the base representing a common ancestor of all the branches in the tree. When two lineages stem from the same branch point, they are called sister taxa. A branch point with more than two groups illustrates a situation for which scientists have not definitively determined relationships. It is important to note that sister taxa share an ancestor, which does not mean that one taxon evolved from the other. The branch point, or split, represents a common ancestor that existed in the past but no longer exists.

## How to Understand Phylogenetic Trees

The following diagram describes the different components of phylogenetic trees. Click on the Information tab in each box to learn more.

**Text Description**

- Understanding a phylogeny is a lot like reading a family tree. The root of the tree represents the ancestral lineage, and the tips of the branches represent the descendants of that ancestor. As you move from the root to the tips, you are moving forward in time.
- When a lineage splits (speciation), it is represented as branching on a phylogeny. When a speciation event occurs, a single ancestral lineage gives rise to two or more daughter lineages.
- Often, one sees phylogenies that include polytomies, nodes with more than two descendant lineages, creating a "pitchfork." A polytomy may mean that we don't have enough data to figure out how the lineages are related. Often, gathering more data can resolve a polytomy, or it may mean that multiple speciation events happened at the same time.
- Phylogenies trace patterns of shared ancestry between lineages. Each lineage has a part of its history that is unique to it alone and parts that are shared with other lineages.
- Similarly, each lineage has ancestors that are unique to that lineage and ancestors that are shared with other lineages — common ancestors.
- A clade is a grouping that includes a common ancestor and all the descendants (living and extinct) of that ancestor. Using a phylogeny, it is easy to tell if a group of lineages forms a clade. Imagine clipping a single branch off the phylogeny — all of the organisms on that pruned branch make up a clade. Clades are nested within one another — they form a nested hierarchy. A clade may include many thousands of species or just a few.

## Knowledge Check

Text Description

**1.** As depicted in the tree for the previous question, which of the species is most distantly related to the others (you can use the back arrow below to look at the tree again)?

a. Brown bear
b. Grey squirrel
c. Spider monkey
d. Humans
e. Giant beaver

**2.** As depicted in the tree for the previous question, which ancestor is the most distant (i.e., nearest to the root of the tree)?

a. Ancestor of bear and human
b. Ancestor of squirrel and monkey
c. Ancestor of human and monkey

**3.** As depicted in the previous tree, which two species are most distantly related to the rest of them? Click on the checkbox next to both species.

a. Pie-billed grebe
b. Night heron
c. Roadrunner
d. Bohemian waxwing
e. Arctic tern

**4.** For the previous question, what was wrong with the incorrect tree?

a. The species moved to opposite sides (i.e., the species on the left side moved to the right and vice versa).
b. The piebilled grebe was no longer shown as being more closely related to the road runner and the night heron.

**5.** As depicted in the previous tree, which two species are most distantly related to the rest of them? Click on the checkbox next to both species.

a. Poison dart frog
b. Horned owl
c. Box turtle
d. Reticulated python
e. Tiger salamander

**6.** As depicted in the previous tree, which characteristic is labelled closest to the root of the tree?

a. Warm-blooded
b. Amniotic egg
c. Rib-fused shell
d. Hard-shelled eggs
e. Cutaneous breathing

**7.** Based on the previous question, which species is most closely related to the great horned owl?

a. Horned owl
b. Poison dart frog
c. Reticulated python
d. Tiger salamander
e. Box turtle

---

**Answers:**

a. Brown bear
a. Ancestor of bear and human
d. Bohemian waxwing; e. Arctic tern;
b. The piebilled grebe was no longer shown as being more closely related to the road runner and the night heron.
a. Poison dart frog; e. Tiger salamander;
b. Amniotic egg
c. Reticulated python

# CHAPTER 3 SUMMARY

## Key Takeaways

- **Macroevolution Explains Large-Scale Evolutionary Change:** Macroevolution encompasses evolutionary events above the species level, including the emergence of major traits (like wings or flowers) and mass extinctions. These changes occur over long periods and are critical to understanding the diversity of life.
- **The Fossil Record and Geologic Time Scale Provide Evolutionary Context:** Fossils offer evidence of how life has changed through time, and the geologic time scale organizes Earth's history into eons, eras, periods, and epochs—correlating major evolutionary changes with global events like extinctions and continental shifts.
- **Continental Drift Drives Evolutionary and Environmental Shifts**: The movement of tectonic plates reshapes continents, affecting ecosystems and climates. This process has triggered evolutionary transitions and extinctions, influencing the structure of the Geologic Time Scale.
- **Mechanisms of Macroevolution Drive Innovation in Body Plans:** Macroevolutionary innovations arise through mechanisms such as gene duplication, changes in developmental (homeotic) genes, paedomorphosis, co-option of traits, and the gradual refinement of complex features through advantageous intermediates.
- **Systematics Organizes Life Based on Evolutionary Relationships**: Systematics combines taxonomy (classification) and phylogenetics (evolutionary history) to group organisms. The hierarchical classification system reflects shared ancestry, using levels like domain, kingdom, and species.
- **Phylogenetic Trees Map Evolutionary Lineages:** Phylogenetic trees visually represent evolutionary relationships, with branch points indicating common ancestors. These trees help scientists understand how species are related and how life diversified from shared origins.

OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Summarize the following content into six key takeaways.

## Flashcards

Click on the flashcards to review key terms discussed in this chapter.

**Text Description**

Front of card:

1. Permian-Triassic extinction
2. Continental drift
3. Mechanisms of macroevolution
4. Paedomorphosis
5. Phylogenetic tree
6. Plate tectonics
7. Systematics
8. Events that ended each of the four major divisions of the GTS
9. Four major divisions in the Geologic Time Scale
10. Fossil record
11. Precambrian
12. Three domains of life
13. Co-option (Exaptation)
14. Homeotic genes
15. Geologic Time Scale
16. Branch point
17. Gene duplication and divergence
18. Macroevolution
19. Phylogenetics
20. Levels of taxonomy (from broadest to smallest)
21. Pangaea
22. Domain

23. Common ancestor
24. Paleozoic era
25. Advantageous Intermediates
26. Mass extinction
27. Cretaceous-Paleogene (K–Pg) extinction
28. Taxon (plural: Taxa)
29. Kingdom
30. Binomial nomenclature
31. Order
32. Trilobite
33. Eukarya
34. Era
35. Precambrian
36. Mesozoic era
37. Tetrapods
38. Taxonomy
39. Evolutionary Developmental Biology (Evo-Devo)

Back of card:

1. The largest mass extinction event in Earth's history, wiping out approximately 90% of marine species and 70% of terrestrial species, ended the Paleozoic era
2. The gradual movement of Earth's continents over geological time due to tectonic plate activity affecting climate, ecosystems, and evolution
3. Evo-Devo – Gene Duplication, Homeotic Genes, Peadomorphosis; Co-option (exaptation); Advantageous intermediates
4. An evolutionary process in which adults retain juvenile traits due to changes in developmental timing
5. A branching diagram that shows evolutionary relationships among organisms based on shared traits and common ancestry
6. The scientific theory describing the movement of Earth's plates over the mantle, causing continental drift and geological activity
7. The scientific study of biological diversity and the evolutionary relationships among organisms, encompassing taxonomy and phylogenetics
8. Precambrian – Cambrian Explosion
   Paleozoic – Permian-Triassic extinction

Mesozoic – K-Pg extinction
Cenozoic – current era

9. Precambrian, Paleozoic, Mesozoic, Cenozoic
10. The collection of all known fossils and their placement in rock layers provides evidence of evolutionary history
11. The earliest and longest division of Earth's history, preceding the Paleozoic Era, Characterized by the origin of life and the development of simple organisms
12. Bacteria, Archaea, Eukarya
13. The evolutionary process where an existing structure or gene is repurposed for a different function
14. Genes that control the development of anatomical structures in organisms; small changes in these genes can lead to significant evolutionary changes in body plans
15. A chronological framework that organizes Earth's history into eons, eras, periods, and epochs, based on geological and fossil evidence
16. A location on a phylogenetic tree where a single lineage splits into two or more distinct lineages, representing a common ancestor
17. A process where a gene is copied, allowing one copy to retain its original function while the other may evolve a new function
18. Large-scale evolutionary changes that occur above the species level over long time scales, including the emergence of new traits and mass extinctions
19. The scientific study of evolutionary relationships among organisms, often represented through phylogenetic trees
20. Domain, Kingdom, Phylum, Class, Order, Family, Genus, Species
21. A supercontinent that existed during the late Paleozoic and early Mesozoic eras, in which all Earth's landmasses were joined together before breaking apart into the continents we know today
22. The highest taxonomic rank in the classification of life, consisting of Bacteria, Archaea, and Eukarya
23. An ancestral species from which two or more descendant species have evolved.
24. A major division of geologic time marked by the emergence of diverse marine life, the colonization of land by plants and animals, began with the Cambrian Explosion and ended with the Permian-Triassic extinction
25. Functional stages in the evolution of complex traits, where each intermediate form provides a selective benefit, allowing gradual refinement over time through natural selection
26. A widespread and rapid decrease in biodiversity, where a large number of species go extinct

in a relatively short geological time period

27. A mass extinction event that led to the extinction of non-avian dinosaurs and many other species, likely caused by a massive asteroid impact; it marked the end of the Mesozoic era
28. A group or rank in a biological classification system (e.g., species, genus, family) representing a unit of organisms
29. A taxonomic category below domain and above phylum; groups related organisms with similar characteristics (e.g., Animalia, Plantae)
30. A two-part scientific naming system for species, consisting of the genus name (capitalized) and species name (lowercase), both italicized (e.g., Canis lupus)
31. A taxonomic category ranking below class and above family in biological classification
32. An extinct group of marine arthropods that were highly diverse and abundant during the Paleozoic Era
33. One of the three domains of life, consisting of organisms with complex cells containing a nucleus, including animals, plants, fungi, and protists
34. A major division of geologic time that follows an eon, marked by significant geological and biological events
35. A major division of geology that spans all of Earth's history before the Cambrian period; It includes the formation of Earth and the earliest life forms
36. A major division of geologic time known as the "Age of Reptiles" and characterized by the dominance of dinosaurs, it ended with the K-Pg extinction
37. Vertebrate animals with four limbs or limb-like appendages, including amphibians, reptiles, birds, and mammals
38. The science of naming, describing, and classifying organisms into groups based on shared characteristics
39. A field of biology that studies how changes in developmental processes and genes lead to evolutionary changes in body structure

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Provide definitions for all the bolded terms in the shared content and list all the terms in alphabetical order.

# CHAPTER 4: PROKARYOTES AND PROTISTS

## Chapter Overview

## Learning Objectives

By the end of this chapter, you will be able to:

- Explain how life may have started on Earth through the process of abiogenesis and what early Earth was like.
- Recognize the basic parts of prokaryotic cells and know the differences between Bacteria and Archaea.
- Explore the helpful and harmful roles of prokaryotes in the environment and human health.
- Learn how prokaryotes reproduce and how they can exchange genetic material in different ways.
- Identify the main types of protists, what they look like, and how they live and move.
- Discover how extremophiles and microbial mats help us understand the beginnings and variety of life on Earth.

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Provide 6 learning objectives for the shared content.

# 4.1 THE ORIGIN OF LIFE

## Abiogenesis: Life from Non-Life

One of the central questions in biology is how life first began on Earth. While several hypotheses have been proposed, the most widely accepted scientific explanation is abiogenesis. **Abiogenesis** is the scientific term for the origin of life from non-living matter. It refers to the natural process by which simple chemical compounds gradually gave rise to more complex molecules, eventually leading to the first living organisms.

## Early Earth

To understand how life began, we first need to imagine what Earth looked like over 4 billion years ago. It was a planet in chaos—hot, violent, and unrecognizable compared to today. The surface was dominated by volcanic activity, with molten rock and lava flows shaping the young landscape. The atmosphere was thick with gases like methane, ammonia, water vapour, and hydrogen**,** but lacked oxygen. Frequent lightning storms and intense ultraviolet radiation from the Sun bombarded the planet, while asteroids and comets regularly slammed into the surface. Despite these harsh conditions, Earth also had vast oceans and a rich supply of chemical ingredients. This dynamic, energy-rich environment may have provided the perfect lab for the chemistry that would eventually give rise to life.

## Four Stages of Abiogenesis

Abiogenesis doesn't describe a single event, but rather a series of steps that transformed simple molecules into the first living systems.

Step 1: Formation of Organic Molecules

Life as we know it is built from **organic molecules** (compounds containing carbon, such as amino acids and nucleotides**)**. These are the building blocks for proteins and nucleic acids (DNA and RNA).

In 1953, chemists Stanley Miller and Harold Urey conducted an experiment to test whether these molecules could form under early Earth conditions. They created a closed system filled with gases thought to be present in Earth's early atmosphere—methane, ammonia, hydrogen, and water vapour—and introduced electrical sparks to simulate lightning. After just a few days, they found that amino acids had formed spontaneously.

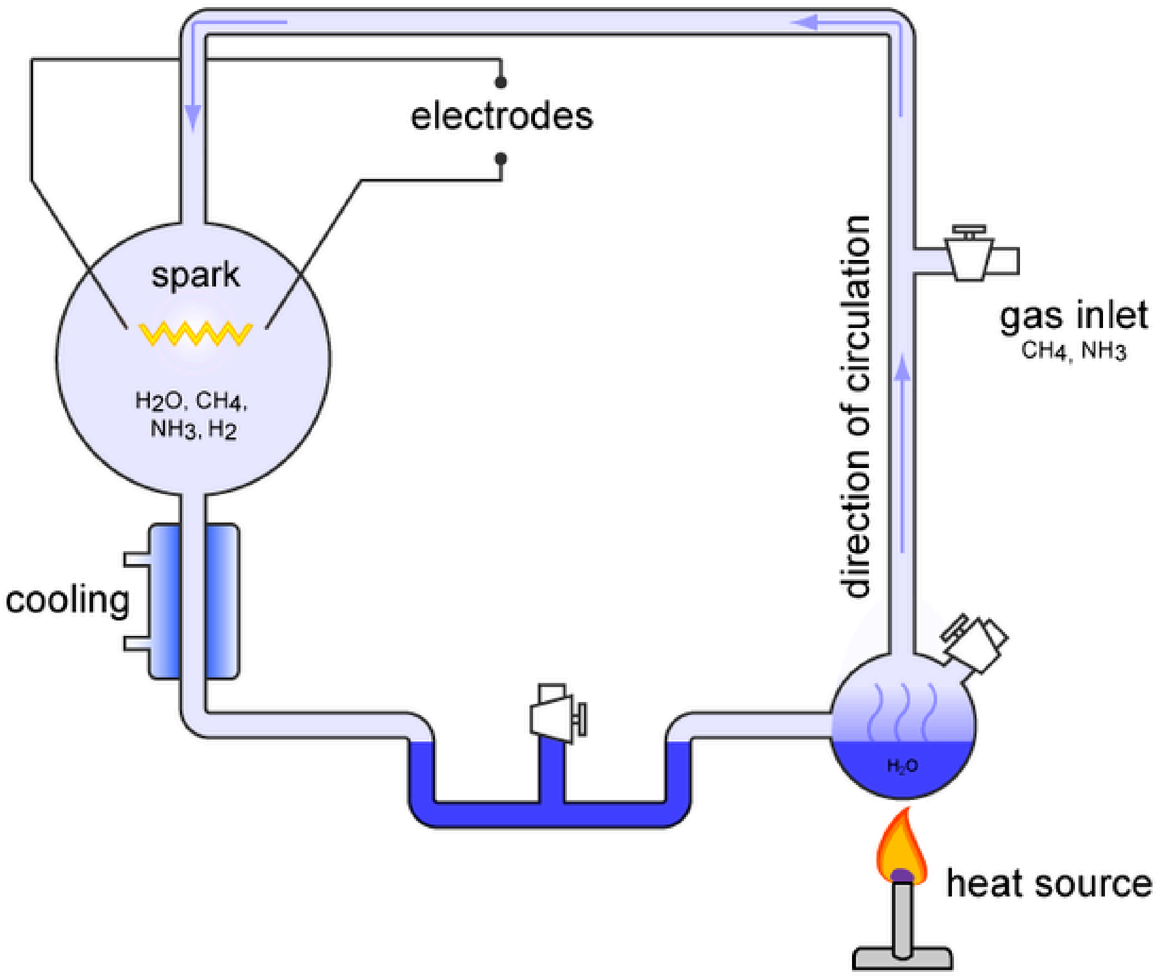


Figure 4.1.1 Image by Carny, CC BY 2.5

**Figure 4.1.1. Image Description**

The diagram illustrates the Miller-Urey experiment setup, which simulated early Earth conditions to test the origin of organic molecules.

- On the right, a heat source boils water ($H_2O$) in a flask, producing water vapour.

- The vapour circulates upward through tubes, mixing with gases ($CH_4$ – methane and $NH_3$ – ammonia) supplied through a gas inlet, along with $H_2$ – hydrogen.
- The mixture passes into a chamber containing electrodes that create a spark discharge, simulating lightning.
- This spark chamber contains the gases ($H_2O$, $CH_4$, $NH_3$, $H_2$) where chemical reactions occur.
- The system is connected to a cooling condenser, which cools the gases, causing water and dissolved compounds to condense and circulate back into the boiling flask.
- The arrows indicate the direction of circulation, showing a continuous cycle of heating, sparking, cooling, and recirculation

This experiment showed that organic molecules can arise naturally from simple chemicals when given the right conditions. Since then, similar experiments have produced sugars, lipids, and even nucleotides. On early Earth, these organic compounds would have accumulated in the ocean where they could mix and react over time. This is often referred to as **primordial soup** because it contained all of the ingredients for life.

Scientists have proposed other hypotheses for how organic molecules may have formed. These include deep-sea hydrothermal vents, where mineral-rich water and heat could drive chemical reactions, and extraterrestrial delivery, where organic compounds may have arrived on Earth via meteorites and comets.

## Step 2: Assembly into Macromolecules

Organic molecules alone aren't enough. Life requires **macromolecules** (large, complex molecules like proteins and nucleic acids) to perform essential functions such as catalyzing reactions and storing genetic information.

But how did small molecules link together into these larger structures? Scientists believe that natural catalysts may have played a key role. For example, clay minerals can attract and concentrate organic molecules on their surfaces. In lab experiments, researchers have shown that nucleotides can spontaneously link into short RNA chains when dripped onto certain types of clay.

Another important factor may have been the rhythmic action of waves on early Earth. As waves splashed onto hot rocks or mineral surfaces, the organic molecules from the primordial soup would have the opportunity to interact. As the water evaporated in the heat, molecules became more concentrated and were more likely to bond.

Experiments simulating these conditions have successfully produced all of the major macromolecules in the lab, supporting the idea that simple environmental processes could have driven the assembly of life's first functional molecules.

### Step 3: Formation of Protocells

The cell membrane serves as a boundary that separates a cell's internal environment from the outside world. A key step in the origin of life likely involved enclosing organic molecules within a simple membrane, forming structures known as **protocells**. These weren't true cells, but they exhibited some life-like properties. Protocells likely formed spontaneously from fatty acids, which can naturally assemble into spherical vesicles in water. These vesicles could trap molecules like RNA and other macromolecules inside of them and create a protected space where chemical reactions could occur more efficiently.

Protocells made in the lab have been shown to mimic early cell-like behaviour, including growth and even division.

### Step 4: Self-Replication

A defining feature of life is the ability to reproduce (to make copies of itself). In modern cells, this process depends on DNA to store genetic information and proteins to carry out the work of copying and expressing that information.

But this raises a fundamental question: how did the first living systems reproduce before DNA and proteins existed? This is often referred to as a "chicken-and-egg" problem. DNA needs proteins to be copied, but the instructions to make those proteins are stored in DNA. So which came first?

One possible solution lies in RNA. What makes RNA special is that some types can do two jobs: they can store genetic information and help chemical reactions happen. Some RNA molecules can even help copy other RNA molecules.

This means that early life may have relied on RNA molecules that could both store information and help copy themselves. Early RNA wasn't perfect and likely made lots of mistakes when copying. Over time, the RNA strands that were better at making accurate copies would have increased in number.

## From Chemistry to Biology

Over time, protocells that were better at capturing resources, maintaining internal stability, and replicating their contents would have had a selective advantage. Through natural selection, these simple structures gradually evolved greater complexity and eventually gave rise to the first true cells. Life was formed. From that moment on, biological evolution began to shape the diversity of life.

All modern life is thought to descend from one such ancestral cell, known as the **Last Universal Common Ancestor (LUCA)**. LUCA wasn't the very first life form, but it is the most recent common ancestor shared by all organisms alive today. It likely lived between 3.5 and 4 billion years ago and already had many of the core features found in modern cells—such as a genetic code, proteins, ribosomes, a cell membrane, and basic metabolic functions.

From LUCA, life branched out. Some lineages evolved into bacteria, others into archaea, and eventually, some gave rise to eukaryotes.

## Knowledge Check

**Text Description**

1. What is the term for the natural process by which life arises from non-living matter?

   a. Biogenesis
   b. Abiogenesis
   c. Photosynthesis
   d. Evolution

2. What did the Miller-Urey experiment demonstrate?

   a. RNA molecules cannot form without DNA
   b. Organic molecules can form naturally from simple chemicals under early Earth conditions
   c. DNA can form spontaneously in any environment
   d. Protocells require oxygen to form

3. Which structures are thought to have enclosed early organic molecules and exhibited some life-like behaviours such as growth and division?

   a. Ribosomes
   b. Organelles
   c. Protocells
   d. Bacteria

4. What unique property of RNA makes it a likely candidate for the first self-replicating molecule?

   a. It can form membranes
   b. It contains proteins
   c. It can store information and catalyze reactions
   d. It is more stable than DNA

5. What is LUCA believed to represent in the history of life?

   a. The first eukaryotic cell
   b. The ancestor of bacteria only
   c. The first living organism ever

d. The most recent common ancestor of all current life

---

**Answers:**

1. b. Abiogenesis
2. b. Organic molecules can form naturally from simple chemicals under early Earth conditions
3. c. Protocells
4. c. It can store information and catalyze reactions
5. d. The most recent common ancestor of all current life

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Create 5 multiple-choice questions using the following content

# 4.2 PROKARYOTES

## Early Life on Earth

**Prokaryotes** were the first forms of life on Earth, appearing 3.5 to 3.8 billion years ago, and they existed for billions of years before plants and animals appeared. The Earth is around 4.54 billion years old. As already discussed, early Earth had a very different atmosphere from the one it has today. It contained less molecular oxygen and was subjected to strong radiation, so the first organisms would have flourished where they were more protected (such as in ocean depths or beneath the surface of the Earth). At this time, too, strong volcanic activity was common on Earth, so it is likely that these first organisms-the first prokaryotes–were adapted to very high temperatures.

## Prokaryotic Diversity

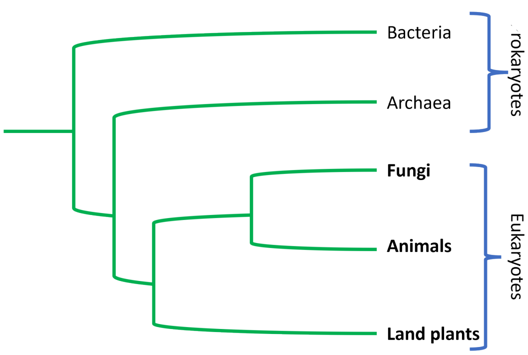


Figure 4.2.1 A phylogenetic tree showing that life branches into prokaryotes (bacteria and archaea) and eukaryotes (fungi, animals, and land plants). Image by Shana Kerr, CC BY-NC-SA 3.0

Prokaryotes are present everywhere. They cover every imaginable surface where there is sufficient moisture, and they live on and inside of other living things. There are more prokaryotes inside and on the exterior of the human body than there are human cells in the body. Some prokaryotes thrive in environments that are inhospitable for most other living things. Prokaryotes recycle nutrients—essential substances (such as carbon and nitrogen)—and they drive the evolution of new ecosystems, some of which are natural while others are man-made. Prokaryotes have been on Earth since long before multicellular life appeared.

The advent of DNA sequencing provided immense insight into the relationships and origins of prokaryotes that were not possible using traditional methods of classification. A major insight identified two groups of prokaryotes that were found to be as different from each other as they were from eukaryotes. These two groups, or domains, are the **Bacteria** and **Archaea**.

# Microbial Mats

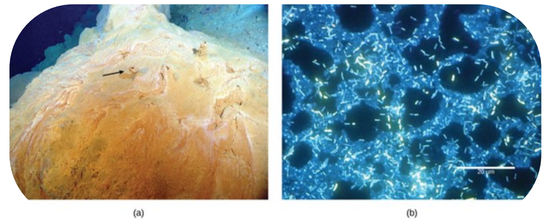

Figure 4.2.2 This (a) microbial mat, about one meter in diameter, grows over a hydrothermal vent in the Pacific Ocean in a region known as the "Pacific Ring of Fire." The mat helps retain microbial nutrients. Chimneys such as the one indicated by the arrow allow gases to escape. (b) In this micrograph, bacteria are visualized using fluorescence microscopy. Image (a) by Dr. Bob Embly, CC BY 4.0, Image (b) by Ricardo Murga and Rodney Donlan, Public Domain

Microbial mats or large biofilms may represent the earliest forms of life on Earth; there is fossil evidence of their presence starting about 3.5 billion years ago. A **microbial mat** is a multi-layered sheet of prokaryotes (Figure 4.2.2) that includes mostly bacteria, but also archaea. Microbial mats are a few centimetres thick, and they typically grow where different types of materials interface, mostly on moist surfaces. The various types of prokaryotes that comprise them carry out different metabolic pathways, and that is the reason for their various colours. Prokaryotes in a microbial mat are held together by a glue-like sticky substance that they secrete, called extracellular matrix.

The first microbial mats likely obtained their energy from chemicals found near hydrothermal vents. A **hydrothermal vent** is a breakage or fissure in the Earth's surface that releases geothermally heated water. With the evolution of photosynthesis about 3 billion years ago, some prokaryotes in microbial mats came to use a more widely available energy source—sunlight—whereas others were still dependent on chemicals from hydrothermal vents for energy and food.

# Stromatolites

Figure 4.2.3 (a)Stromatolites, Shark Bay, Western Australia. Image by Martin Barnes, Public Domain, (b)Siyeh rock formation of Glacier National Park, Montana, USA. Image by P. Carrara, NPS, Public Domain

Fossilized microbial mats represent the earliest record of life on Earth. A **stromatolite** is a sedimentary structure formed when minerals are precipitated out of water by prokaryotes in a microbial mat (Fig. 4.2.3). Stromatolites form layered rocks made of carbonate or silicate. Although most stromatolites are artifacts from the past, there are places on Earth where stromatolites are still forming. For example, growing stromatolites have been found in the Anza-Borrego Desert State Park in San Diego County, California.

# Life in Extreme Environments

Prokaryotes thrive in a vast array of environments: some grow in conditions that would seem very normal to us, whereas others are able to thrive and grow under conditions that would kill a plant or animal. Prokaryotes that grow under extreme conditions are called **extremophiles**, meaning "lovers of extremes." Extremophiles have been found in extreme environments of all kinds, including the depths of the oceans, hot springs, the Arctic and the Antarctic, very dry places, deep inside Earth, harsh chemical environments, and high radiation environments. Extremophiles give us a better understanding of prokaryotic diversity and open up the possibility of the discovery of new therapeutic drugs or industrial applications. They have also opened up the possibility of finding life in other places in the solar system, which have harsher environments than those typically found on Earth. Because they have specialized adaptations that allow them to live in extreme conditions, many extremophiles cannot survive in moderate environments.

There are many different groups of extremophiles, and they are identified based on the conditions in which they grow best. **Thermophiles** are adapted for extreme heat (temperatures ranging from 60–80 °C). **Acidophiles** live in extremely acidic conditions (pH 3 or below). **Halophiles** live in extremely salty environments (salt concentration of at least 0.2 M).

One example of a very harsh environment is the Dead Sea, a hypersaline basin that is located between Jordan and Israel. Despite its name, the Dead Sea is not completely lifeless. While its extreme salinity (about 10 times saltier than the ocean) prevents fish, aquatic plants, and most macroscopic organisms from surviving, it is home to a variety of microorganisms specially adapted to these harsh conditions (e.g. halophiles).

Figure 4.2.4 Photo of the Dead Sea, Image (left) by Alexandermcnabb, CC BY-SA 4.0, and cluster of cells of Halobacterium sp. strain NRC-1 (halophiles), Image (right) by NASA, Public Domain

# Prokaryotic Cell Structure

A **prokaryotic cell** is a simple, single-celled (unicellular) organism that lacks a nucleus or any other membrane-bound organelle. Prokaryotic DNA is found in the central part of the cell – a darkened region called the **nucleoid** (Fig. 4.2.5). Some structures are present in some prokaryotic species, but not in others. For example, the **capsule** found in some species enables the organism to attach to surfaces and protects it from dehydration. Some species may also have **flagella** (singular, flagellum) used for locomotion, and **pili** (singular, pilus) used for attachment to surfaces and to other bacteria for conjugation (see below). **Plasmids**, which consist of small, circular pieces of DNA outside of the main chromosome, are also present in many species of bacteria.

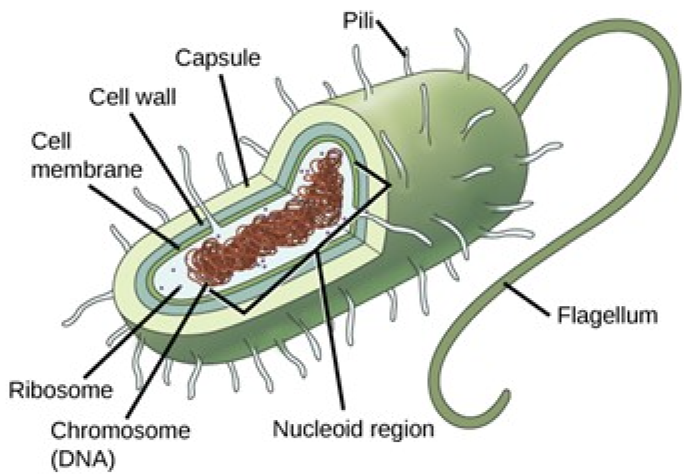


Figure 4.2.5 The features of a typical prokaryotic cell are shown. Image by CNX OpenStax, CC BY 4.0

Most prokaryotes have a cell wall lying outside the plasma membrane. The composition of the cell wall differs significantly between the domains Bacteria and Archaea (and their cell walls also differ from the eukaryotic cell walls found in plants and fungi). The cell wall functions as a protective layer and is responsible for the organism's shape.

Prokaryotes come in various shapes, but many fall into three categories: **cocci** (spherical), **bacilli** (rod-shaped), and **spirilla** (spiral-shaped) (Figure 4.2.6).

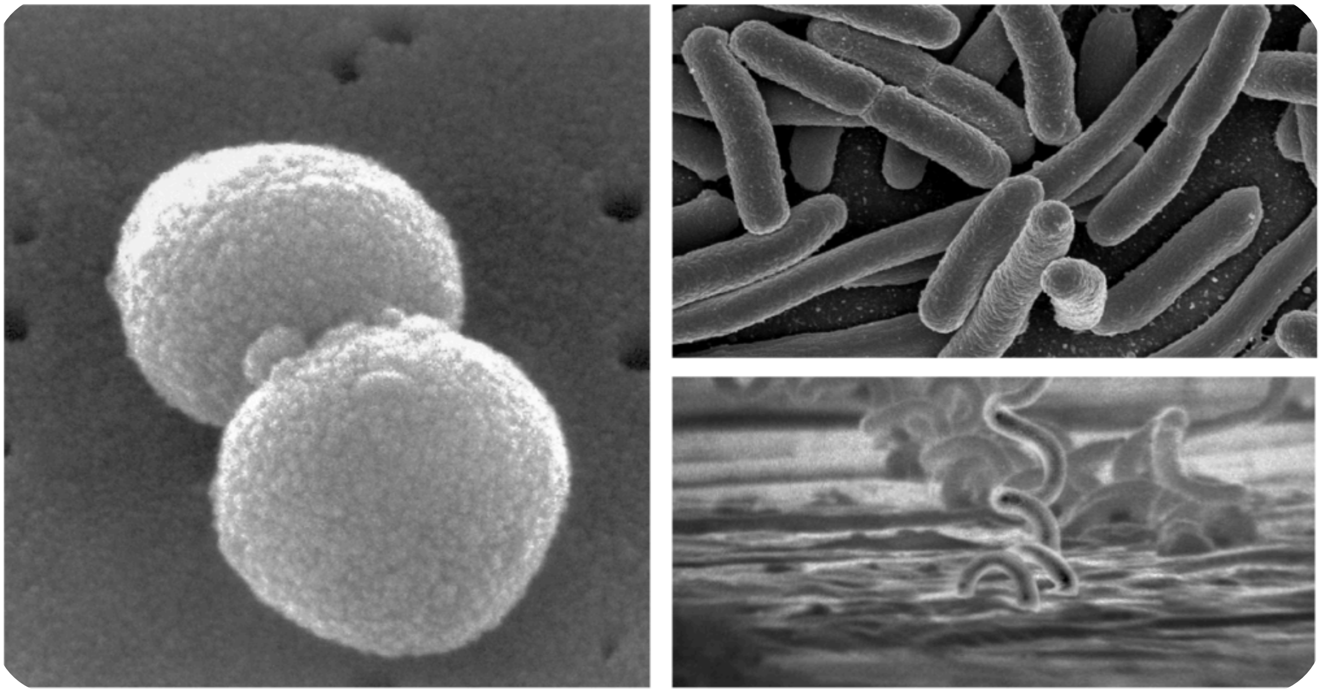

Figure 4.2.6 Image (left): "Streptococcus pneumoniae" by Janice Haney Carr, Public Domain. Image (top right): "E-Coli Bacteria", by NIAID, Public Domain, Image (bottom right): "Treponema pallidum", by CDC, Public Domain

## Reproduction

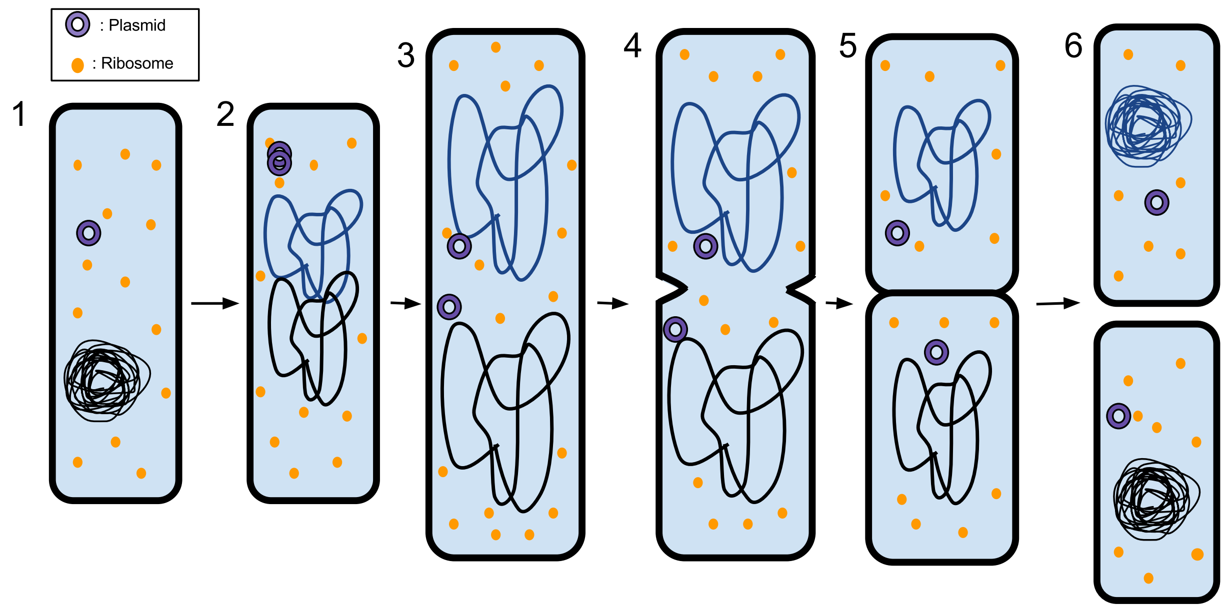


Figure 4.2.7 Binary fission in a prokaryote 1. The bacterium before binary fission is when the DNA is tightly coiled. 2. The DNA of the bacterium has replicated. 3. The DNA is pulled to the separate poles of the bacterium as it increases size to prepare for splitting. 4. The growth of a new cell wall begins to separate the bacterium. 5. The new cell wall fully develops, resulting in the complete split of the bacterium. 6. The new daughter cells have tightly coiled DNA, ribosomes, and plasmids. Image by Ecoddington14, CC BY-SA 3.0

Reproduction in prokaryotes is primarily asexual and takes place by binary fission. Recall that the DNA of a prokaryote usually exists as a single, circular chromosome. Prokaryotes do not undergo mitosis. Rather, the chromosome loop is replicated, and the two resulting copies attached to the plasma membrane move apart as the cell grows in a process called **binary fission**. The prokaryote, now enlarged, is pinched inward at its equator, and the two resulting cells, which are clones, separate. Binary fission does not provide an opportunity for genetic recombination, but prokaryotes can alter their genetic makeup in three ways:

- In a process called **transformation**, the cell takes in DNA found in its environment that is shed by other prokaryotes, alive or dead. A pathogen is an organism that causes a disease. If a nonpathogenic bacterium takes up DNA from a pathogen and incorporates the new DNA in its own chromosome, it too may become pathogenic.
- In **transduction**, bacteriophages, the viruses that infect bacteria, move DNA from one bacterium to another. Archaea have a different set of viruses that infect them and translocate genetic material from one individual to another.
- During **conjugation**, DNA is transferred from one prokaryote to another by means of a pilus that brings the organisms into contact with one another. The DNA transferred is usually a plasmid, but parts

of the chromosome can also be moved.

Cycles of binary fission can be very rapid, on the order of minutes for some species. This short generation time, coupled with mechanisms of genetic recombination, results in the rapid evolution of prokaryotes, allowing them to respond to environmental changes (such as the introduction of an antibiotic) very quickly.

## Prokaryote Metabolism

Like all living things, prokaryotes need energy and carbon. They meet these needs in a variety of ways.

Energy metabolism in prokaryotes is classified as one of the following:

- **Phototrophic** organisms capture light energy from the sun and convert it into chemical energy inside their cells.
- **Chemotrophic** organisms break down either organic or inorganic molecules to supply energy for the cell.

In terms of carbon metabolism, prokaryotes are classified as either:

- **Heterotrophic** organisms use organic compounds, usually from other organisms, as carbon sources.
- **Autotrophic** organisms use carbon dioxide ($CO_2$) as their only source or their main source of carbon. Many autotrophic bacteria are photosynthetic and get their carbon from the carbon dioxide in the atmosphere.

Prokaryotes have just about every possible combination of energy and carbon metabolism, but most are **chemoheterotrophs**, meaning that they depend on other organisms for both energy and carbon. Many break down organic wastes and the remains of dead organisms. They play vital roles as decomposers and help recycle carbon and nitrogen. **Photoautotrophic** prokaryotes are also common and are important producers. They are especially important in aquatic ecosystems.

## Bacterial Diseases in Humans

Although many prokaryotes are harmless or even beneficial, some bacteria are capable of causing serious disease. These **pathogenic bacteria** disrupt normal body functions by producing toxins or invading and destroying tissues. They can spread through air, water, food, direct contact, or vectors like insects. These infections can affect nearly every part of the body. Many bacterial diseases are **zoonotic**, meaning they originate in animals and can be transmitted to humans.

Historically, bacterial diseases have caused some of the most catastrophic pandemics. One of the most devastating pandemics was the Black Death (1346 to 1361), a bubonic plague pandemic caused by the bacterium *Yersinia pestis*, which was carried by fleas living on black rats. The Black Death killed more than 100 million people and reduced the world's population to about 350 to 375 million. Although modern antibiotics have made plague treatable, it still causes a few thousand cases globally each year.

Today, bacterial diseases remain a major global health concern, especially in regions with limited access to healthcare. However, modern science and public health measures have significantly reduced their impact. The primary methods for preventing bacterial disease are:

- **Sanitation**: Clean water, sewage treatment, and hygiene practices prevent the spread of many diseases.
- **Antibiotics**: These drugs target bacterial infections and are estimated to have saved hundreds of millions of lives since their widespread use in the mid-1900s. However, the rise of antibiotic resistance is now threatening these gains (see below).
- **Vaccination**: Some bacterial diseases, like tetanus and diphtheria, can be prevented with vaccines.
- **Education and public health**: Education is one of the most powerful tools in preventing bacterial disease. Through efforts led by organizations like the WHO, CDC, and UNICEF, public health education has helped reduce infections by promoting hand hygiene, safe food handling, proper antibiotic use, and clean water practices—saving countless lives worldwide.

In Canada, public health education has played a key role in addressing the rise of **Lyme disease**, a bacterial infection transmitted by black-legged ticks. As the range of these ticks expands due to climate change, organizations like the Public Health Agency of Canada and local health units have launched awareness campaigns to educate the public about tick prevention, safe outdoor practices, and early symptoms.

Educational efforts emphasize recognizing early symptoms, which typically appear within 3 to 30 days after a tick bite. These include a **bull's-eye-shaped rash**, fever, chills, fatigue, headache, and muscle or joint pain. If left untreated, the infection can progress to more serious complications such as neurological issues, heart problems, and severe arthritis.

To prevent Lyme disease, public health messages encourage people to:

- Avoid tall grass and wooded areas where ticks are common
- Wear long sleeves and pants, and use insect repellents containing DEET
- Perform full-body tick checks after outdoor activities
- If a tick is found **embedded** (attached and feeding on the skin), remove it carefully with fine-tipped tweezers and seek medical attention for possible treatment or monitoring


Figure 4.2.8 Image Left: "Deer Tick", by Hill Walker, CC BY-SA 2.0, Image Middle: "Adult Deer Tick" by Scott Bauer, Public Domain, Image Right: "Classic Lyme Disease Rash", by Anmol Pitliya, CC BY-SA 3.0

### The Antibiotic Crisis

In recent years, growing concern has emerged over what many call the **antibiotic crisis** – a situation where once-effective antibiotics are becoming less reliable due to the rise of antibiotic-resistant bacteria, or "**superbugs**."

One of the main drivers of this crisis is the misuse and overuse of antibiotics**.** Antibiotics are often taken unnecessarily, such as for viral infections where they have no effect. They are also frequently taken improperly. For example, when patients stop treatment early, not all bacteria are eliminated. The ones that survive are often those with some level of natural resistance. These resistant bacteria then multiply and become more prevalent. This is a textbook example of natural selection at work.

A well-known example of antibiotic resistance is **methicillin-resistant *Staphylococcus aureus* (MRSA)**. While *S. aureus* is a common bacterium that normally lives harmlessly on the skin or in the nose, MRSA is a dangerous strain that resists many commonly used antibiotics, including methicillin, penicillin, and amoxicillin. Initially confined to hospitals and long-term care facilities, MRSA has now spread into the general population, affecting otherwise healthy individuals in schools, gyms, and military settings.

The antibiotic crisis poses a serious threat to global health. Infections that were once easily treatable are becoming harder, and sometimes impossible, to cure. Surgeries, cancer treatments, and organ transplants all rely on effective antibiotics to prevent infection. Without them, modern medicine would be set back by decades.

To tackle this problem, we need to take several steps: use antibiotics more carefully in healthcare, avoid giving them when they're not needed, control their use in farming, support the creation of new antibiotics, and teach people how to use them responsibly. Without urgent action, we risk entering a post-antibiotic era where even minor infections could once again become deadly.

Foodborne Diseases

We already mentioned that prokaryotes are everywhere. They readily colonize the surface of any type of material, and food is not an exception. Outbreaks of bacterial infection related to food consumption are common. A **foodborne disease** (colloquially called "food poisoning") is an illness resulting from the consumption of food contaminated with pathogenic bacteria, viruses, or other parasites. In Canada, an estimated 4 million people—about 1 in 8—are affected by foodborne illness annually, leading to approximately 11,600 hospitalizations and 238 deaths (Public Health Agency of Canada, 2016).

The characteristics of foodborne illnesses have changed over time. In the past, it was relatively common to hear about sporadic cases of **botulism**, the potentially fatal disease produced by a toxin from the anaerobic bacterium *Clostridium botulinum*. A can, jar, or package created a suitable anaerobic environment where *Clostridium* could grow. Proper sterilization and canning procedures have reduced the incidence of this disease.

In Canada, most cases of foodborne illnesses are now linked to contaminated produce, undercooked meats, and cross-contamination during food preparation.

## Beneficial Prokaryotes

Not all prokaryotes are pathogenic. On the contrary, pathogens represent only a very small percentage of the diversity of the microbial world. In fact, our life and all life on this planet would not be possible without prokaryotes.

## Environmental Roles

Prokaryotes play a vital role in the environment. Some act as **decomposers**, breaking down dead plants and animals and recycling nutrients back into the soil. Others help plants grow by **fixing nitrogen**, meaning they take nitrogen from the air and turn it into a form that plants can use. There are also prokaryotes used in **bioremediation**, which means they help clean up pollution, such as oil spills or toxic waste, by breaking down harmful substances into safer ones.

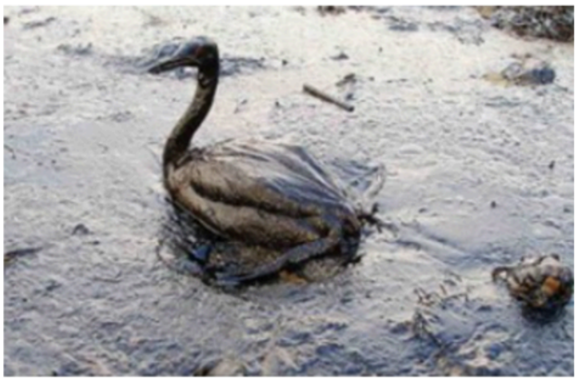

Figure 4.2.9 Image (left): "Oiled Black Bird" by Igor GOLUBENKOV, CC BY 2.0, Image (right): "Oil Cleanup After Valdez Spill" by Svdmolen, Public Domain

## Food Production

Prokaryotes are often used in food production, especially in the making of many fermented foods. Bacteria are used to produce yogurt, cheese, and other dairy products. In pickling, they preserve vegetables like cucumbers and cabbage by creating an acidic environment that prevents spoilage. In cured meats, bacteria are used to ferment the meat, enhancing flavour and extending shelf life.


Figure 4.2.10 “Kaïkou Cheese” by F.rodrigo, Public Domain, Sammich by Alisdair McDiarmid, CC BY 2.0, “Fish Sauce” by Addilyn Ragsdill, Unsplash License, “Yogurt being drained through cheesecloth“, Mom the Barbarian, CC BY 2.0

## Human Microbiota

Humans live in close partnership with trillions of prokaryotes, forming what is known as the **human microbiota**. These microbial communities live on and inside our bodies, especially in the gut, where they help digest food, produce vitamins like vitamin K, support the immune system, and protect against harmful microbes. In fact, microbial cells in and on the human body outnumber human cells. While many of these microbes have **mutualistic** relationships with us (both sides benefit), others are **commensal** (they benefit without affecting us). Microbes also live on the skin, where they may help prevent infections. Scientists are still uncovering the full impact of these microbes on human health.

# Knowledge Check

**Text Description**

**1.** Which of the following statements about prokaryotes is TRUE?

a. They were the first forms of life on Earth
b. They require oxygen-rich environments to survive
c. They lack DNA
d. They evolved after eukaryotes

**2.** Which prokaryotes are able to survive in extreme salinity, such as in the Dead Sea?

a. Stromatolites
b. Halophiles
c. Thermophiles
d. Acidophiles

**3.** What is the primary method of reproduction in prokaryotes?

a. Budding
b. Mitosis
c. Binary fission
d. Meiosis

**4.** Which of the following is a key role of prokaryotes in the environment?

a. Creating muscle tissue in animals
b. Digesting cellulose in human stomachs
c. Producing light in deep-sea organisms
d. Recycling nutrients by breaking down organic matter

**5.** What is the main reason for the current antibiotic crisis?

a. Overuse and misuse of antibiotics leading to resistant bacteria
b. Genetic engineering of superbugs in labs
c. Too few antibiotics are being used in hospitals

d. Viruses adapting to antibiotic treatment

---

**Answers:**

1. a. They were the first forms of life on Earth
2. b. Halophiles
3. c. Binary fission
4. d. Recycling nutrients by breaking down organic matter
5. a. Overuse and misuse of antibiotics leading to resistant bacteria

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Create 5 multiple-choice questions using the following content

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# 4.3 PROTISTS

## Classification of Protists on the Phylogenetic Tree of Life

**Protists** are a diverse group of mostly single-celled organisms that don't fit neatly into the other kingdoms of life. They are eukaryotes, meaning their cells have a nucleus and other membrane-bound organelles, but they are not animals, plants, or fungi. Because of their diversity, protists are often considered a "catch-all" category in biological classification.

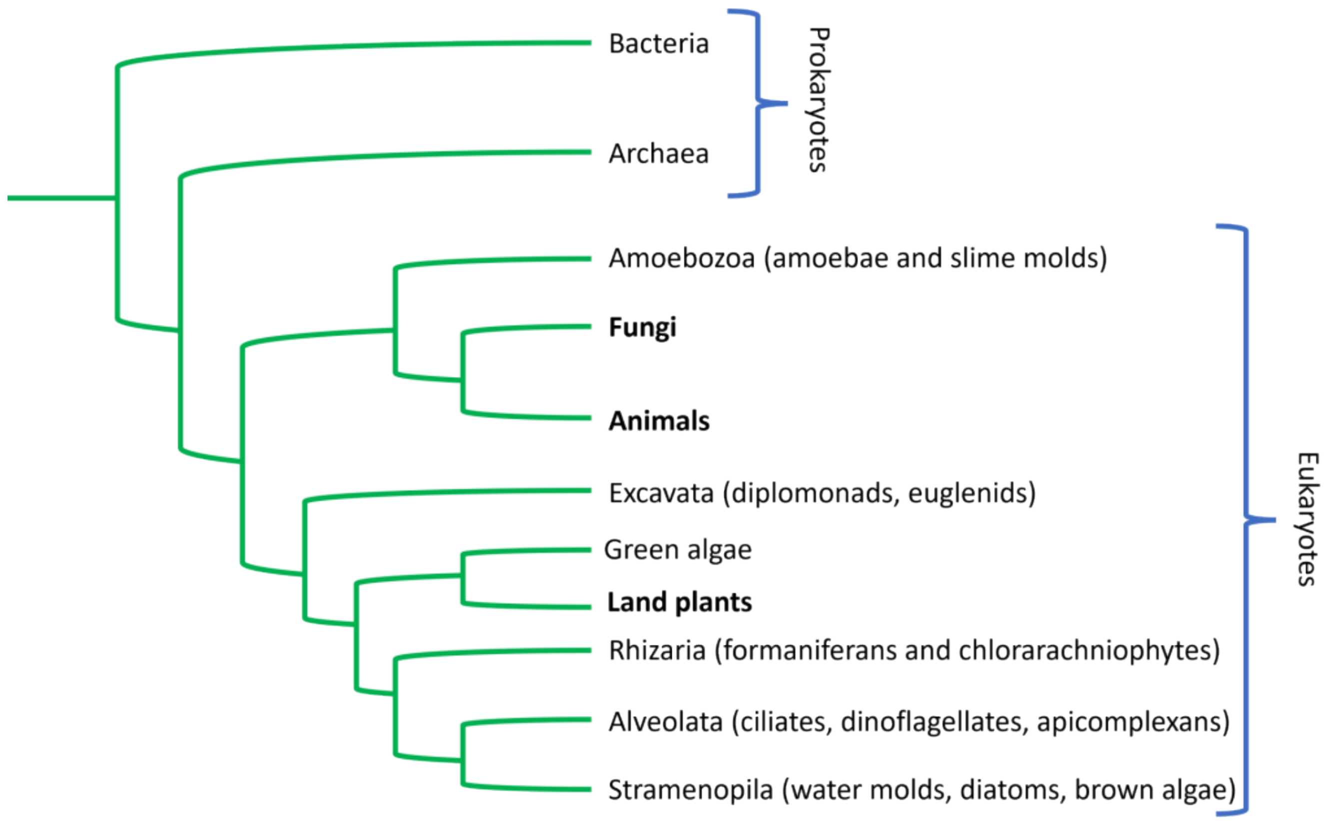


Figure 4.3.1 Simplified tree of life emphasizing evolutionary relationships among eukaryotic lineages. Image by Shana KerrImage, CC BY NC-SA

#### Figure 4.3.1 Image Description

The image is a phylogenetic tree showing the evolutionary relationships among major groups of life.

On the left, a single ancestral line branches into Prokaryotes and Eukaryotes. Prokaryotes include:

- Bacteria
- Archaea

Eukaryotes include a wide range of lineages:

- Amoebozoa (amoebae and slime molds)
- Fungi
- Animals
- Excavata (diplomonads, euglenids)
- Green algae
- Land plants
- Rhizaria (foraminiferans and chlorarachniophytes)
- Alveolata (ciliates, dinoflagellates, apicomplexans)
- Stramenopila (water molds, diatoms, brown algae)

The tree highlights the split between Prokaryotes (Bacteria and Archaea) and the more diverse Eukaryotes, which include single-celled organisms, fungi, animals, algae, and plants.

# Characteristics of Protists

There are currently over 100,000 described living species of protists, though scientists believe many more remain undiscovered. Given this diversity, it is not surprising that few characteristics are common to all protists.

## Habitat

Nearly all protists exist in some type of aquatic environment, including freshwater and marine environments, damp soil, and even snow. Several protist species are parasites that infect animals or plants. A **parasite** is an organism that lives on or in another organism and feeds on it, often without killing it. A few protist species live on dead organisms or their wastes, and contribute to their decay.

## Structure

Protist cells are among the most complex of all eukaryotic cells. While most are microscopic and unicellular, some form colonies or even true multicellular structures. Others, like certain seaweeds, are massive single cells with multiple nuclei (sometimes reaching three meters in length!). Most protists are motile and have evolved various ways to move: some use flagella or cilia, while others extend pseudopodia to crawl. Some can even sense and move toward light.

## Human Pathogens

Many protists are pathogenic parasites that must infect other organisms to survive and reproduce. These parasitic protists are responsible for several serious human diseases, including malaria, African sleeping sickness, and giardiasis ("Beaver Fever", a waterborne gastroenteritis). In addition to affecting humans, some protist pathogens target plants, causing widespread crop damage.

Figure 4.3.2 A Culex mosquito. Image by Muhammad Mahdi Karim, GNU Free Documentation License

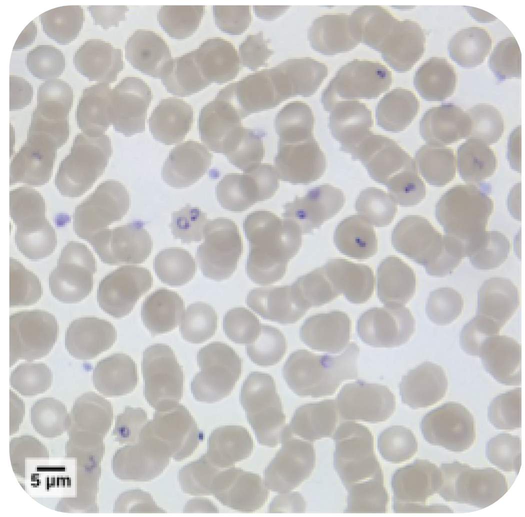


Figure 4.3.3 This light micrograph shows a 100× magnification of red blood cells infected with Plasmodium falciparum (seen as purple). Image by MichaelZahniser, Public Domain

**Malaria** is a life-threatening disease caused by parasites of the genus *Plasmodium*. These parasites must infect both a mosquito and a vertebrate host to complete their life cycle. In humans, the parasite first develops in liver cells and then invades red blood cells, where it multiplies asexually. It eventually bursts out, destroying the blood cells and releasing waste products that trigger intense immune responses, including high fever and delirium. The most deadly species, *Plasmodium falciparum*, can destroy over half of a person's circulating red blood cells, leading to severe anemia. It is transmitted to humans by the *Anopheles gambiae* mosquito, a highly aggressive vector (an organism that spreads disease from one host to another) found primarily in Africa. Controlling this mosquito through insecticides, bed nets, and environmental management is essential to malaria prevention. According to the World Health Organization, malaria causes hundreds of thousands of deaths each year, with the vast majority occurring in sub-Saharan Africa. Over the course of human history, malaria is estimated to have caused up to 5 billion deaths, making it one of the deadliest diseases ever known.

## Protist Diversity

Protists are incredibly diverse, so scientists often group them into three major categories based on how they obtain energy:

## Protozoa (Animal-like Protists)

**Protozoans** are animal-like protists that are **unicellular**, **heterotrophic**, and often **motile**, meaning they can move to find food.

They are typically grouped into four main sub-categories based on their movement and structure:

### Amoebas

Amoebas move using **pseudopodia** (temporary extensions of their cell membrane).

Figure 4.3.4 "Amoeba proteus with pseudopodia", by SmallRex, CC BY-SA 4.0

### Flagellates

**Flagellates** use one or more flagella to swim. Some are free-living, while others are parasitic.

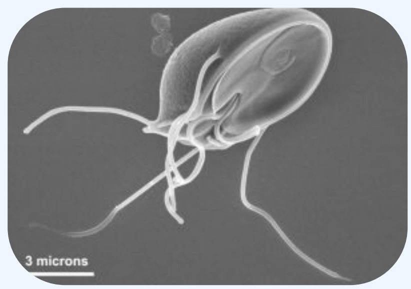


Figure 4.3.5 Giardia muris has four pairs of flagella that are responsible for the organism's motility. "Giardiasis06" by Jesus Hernandez, CC BY-SA 3.0

### Ciliates

**Ciliates** are covered in cilia to help them move and feed.

### Apicomplexans

**Apicomplexans** are non-motile and often parasitic.

Figure 4.3.6 “The ciliated protozoan Paramecium caudatum” by Deuterostome, CC BY-SA 3.0

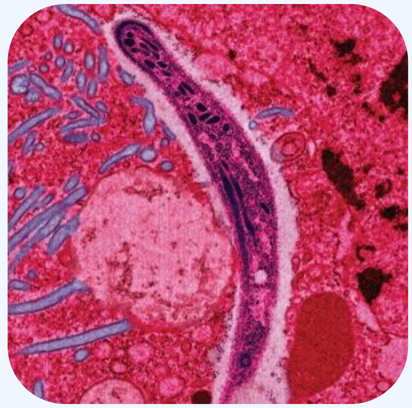

Figure 4.3.7 Image by Ute Frevert; false colour by Margaret Shear, CC BY 2.5

## Fungus-like Protists

Fungus-like protists are heterotrophic organisms that absorb nutrients from decaying organic matter, similar to true fungi. They are often found in moist environments and play an important role as decomposers. This group includes **slime moulds,** which exhibit a unique life cycle. In their feeding stage, slime molds exist as unicellular, amoeba-like organisms that engulf food particles. However, under certain conditions, many of these cells can unite to form large, multicellular structures that move and reproduce collectively.

Figure 4.3.8 Mucilago crustacea, “dog’s vomit slime mould” by Dietzel, CC BY-SA 3.0

## Algae (Plant-like Protists)

**Algae** are autotrophic protists that perform photosynthesis, much like plants. They are incredibly diverse and can be unicellular**,** colonial, or multicellular. Unicellular algae are found in various aquatic environments and play a crucial role as primary producers, commonly referred to as **phytoplankton**.

Multicellular algae, also known as **seaweeds**, are typically classified into sub-groups based on their pigments:

- **Green algae** are closely related to land plants.
- **Brown algae** include large seaweeds such as kelp.
- **Red algae** are often found in deeper ocean waters due to their ability to absorb blue light.

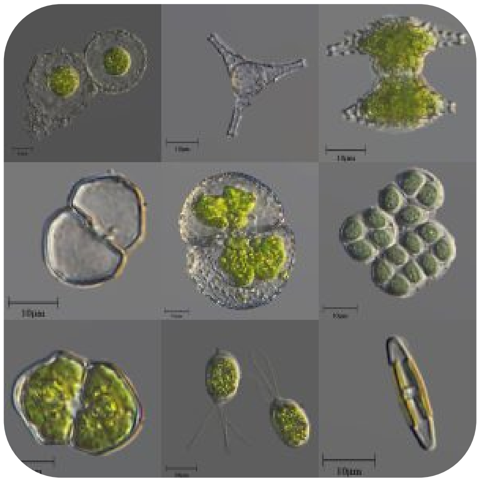

Figure 4.3.9 Freshwater microscopic unicellular and colonial algae. Image by Alexander Klepnev, CC BY 4.0

Green algae

Figure 4.3.10 "Codium Fragile (Dead Man's Fingers)" by Flyingdream, Public Domain

Brown algae

Figure 4.3.11 Two species of Fucus under water in the intertidal zone. Image by Ansgar Gruber, CC BY-SA 4.0

Red algae

Figure 4.3.12 "Gracilaria" by Emoody26, GNU Free Documentation LIcense

## Knowledge Check

**Text Description**

1. What makes protists a unique group in biological classification?

   a. They all cause disease in humans
   b. They are eukaryotes that don't belong to animals, plants, or fungi
   c. They are the most ancient life forms on Earth
   d. They are all multicellular and autotrophic

2. Which of the following correctly matches a protist group with its method of movement?

   a. Flagellates – flagella
   b. Amoebas – cilia
   c. Ciliates – flagella
   d. Apicomplexans – pseudopodia

3. Which deadly disease is caused by a protist and transmitted by the *Anopheles* mosquito?

   a. Giardiasis
   b. Malaria
   c. Lyme disease
   d. African sleeping sickness

4. Which group of protists acts like fungi by absorbing nutrients from decaying organic matter?

   a. Flagellates
   b. Algae
   c. Apicomplexans
   d. Slime molds

5. What role do unicellular algae (phytoplankton) primarily play in aquatic ecosystems?

   a. Predators of bacteria
   b. Decomposers of organic waste
   c. Primary producers through photosynthesis

d. Parasites of plants

6. Categories: Animal-Like Protists, Fungus-Like Protists, Plant-Like Protists

Draggable Terms: Protozoa, Slime molds, Algae, Phytoplankton, Amoebas, Decomposers, Seaweeds, Flagellates, Ciliates, Photosynthetic, Apicomplexans, Unicelluar/heterotrophic/motile

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Answers:

1. b. They are eukaryotes that don't belong to animals, plants, or fungi
2. a. Flagellates – flagella
3. b. Malaria
4. d. Slime molds
5. c. Primary producers through photosynthesis
6. **Animal-Like Protists:** Protozoa, Amoebas, Flagellates, Ciliates, Apicomplexans, Unicellular/heterotrophic/motile. **Fungus-Like Protists:** Slime molds, Decomposers. **Plant-Like Protists:** Algae, Phytoplankton, Seaweeds, Photosynthetic.

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Create 5 multiple-choice questions using the following content

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# CHAPTER 4 SUMMARY

## Key Takeaways

- **Abiogenesis explains the origin of life from non-living matter**, beginning with the formation of organic molecules, followed by the development of macromolecules, protocells, and self-replicating systems, all potentially driven by early Earth's harsh yet chemically rich conditions.
- **Prokaryotes were the first forms of life on Earth**, thriving in extreme environments and evolving into the diverse domains of Bacteria and Archaea, with key roles in ecosystems as decomposers, recyclers, and symbionts.
- **Prokaryotic cells are simple but highly adaptable**, lacking membrane-bound organelles, and reproducing asexually through binary fission, with additional genetic diversity generated via transformation, transduction, and conjugation.
- **Prokaryotes exhibit a wide range of metabolic strategies**, including photoautotrophy, chemoheterotrophy, and nitrogen fixation, allowing them to survive in varied and extreme environments while supporting ecosystems.
- **Some prokaryotes cause disease**, including foodborne illnesses and antibiotic-resistant infections like MRSA, but most are beneficial, supporting health, food production, and environmental processes such as bioremediation.
- **Protists are a diverse group of mostly single-celled eukaryotes**, categorized into protozoa, algae, and fungus-like types, with important ecological roles and some causing serious diseases such as malaria and giardiasis.

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Summarize the following content into six key takeaways.

# Flashcards

**Text Description**

Front of card

1. 3 major categories of protists
2. 3 methods of genetic recombination in prokaryotes
3. 4 Stages of Abiogenesis
4. 4 sub-categories of protozoans
5. Abiogenesis
6. Acidophiles
7. Algae
8. Amoebas
9. Antibiotic crisis
10. Antibiotics
11. Apicomplexans
12. Archaea
13. Autotrophic
14. Bacilli
15. Bacteria
16. Binary fission
17. Bioremediation
18. Botulism
19. Brown algae
20. Bull's-eye-shaped rash
21. Capsule
22. Cell wall
23. Chemoheterotrophs
24. Chemotrophic
25. Ciliates
26. Cocci
27. Commensal
28. Conjugation
29. Decomposers

30. DNA
31. Eukaryotes
32. Extremophiles
33. Flagella
34. Flagellates
35. Foodborne disease
36. Fungus-like protists
37. Green algae
38. Halophiles
39. Heterotrophic
40. Human microbiota
41. Hydrothermal vent
42. LUCA (Last Universal Common Ancestor)
43. Lyme disease
44. Macromolecules
45. Malaria
46. Methods for preventing bacterial disease
47. Methicillin-resistant Staphylococcus aureus (MRSA)
48. Microbial mat
49. Mutualistic
50. Nucleoid
51. Organic molecules
52. Parasite
53. Pathogen
54. Phytoplankton
55. Photoautotrophs
56. Phototrophic
57. Pili
58. Plasmids
59. Primordial soup
60. Prokaryotes
61. Prokaryotic cell
62. Protists
63. Protocells
64. Protozoans

65. Pseudopodia
66. Red algae
67. Roles of beneficial prokaryotes
68. Sanitation
69. Seaweed
70. Self-replication
71. Spirilla
72. Stromatolite
73. Superbugs
74. Thermophiles
75. Transduction
76. Transformation
77. Types of algae
78. Vaccination
79. Zoonotic

Back of card

1. Protozoa (animal-like protists), Slime moulds (fungus-like protists), Algae (plant-like protists)
2. Transformation, transduction, conjugation
3. Formation of Organic Molecules, Assembly into Macromolecules, Formation of Protocells, Self-Replication
4. Amoebas, Flagellates, Ciliates, Apicomplexans
5. The scientific hypothesis that life originated from non-living matter through natural processes, such as chemical reactions in early Earth's environment
6. Prokaryotes that thrive in extremely acidic conditions (pH 3 or below)
7. Photosynthetic protists that live in aquatic environments and range from single-celled phytoplankton to large multicellular seaweeds
8. Protozoans that move using pseudopodia—temporary extensions of their cell membrane
9. A global health concern caused by the overuse and misuse of antibiotics, leading to the rise of resistant bacteria that are difficult to treat
10. Drugs used to treat bacterial infections by killing or inhibiting bacterial growth
11. Non-motile, parasitic protozoans
12. One of the two domains of prokaryotes, distinct from Bacteria and more closely related to eukaryotes in some ways
13. Organisms that use carbon dioxide ($CO^2$) as their main or only carbon source

14. Rod-shaped prokaryotic cells
15. One of the two domains of prokaryotes; single-celled organisms
16. A form of asexual reproduction where a prokaryote replicates its DNA and splits into two identical cells
17. The use of living organisms, such as bacteria or fungi, to clean up environmental pollutants, including oil spills and toxic waste
18. A rare but serious illness caused by a toxin produced by the bacterium Clostridium botulinum, often linked to improperly preserved foods
19. Large, multicellular algae commonly found in marine environments; includes kelp
20. A common early symptom of Lyme disease, forming around the site of a tick bite
21. A protective, sticky outer layer in some prokaryotes that aids in attachment and prevents dehydration
22. A rigid structure outside the plasma membrane that provides shape and protection to prokaryotic cells
23. Organisms that obtain both energy and carbon from organic compounds
24. Organisms that derive energy by breaking down organic or inorganic molecules
25. Protozoans that use tiny hair-like structures called cilia to move and feed
26. Spherical-shaped prokaryotic cells
27. A type of symbiotic relationship in which one organism benefits while the other is neither helped nor harmed
28. A process in which prokaryotes transfer genetic material through a pilus connecting two cells
29. Organisms that break down dead organic matter and recycle nutrients back into the environment
30. Deoxyribonucleic acid, the molecule that stores genetic instructions in living organisms
31. Organisms whose cells contain a nucleus and membrane-bound organelles
32. Prokaryotes that thrive in extreme conditions such as high heat, salinity, or acidity
33. Long, whip-like appendages that aid in movement for some prokaryotic and eukaryotic cells
34. Protozoans that use one or more flagella to move
35. Illness caused by consuming contaminated food or beverages, often due to bacteria
36. Heterotrophic protists that absorb nutrients from decaying material, similar to fungi; Includes slime moulds
37. A group of photosynthetic protists closely related to land plants
38. Prokaryotes that live in extremely salty environments
39. Organisms that obtain their carbon from organic compounds produced by other organisms
40. The community of prokaryotic and other microorganisms that live in and on the human body

41. An opening in the seafloor where heated, mineral-rich water flows out
42. The most recent common ancestor of all organisms alive today
43. A bacterial infection transmitted by ticks
44. Large, complex molecules such as proteins, nucleic acids, lipids, and carbohydrates
45. A disease caused by Plasmodium parasites, transmitted to humans through the bite of infected mosquitoes
46. Sanitation, antibiotics, vaccination, education
47. A dangerous bacterial strain resistant to multiple antibiotics
48. A multi-layered sheet of prokaryotes that often forms at the interface of different materials or environments
49. A relationship where both organisms involved benefit
50. The region in a prokaryotic cell where the DNA is located
51. Carbon-based molecules that form the building blocks of life, including carbohydrates, proteins, lipids, and nucleic acids
52. An organism that lives on or in another and benefits at the host's expense
53. An organism that causes disease
54. Microscopic, photosynthetic organisms that float in aquatic environments and form the base of most marine food webs
55. Organisms that perform photosynthesis and use $CO^2$ as a carbon source
56. Organisms that derive energy from sunlight
57. Hair-like structures used by prokaryotes for attachment and DNA transfer during conjugation
58. Small, circular DNA molecules found in prokaryotes, separate from the main chromosome
59. A hypothetical solution of organic compounds in early Earth's oceans from which life is thought to have originated
60. Unicellular organisms that lack a nucleus and membrane-bound organelles
61. A simple, single-celled organism without a nucleus or membrane-bound organelles
62. A diverse group of mostly unicellular eukaryotic organisms that are not classified as animals, plants, or fungi; includes protozoans, algae, and slime moulds
63. Membrane-bound structures that resemble simple cells and may have preceded true living cells
64. Animal-like protists that are unicellular, heterotrophic, and often motile
65. Temporary extensions of the cell membrane used for movement or feeding
66. Photosynthetic protists that can live in deeper waters due to their light-absorbing pigments
67. Environmental roles (e.g. decomposers); Food production (e.g. fermented foods); Human

microbiota (e.g. in the gut)

68. Practices that maintain cleanliness and prevent disease transmission, especially through water and waste
69. A general term for large, multicellular marine algae, including green, brown, and red algae
70. The ability of molecules (like RNA) or cells to make copies of themselves
71. Spiral-shaped prokaryotic cells
72. Layered sedimentary formations created by the activity of microorganisms, particularly cyanobacteria
73. Antibiotic-resistant bacteria that are difficult or impossible to treat with current medications
74. Prokaryotes adapted to very high temperatures
75. A form of genetic transfer in prokaryotes using viruses to move DNA between cells
76. A process in which prokaryotic cells take up free DNA from their environment and incorporate it into their own genome
77. Phytoplankton (unicellular algae) and seaweeds (green algae, brown algae, red algae)
78. The administration of a substance (often weakened or dead pathogens) to stimulate immune protection
79. Describes diseases that can be transmitted from animals to humans

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Provide definitions for all the bolded terms in the shared content and list all the terms in alphabetical order.

# CHAPTER 5: PLANTS AND FUNGI

## Chapter Overview

## Learning Objectives

By the end of this chapter, you will be able to:

- Explain how land plants evolved from aquatic green algae and adapted to life on land.
- Identify key terrestrial adaptations in plants, including the waxy cuticle, stomata, roots, gametangia, and alternation of generations.
- Compare the major plant groups—bryophytes, seedless vascular plants, gymnosperms, and angiosperms—based on their structures and reproductive strategies.
- Describe the reproductive processes in each plant group using terms like spores, seeds, pollen, flowers, and fruits.
- Analyze how plant structures like roots, vascular tissue, and lignin support survival in different environments.
- Interpret how plant-pollinator interactions and seed dispersal strategies increase angiosperm success and diversity.

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Provide 6 learning objectives for the shared content.

# 5.1 PLANT ADAPTATIONS TO LIFE ON LAND

## Classification of Land Plants on the Phylogenetic Tree of Life

**Plants** are a group of eukaryotic photoautotrophs that evolved to live on land. As eukaryotes, their cells contain a nucleus, mitochondria, and a complex system of internal membranes including the endoplasmic reticulum and Golgi apparatus. As photosynthetic eukaryotes, their cells also contain chloroplasts.

Plants are a **monophyletic** group (or clade), meaning they include a common ancestor and all of its descendants. In other words, all plants share a single evolutionary origin. Land plants evolved from a photosynthetic ancestor shared with green algae, a group of protists.

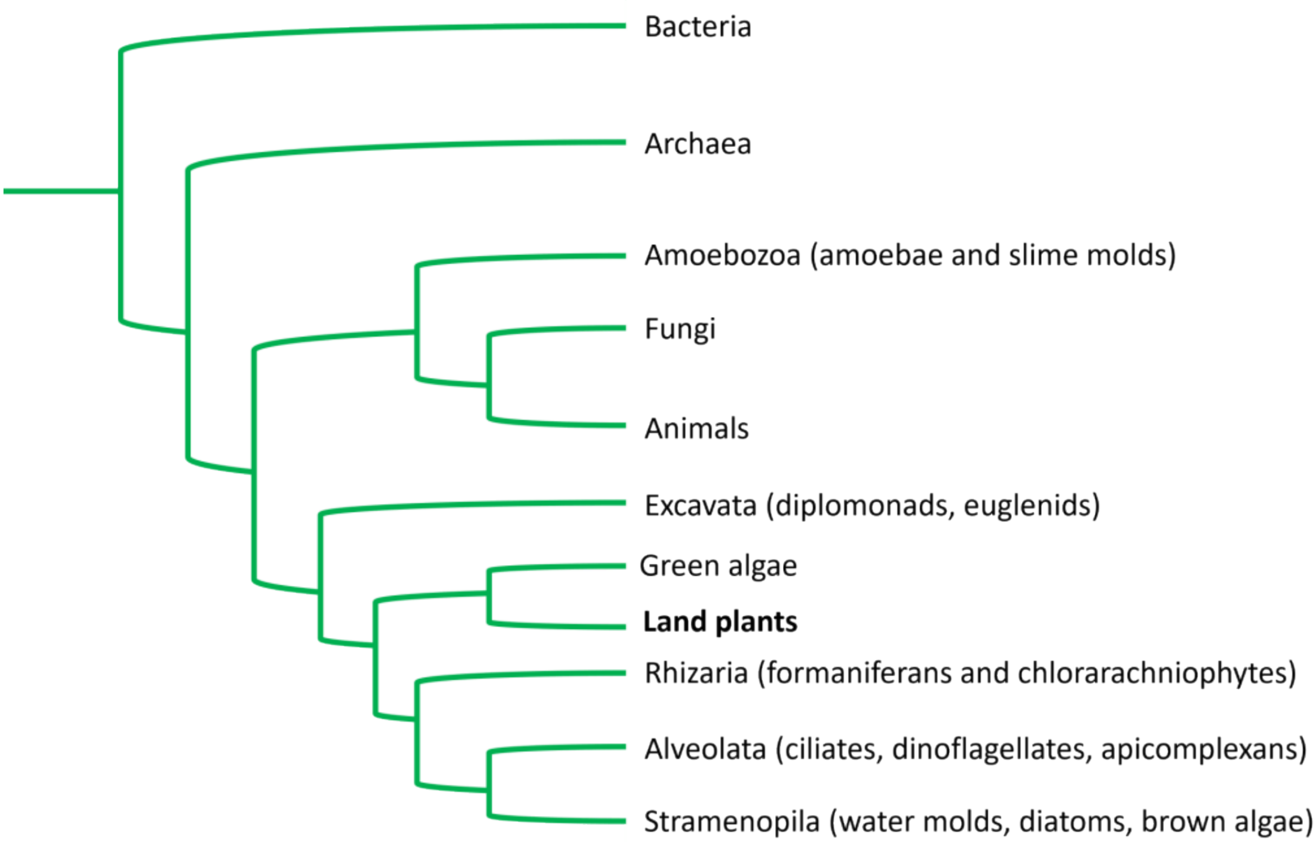


Figure 5.1.1 Simplified tree of life emphasizing land plants. Image by Shana Kerr, CC BY-NC-SA

# Life in Water Compared to Land

The ancestor of all plants was an aquatic, green algal-like species with a cell wall composed of cellulose. Living in the water provides a number of advantages compared to life on land:

- In water or near it, plants can absorb water from their surroundings with no need for any special organ for absorbing the water, and no need for any special tissue to prevent desiccation (drying out).
- Water provides a sort of external support structure and buoyancy to living things; in contrast, living on land requires additional structural support to avoid falling over.
- Sperm and egg can easily swim to each other in a water environment, and do not need protection from desiccation. Sperm and egg require alternative strategies for getting to each other and avoiding drying out when on land.
- Water filters out a significant amount of ultraviolet (UV) light, which is highly destructive to DNA (and one of the reasons to wear sunblock). No such filtering occurs in air, so terrestrial organisms require alternative strategies for protection against UV radiation.

If life on land presents so many challenges, why did any plants evolve to live on land? Life on land offers several advantages:

- Sunlight is abundant in the air compared to water. Water acts as a filter, altering the spectral quality of light absorbed by the photosynthetic pigment chlorophyll.
- Carbon dioxide, the required carbon source for green plants, is more readily available in air than in water, since it diffuses faster in air.
- Land plants evolved before land animals; therefore, no predators threatened early plant life. This situation changed over time as animals colonized land, where they fed on the abundant sources of nutrients in the established flora. As a result of this selective pressure by plant-eating animals, plants evolved adaptations to deter predation, such as spines, thorns, and toxic chemicals.

# Terrestrial Adaptations

The evolution of specific adaptations in aquatic algae allowed them to transition to a terrestrial environment.

The 5 major terrestrial adaptations which are present in many land plants include:

- Waxy **cuticle**: Covers the outer surface of the plant and prevents drying out through evaporation. It also provides partial protection against radiation damage from UV light. A waxy cuticle is universally present in all land plants, though it is much thinner in nonvascular plants called bryophytes compared to all other land plants.

- **Stomata** (singular: stoma): Are pores or holes that allow for the exchange of gases (such as oxygen and carbon dioxide) between plant cells and the environment. They are necessary in land plants because the waxy cuticle blocks the free flow of gases. Stomata are present in all land plant lineages except liverworts, which are closely related to mosses.
- **Roots** or Root-Like Structures: These anchor plants to the soil. True roots grow deeper into the soil and also help with water absorption.
- **Gametangia**: These are specialized structures that protect gametes from drying out. **Archegonia** produce eggs, whereas **antheridia** produce sperm. After fertilization, the zygote remains in the archegonium, where it is protected and nourished to develop into an embryo.
- **Alternation of generations** is a type of life cycle found in all plants in which the organism alternates between two multicellular stages:

    1. **Gametophyte:** A haploid (n) stage that produces gametes (sperm and egg) through mitosis.
    2. **Sporophyte:** A diploid (2n) stage that produces haploid spores through meiosis.

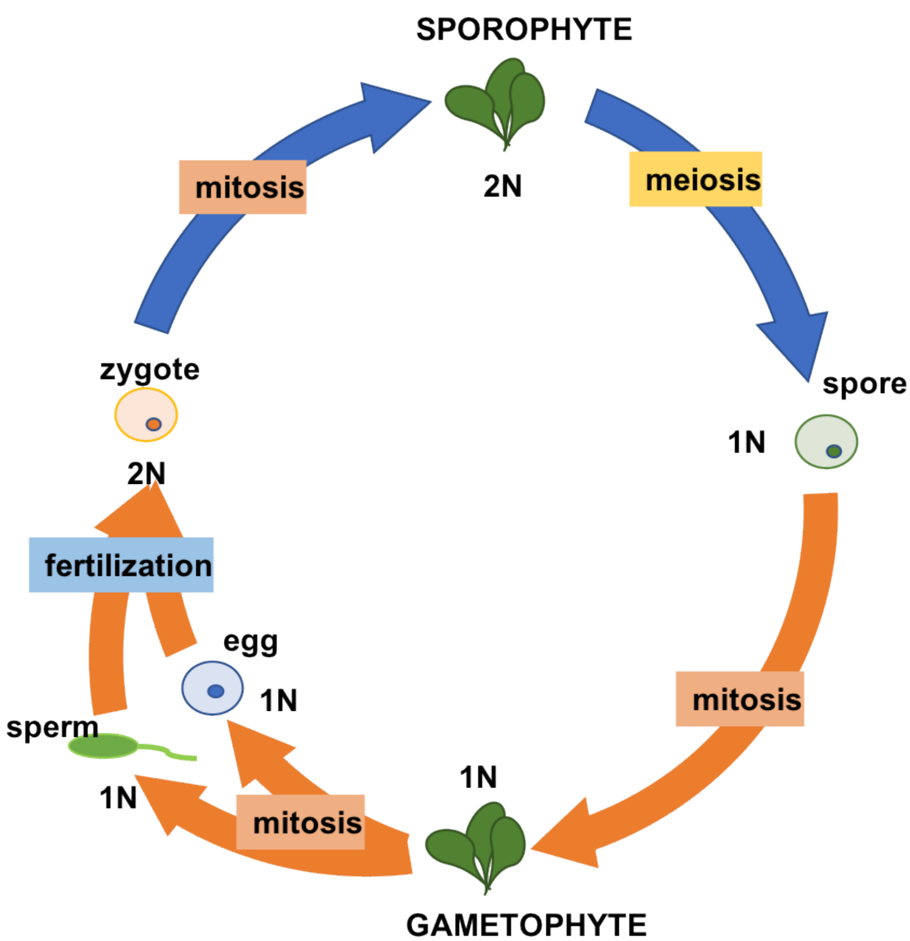


Figure 5.1.2 The life cycle stages that alternate between haploid (1N) and diploid (2N) phases. Image by D. Jennings, CC-BY 4.0

**Figure 5.1.2 Image Description**

The diagram illustrates the alternation of generations in plants, showing the life cycle stages that alternate between haploid (1N) and diploid (2N) phases.

- At the top, a diploid plant (sporophyte, 2N) undergoes meiosis, producing haploid spores (1N).
- The spore grows into a haploid gametophyte (1N) through mitosis.
- The gametophyte produces haploid gametes: sperm (1N) and egg (1N).
- During fertilization, sperm and egg unite to form a diploid zygote (2N).
- The zygote undergoes mitosis, growing into a new diploid sporophyte (2N), completing the cycle.

Blue arrows mark the sporophyte (diploid) phase, while orange arrows mark the gametophyte (haploid) phase. The cycle highlights the alternation between sexual and asexual reproductive stages.

Alternation of generations is not a unique adaptation to life on land (it also occurs in some aquatic green algae), but *modifications* to this life cycle in land plants do function as adaptations.

## Knowledge Check

**Text Description**

1. What feature helps land plants prevent water loss and provides some protection against UV radiation?

   a. Gametangia
   b. Waxy cuticle
   c. Stomata
   d. Roots

2. Which of the following is not considered one of the five major terrestrial adaptations in land plants?

   a. Stomata
   b. Alternation of generations
   c. Roots or root-like structures
   d. Chloroplasts

3. What is the correct function of gametangia in land plants?

   a. They anchor the plant to soil
   b. They facilitate gas exchange
   c. They protect gametes from drying out
   d. They produce energy from sunlight

4. Why was moving to land advantageous for early plants despite the challenges?

   a. Land offered greater structural support
   b. Carbon dioxide and sunlight were more abundant
   c. Sperm could swim more easily on land
   d. DNA was less exposed to UV radiation

5. What does "alternation of generations" refer to in the plant life cycle?

   a. Alternating between aquatic and terrestrial habitats
   b. Alternating between gametophyte and sporophyte stages

c. Alternating between photosynthesis and respiration
d. Alternating between root and shoot growth phases

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Answers:

1. b. Waxy cuticle
2. d. Chloroplasts
3. c. They protect gametes from drying out
4. b. Carbon dioxide and sunlight were more abundant
5. b. Alternating between gametophyte and sporophyte stages

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Create 5 multiple-choice questions using the following content

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# 5.2 MAJOR PLANT GROUPS

As plants began to colonize land, they evolved additional adaptations that helped them survive and reproduce in terrestrial environments. These adaptations vary among different plant groups and help define their unique characteristics. In this section, we will focus on four major groups of land plants: nonvascular plants (bryophytes), seedless vascular plants, seed plants (gymnosperms), and flowering plants (angiosperms).

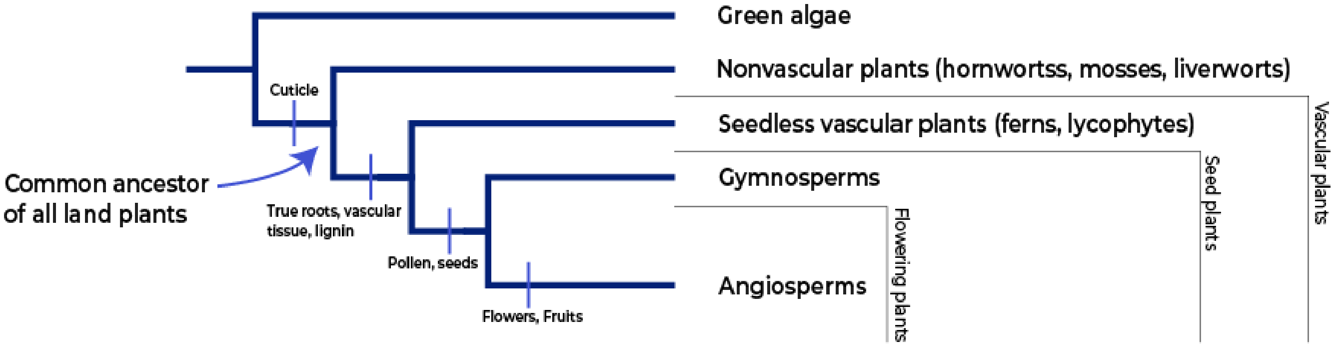


Figure 5.2.1 Plant phylogeny showing major plant lineages and adaptations. [Image](#) by Shana Kerr, [CC BY-NC-SA 3.0,](#) Modifications: Removed Plantae lineage

**Figure 5.2.1 Image Description**

The image is a phylogenetic tree of land plants, showing their evolutionary relationships and key innovations.

- On the left, a branch labelled "Common ancestor of all land plants" leads to multiple lineages.
- Green algae is shown as the outgroup, diverging before land plants.
- Nonvascular plants (hornworts, mosses, liverworts) are the earliest land plants, marked by the development of a cuticle.
- Next, seedless vascular plants (ferns, lycophytes) evolved, associated with the appearance of true roots, vascular tissue, and lignin.
- Seed plants are split into:
  - Gymnosperms, defined by the evolution of pollen and seeds.
  - Angiosperms (flowering plants), defined by the evolution of flowers and fruits.

Additional side labels group vascular plants (including seedless vascular plants, gymnosperms, and angiosperms) and seed plants (gymnosperms and angiosperms).

This diagram highlights the evolutionary milestones that shaped plant diversification from green algae to modern flowering plants.

## Nonvascular Plants (Bryophytes)

**Nonvascular plants,** also known informally as **Bryophytes,** appeared around 490 million years ago and are the closest living relatives of early terrestrial plants. Their major adaptations to life on land include a **waxy cuticle** and root-like structures called **rhizoids**. Rhizoids anchor the plant, but they lack vascular tissue and do not actively absorb water. As a result, bryophytes must live in very moist environments. They are also heavily dependent on water because their sperm are flagellated, so they require water for mating (sperm must swim in water to find the egg). Bryophytes are very short because they have no mechanism for transporting water up against gravity.

The bryophytes are divided into three groups: liverworts, hornworts, and mosses. There are about 18,000 species of bryophytes, but the majority are mosses, so they will be the focus of this section.

**Mosses** are commonly found in moist, shaded environments such as forest floors, where they often carpet the soil, bases of trees, rocks, and fallen logs. They are also abundant in wetlands where they grow in dense mats that act like sponges – trapping water, slowing its flow and filtering out sediment. In the tundra, their shallow rhizoids allow them to anchor to surfaces without digging into the frozen soil. They help reduce erosion, retain moisture and nutrients, and provide shelter for small animals as well as food for larger herbivores. Their small size and dense growth help insulate them from the cold. Mosses can also dry out and go dormant, then reactivate when conditions improve.

Figure 5.2.2 Mosses growing on the side of a large rock in a forest (image on left), "Family Neckeraceae" by morekari, Public Domain, Green feathery moss with reddish-brown sporophytes growing upward (image on right), "Moss spores" by Lordgrunt, CC BY 3.0

### Moss Life Cycle

In a bryophyte, the conspicuous vegetative part of the plant is the gametophyte. The sporophyte grows from the gametophyte. It is less noticeable and can only be seen seasonally. It often grows in the spring or early summer, releases spores, then withers and detaches. In the image below, the gametophyte (haploid) structures are shown in green, and the sporophyte (diploid) in brown. Click on each hotspot to view each step of the lifecycle.

**Text Description**
Diagram of moss alternation of generations showing diploid sporophytes (2n) producing spores by meiosis, which grow by mitosis into male and female gametophytes (1n). Male gametophytes produce sperm, and female gametophytes produce eggs; fertilization forms a diploid zygote that grows into a new sporophyte, completing the cycle.

Clickable hotspots:

Step 1: Gametophytes (n) produce gametes (n) through mitosis. Antheridium produces sperm. Archegonium produces egg.

Step 2: Sperm swim to nearby gametophytes to fertilize egg in the antheridium, forming a zygote (2n).

Step 3: Zygote develops into embryo, which then grows (through mitosis) into new sporophyte (2n).

Step 4: Sporophyte (2n) produces spores (n) through meiosis.

Step 5: Spores blow to a new location and grow into a new gametophyte (mitosis). The gametophyte is the conspicuous part of the plant.

## Seedless Vascular Plants

**Seedless vascular** plants appeared around 430 million years ago and represent a major evolutionary step in plant adaptation to life on land. Compared to nonvascular plants like bryophytes, seedless vascular plants have three key adaptations:

1. **True roots** grow deeper into the soil than the rhizoids of bryophytes. This allows seedless vascular plants to absorb more water and nutrients. Many also form partnerships with mycorrhizal fungi (more

information in section 5.3), which help them extract even more resources from the soil.

2. **Vascular tissue** consists of two types of specialized cells: **xylem**, which transports water from the roots to the leaves, and **phloem**, which distributes sugars made during photosynthesis throughout the plant. This internal transport system allows seedless vascular plants to grow much taller than bryophytes and thrive in more diverse environments.
3. **Lignin** is a tough, rigid substance that hardens cell walls. It provides structural support and allows plants to stand straight up.

These features allowed seedless vascular plants to grow larger and colonize drier environments. That being said, like bryophytes, seedless vascular plants still rely on water for reproduction. Their sperm are flagellated and must swim through water to reach the egg, so these plants are still most common in moist environments.

The seedless vascular plants include club mosses, horsetails, and ferns (Figure 5.2.3). Seedless vascular plants are commonly found in shaded forests, wetlands, and other damp habitats. With their large fronds, **ferns** are the most readily recognizable seedless vascular plants. About 12,000 species of ferns live in environments ranging from the tropics to temperate forests.

Figure 5.2.3 "Clubmoss" (right), by reuvenm, Public Domain, "Horsetail" (middle) by CNX OpenStax, CC BY 4.0, "Fern" (right) by morekari, Public Domain

### Fern Life Cycle

Seedless vascular plants have a **sporophyte-dominated life cycle**, meaning the large, visible plant is the diploid sporophyte. This sporophyte produces haploid spores that grow into small, short-lived gametophytes.

Sporophyte tissues, which are usually but not necessarily diploid, are shown in green. Gametophyte tissues and spores, which are often but not necessarily haploid, are shown in brown. Spores are generated by meiosis in sporangia. Gametes, both eggs and sperm, are generated by mitosis in archegonia and antheridia, respectively. For simplicity, fertilization is depicted between an egg and sperm from the same gametophyte, but fertilization is also likely to occur between gametes from different gametophytes that are derived from the same or different sporophytes. Click on each hotspot to view each step of the lifecycle.

**Text Description**
Diagram of the alternation of generations in ferns. On the left, the diploid sporophyte (2n, green) produces spores in sporangia through meiosis. The spores develop into a haploid gametophyte (n, brown). The gametophyte contains antheridia that produce sperm and archegonia that contain eggs, formed by mitosis. Fertilization occurs when sperm swim to the egg, creating a zygote (2n), which grows into a new sporophyte, restarting the cycle.

Clickable hotspots:

Step 1: Gametophytes (n) produce gametes (n) through mitosis. Antheridium produces sperm. Archegonium produces an egg.

Step 2: Sperm swim to nearby gametophytes to fertilize the egg in the antheridium, forming a zygote (2n).

Step 3: Zygote develops into an embryo, which then grows (through mitosis) into a new sporophyte (2n). The sporophyte is the conspicuous part of the plant.

Step 4: Sporophyte (2n) produces spores (n) through meiosis.

Step 5: Spores blow to a new location and grow into a new gametophyte (mitosis).

## Gymnosperms

**Gymnosperms**, or “naked seed” plants, first appeared around 350 million years ago and represent a major evolutionary advancement in plant reproduction. They possess all the adaptations of seedless vascular plants, but also have two additional adaptations that allowed them to thrive in drier environments:

1. **Pollen** is a protective structure that carries sperm cells. Unlike the flagellated sperm of mosses and ferns, gymnosperm sperm do not need to swim through water. Instead, pollen is carried by the wind to reach the female part of the plant. This adaptation allows gymnosperms to reproduce in dry conditions.
2. **Seeds** protect the developing embryo. A seed contains a food supply and a protective outer coat that protects the embryo against desiccation (drying out). Seeds can also remain dormant until the environment is right for growth.

There are only around 1000 living species of gymnosperms, and the majority of them are conifers. **Conifers** are tall trees with needle-like leaves. Water evaporation from leaves is reduced by their narrow shape and a thick cuticle. Snow easily slides off needle-shaped leaves, keeping the snow load light and reducing broken branches. Such adaptations to cold and dry weather explain the predominance of conifers at high altitudes and in cold climates. Conifers include familiar evergreen trees such as pines, spruces, firs, cedars, sequoias, and yews. A few species, like tamaracks, are deciduous and lose their leaves in fall. Many coniferous trees are harvested for paper and timber.

A) B) C)

D) E) F)

Figure 5.2.4 "Eastern white cedar" (A) by morekari, Public Domain, "Jack pines" (B) by reuvenm, Public Domain, "Balsam Fir" (C) by reuvenm, Public Domain, "Easter white pine" (D) by morekari, Public Domain, "Tamarack (a deciduous gymnosperm)" (E) by Famartin, CC BY-SA 4.0, "Scots Pine" (F) by morekari, Public Domain

### Pine Life Cycle

In a typical gymnosperm life cycle, the large, visible tree is the diploid sporophyte. It produces male cones (which make pollen) and female cones (which contain ovules). After fertilization, the ovule develops into a seed. Click on each hotspot to view each step of the lifecycle.

**Text Description**
The diagram illustrates the pine life cycle in a circular sequence. At the top, a mature sporophyte tree produces male cones (pollen cones) and female cones (seed cones). The male cones release pollen grains (male gametophytes), which fertilize the eggs contained in female cones. Fertilization produces a zygote, which develops into an embryo inside a seed. The seed germinates into a young sporophyte, which grows into a mature pine tree, completing the cycle.

Clickable hotspots:

Step 1: Gametophytes (n) produce gametes (n) through mitosis. Male gametophyte is a pollen grain found in male cones. Female gametophyte develops within an ovule in female cones.

Step 2: Pollen is carried by wind to fertilize the egg, forming a zygote (2n) inside the ovule of the female cone.

Step 3: Zygote develops into embryo. Ovule develops into seed.

Step 4: Seed is dispersed, then germinates and grows (through mitosis) into new sporophyte (2n). The sporophyte is the conspicuous part of the plant (the tree).

Step 5: Sporophyte (2n) produces spores (n) through meiosis. Spores develop into gametophytes inside of cones.

## Angiosperms

**Angiosperms**, or flowering plants, are the most diverse and widespread group of plants on Earth, with over 300,000 known species. They first appeared around 130 million years ago and now dominate most terrestrial ecosystems. Angiosperms include nearly all the plants we eat (e.g. grains, fruits, vegetables, nuts) as well as most ornamental plants. Like gymnosperms, angiosperms have seeds and pollen, but they also have two additional adaptations that make them especially successful:

1. **Flowers** are specialized structures that help with reproduction. They attract pollinators like insects,

birds, and bats, which carry pollen from one flower to another. This is more efficient than relying on wind and increases the chances of successful fertilization.

2. **Fruits** are any structure that develops from a flower ovary and helps in seed dispersal, such as something sweet that is eaten by an animal so that the seed is deposited somewhere new in the feces (and with its own personal supply of fertilizer!). Fruits thus provide a mechanism for seeds to colonize new territories away from the parent plant.

## Flowers

Flowers use a variety of strategies to spread pollen. Some rely on the wind by releasing lots of lightweight pollen into the air. Others have evolved to attract pollinators. Bright colours like red, yellow, and purple catch the attention of bees, butterflies, and birds. Many flowers produce **nectar**, a sugary liquid, to provide pollinators with a reward to encourage visits. Others use **mimicry**, imitating the look or scent of something else, like a female insect, to trick pollinators into stopping by. Some flowers even produce strong, unpleasant odours that smell like rotting meat to attract carrion flies or beetles. These diverse adaptations increase the chances of successful pollination.

Figure 5.2.5 Diversity of flower morphology. "Canada Plum" by reuvenm, "Manitoba Maple", by reuvenm, "Red Columbine" by reuvenm, "Jack-in-the-Pulpit" by reuvenm, "Bloodroot", by morekari, "Early Blue Cohosh" by morekari, "Eurasian Sweet Violet" by morekari, "Red Trillium" by reuvenm, "Pink Lady's Slipper" by morekari, "Chicory" by morekari, "Swamp milkweed" by reuvenm, "Northern Seaside Goldenrod" by reuvenm, Public Domain

Although they come in many shapes and colours, most flowers share the same basic parts:

- **Sepals** are the outermost parts of the flower. They are usually green and protect the flower bud before it opens.
- **Petals** are located just inside the sepals. They are often brightly colored to attract pollinators.
- **Stamens** are the male reproductive parts. Each stamen has a thin stalk called a **filament** and a top part called an **anther**, where **pollen** is made.
- **Carpels** (also called **pistils**) are the female reproductive parts. A carpel includes:
  - **Stigma** – a sticky surface where pollen lands
  - **Style** – a tube that connects the stigma to the ovary,
  - **Ovary** – which contains one or more **ovules**. Each ovule holds an egg and will become a seed after fertilization.

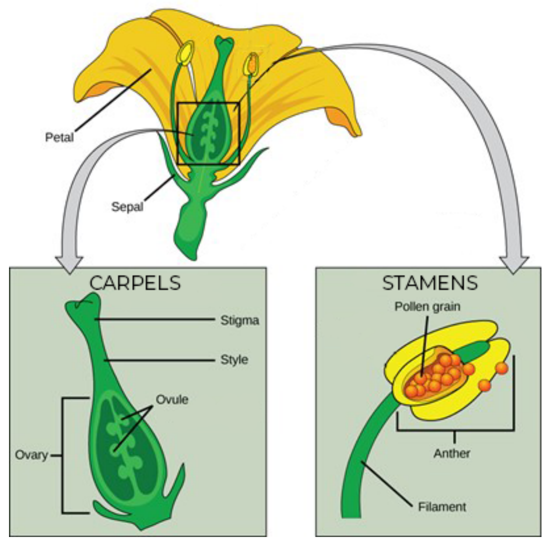


Figure 5.2.6 Diagram of a flower showing the female gynoecium (carpel) with stigma, style, ovary, and ovules, and the male androecium (stamen) with filament, anther, and microsporangia, along with petals (corolla) and sepals (calyx). Modification of Image by CNX OpenStax, CC BY 4.0

## Life Cycle of an Angiosperm

Similar to gymnosperms, the large, visible plant for angiosperms is the diploid sporophyte. The male and female gametophytes are tiny and develop inside the flower. Click on each hotspot to view each step of the lifecycle.

**Text Description**
Diagram of the angiosperm life cycle showing meiosis and mitosis producing female gametophytes (embryo sac with egg) and male gametophytes (pollen grains). During pollination, pollen grows a tube to deliver sperm to the egg for fertilization, forming a zygote that develops into a seed and germinates into a mature flowering plant.

Clickable hotspots:

Step 1: Gametophytes (n) produce gametes (n) through mitosis. The male gametophyte is a pollen grain in the anther of a flower. The female gametophyte (embryo sac) develops inside an ovule within the ovary of a flower.

Step 2: Pollen is transferred (by wind or pollinators) to the stigma of a flower, where it grows a pollen tube to fertilize the egg inside the ovule, forming a zygote (2n). This process includes double fertilization – a second sperm fertilizes a nearby cell to form endosperm, which nourishes the embryo.

Step 3: The zygote develops into an embryo. The ovule becomes a seed, and the ovary develops into fruit.

Step 4: The seed is dispersed, then germinates and grows (through mitosis) into a new sporophyte (2n). The sporophyte is the visible flowering plant.

Step 5: The sporophyte (2n) produces spores (n) through meiosis. Spores develop into gametophytes (pollen and embryo sacs) inside the flower.

## Fruit

After fertilization, the ovule develops into a seed, and the surrounding ovary develops into the fruit. That means that a **fruit** is a ripened ovary that contains one or more seeds. Many foods we call vegetables are actually fruits because they come from the ovary and contain seeds (e.g. eggplants, zucchini, string beans, and bell peppers). Even acorns and maple keys (called *samaras*) are considered fruits.

Fruits come in two main types:

- **Fleshy fruits** are soft and juicy (e.g. berries, peaches, tomatoes).
- **Dry fruits** are hard or papery when mature (e.g. nuts, rice, wheat).

Some fruits form from a single ovary (e.g. apple) while others form from multiple ovaries in one flower (e.g. raspberries). Still others develop from clusters of flowers (e.g. pineapples).

Fruits play an important role in **seed dispersal**. Their shapes and features reflect how they spread:

- **Wind dispersal**: Lightweight or winged fruits that are carried by the wind (e.g. dandelions and maple keys)
- **Animal ingestion**: Colourful, sweet, and juicy fruits are eaten by animals then the seeds are later dropped in their feces (e.g. most fleshy fruits)
- **Animal transportation**: Some fruits have hooks or burs that stick to fur or clothing and get carried away (e.g. burdock)
- **Water dispersal**: Floating fruits travel across water to new locations (e.g. coconuts)

## Knowledge Check

**Text Description**

1. Which of the following features is found in gymnosperms but not in seedless vascular plants?

   a. True roots
   b. Vascular tissue
   c. Pollen
   d. Fronds

2. In which plant group is the gametophyte the dominant and most visible stage of the life cycle?

   a. Angiosperms
   b. Gymnosperms
   c. Seedless vascular plants

d. Bryophytes

3. What adaptation allows angiosperms to disperse their seeds more effectively than gymnosperms?

a. Pollen
b. Flowers
c. Fruits
d. Spores

4. Which of the following is true of seedless vascular plants but not bryophytes?

a. They rely on water for fertilization
b. They have lignin to support vertical growth
c. They produce spores
d. They live in moist environments

5. What is a key reproductive advantage that flowers provide to angiosperms?

a. Flowers store water during drought
b. Flowers produce food through photosynthesis
c. Flowers attract pollinators, increasing fertilization success
d. Flowers protect seeds from UV radiation

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Answers:

1. c. Pollen
2. d. Bryophytes
3. c. Fruits
4. b. They have lignin to support vertical growth
5. c. Flowers attract pollinators, increasing fertilization success

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Create 5 multiple-choice questions using the following content

# 5.3 FUNGI

**Fungi** are a diverse kingdom of eukaryotic organisms that obtain nutrients by absorbing them from organic matter. While scientists have identified over 100,000 species of fungi, this is only a fraction of the over two million species that likely exist. They include mushrooms, yeasts, moulds, and more.

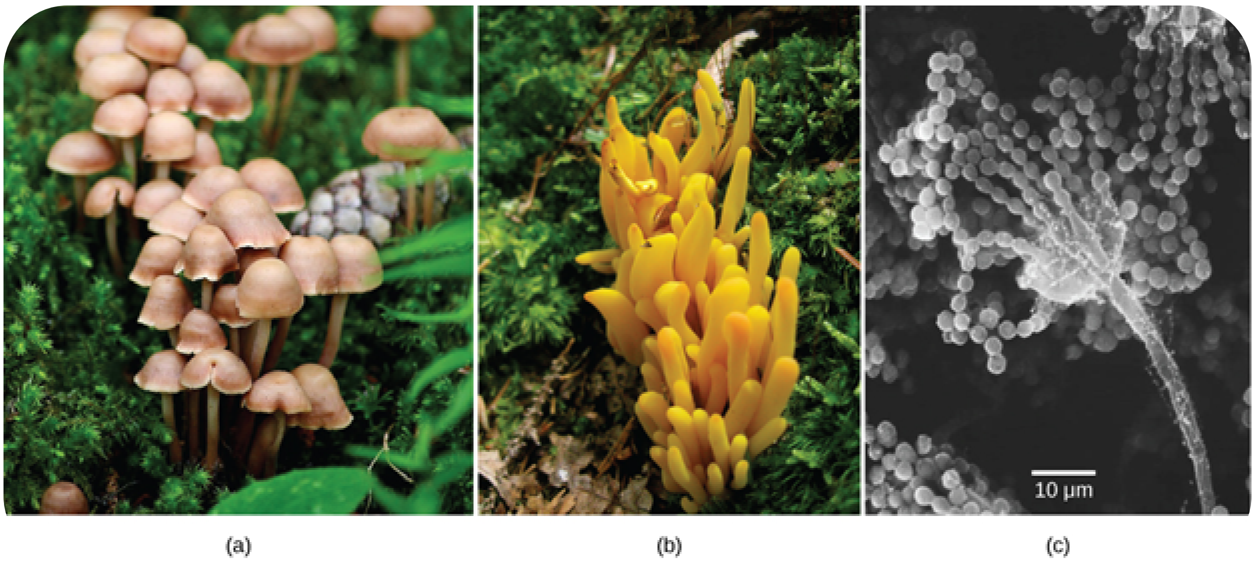


Figure 5.3.1 Many species of fungus produce the familiar mushroom (a), which is a reproductive structure. This (b) coral fungus displays brightly colored fruiting bodies. This electron micrograph shows (c) the spore-bearing structures of Aspergillus, a type of toxic fungus found mostly in soil and plants. Image by Open Stax, CC BY 4.0

## Structure

Fungi are made up of eukaryotic cells, meaning they have a nucleus and other membrane-bound organelles. Most fungi grow as **hyphae**, thread-like structures that form a network called a **mycelium** (Figure 5.3.2), which allows them to efficiently absorb nutrients from their surroundings.

Figure 5.3.2 Mycelium, Photo by Lex vB, CC BY-SA 3.0

Fungi were once considered plant-like organisms, but DNA evidence has shown that fungi are more closely related to animals. Like animals, fungi are heterotrophic – they cannot perform photosynthesis because they do not have chloroplasts. Fungi share a few other traits with animals. Their cell walls are composed of **chitin**, the same tough material found in the exoskeletons of arthropods. Like animals, fungi also store carbohydrates as **glycogen**.

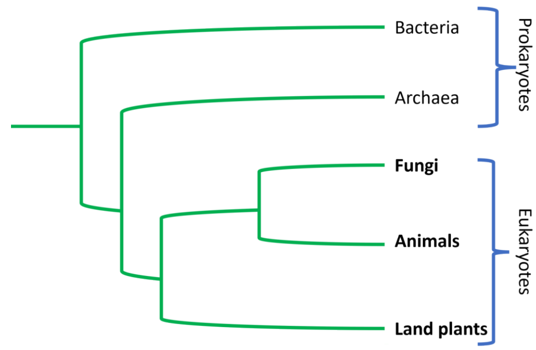


Figure 5.3.3 Simplified evolutionary tree showing **Prokaryotes** (Bacteria and Archaea) branching separately from **Eukaryotes** (Fungi, Animals, and Land plants). Image by Shana Kerr, CC BY-NC-SA 3.0

Figure 5.3.4: *Amanita muscaria*. Photo, by Holger Krisp, CC BY 3.0

Fungi also produce a variety of pigments, including **melanin**, which helps protect cells from ultraviolet (UV) radiation – a function it also serves in human skin and hair. Other fungal pigments may be toxic or unpalatable, which deters animals from eating them. For example, the bright red pigment in *Amanita muscaria* (fly agaric) serves as a warning of its toxicity.

Some fungi, like yeasts, are unicellular, but most are multicellular and form visible structures like mushrooms. Most fungi are **nonmotile**, meaning they don't move.

# Nutrition

Fungi are **heterotrophs**, meaning they obtain their food from other organisms. However, unlike animals that ingest food and then digest it internally, fungi take a different approach. They secrete enzymes into their environment to break down complex organic materials into simpler molecules, which they then *absorb* through their cell walls.

Fungi use different strategies to access nutrients. Most fungi act as **decomposers**, breaking down dead organic matter such as fallen leaves, wood, and animal remains. These fungi play a crucial role in recycling nutrients in ecosystems. Others are **parasites** which feed on living organisms and often cause disease (see Pathogenic Fungi below). Still others form **mutualistic relationships** with other organisms (see Mutualistic Fungi below).

# Reproduction

Many fungi can reproduce sexually and asexually, depending on environmental conditions. For example, when resources are plentiful, asexual reproduction may dominate. In contrast, stressful or changing conditions may trigger sexual reproduction to produce more resilient offspring.

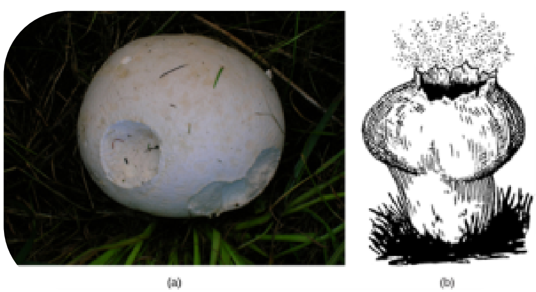


Figure 5.3.5: Puffball and spores. The (a) giant puffball mushroom releases (b) a cloud of spores when it reaches maturity. Photo (a) by Rosser, Roger Griffith, Public Domain, Image (b) by Pearson Scott Foresman, Public Domain

In both sexual and asexual reproduction, fungi reproduce using **spores**, which are tiny, often microscopic cells capable of growing into new fungi. Spores disperse from the parent organism by either floating on the wind or hitching a ride on an animal. Fungal spores are smaller and lighter than plant seeds. For example, the giant puffball mushroom bursts open and releases trillions of spores in a massive cloud of what looks like finely particulate dust. The huge number of spores released increases the likelihood of landing in an environment that will support growth (Figure 5.3.5).

In many common fungi, what we recognize as a **mushroom** is actually just the reproductive structure, known as the fruiting body. This is the visible part of the fungus that emerges above ground to release spores. The main body of the fungus (the mycelium) is typically hidden in soil, wood, or other organic material. On the underside of the mushroom cap are thin, blade-like structures called **gills**, which provide a large surface area for spore production and dispersal.

# Beneficial Fungi

## Importance to Ecosystems

Food webs would be incomplete without organisms that decompose organic matter, and fungi are key participants in this process. Decomposition allows for cycling of nutrients such as carbon, nitrogen, and phosphorus back into the environment so they are available to living things, rather than being trapped in dead organisms. Fungi are particularly important because they have evolved enzymes to break down cellulose and lignin, components of plant cell walls that few other organisms are able to digest, releasing their carbon content.

Figure 5.3.6 Turkey-Tail (Trametes versicolor), by morekari, Public Domain

Another crucial role fungi play in ecosystems is forming **mycorrhizae**, mutually beneficial associations with plant roots. *Mycorrhiza*, a term combining the Greek roots *myco* (fungus) and *rhizo* (root), refers to the symbiotic relationship between vascular plant roots and fungi. Somewhere between 80–90% of all plant species have mycorrhizal partners. In these associations, the fungal mycelia use their extensive network of hyphae and large surface area in contact with the soil to channel water and minerals into the plant. In return, the plant provides the fungus with sugars produced through photosynthesis to fuel its metabolism.

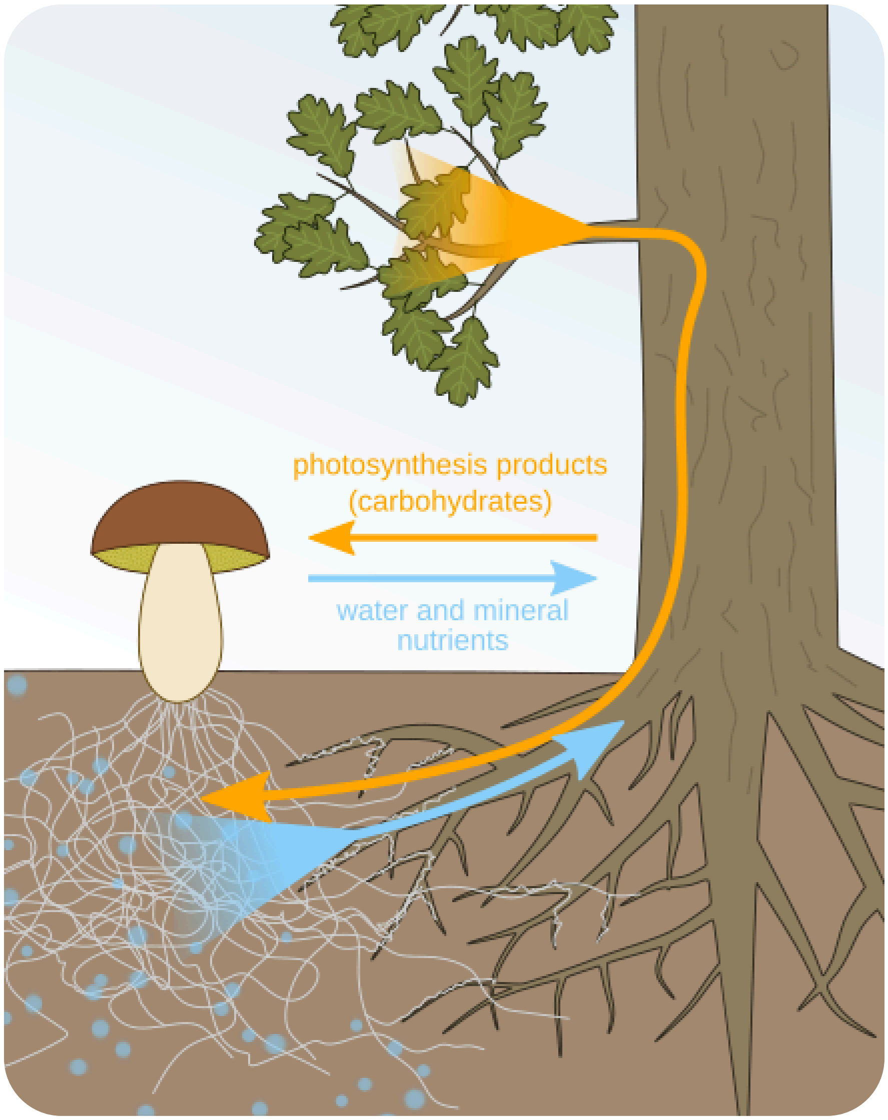


Figure 5.3.7 Diagram of a mycorrhizal mutualism showing a tree exchanging photosynthese products (carbohydrates) with a fungus in return for water and mineral nutrients absorbed from the soil. Image by Nefronus, CC BY-SA 4.0

## Food Production

Fungi have long been used in the production of food and beverages. **Yeasts** are single-celled fungi that play a key role in fermentation. They help make bread rise and are essential in brewing beer and fermenting wine.

We also eat many types of fungi. Some mushrooms, like morels, shiitake mushrooms, chanterelles, and truffles, are even considered delicacies (Figure 5.3.8).

Figure 5.3.8 The morel mushroom is an ascomycete that is much appreciated for its delicate taste. Photo by Jason Hollinger, CC BY 2.0

## Medicine and Pharmaceuticals

Figure 5.3.9 Penicillium chrysogenum, Photo by Crulina 98, CC BY-SA 3.0

Fungi have had a profound impact on modern medicine. The discovery of **penicillin**, the first widely used antibiotic, came from the fungus *Penicillium notatum* and revolutionized the treatment of bacterial infections. Since then, fungi have been used to develop a variety of other important drugs. Some fungal compounds are used to suppress the immune system in transplant patients, while others help manage chronic conditions such as high cholesterol. Ongoing research continues to explore fungi as sources of new antibiotics and even as anticancer agents.

## Harmful Fungi

While many fungi are beneficial, others can cause harm to a variety of different organisms.

### Plant Pathogens

Fungi are responsible for many serious plant diseases that affect both wild and cultivated species. For example, Dutch elm disease is a particularly devastating fungal infection that destroys many native species of elm (*Ulmus* spp.). The fungus infects the vascular system of the tree. It was accidentally introduced to North America in the 1900s and decimated elm trees across the continent. Dutch elm disease is caused by the fungus *Ophiostoma ulmi*. The elm bark beetle acts as a vector and transmits the disease from tree to tree. Many European and Asiatic elms are less susceptible than American elms.

The production of enough good-quality crops is essential to our existence. Plant diseases have ruined crops, bringing widespread famine. Most plant pathogens are fungi that cause tissue decay and eventual death of the host (Figure 5.3.10). In addition to destroying plant tissue directly, some plant pathogens spoil crops by producing potent toxins. Fungi are also responsible for food spoilage and the rotting of stored crops. For example, the fungus *Claviceps purpurea* causes ergot, a disease of cereal crops (especially of rye). Although the fungus reduces the yield of cereals, the effects of the ergot's alkaloid toxins on humans and animals are of much greater significance: In animals, the disease is referred to as ergotism. The most common signs and symptoms are convulsions, hallucination, gangrene, and loss of milk in cattle. The active ingredient of ergot is lysergic acid, which is a precursor of the drug LSD. Smuts, rusts, and powdery or downy mildew are other examples of common fungal pathogens that affect crops.

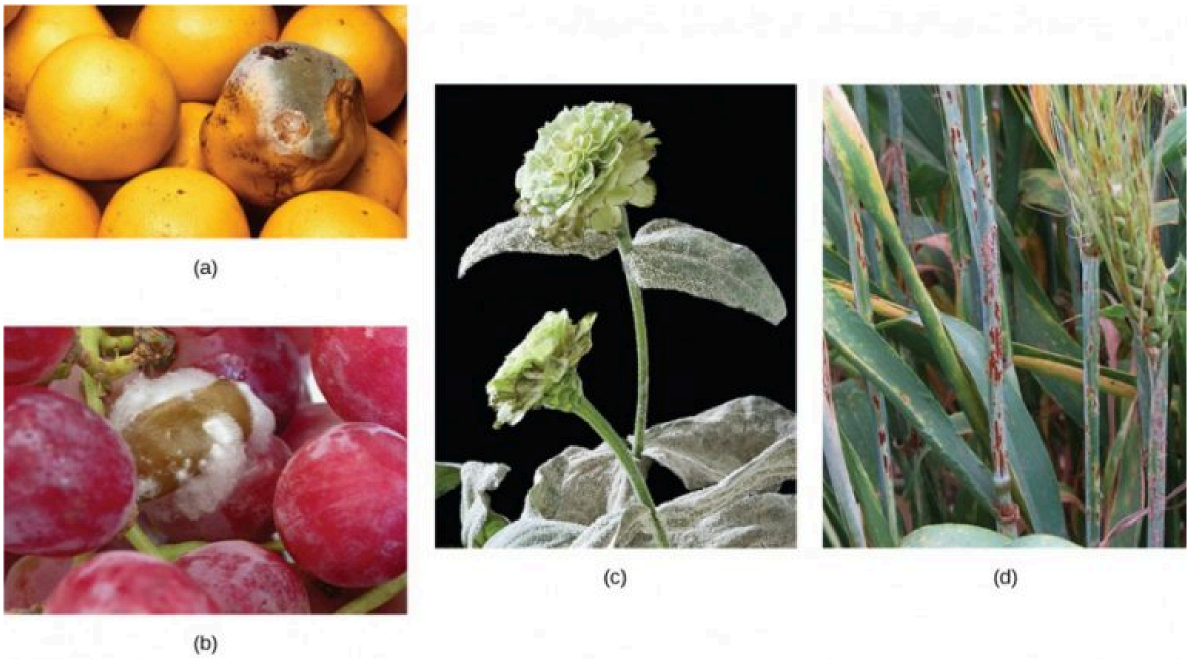


Figure 5.3.10 Some fungal pathogens include (a) green mould on grapefruit, (b) fungus on grapes, (c) powdery mildew on a zinnia, and (d) stem rust on a sheaf of barley. Photo (a) by Scott Bauer, USDA ARS, Photo (b) Joseph Smilanick, USDA ARS, Photo (c) by Stephen Ausmus, USDA ARS, Photo (d) by Joseph Smilanick, USDA ARS, Public Domain

## Animal pathogens

Figure 5.3.11 Little Brown Bat with White Nose Syndrome. Photo by Marvin Moriarty/USFWS, Public Domain

Fungi can affect animals, including humans, in several ways. Fungi attack animals directly by colonizing and destroying tissues. Humans and other animals can be poisoned by eating toxic mushrooms or foods contaminated by fungi. In addition, individuals who display hypersensitivity to moulds and spores develop strong and dangerous allergic reactions. Fungal infections are generally very difficult to treat because, unlike bacteria, fungi are eukaryotes. Antibiotics only target prokaryotic cells, whereas compounds that kill fungi also adversely affect the eukaryotic animal host.

Many fungal infections (**mycoses**) are superficial and termed cutaneous (meaning "skin") mycoses. Two common examples are athlete's foot and ringworm, both caused by fungi that feed on keratin (a protein found in hair, skin, and nails). These infections are easily spread through direct contact or contaminated surfaces like locker room floors or shared towels. They are often uncomfortable but are usually easily treated with over-the-counter topical creams and powders.

Figure 5.3.12 Ringworm. Photo by CDC/Dr. Lucille K. Georg, Public Domain

Fungi can also have devastating effects on wildlife. One striking example is white-nose syndrome, a fungal disease which affects hibernating bats. The fungus grows on the bats' skin, particularly around the nose and wings, and disrupts their hibernation cycles. As a result, the bats wake more frequently, burn through their energy reserves, and often die of starvation. This disease has led to dramatic declines in bat populations across North America.

## Knowledge Check

**Text Description**

1. What is the main structural component of fungal cell walls that also appears in the exoskeletons of arthropods?

   a. Cellulose
   b. Glycogen
   c. Chitin
   d. Keratin

2. Which part of a fungus is typically visible above ground and responsible for spore production?

   a. Mycelium
   b. Hyphae
   c. Fruiting body (mushroom)
   d. Rhizoids

3. Which of the following best describes how fungi obtain their nutrients?

   a. By ingesting food and digesting it internally
   b. Through photosynthesis using chloroplasts
   c. By secreting enzymes and absorbing nutrients externally
   d. By forming roots that absorb nutrients from soil

4. What is the mutualistic relationship between fungi and plant roots called?

   a. Symbiogenesis
   b. Mycorrhizae
   c. Rhizobium
   d. Hyphal fusion

5. Why are fungal infections often more difficult to treat in humans than bacterial infections?

   a. Fungi grow faster than bacteria
   b. Fungi are not affected by antibiotics targeting prokaryotes
   c. Fungi lack DNA, making treatment hard

d. Fungi reproduce only sexually

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Answers:

1. c. Chitin
2. c. Fruiting body (mushroom)
3. c. By secreting enzymes and absorbing nutrients externally
4. b. Mycorrhizae
5. b. Fungi are not affected by antibiotics targeting prokaryotes

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Prompt: Create 5 multiple-choice questions using the following content

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# CHAPTER 5 SUMMARY

## Key Takeaways

- **Land plants evolved from green algae** and developed adaptations such as a waxy cuticle, stomata, roots, gametangia, and alternation of generations to survive and reproduce on land.
- **Bryophytes (nonvascular plants)** were the first land plants and depend on moist environments due to their lack of vascular tissue and reliance on water for reproduction.
- **Seedless vascular plants** like ferns evolved vascular tissues (xylem and phloem), lignin, and true roots, allowing greater height and habitat range, but still rely on water for fertilization.
- **Gymnosperms** introduced pollen and seeds, enabling reproduction without water and better protection for embryos, which helped them thrive in drier environments.
- **Angiosperms** evolved flowers and fruits, improving pollination and seed dispersal through animal interactions, making them the most diverse and widespread plant group.
- **Fungi differ from plants** by absorbing nutrients from their environment, decomposing organic matter, forming mutualistic relationships, and contributing to medicine, food production, and ecosystem health.

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Prompt: Summarize the following content into six key takeaways.

## Flashcards

Text Description

Front of card

1. Anther
2. Antheridium
3. Archegonium
4. Bryophytes
5. Carpel
6. Cellulose
7. Chitin
8. Cuticle
9. Decomposers
10. Dry fruits
11. Embryo
12. Endosperm
13. Fertilization
14. Filament
15. Flagellated
16. Fleshy fruits
17. Fungi
18. Gametes
19. Gametophyte
20. Gills
21. Glycogen
22. Gymnosperms
23. Heterotrophs
24. Hyphae
25. Lignin
26. Melanin
27. Mitotic (mitosis)
28. Mycelium
29. Mycorrhizae

30. Nectar
31. Nonmotile
32. Nonvascular plants
33. Ovary
34. Ovule
35. Parasites
36. Petals
37. Phloem
38. Photosynthesis
39. Pollen
40. Pollinators
41. Rhizoids
42. Roots
43. Seed
44. Seedless vascular plants
45. Sepals
46. Sporangium
47. Sporophyte
48. Fungal spores
49. Stamens
50. Stigma
51. Style
52. Vascular tissue
53. Xylem
54. Zygote
55. Plants
56. Monophyletic
57. Stomata
58. Gametangia
59. Alternation of generations
60. Moss
61. Fern
62. Conifer
63. Angiosperms
64. Flower

65. Fruits
66. Mimicry
67. Mushroom
68. Yeast
69. Penicillin
70. Mycosis
71. Advantages for plants to live on land
72. 5 major terrestrial adaptations present in most land plants
73. Key terrestrial adaptations for bryophytes
74. Key terrestrial adaptations for seedless vascular plants
75. Key terrestrial adaptations for gymnosperms
76. Key terrestrial adaptations for angiosperms
77. 4 parts of a flower
78. Role of fruits
79. Type of fruits
80. Methods of seed dispersal
81. Fungal modes of nutrition
82. How are fungi beneficial?
83. How are fungi harmful?
84. Steps in Moss Life Cycle
85. Steps in Fern Life Cycle
86. Steps in Pine Life Cycle
87. Steps in Angiosperm Life Cycle

Back of card

1. The part of a stamen that produces and contains pollen
2. A structure that produces sperm in the gametophyte generation of plants
3. A structure that produces eggs in the gametophyte generation of plants
4. Nonvascular plants, including mosses, liverworts, and hornworts, that lack vascular tissue and require moist environments
5. The female reproductive organ of a flower, including the stigma, style, and ovary; also called a pistil
6. A complex carbohydrate that forms the structural component of plant cell walls
7. A tough, flexible compound found in the cell walls of fungi and in the exoskeletons of arthropods

8. A waxy, water-repellent layer on the surface of plant leaves and stems that helps prevent water loss
9. Organisms that break down dead organic material and recycle nutrients into ecosystems
10. Fruits that are hard or papery when mature, such as nuts, wheat, or rice; often spread by air, water or attached to animals
11. The early developmental stage of a plant or animal that arises from a fertilized egg
12. A tissue in seeds of flowering plants that provides nourishment to the developing embryo, formed during double fertilization.
13. The fusion of sperm and egg to form a zygote
14. The stalk of a stamen that supports the anther
15. Having one or more whip-like tails (flagella) used for movement; describes the sperm of mosses and ferns
16. Fruits that are soft and juicy when mature, like peaches and berries, are often consumed by animals to help spread seeds
17. A kingdom of eukaryotic organisms that absorb nutrients from organic material
18. Reproductive cells (sperm and egg) that unite during fertilization
19. The haploid, gamete-producing stage in a plant's life cycle
20. Blade-like structures on the underside of a mushroom cap, where spores are produced
21. A carbohydrate that fungi and animals use to store energy
22. Seed-producing plants like conifers, whose seeds are not enclosed in fruits
23. Organisms that cannot make their own food and rely on consuming other organisms for energy
24. Long, thread-like filaments that make up the body of a fungus
25. A complex organic compound that hardens cell walls in vascular plants, giving them rigidity
26. A dark pigment that provides protection against UV radiation; found in both fungi and animals
27. A process of cell division that results in two identical cells; used in growth and asexual reproduction
28. The network of hyphae that forms the main body of a fungus
29. Symbiotic relationships between fungi and plant roots that improve nutrient and water uptake
30. A sugary fluid produced by flowers to attract pollinators
31. Incapable of movement
32. Plants that lack vascular tissue (xylem and phloem), including mosses, liverworts, and hornworts; informally known as bryophytes

33. The part of the carpel that contains ovules and matures into a fruit after fertilization
34. The structure in seed plants that contains the female gametophyte and develops into a seed after fertilization
35. Organisms that live on or in a host organism and derive nutrients at the host's expense
36. Colourful parts of a flower that attract pollinators
37. Vascular tissue in plants that transports sugars from the leaves to the rest of the plant
38. The process by which green plants use sunlight to produce food from carbon dioxide and water
39. A structure that contains the male gametes (sperm) of seed plants
40. Animals, such as bees or birds, that carry pollen from one flower to another
41. Root-like structures in nonvascular plants that anchor the plant but do not absorb water
42. Organs in vascular plants that absorb water and nutrients from the soil and anchor the plant
43. A structure in seed plants that contains a developing embryo and a food supply, enclosed in a protective coat
44. Plants that have vascular tissue but reproduce via spores instead of seeds; ferns
45. The outer parts of a flower, usually green, that protect the flower bud before it opens
46. A structure where spores are formed
47. The diploid, spore-producing stage in a plant's life cycle
48. Microscopic, reproductive cells that grow into a new fungus
49. The male reproductive parts of a flower, consisting of a filament and anther
50. The sticky top part of a carpel, where pollen lands
51. A tube that connects the stigma to the ovary in a flower
52. Specialized plant tissue (xylem and phloem) for conducting water, minerals, and nutrients
53. Vascular tissue that transports water from roots to leaves
54. The cell formed by the union of a sperm and egg; the first cell of a new organism
55. Multicellular, photosynthetic organisms that belong to the kingdom Plantae
56. A group of organisms that includes a common ancestor and all of its descendants, representing a single branch on the tree of life
57. Small openings on the surfaces of leaves and stems that allow for gas exchange ($CO^2$ in, $O^2$ and water vapour out) between the plant and the environment
58. Specialized structures in plants, algae, and fungi where gametes (sperm or eggs) are produced
59. A life cycle in plants and some algae that alternates between a haploid gametophyte stage and a diploid sporophyte stage
60. A type of bryophyte that grows in moist environments; it has a dominant gametophyte

stage and reproduces via spores

61. A seedless vascular plant with large, divided leaves (fronds); it has a dominant sporophyte stage and reproduces via spores
62. A type of gymnosperm that produces seeds in cones; typically has needle-like leaves; includes pines, spruces, and firs
63. Flowering plants that produce seeds enclosed in fruits; the most diverse and widespread group of plants
64. The reproductive structure of angiosperms
65. Mature ovaries of flowering plants that contain seeds; they aid in seed dispersal
66. An evolutionary adaptation in which one organism resembles another to gain an advantage
67. The fruiting body of certain fungi that produces and releases spores
68. Single-celled fungi; commonly used in food production
69. An antibiotic substance produced by the Penicillium fungus that kills or inhibits the growth of certain bacteria
70. A fungal infection in animals or humans, ranging from superficial skin infections to serious systemic diseases
71. Easier access to sunlight and carbon dioxide, initially, no predators
72. Waxy cuticle, stomata, roots, gametangia, alternation of generations
73. Waxy cuticle, rhizoids
74. True roots, vascular tissue, lignin
75. Pollen, seeds
76. Flowers, fruits
77. Sepals, petals, stamens, carpels
78. Seed dispersal
79. Fleshy fruits (berries, peaches); Dry fruits (nuts, wheat)
80. Wind, animal ingestion, animal transportation, water
81. All heterotrophs get nutrition in different ways (decomposers, parasites, and mutualistic relationships)
82. Important for ecosystems (decomposers, mycorrhizae); Food production (fermentation, mushrooms); Medicine (penicillin)
83. Plant pathogens (Dutch elm disease, ergot); Animal pathogens (toxic, infections)
84. Steps:

    1. Gametophytes (n) produce gametes (n) through mitosis. Antheridium produces sperm. Archegonium produces egg.
    2. Sperm swim to nearby gametophytes to fertilize egg in the antheridium, forming a

zygote
3. Zygote develops into embryo, which then grows (through mitosis) into new sporophyte (2n).
4. Sporophyte (2n) produces spores (n) through meiosis.
5. Spores blow to a new location and grow into a new gametophyte (mitosis). The gametophyte is the conspicuous part of the plant.

85. Steps:

    1. Gametophytes (n) produce gametes (n) through mitosis. Antheridium produces sperm. Archegonium produces egg.
    2. Sperm swim to nearby gametophytes to fertilize egg in the antheridium, forming a zygote (2n).
    3. Zygote develops into embryo, which then grows (through mitosis) into new sporophyte (2n). The sporophyte is the conspicuous part of the plant.
    4. Sporophyte (2n) produces spores (n) through meiosis.
    5. Spores blow to a new location and grow into a new gametophyte (mitosis).

86. Steps:

    1. Gametophytes (n) produce gametes (n) through mitosis. Male gametophyte is a pollen grain found in male cones. Female gametophyte develops within an ovule in female cones.
    2. Pollen is carried by wind to fertilize egg, forming a zygote (2n) inside the ovule of the female cone.
    3. Zygote develops into an embryo. Ovule develops into seed.
    4. Seed is dispersed, then germinates and grows (through mitosis) into new sporophyte (2n). The sporophyte is the conspicuous part of the plant (the tree).
    5. Sporophyte (2n) produces spores (n) through meiosis. Spores develop into gametophytes inside of cones.

87. Steps:

    1. Gametophytes (n) produce gametes (n) through mitosis. Male gametophyte is a pollen grain in anther of a flower. Female gametophyte (embryo sac) develops inside an ovule within the ovary of a flower.
    2. Pollen is transferred (by wind or pollinators) to stigma of a flower where it grows a pollen tube to fertilize the egg inside the ovule, forming a zygote (2n). This process

includes double fertilization – the second sperm fertilizes the nearby cell to form endosperm, which nourishes the embryo.

3. Zygote develops into an embryo. Ovule becomes a seed, and the ovary develops into a fruit.
4. Seed is dispersed, then germinates and grows (through mitosis) into a new sporophyte (2n). The sporophyte is the visible flowering plant.
5. The sporophyte (2n) produces spores (n) through meiosis. Spores develop into gametophytes (pollen and embryo sacs) inside the flower.

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Prompt: Provide definitions for all the bolded terms in the shared content and list all the terms in alphabetical order.

# CHAPTER 6: INVERTEBRATE ANIMALS

## Chapter Overview

## Learning Objectives

By the end of this chapter, you will be able to:

- Describe the general characteristics shared by all animals, including cell structure, nutrition, and modes of reproduction.
- Differentiate between asymmetrical, radial, and bilateral body symmetries and provide examples of animals that exhibit each type.
- Explain the basis of animal classification, including the roles of body structure and genetic evidence in determining phyla.
- Distinguish between invertebrates and vertebrates, and identify the relative diversity of each within the animal kingdom.
- Compare and contrast the major invertebrate phyla (e.g., Porifera, Cnidaria, Platyhelminthes, Nematoda, Mollusca, Annelida, Arthropoda, Echinodermata), highlighting their key structural and functional traits.
- Identify the defining features of chordates, including the four key developmental characteristics, and differentiate between vertebrate and invertebrate chordates.

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Prompt: Provide 6 learning objectives for the shared content.

# 6.1 GENERAL FEATURES OF ANIMALS

Figure 6.1.1. Great Blue Heron eating fish. Photo by winnu, CC BY 2.0

Even though animals are incredibly diverse, they share common features that distinguish them from organisms in other kingdoms. All animals are **eukaryotic**, **multicellular** organisms, and almost all animals have **specialized tissues** (groups of similar cells that work together to carry out a specific function). Most animals are **motile**, at least during certain life stages. All animals are **heterotrophic**, ingesting living or dead organic matter. This form of obtaining energy distinguishes them from autotrophic organisms, such as most plants, which make their own nutrients through photosynthesis and from fungi that digest their food externally. Animals may be carnivores, herbivores, omnivores, or parasites. Most animals reproduce sexually. The offspring pass through a series of developmental stages that establish a determined body plan (shape), unlike plants, for example, in which the exact shape of the body is indeterminate.

## Classification of Animals

Animals are classified into different phyla using a combination of physical traits and genetic data.

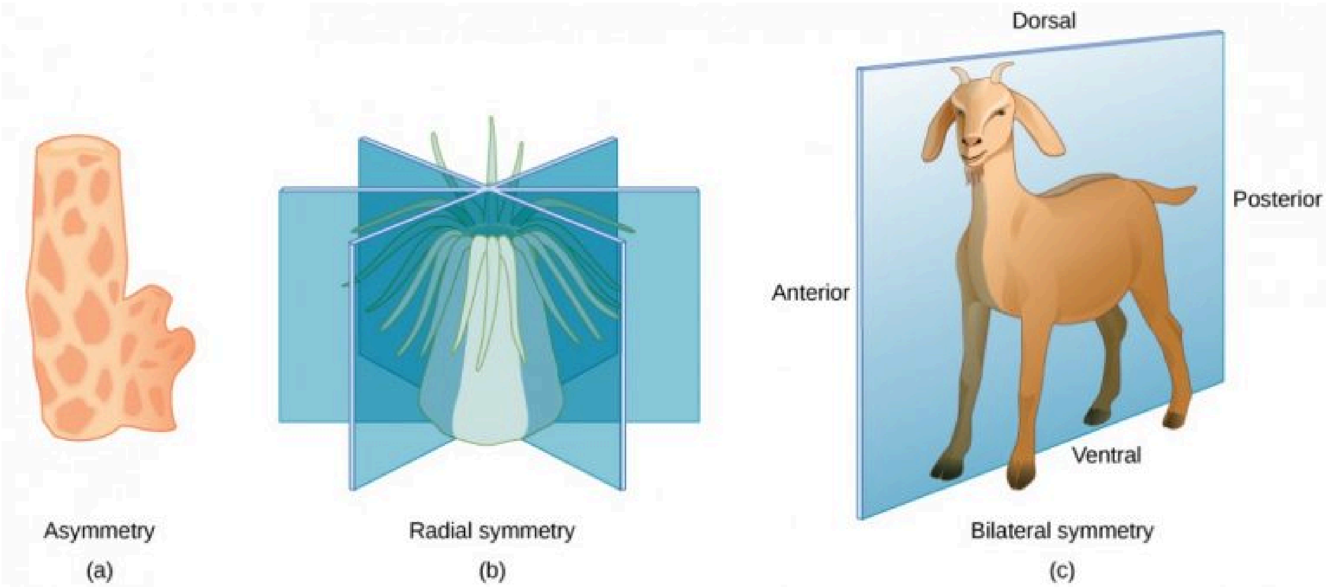


Figure 6.1.2 Animals exhibit different types of body symmetry. The (a) sponge is asymmetrical and has no planes of symmetry, the (b) sea anemone has radial symmetry with multiple planes of symmetry, and the (c) goat has bilateral symmetry with one plane of symmetry. Image by OpenStax, CC BY 4.0

The first major division that you can see in the phylogenetic tree is based on body symmetry. Animals may be asymmetrical, radial, or bilateral in form (Figure 6.1.2). **Asymmetrical** animals are animals with no pattern or symmetry (Figure 6.1.2a); an example of an asymmetrical animal is a sponge. An organism with **radial symmetry** (Figure 6.1.2b) has a longitudinal (up-and-down) orientation: Any plane cut along this up–down axis produces roughly mirror-image halves. An example of an organism with radial symmetry is a sea anemone. **Bilateral symmetry** is illustrated in Figure 6.1.2c using a goat. The goat also has upper and lower sides to it, but they are not symmetrical. A vertical plane cut from front to back separates the animal into roughly mirror-image right and left sides. Animals with bilateral symmetry also have a "head" and "tail" (**anterior** versus **posterior**) and a back and underside (**dorsal** versus **ventral**).

Animals are often informally divided into two broad categories: invertebrates and vertebrates. **Invertebrates** are animals without a backbone, whereas **vertebrates** are animals that have a backbone. Scientists currently recognize about 35 different groups of animals (phyla) on Earth. Most of these groups only contain invertebrates. In fact, about 95% of all animal species are invertebrates. Although vertebrates, such as mammals, birds, and fish, are more familiar to us, they make up only a small part of the animal kingdom and all belong to just one phylum – Chordata.

Let's explore the nine most diverse phyla of animals, starting with the invertebrates, by referring to Figure 6.1.3 below.

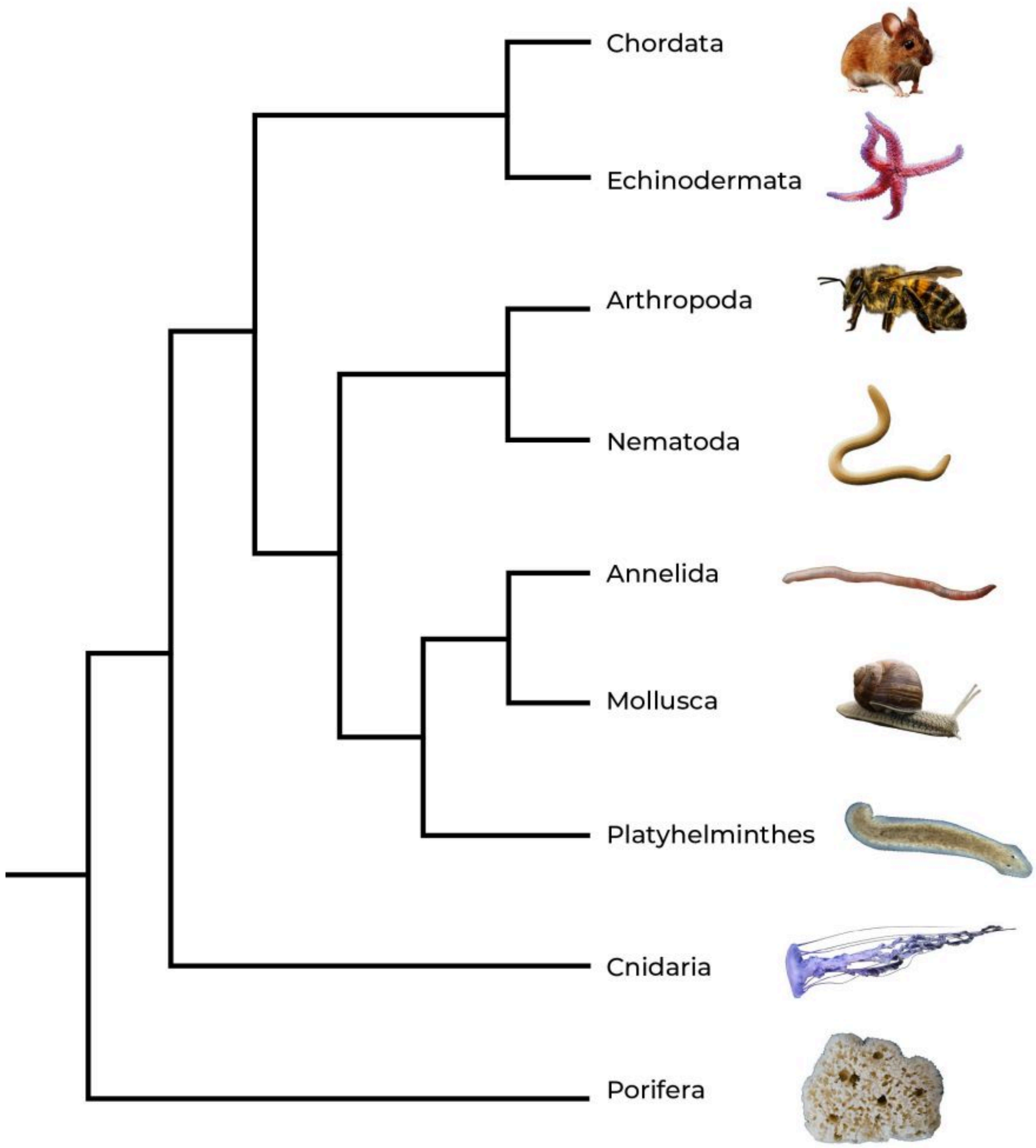


Figure 6.1.3 The phylogenetic tree of major animal groups showing evolutionary relationships from sponges and jellyfish to flatworms, mollusks, worms, arthropods, echinoderms, and chordates. The tree illustrates evolutionary relationships among these phyla, with simpler organisms like sponges and cnidarians branching earlier, and more complex groups like chordates appearing later. Image by Koen Liddiard, [CC BY-NC-SA 4.0](https://creativecommons.org/licenses/by-nc-sa/4.0/)

## Knowledge Check

**Text Description**

1. Which of the following traits is shared by all animals?

   a. The ability to photosynthesize
   b. External digestion of food
   c. Eukaryotic, multicellular body structure
   d. Indeterminate body plan

2. Which of the following best describes animals that are bilaterally symmetrical?

   a. They have a circular shape with identical parts around a central axis
   b. They can be divided into right and left mirror-image halves
   c. They have no consistent shape or pattern
   d. They always have a backbone

3. What distinguishes animals from fungi and plants in how they obtain energy?

   a. Animals photosynthesize like plants
   b. Animals externally digest food like fungi
   c. Animals ingest organic material internally
   d. Animals absorb minerals directly from the soil

4. Which statement about vertebrates and invertebrates is true?

   a. Vertebrates make up the majority of animal species
   b. Invertebrates all belong to the phylum Chordata
   c. Invertebrates lack a backbone and make up about 95% of animals
   d. All animals with bilateral symmetry are vertebrates

5. What does the term "body plan" refer to in animals?

   a. Their method of digestion
   b. Their ability to reproduce
   c. Their overall shape and symmetry developed during early growth
   d. Their classification as vertebrate or invertebrate

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Answers:

1. c. Eukaryotic, multicellular body structure
2. b. They can be divided into right and left mirror-image halves
3. c. Animals ingest organic material internally
4. c. Invertebrates lack a backbone and make up about 95% of animals
5. c. Their overall shape and symmetry developed during early growth

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Prompt: Create 5 multiple-choice questions using the following content

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# 6.2 INVERTEBRATE GROUPS

## Sponges

Figure 6.2.1 "Stove-pipe Sponge-pink variation" by Nick Hobgood, CC BY-SA 3.0

**Sponges** (phylum Porifera) are the simplest animals. They live in water, mostly in the ocean, and are usually attached to surfaces like rocks. Because they don't move as adults, they can easily be mistaken for plants. However, sponges are animals that have been around for over 500 million years. Scientists believe that sponges probably evolved very early from colonial protists – single-celled organisms that lived together in groups.

Sponges don't have true tissues, organs, or a nervous system. Instead, their bodies are made up of loosely organized cells. The sponge's body is full of pores and channels. Water enters through the small openings, flows into a central cavity, and then exits through a larger opening at the top. Water constantly flows through their bodies, bringing in food and oxygen and carrying away waste. Sponges are **filter feeders**, meaning they feed by straining tiny food particles from the water as it flows through their bodies. This water movement is powered by special cells called **choanocytes,** which have flagella that beat to create a current. These cells also trap and engulf tiny food particles from the water. **Amoebocytes** then help digest food and carry it to other cells.

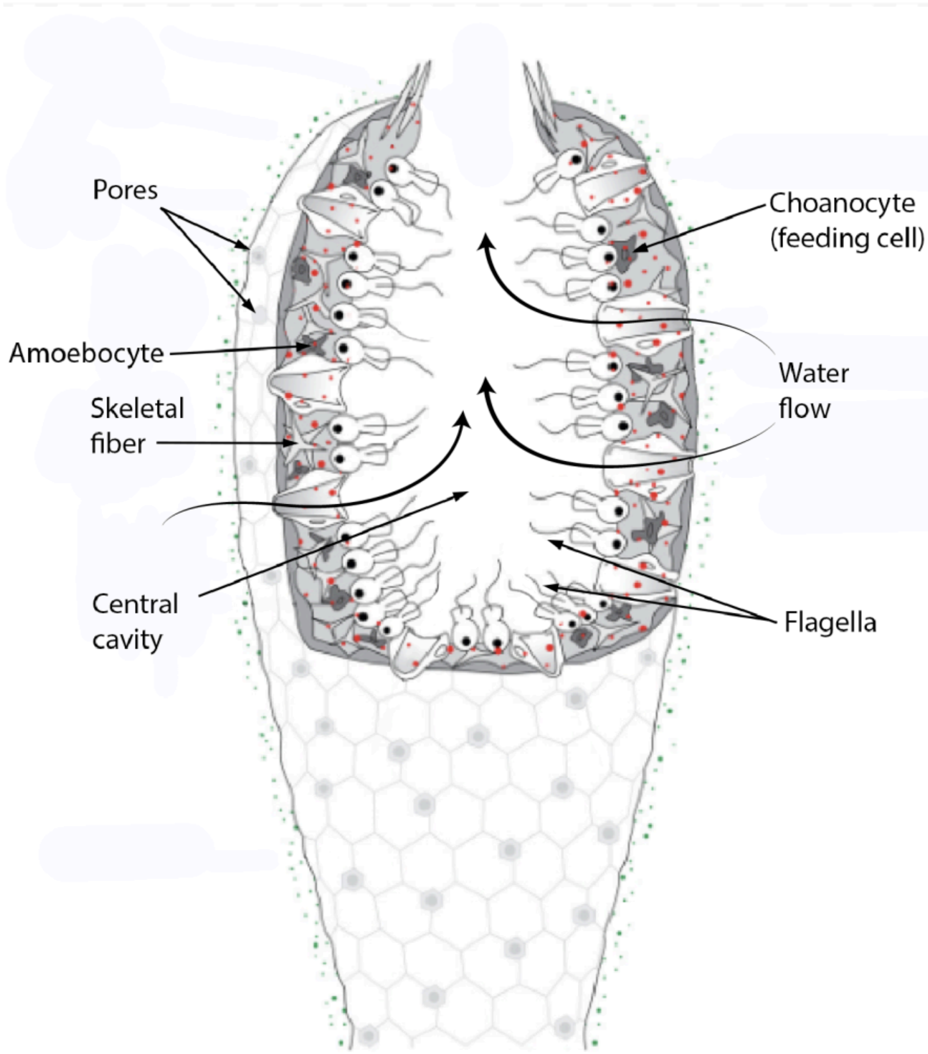



Figure 6.2.2 The body of a sponge. "Image" by Webster NS, CC BY 4.0, Modifications: Labels edited

Sponges reproduce both sexually and asexually. Asexual reproduction is either by **fragmentation** (in which a piece of the sponge breaks off and develops into a new individual) or **budding** (an outgrowth from the parent that eventually detaches). Most sponges are **hermaphroditic**, meaning one individual can produce both eggs and sperm. Sperm is released, whereas the eggs are retained within the central cavity. Sperm carried by water currents fertilize the eggs of other sponges. Early larval development occurs within the sponge, and free-swimming larvae are then released. This is the only time that sponges exhibit mobility.

# Cnidarians

**Cnidarians** (phylum Cnidaria) are simple animals with true tissues, radial symmetry, and tentacles armed with stinging cells. This group includes sea anemones, corals, hydras, and jellies (often called jellyfish, though they are not actually fish). Most of the roughly 10,000 known cnidarian species live in the ocean.

Figure 6.2.3 The diversity of cnidarians. "Coral" by Frédéric Ducarme, CC BY-NC-ND, "Green Hydra" by carolbeauchesne, CC BY-NC 4.0, "Lion's Mane Jellies" by emma12fowler, CC BY-NC 4.0, "Plumose sea anemone" by teriyakiturtle, CC BY-NC 4.0

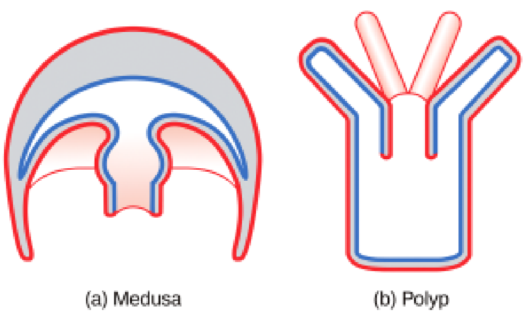



Figure 6.2.4 Cnidarians have two distinct body plans: the (a) medusa and the (b) polyp. All cnidarians have two tissue layers, with a jelly-like mesoglea between them. Image by Openstax, CC BY 4.0 Modification: Removed text.

Cnidarians display two distinct body plans:

**Polyp**: Usually attached to a surface with its mouth facing upward (e.g. *Hydra*)

**Medusa:** Free-swimming and shaped like an umbrella with the mouth and tentacles hanging downward (e.g. jellies)

Some cnidarians live only as polyps, others only as medusae, and some alternate between both forms during their life cycle.

Cnidarians are carnivores. The **tentacles** are lined with special stinging cells called **cnidocytes**, which contain tiny, coiled threads that can shoot out and deliver toxins to stun or kill prey. They use their tentacles to capture prey and bring it into their digestive space, called the **gastrovascular cavity**. This space has only one opening that serves as both the mouth and anus (an incomplete digestive system). Food is taken into the gastrovascular cavity, enzymes are secreted into the cavity, and the cells lining the cavity absorb the nutrient products of the extracellular digestive process.

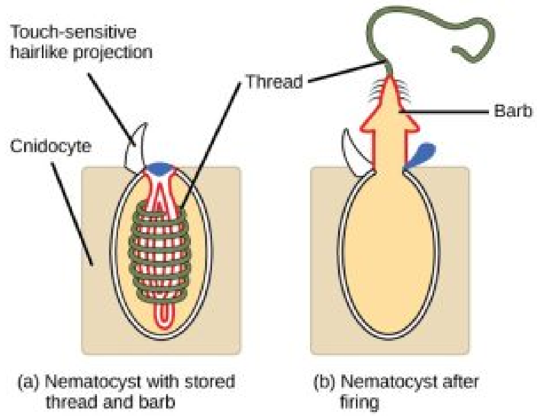



Figure 6.2.5 Cnidocytes contain large organelles called (a) nematocysts that store a coiled thread and barb. When hairlike projections on the cell surface are touched, (b) the thread, barb, and a toxin are fired from the organelle. Image by Openstax, CC BY 4.0

## Flatworms

**Flatworms** (phylum Platyhelminthes) are among the simplest animals to exhibit bilateral symmetry. Flatworms have flattened, ribbon-like bodies and range in size from microscopic to several meters long. They lack specialized circulatory and respiratory systems, so gas exchange and nutrient distribution occur by diffusion, which limits their body thickness and contributes to their flat shape.

Figure 6.2.6 "Dugesia Subtentaculata" by Eduard Solà, CC BY-SA 3.0

Most flatworms have a gastrovascular cavity with a single opening that serves as both mouth and anus. They also have a simple nervous system, which consists of two longitudinal nerve cords and a concentration of nerve cells (ganglia) at the head end. Some species have light-sensitive eyespots and chemical sensors that help them navigate their environment.

Most flatworms are hermaphroditic, possessing both male and female reproductive organs. Some species can also reproduce asexually through fragmentation and regeneration – a whole new worm can grow from just a small piece of the original!

Flatworms live in a variety of environments, including marine, freshwater, and moist terrestrial habitats. Some are free-living, while many others are parasitic. **Free-living** organisms live independently in their natural environments and obtain their own food. In contrast, **parasitic** organisms live inside or on a host organism and rely on the host for nutrients.

An example of a free-living flatworm is a **planarian**. The gastrovascular cavity of planarians is highly branched, increasing surface area for digestion and nutrient absorption. A muscular feeding tube extends from the mouth to suck in food.

**Tapeworms** are parasitic flatworms that live in the intestines of vertebrates. They remain fixed using a specialized head that contains hooks and suckers. They have long, ribbon-like bodies made up of repeating units that can grow several meters long. Tapeworms do not have a digestive system; they absorb nutrients from the food matter passing them in the host's intestine. Tapeworms have an interesting life cycle that often includes living in the muscle tissue of an intermediate host. When the muscle tissue is eaten by the primary host, the cycle is completed. There are several tapeworm parasites of humans that are acquired by eating uncooked or poorly cooked pork, beef, and fish.

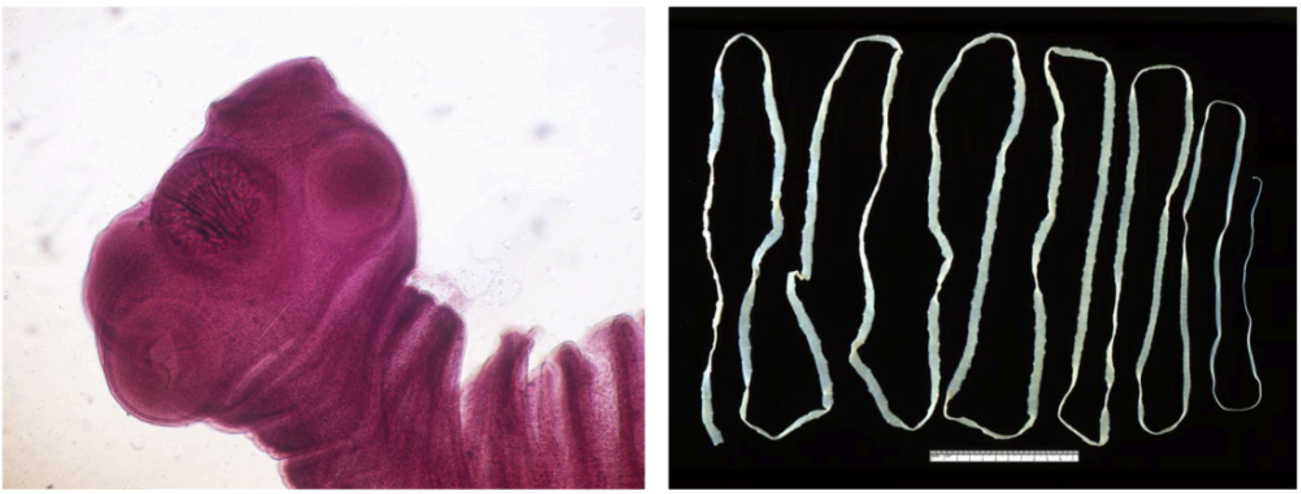


Figure 6.2.7 On the left, a close-up microscopic view highlights the scolex (head) of the tapeworm, stained purple, with visible suckers and hook-like structures for attachment. On the right, a full-body view displays the long, segmented structure of the tapeworm spread out in multiple parallel sections against a black background, showing its ribbon-like form. "Taenia solium scolex" (left) by Roberto. J. Galindo, GNU Free Documentation License, "Eucestoda" (right) by US Centers for Disease Control and Prevention (CDC), Public Domain

## Nematodes

**Nematodes** (phylum Nematoda), also known as roundworms, are slender, cylindrical worms that are tapered at each end. Nematodes are present in all habitats and are extremely common, although they are usually not visible. Their bodies are covered by a tough, flexible cuticle that they must shed to grow. They move with a whip-like motion using only longitudinal muscles.

Nematodes have a **complete digestive system** with a mouth and anus. While many are free-living decomposers, others are parasites of plants and animals, including humans. Parasitic species include pinworms and hookworms, and can be transmitted through contaminated food, soil, or water.

Figure 6.2.8 "Nematodes" by gyefiri, CC BY-NC 4.0

## Arthropods

**Arthropods** (phylum Arthropoda) are the most diverse and numerous animals on Earth, accounting for about 85% of all known animal species, with many still undiscovered or undescribed. Arthropods have adapted to nearly every environment, from deep oceans to the skies.

Their name means "jointed legs," which reflects one of their key features. These **jointed appendages** are highly specialized to serve a specific function, such as locomotion (walking, swimming, flying), feeding or defence. This specialization allows arthropods to adapt to a wide range of environments and lifestyles.

Arthropods have an **exoskeleton,** a rigid external covering that provides support, protection, and a surface for muscle attachment. It must be shed periodically for growth, in a process called **moulting**. Their body segments are often grouped into functional regions such as the head, thorax, and abdomen. They have a complete digestive system.

Arthropods are classified into four major subgroups:

## Insects

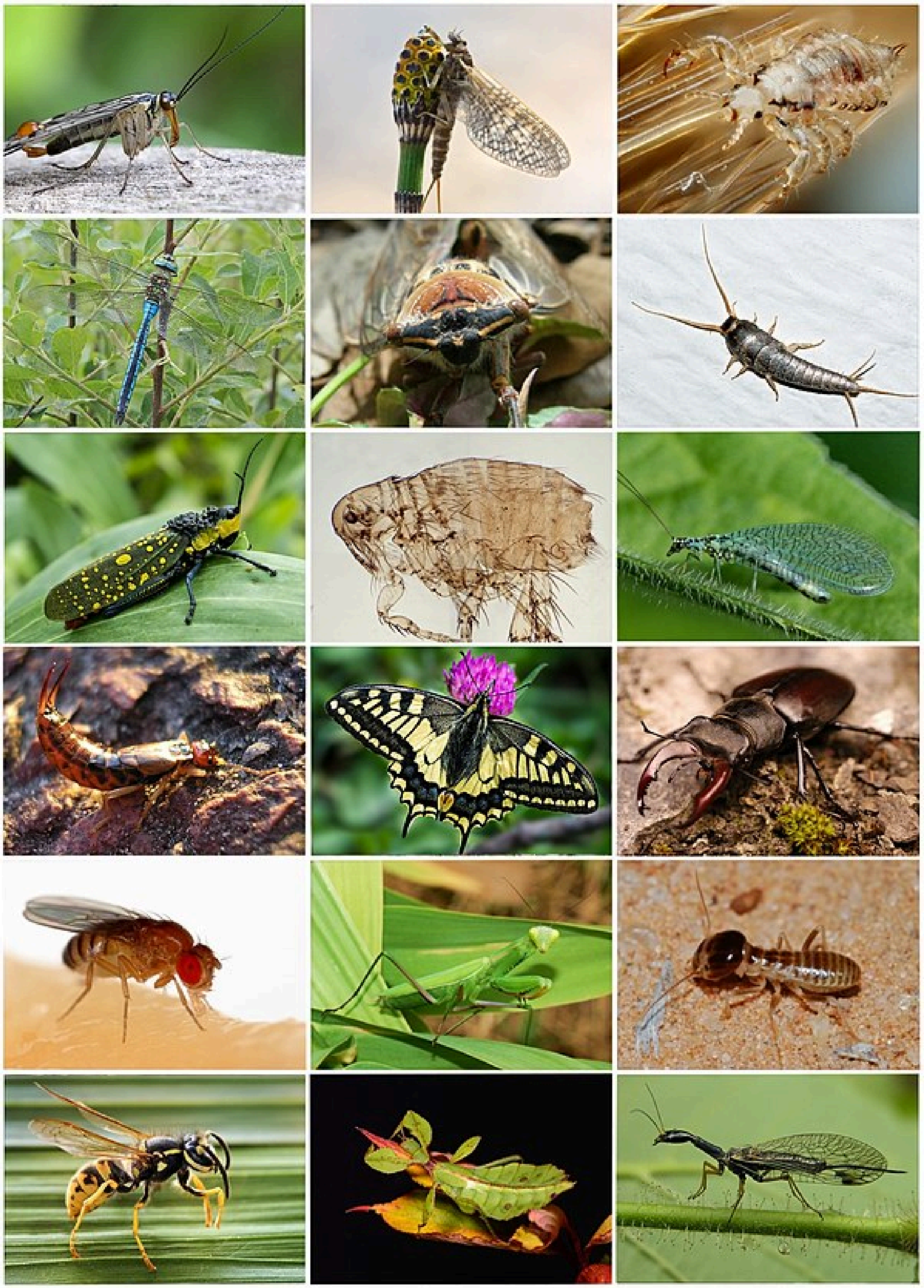


Figure 6.2.9 Left to right, top to bottom: "Common scorpionfly" by Richard Bartz, CC BY-SA 2.5, "March Brown Mayfly" by Richard Bartz, CC BY-SA 2.5, "Male Human Head Louse" by Gilles San Martin, CC BY-SA 2.0, "Blue Emporer" by Ocrdu, CC BY-SA 4.0, "Double Drummer" by Jan Anderson, CC BY-SA 2.0, "Silverfish" by Christian Fischer, CC BY-SA 3.0, "Aularches miliaris" by Crisco 1492, CC BY-SA 3.0, "Ctenocephalides-canis" by Luis Fernandez, CC BY-SA 2.5, "Chrysopidae" by Mathias Krumbholz, CC BY-SA 3.0, "F-auricularia" by Pudding4brains, Public Domain, "Old World Swallowtail (Papilio machaon)" by Uoaei1, CC BY-SA 4.0, "Lucanus cervus" by Simon A. Eugster, CC BY 3.0 Uported, "Drosophila melanogaster proboscis" by Sanjay Acharya, CC BY-SA 4.0, "Mantid religiosa" by Alvesgaspar, CC BY-SA 3.0 Unported, "Northern Harvester Termite (Hodotermes mossambicus)" by Bernard Dupont, CC BY-SA 2.0, "Vespula germanica" by Richard Bartz aka Makro Freak, CC BY-SA 2.5, "Phyllium Philippinicum" by Ebe.wiki, CC BY-SA 4.0, "Dichrostigma flavipes" by Beentree, CC BY-SA 3.0 Unported.

**Insects** are the largest group of arthropods and are found in nearly every terrestrial and freshwater habitat. They have a body divided into head, thorax, and abdomen, with three pairs of legs and usually one or two pairs of wings attached to the thorax. Insects breathe through tracheal tubes and have a well-developed nervous system. Common examples include ants, butterflies, beetles, and bees.

Many insects undergo **metamorphosis**, a developmental process that transforms them from immature forms into adults. The larval stage is often specialized for feeding and growth, while the adult is typically adapted for reproduction and dispersal. In **complete metamorphosis**, insects pass through distinct stages from egg, larva, pupa, and adult. A familiar example is the butterfly, which begins life as a caterpillar (larva), forms a chrysalis (pupa), and emerges as a winged adult.

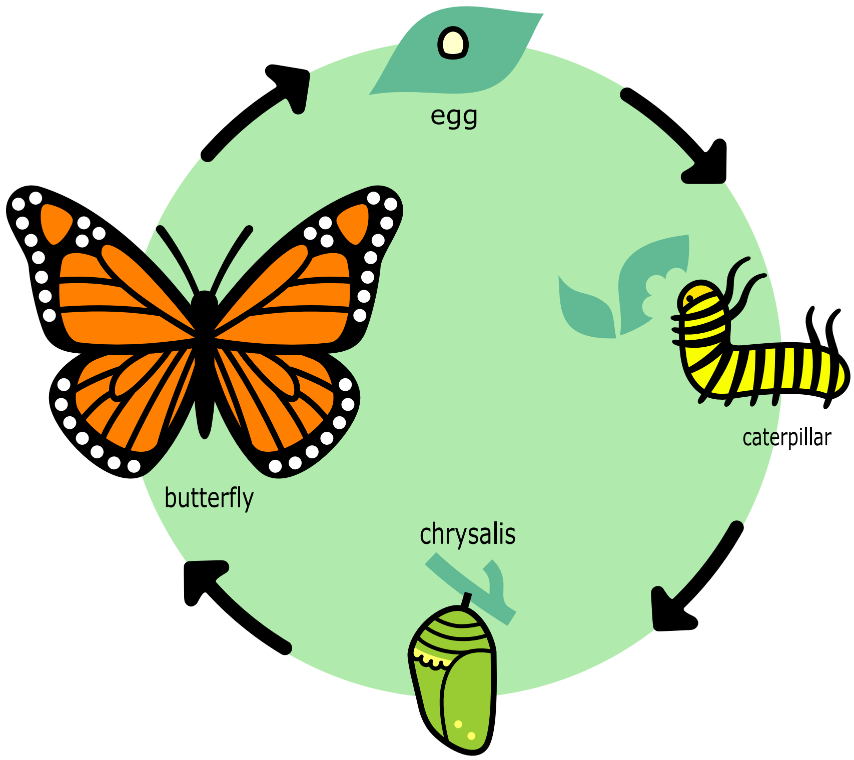



Figure 6.2.10 A butterfly lays eggs on a leaf. The eggs hatch into a caterpillar (larva), which grows and feeds on leaves. The caterpillar then transforms into a pupa (chrysalis), shown attached to a branch. Finally, the adult butterfly emerges from the chrysalis, completing the cycle and beginning the process again."Butterfly LIfe Cycle Diagram" by Cyanocorax, CC0 1.0

Figure 6.2.11 "Mayfly nymypth" by Dave Huth, CC BY 2.0

In contrast, **incomplete metamorphosis** involves a gradual transformation from nymph to adult. Nymphs often resemble smaller, wingless versions of the adult and gradually develop adult features through successive moults. Insects such as mayflies, caddisflies, and stoneflies have aquatic nymphs that live in freshwater habitats and play important roles in the ecosystem. Because these nymphs are sensitive to pollution, they are widely used as **bioindicators** to assess the health of rivers, streams, and lakes.

### Myriapods

**Myriapods** are terrestrial arthropods with long, segmented bodies and many legs. The most commonly found examples are centipedes and millipedes. **Centipedes** are fast-moving predators with one pair of legs per segment. **Millipedes** are slower detritivores with two pairs of legs per segment.

Figure 6.2.12 "Scolopendra" (left) by Fritz Geller-Grimm, CC BY-SA 2.5, "Tachypodoiulus niger" (middle) by Stemonitis, CC BY 2.5, "House centipede" (right) by Filip. vidinovski, GNU Free Documentation License

## Crustaceans


Figure 6.2.13 "Krill" by Uwe Kils, CC BY-SA 3.0, "Isopod" by Frenc Vilisics, modified by Stemonitis, CC BY-SA 3.0, "Crab" by Peter Wilton, CC BY 2.0, "Lobster" by Karlj, Public Domain, "Copepod" by Uwe Kils, CC BY-SA 3.0, "Barnacle" by MichaelMaggs, CC BY-SA 3.0, "Crayfish" by MikeMurphy, Public Domain, "Shrimp" by Хомелка, CC BY-SA 3.0

**Crustaceans** are primarily aquatic arthropods, including crabs, lobsters, shrimp, and barnacles. Some, like pill bugs or sow bugs, are adapted to life on land. Their bodies often have a **cephalothorax** (fused head and thorax) covered by a carapace. The exoskeleton of many species is also infused with calcium carbonate, which makes it even stronger than in other arthropods. Most crustaceans are carnivorous, but detritivores and filter feeders are also common.

Arachnids

Fige 6.2.14 Left to right, top to bottom: Araneus diadematus (Araneae), Mastigoproctus scabrosus (Thelyphonida), Hubbardia briggsi (Schizomida), Buthus occitanus (Scorpiones), Lasiochernes cretonatus (Pseudoscorpiones), Metasolpuga picta (Solifugae), Ricinoides atewa (Ricinulei), Opilio canestrinii (Opiliones), Eukoenenia spelaea (Palpigradi), Tromb idium holosericeum (Acariformes), Ixodes pacificus (Parasitiformes), Image by Lucarelli, 

**Arachnids** typically have eight legs, two body segments (cephalothorax and abdomen) and no antennae. Their first pair of appendages are often modified for feeding or injecting venom. This group includes spiders, scorpions, and ticks.

## Mollusks

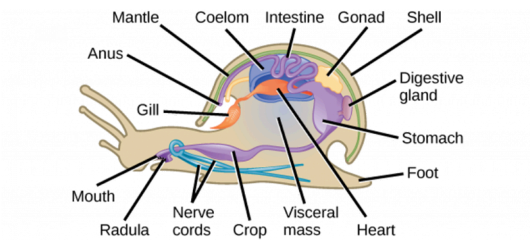



Figure 6.2.15 There are many species and variations of mollusks; the gastropod mollusk anatomy is shown here, which shares many characteristics common with other groups. The shell is cut away to reveal major organs, including the brain, heart, kidney, digestive tract, reproductive organs, and nervous system. The head with tentacles is on the left, and the muscular foot runs along the bottom. Image by OpenStax, CC BY 4.0

**Mollusks** (phylum Mollusca) are a diverse group of mostly marine animals, with over 85,000 described species and many more likely undiscovered. The name *Mollusca* means "soft-bodied," and while many mollusks have hard shells, their soft internal anatomy is a defining feature. All mollusks share a basic body plan that includes a **muscular foot** (used for movement or attachment), a **visceral mass** (containing most internal organs), and a **mantle** (a tissue layer that may secrete a calcium carbonate shell). Many also have a **radula**, a tongue-like structure with rows of tiny teeth used for feeding. They have a complete digestive system with a mouth and an anus.

Mollusks are the second most diverse animal phylum. Although they are mostly marine, they can also be found in freshwater and terrestrial environments.

They are classified into several groups, but the three major groups are:

### Bivalves

**Bivalves** are aquatic mollusks with bodies enclosed in a pair of hinged shells, or valves, joined at the dorsal (back) side. They lack a radula and instead feed by filtering food particles from water, which they draw in through a siphon. Bivalves include clams, oysters, mussels, and scallops.

Figure 6.2.16 Left to right: "Eastern Oyster" by pyta, CC BY-NC 4.0, "Icelandic Scallop" by alex_shure, CC BY-NC 4.0, "Pacific Littleneck Clam" by quillipede, CC BY-NC 4.0, "Black Mussels" by nartb, Public Domain

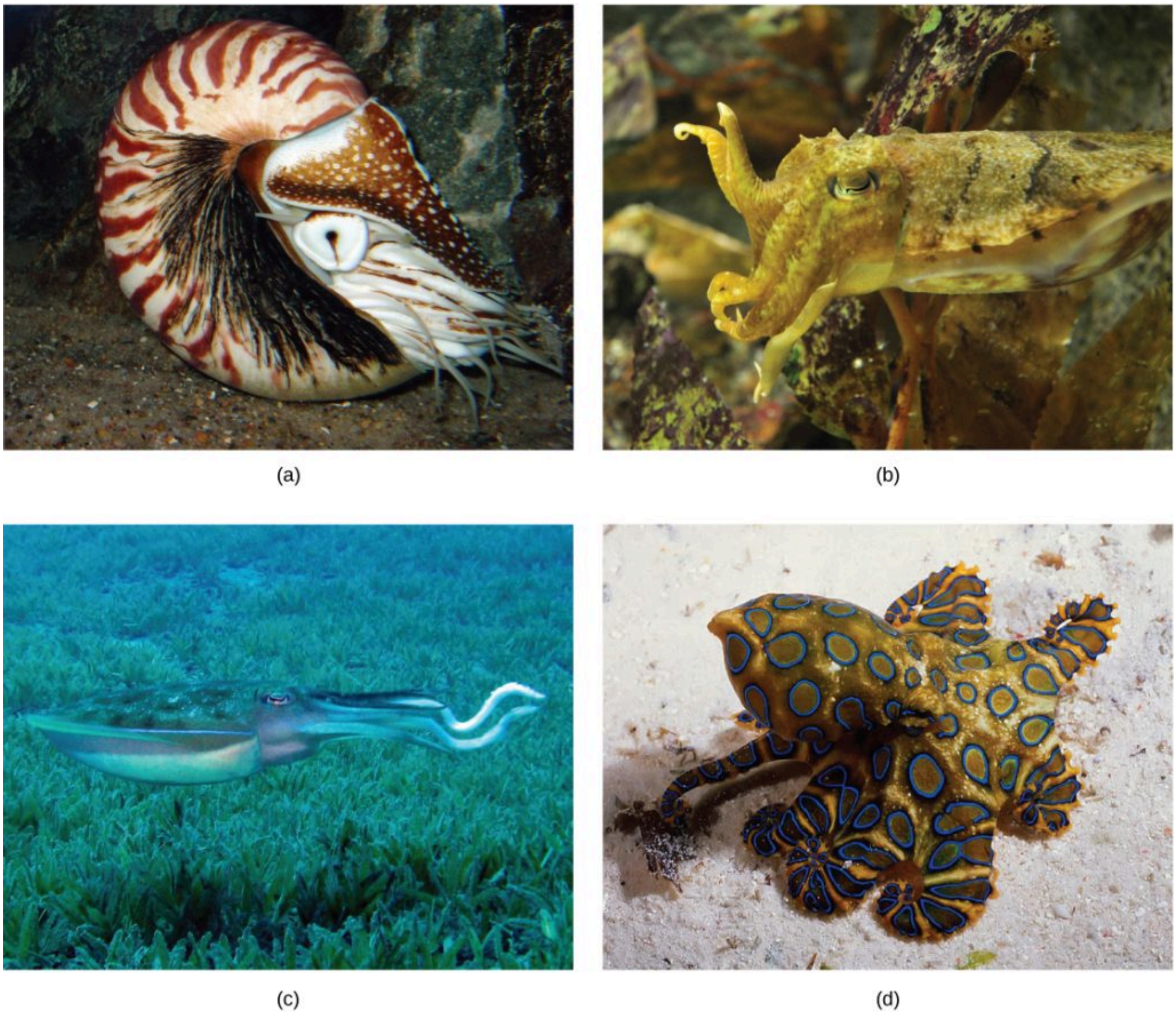
### Gastropods

**Gastropods** have a soft, asymmetrical body typically protected by a coiled shell, though some species lack a shell entirely. They can be found in marine, freshwater, and terrestrial environments. They move using a broad, muscular foot and feed with a radula that has a ribbon-like structure covered in tiny teeth. Many gastropods have a distinct head with tentacles and eyes. Gastropods include snails and slugs.

Figure 6.2.17 (a) Like many gastropods, this snail has a stomach foot and a coiled shell. (b) This slug, which is also a gastropod, lacks a shell. (credit a: modification of work by Murray Stevenson; credit b: modification of work by Rosendahl). Image by OpenStax, CC BY 4.0

## Cephalopods

**Cephalopods** have a highly specialized body with a prominent head, large eyes, and a set of tentacles that surround the mouth. They are able to move quickly via jet propulsion by contracting the mantle cavity to forcefully eject a stream of water. They have a well-developed brain, which supports advanced behaviours such as problem-solving, learning, and communication. Some cephalopods are able to quickly change colour using pigment cells in their skin, which helps them camouflage or startle predators. Cephalopods include octopuses, squids, cuttlefish, and nautiluses.



(a) (b) (c) (d)

Figure 6.2.18 The (a) nautilus, (b) giant cuttlefish, (c) reef squid, and (d) blue-ring octopus are all members of the class Cephalopoda. (credit a: modification of work by J. Baecker; credit b: modification of work by Adrian Mohedano; credit c: modification of work by Silke Baron; credit d: modification of work by Angell Williams). Image by OpenStax, CC BY 4.0

## Annelids

**Annelids** (phylum Annelida) are segmented worms found in marine, freshwater, and moist terrestrial environments. Their name comes from the Latin annellus, meaning "little ring," referring to their ring-like body segments. This segmentation allows for flexibility and specialization of body regions. Annelids have a bilaterally symmetrical body structure, a complete digestive system, and a closed circulatory system. Many annelids have **chaetae,** bristle-like structures used for movement.

### Earthworms

Figure 6.2.19 "Genus Lumbricus" by quillipede, Public Domain

**Earthworms** are terrestrial or freshwater annelids with a smooth, segmented body and few chaetae per segment. They have a clitellum, a thickened ring that secretes mucus during reproduction and forms a cocoon for the eggs. Earthworms play an important role in soil health by aerating and enriching it.

### Leeches

Figure 6.2.20 "Leeches" by bradenjudson, Public Domain

**Leeches** are mostly freshwater annelids with suckers at both ends of the body and no chaetae. Their body segmentation is often not reflected internally, allowing them to expand when feeding. Some leeches are blood-feeding parasites, while others are predators or scavengers.

### Polychaetes

Figure 6.2.21 "Genus Serpula" by stephbrulot, Public Domain

**Polychaetes** are mostly marine worms with many chaetae arranged on paired, fleshy appendages used in movement and gas exchange. They are often colourful and may live freely or in protective tubes.

# Echinoderms

**Echinoderms** (phylum Echinodermata) are marine invertebrates known for their spiny skin and unique body structure. Adults exhibit radial symmetry, but their larvae are bilaterally symmetrical, reflecting their evolutionary ties to other bilaterally symmetrical animals. This phylum includes about 7,000 species, such as sea stars, sea urchins, sand dollars, brittle stars, and sea cucumbers.

Figure 6.2.22 "Giant California Sea Cucumber" by david broadland (top left), Public Domain, "Eccentric Sand Dollar" (bottom left) by enspring, Public Domain, "Blood Stars" (bottom middle), by stephbrulot, Public Domain, "Red Sea Urchin" (far right) by carolynprentice, Public Domain

Many echinoderms have remarkable regenerative abilities that make them capable of regrowing lost body parts, even from small fragments. They possess an **endoskeleton** (internal skeleton) made of small, hard plates of calcium carbonate, which provides support and protection.

Echinoderms have a **water vascular system**, a network of fluid-filled canals used for movement, gas exchange, and nutrient transport. They have **tube feet**, powered by hydraulic pressure, that extend through the body wall and allow for slow but powerful movements that are even strong enough to pry open the shells of bivalves.

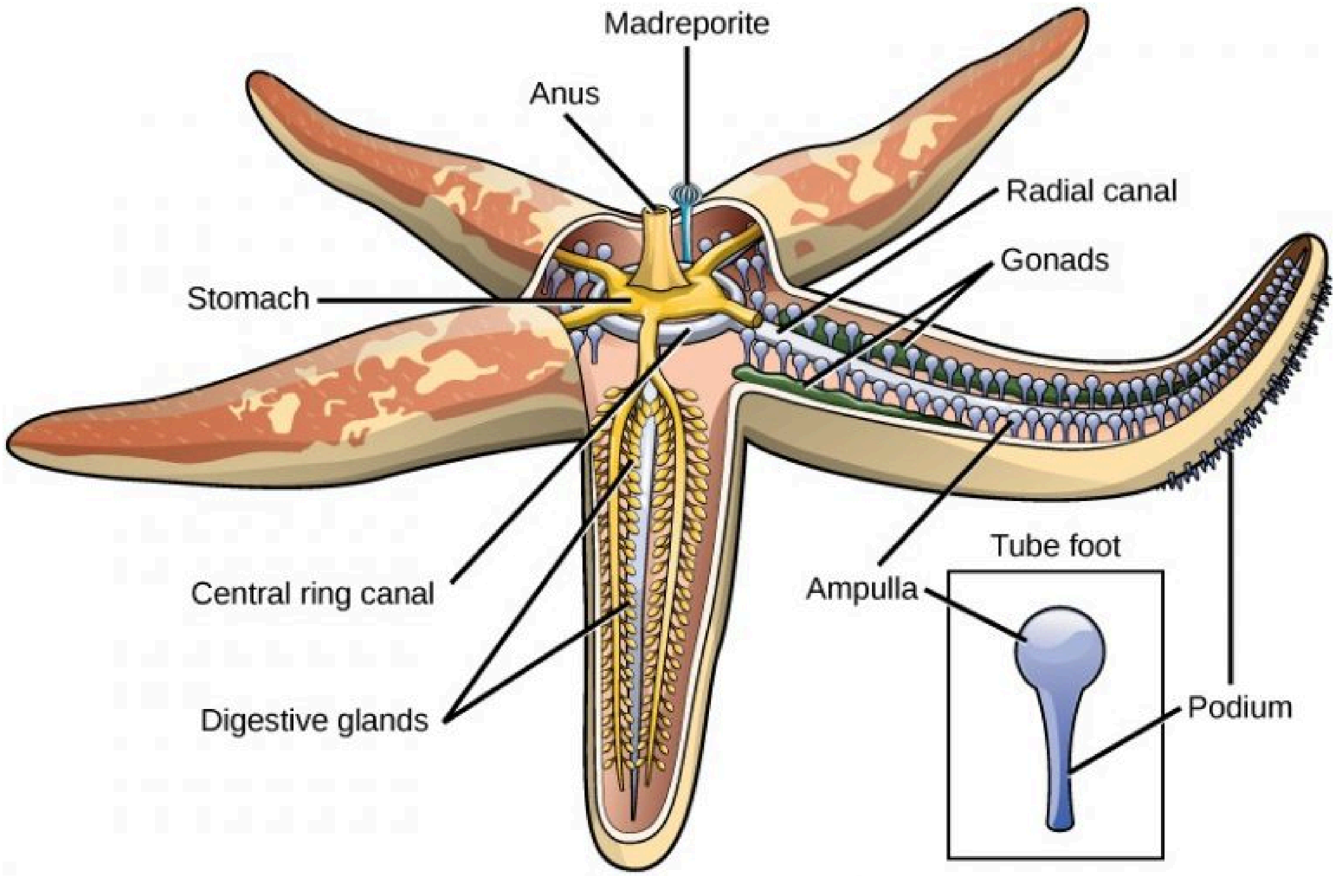



Figure 6.2.23 This diagram shows the anatomy of a sea star. Image by OpenStax, CC BY 4.0

**Figure 6.2.23 Image Description**

The image shows the internal anatomy of a starfish (sea star) with one arm cut open to reveal labelled structures. At the center is the stomach connected to a central ring canal, which branches into radial canals extending along each arm. Surrounding the canals are digestive glands and gonads. The madreporite is located on the aboral (upper) surface, near the center, with the anus nearby. Along the underside of the arm, the tube feet are shown, each connected to an ampulla. An inset highlights the tube foot structure, showing the ampulla and podium.

## Chordates

**Chordates** (phylum Chordata) are animals that share four key features at some point in their development:

1. **Notochord:** The notochord is a flexible, rod-shaped structure that runs along the length of the body. It provides skeletal support and helps define the animal's basic body plan. In invertebrate chordates, the notochord remains throughout life. In vertebrates, it is present during embryonic development and is later replaced by the vertebral column (spine).

2. **Dorsal Hollow Nerve Cord:** This is a tube-like structure located above the notochord. It eventually forms the central nervous system—the brain and spinal cord. This is different from other invertebrates, which typically have solid nerve cords located on the ventral (belly) side.
3. **Pharyngeal Slits:** These are openings in the pharynx (the region behind the mouth) that connect to the outside environment. In aquatic chordates, they function in filter feeding or develop into gills for breathing. In terrestrial vertebrates, they are modified into structures such as parts of the ear, tonsils, or jaw supports.
4. **Post-Anal Tail:** This is a tail that extends beyond the anus. In many aquatic species, it helps with locomotion. In land animals, it may help with balance, communication, or courtship. In some species, like humans, the tail is present only during embryonic development and becomes vestigial in adults.

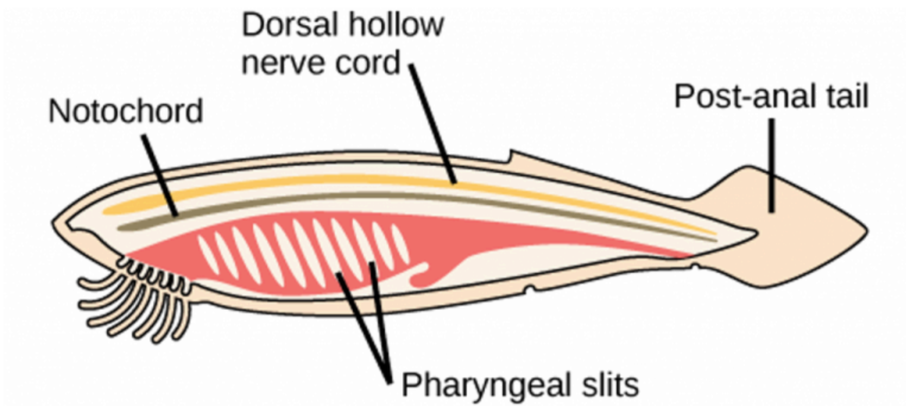



Figure 6.2.24 In chordates, four common features appear at some point in development: a notochord, a dorsal hollow nerve cord, pharyngeal slits, and a post-anal tail. The anatomy of a cephalochordate shown here illustrates all of these features. Image by OpenStax, CC BY 4.0

While most chordates are vertebrates (see more information in Chapter 7), there are two small groups of **invertebrate chordates**:

Tunicates

**Tunicates**, also called sea squirts, are marine animals that live in dark or shaded areas attached to rocks in shallow ocean waters. As adults, they have a sac-like body and filter food using pharyngeal slits. Although adult tunicates lack a notochord, nerve cord, and tail, their larvae have all four chordate features. A tunicate larva resembles a tiny tadpole, which swims for a few days then eventually attaches to a surface. It then undergoes metamorphosis to become the adult form, at which point the notochord, nerve cord, and tail disappear.

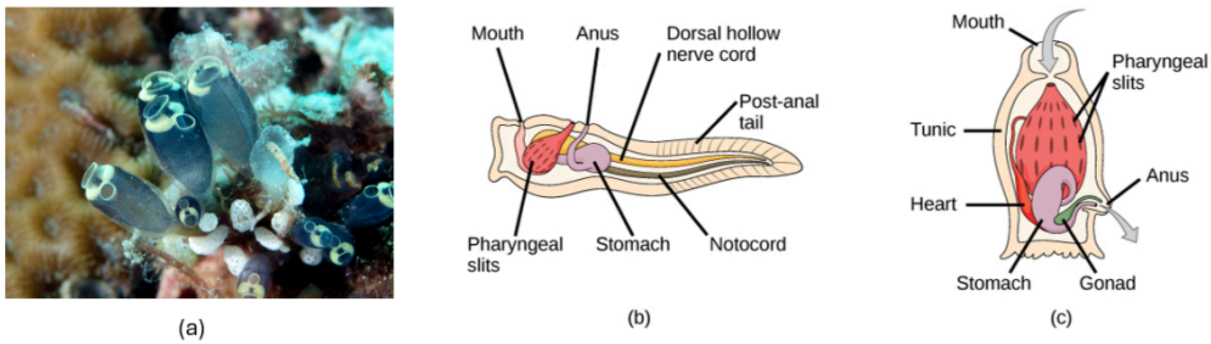



Figure 6.2.25 Image (a): Several live tunicates attached to a coral reef, each with a tubular, translucent body and two siphon openings visible at the top. "Tunicate (Claveline robusta)" by Rickard Zerpe, CC BY 2.0 (b): The larval stage showing key chordate features such as the mouth, anus, stomach, pharyngeal slits, notochord, dorsal hollow nerve cord, and post-anal tail. (c) The adult stage with its sac-like body encased in a tunic. Labels indicate the mouth, pharyngeal slits, stomach, gonad, heart, and anus. Image by OpenStax, CC BY 4.0

## Lancelets

**Lancelets** are small, blade-like animals that grow to only a few centimetres in length. They are typically found buried in sand in warm, shallow marine waters. Unlike many other chordates, adult lancelets retain the four key features of chordates: a notochord, a dorsal hollow nerve cord, pharyngeal slits, and a post-anal tail. They swim using their tail and filter food from the water using their pharyngeal slits. Lancelets represent an ancient lineage, with fossils dating back to the middle of the Cambrian period over 500 million years ago. They are considered the closest living relatives of vertebrates, so they offer valuable insight into early chordate evolution.

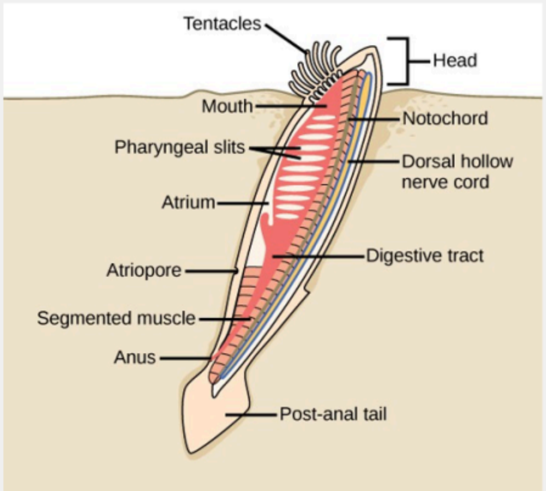



Figure 6.2.26 On the left, a labelled diagram illustrates the anatomy: tentacles and mouth at the front, pharyngeal slits leading to the atrium, a dorsal hollow nerve cord, a notochord, a digestive tract, segmented muscles, an anus, and a post-anal tail. The atriopore and head region are also labelled. On the right, a photo of a real lancelet is shown, elongated and translucent with a tapered body, highlighting its simple, fish-like appearance. Image (left) by CNX OpenStax, CC BY 4.0, "Branchiostoma Lanceolatum" (right) by Hans Hillewaert, CC BY-SA 4.0

## Knowledge Check

**Text Description**

1. Which of the following is true about sponges (phylum Porifera)?

   a. They have a nervous system and true tissues
   b. They are free-swimming as adults
   c. They filter feed using choanocytes
   d. They reproduce only asexually

2. What feature is used by cnidarians to capture prey?

   a. Tentacles with cilia
   b. Radula
   c. Cnidocytes with stinging threads
   d. Gills with toxin glands

3. What is a key characteristic of flatworms (phylum Platyhelminthes)?

   a. They have a complete digestive system
   b. They are radially symmetrical
   c. They rely on diffusion for gas exchange
   d. They have segmented bodies

4. Which of the following accurately describes arthropods?

   a. They lack a circulatory system
   b. They have jointed appendages and an exoskeleton
   c. They have soft, unsegmented bodies
   d. They reproduce only through asexual budding

5. Which invertebrate phylum includes animals with a water vascular system and tube feet?

   a. Molluska
   b. Arthropoda
   c. Echinodermata
   d. Annelida

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Answers:

1. c. They filter feed using choanocytes
2. c. Cnidocytes with stinging threads
3. c. They rely on diffusion for gas exchange
4. b. They have jointed appendages and an exoskeleton
5. c. Echinodermata

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Prompt: Create 5 multiple-choice questions using the following content

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# CHAPTER 6 SUMMARY

## Key Takeaways

- **All animals share key biological traits**: Animals are eukaryotic, multicellular, heterotrophic organisms with specialized tissues. Most are motile at some life stage and reproduce sexually, progressing through defined developmental stages that result in a set body plan.
- **Animals are classified based on body structure and genetics**: Major classification features include body symmetry (asymmetrical, radial, or bilateral), tissue development, and embryonic traits. These characteristics help determine an animal's placement within one of approximately 35 recognized phyla.
- **Invertebrates dominate animal diversity**: About 95% of all animal species lack a backbone and fall into diverse phyla such as Porifera (sponges), Cnidaria (jellies, corals), Platyhelminthes (flatworms), Nematoda (roundworms), Mollusca, Annelida (segmented worms), Arthropoda (insects, crustaceans, arachnids), and Echinodermata (sea stars, sea urchins).
- **Arthropods are the most numerous and adaptable animals**: With jointed limbs, segmented bodies, and exoskeletons, arthropods include insects, crustaceans, arachnids, and myriapods. Insects are particularly diverse and undergo metamorphosis, contributing significantly to ecosystems and bioindication.
- **Chordates are defined by four key features**: These include a notochord, dorsal hollow nerve cord, pharyngeal slits, and a post-anal tail. While vertebrates (like mammals and fish) are the most familiar, invertebrate chordates like tunicates and lancelets help illustrate the evolutionary history of this phylum.

- **Body plans, feeding strategies, and habitats vary widely**: From filter-feeding sponges and stinging cnidarians to regenerative echinoderms and intelligent cephalopods, animals exhibit remarkable structural and functional diversity adapted to aquatic and terrestrial environments.

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Summarize the following content into six key takeaways.

## Flashcards

Text Description
**Front of Card**

1. Amoebocytes
2. Annelids
3. Anterior
4. Arachnids
5. Arthropods
6. Asymmetrical
7. Bilateral Symmetry
8. Bioindicators
9. Bivalves
10. Budding
11. Centipedes
12. Cephalopods
13. Cephalothorax
14. Chaetae
15. Choanocytes
16. Chordates

17. Cnidarians
18. Cnidocytes
19. Complete Digestive System
20. Complete metamorphosis
21. Crustaceans
22. Dorsal
23. Dorsal Hollow Nerve Cord
24. Earthworms
25. Echinoderms
26. Endoskeleton
27. Exoskeleton
28. Filter Feeders
29. Flatworms
30. Fragmentation
31. Free-living
32. Gastrovascular Cavity
33. Gastropods
34. Hermaphroditic
35. Heterotrophic
36. Incomplete metamorphosis
37. Insects
38. Invertebrates
39. Jointed Appendages
40. Lancelets
41. Larva
42. Lateral
43. Leeches
44. Mantle
45. Medusa
46. Metamorphosis
47. Millipedes
48. Mollusks
49. Molting
50. Motile
51. Multicellular

52. Muscular foot
53. Myriapods
54. Nematodes
55. Notochord
56. Omnivores
57. Parasites
58. Pharyngeal Slits
59. Planarian
60. Polychaetes
61. Polyp
62. Post-Anal Tail
63. Posterior
64. Radial Symmetry
65. Radula
66. Segmented
67. Sexual Reproduction
68. Specialized Tissues
69. Sponges
70. Tapeworm
71. Tentacles
72. Tube Feet
73. Tunicates
74. Ventral
75. Vertebrates
76. Visceral Mass
77. Water Vascular System
78. General features of animals
79. 4 major groups of arthropods
80. 3 major groups of mollusks
81. 3 major groups of annelids
82. 4 key features of chordates
83. 2 groups of invertebrate chordates

**Back of Card**

1. Specialized cells in sponges that help digest food and transport nutrients to other cells

2. Segmented worms (phylum Annelida) with a body divided into ring-like segments; includes earthworms, leeches, and polychaetes
3. The front or head end of an animal with bilateral symmetry
4. Arthropods with two body segments (cephalothorax and abdomen), eight legs, and no antennae; includes spiders, scorpions, ticks, and mites
5. Invertebrates with segmented bodies, jointed appendages, and an exoskeleton; includes insects, arachnids, crustaceans, and myriapods
6. Lacking any symmetry or consistent body shape; no plane can divide the body into mirrored halves (e.g. sponges)
7. Body plan in which a single vertical plane can divide the body into left and right mirror-image halves; associated with more complex body structures
8. Organisms that are sensitive to environmental changes and used to assess ecosystem health, such as aquatic insect larvae in freshwater systems
9. Mollusks with two hinged shells and a laterally compressed body; they are filter feeders; includes clams, oysters, mussels, and scallops
10. A form of asexual reproduction where a new organism grows out of the body of the parent and eventually detaches
11. Fast-moving myriapods with one pair of legs per body segment; they are carnivorous and have venomous claws
12. Highly developed mollusks with a prominent head, tentacles, and a reduced or absent shell; includes octopuses, squids, and cuttlefish
13. A fused head and thorax found in some arthropods like crustaceans and arachnids
14. Bristle-like structures used for movement in many annelids
15. Cells in sponges that use flagella to generate water currents and trap food particles
16. Animals that possess a notochord, a dorsal hollow nerve cord, pharyngeal slits, and a post-anal tail at some stage in development
17. Simple aquatic animals (phylum Cnidaria) with true tissues, radial symmetry, and tentacles with stinging cells; includes jellies, corals, sea anemones, and hydras
18. Specialized stinging cells in cnidarians that eject coiled threads to deliver toxins
19. A digestive system with two openings—a mouth and an anus—allowing food to move in one direction
20. A developmental process with four distinct stages; egg → larva → pupa → adult
21. Aquatic arthropods with two pairs of antennae, a hard exoskeleton, and often a cephalothorax; includes crabs, lobsters, and shrimp
22. Refers to the upper or back side of an organism

23. A nerve cord located on the back (dorsal) side, forming the brain and spinal cord; a key feature of chordates
24. Terrestrial annelids segmented bodies; Burrow in soil, aerate it, and decompose organic matter
25. Marine animals (phylum Echinodermata) with spiny skin, radial symmetry in adults, and a water vascular system; includes sea stars and sea urchins
26. An internal skeleton made of hard structures such as bone or calcium carbonate plates
27. A rigid external body covering in arthropods that provides support and protection
28. Organisms that feed by straining suspended matter and food particles from water (e.g. sponges, bivalves)
29. Simple, soft-bodied invertebrates with bilateral symmetry; includes planarians and tapeworms
30. Asexual reproduction method where a piece of an organism breaks off and grows into a new individual
31. Describes organisms that do not rely on a host and live independently in their environment
32. A central digestive space with a single opening that acts as both mouth and anus, seen in flatworms and cnidarians
33. Mollusks with a muscular foot and often a coiled shell; includes snails and slugs
34. An organism that has both male and female reproductive organs
35. Organisms that obtain their nutrients by consuming other organisms or organic matter
36. A developmental process where the young (nymphs) resemble the adult but lack fully developed wings and reproductive organs
37. The largest group of arthropods, with a three-part body (head, thorax, abdomen), three pairs of legs, and often wings
38. Animals that lack a backbone
39. Limbs with joints, a key feature of arthropods allowing for complex movement
40. Small, blade-like invertebrate chordates; found buried in sand; filter feeders
41. The juvenile form of an animal that undergoes metamorphosis, differing significantly in structure from the adult.
42. Referring to the sides of an organism.
43. Annelids with suckers at both ends; some are bloodsucking parasites, while others are predators or scavengers
44. A layer of tissue in mollusks that secretes the shell and encloses the internal organs
45. The free-swimming, umbrella-shaped life stage of some cnidarians, with the mouth and tentacles facing downward

46. A developmental process where animals transform from immature to adult forms in distinct stages
47. Slow-moving myriapods with two pairs of legs per body segment; feed on decaying plant matter
48. A diverse phylum of invertebrates with soft bodies, often protected by a shell; includes snails, clams, and squids
49. The process by which arthropods shed their exoskeleton to grow
50. Capable of movement; describes organisms or cells that can move independently using structures like cilia, flagella, or muscles
51. Composed of multiple cells; a characteristic of all animals
52. A structure used by mollusks for movement or attachment
53. Arthropods with many body segments and legs; includes centipedes and millipedes
54. Also known as roundworms, these are unsegmented worms with complete digestive systems
55. A flexible rod that provides support in chordates; later replaced by the vertebral column in vertebrates; a key feature of chordates
56. Animals that consume both plants and animals
57. Organisms that live on or inside a host, relying on it for nutrients
58. Openings in the throat region of chordates; they serve in filter feeding, respiration, or develop into various structures; a key feature of chordates
59. A free-living flatworm known for its ability to regenerate from fragments
60. Marine annelids with many bristles (chaetae)
61. A sessile (non-moving), cylindrical body form of cnidarians with the mouth facing upward
62. A tail that extends beyond the anus; a key feature of chordates
63. The rear or tail end of an animal with bilateral symmetry
64. A body plan where parts are arranged around a central axis, and multiple planes yield mirror images (e.g. sea anemone)
65. A tongue-like feeding organ in many mollusks that scrapes or cuts food
66. Divided into repetitive body sections, as seen in annelids and arthropods.
67. A form of reproduction involving the fusion of male and female gametes (sperm and egg).
68. Groups of similar cells in animals that perform specific functions (e.g., muscle, nerve, epithelial tissues)
69. Aquatic animals (phylum Porifera) that lack true tissues and organs, and feed by filtering water
70. A parasitic flatworm that lives in the intestines of vertebrates, absorbing nutrients through

its skin and lacking a digestive system

71. Flexible, elongated appendages used for feeding and sensing, commonly found in cnidarians and cephalopods
72. Small, flexible extensions used for movement and feeding in echinoderms, operated by hydraulic pressure
73. Invertebrate chordates that filter feed using pharyngeal slits and lose most chordate features after larval metamorphosis
74. Refers to the underside or belly of an organism, opposite the dorsal side
75. Animals with a backbone
76. The part of a mollusk's body that contains most of its internal organs
77. A fluid-filled system in echinoderms used for movement, gas exchange, and nutrient transport
78. Eukaryotic, multicellular, specialized tissues, motile, heterotrophic
79. Insects, Myriapods, Crustaceans, Arachnids
80. Bivalves, Gastropods, Cephalopods
81. Earthworms, Leeches, Polychaetes
82. Notochord, Dorsal hollow nerve cord, Pharyngeal slits, Post-anal tail
83. Tunicates, Lancelets

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Prompt: Provide definitions for all the bolded terms in the shared content and list all the terms in alphabetical order.

# CHAPTER 7: VERTEBRATE ANIMALS

## Chapter Overview

## Learning Objectives

By the end of this chapter, you will be able to:

- Identify the key characteristics that distinguish vertebrates from other chordates, including the presence of a backbone, cranium, and complex organ systems.
- Classify vertebrates into major groups (fishes, amphibians, reptiles, birds, mammals) and describe defining features of each group.
- Compare and contrast jawless, cartilaginous, and bony fishes in terms of anatomy, habitat, and evolutionary traits.
- Explain the evolutionary significance of major adaptations such as the amniotic egg, endothermy, and bipedalism in the context of vertebrate diversification.
- Describe the unique traits and behaviours of primates—including humans—that reflect their evolutionary adaptations to arboreal life and social living.
- Trace the key milestones in human evolution by examining derived traits, tool use, brain size, and cultural development from early hominins to *Homo sapiens*.

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Prompt: Provide 6 learning objectives for the shared content.

# 7.1 GENERAL FEATURES OF VERTEBRATES

Vertebrates are among the most recognizable organisms in the animal kingdom. If you were to list the first five animals that come to mind, there's a high chance they would all be vertebrates.

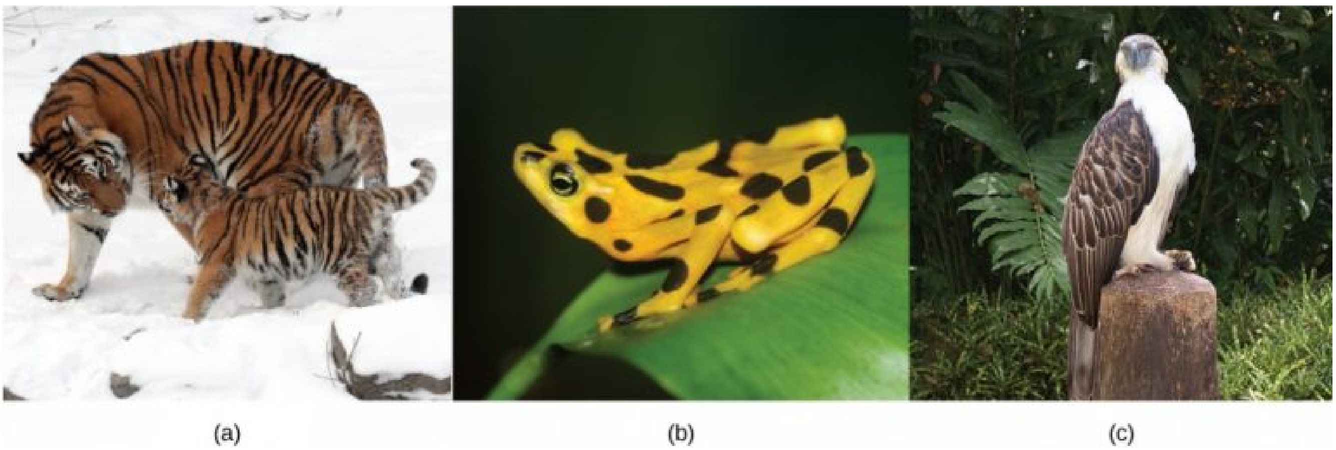


Figure 7.1.1 Examples of critically endangered vertebrate species include (a) "the Siberian tiger (Panthera tigris altaica)", by Dave Pape, Public Domain, (b) "the Panamanian golden frog (Atelopus zeteki)" by Brian Gratwicke, CC BY 2.0 and (c) "the Philippine eagle (Pithecophaga jefferyi)" by scorpious18, CC BY 2.0

Like echinoderms, **vertebrates** possess an endoskeleton. However, vertebrate endoskeletons are unique in that they include a skull and a backbone, which protects the spinal cord. The backbone is made up of a series of bones called **vertebrae**, which is where the name "vertebrates" comes from. These animals also have closed circulatory systems, well-developed nervous systems, and complex internal organs.

Vertebrates are a diverse group within the phylum Chordata, with over 62,000 identified species. They are traditionally classified into five major groups: fishes, amphibians, reptiles, birds, and mammals.

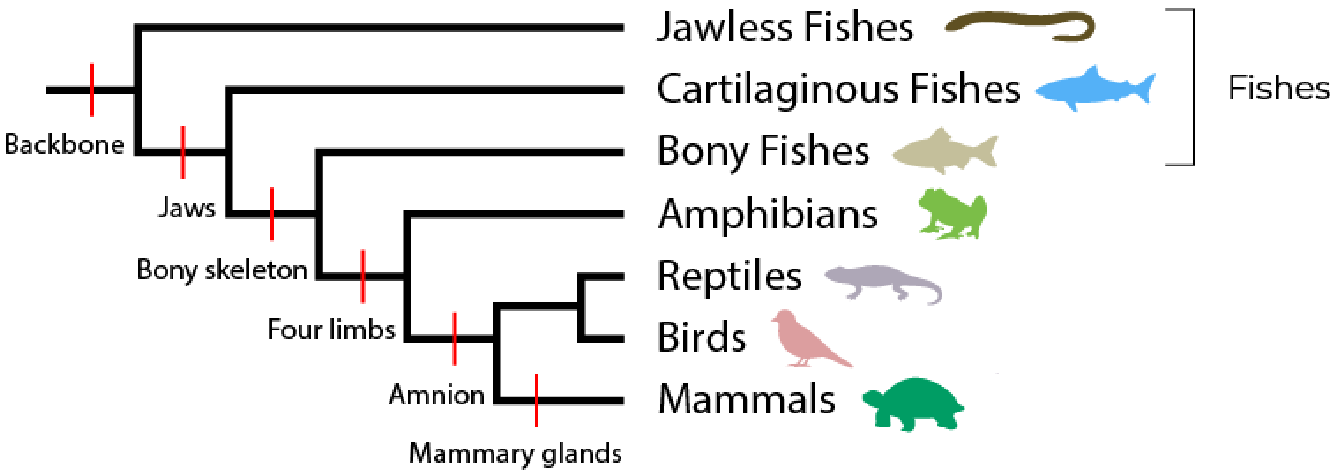


Figure 7.1.2 "Classification of Vertebrates" by Koen Liddiard, CC BY-NC-SA 4.0

### Figure 7.1.2 Image Description

The image is a simplified phylogenetic tree showing the evolutionary relationships among major vertebrate groups. Branch points are marked with evolutionary traits: backbone, jaws, bony skeleton, four limbs, amnion, and mammary glands. From left to right, the tree branches into jawless fishes (illustrated by a worm-like figure), cartilaginous fishes (shark icon), bony fishes (fish icon), amphibians (frog icon), reptiles (lizard icon), birds (bird icon), and mammals (turtle-like icon). The diagram highlights that all vertebrates share a backbone, while additional traits define each subsequent group.

---

# 7.2 VERTEBRATE GROUPS

## Fishes

**Fishes** are the most ancient and diverse group of vertebrates, with an estimated 31,000 living species. They were the first vertebrates to evolve, and the earliest of these were jawless fishes. Today's jawless fishes are distinct from invertebrate chordates due to their cranium and complex sense organs, including eyes.

Unlike sessile, filter-feeding invertebrates, fishes are active feeders and occupy a wide range of aquatic habitats. Most fishes have a **lateral line system**, which detects movement and vibrations in the water. It is considered the equivalent of "hearing" in terrestrial vertebrates. The lateral line is visible as a darker stripe that runs along the length of the fish's body.

### Jawless Fishes

**Jawless fishes** represent an ancient lineage of craniates (animals with a skull), which includes all chordates except tunicates and lancelets. These fishes first appeared over 500 million years ago.

Major groups of jawless fishes include:

## Hagfishes

Figure 7.2.1: "Broadgilled Hagfish", by liamclaytonmedia, CC0 1.0

**Hagfishes** are eel-like scavengers that live on the ocean floor and feed on dead or dying animals. They are known to enter the bodies of these carcasses to devour them from the inside. They are entirely marine and are found in oceans worldwide, except in polar regions. A unique feature of hagfishes is their ability to secrete large amounts of slime (mucus) from specialized glands to help them escape from the grip of predators. Their skeleton is made of cartilage and includes a flexible notochord and a skull, but they lack a vertebral column, so they are not considered true vertebrates.

## Lampreys

Figure 7.2.2: Sea Lampreys, Photo (left) by satteln, CC BY-NC 4.0, Photo (right) by jilldevito , CC0 1.0

**Lampreys** resemble hagfishes in shape and size but differ in having a braincase and rudimentary vertebrae. They also lack paired fins and bones. Adult lampreys have a toothed, funnel-like mouth used by some species to parasitize other fish. Most lampreys, however, are free-living. They are found in coastal and freshwater environments across temperate regions. All lampreys spawn in freshwater, where their larvae live as suspension feeders for several years before maturing, reproducing, and dying shortly after.

## Jawed Fishes

The evolution of jaws was a major milestone in vertebrate history. Jaws are hinged structures attached to the skull and enabled early fishes to grasp and process a wider variety of food sources that were unavailable to jawless fishes. They also have paired fins, which make them agile swimmers.

Major groups of jawed fishes include:

### Cartilaginous Fishes

**Cartilaginous fishes**, such as sharks and rays, have skeletons made of cartilage. Some parts of their skeletons are reinforced with calcium carbonate, but this is not actual bone. Most cartilaginous fishes are marine, but there are a few freshwater species. **Sharks** are typically carnivorous, using their sharp teeth to capture and tear prey. Sharks have evolved replenishing teeth – as older teeth are lost or worn down, new ones move forward from rows within the jaw to take their place, ensuring they always have functional teeth for feeding.

Sharks also possess highly developed sensory systems, including a keen sense of smell and **electroreception** (the ability to detect electrical fields produced by other organisms). Many shark species must swim continuously to maintain water flow over their gills and to keep breathing.

Figure 7.2.3 "Blacktip Reef Shark", by shuetrim, CC BY 4.0

**Rays** are closely related to sharks but have flattened bodies, enlarged pectoral fins fused to the head, and gill slits on their underside. They are mostly bottom-dwellers in marine environments.

Figure 7.2.4 "Southern Fiddler Ray", by djnugent, CC0 1.0

## Bony Fishes

**Bony fishes** are the largest and most diverse group of vertebrates, with around 30,000 known species. They are characterized by a skeleton made primarily of bone, which provides strong structural support and allows for a wide range of body shapes. Their skin is typically covered in overlapping scales, and mucus-secreting glands help reduce drag while swimming. Unlike many cartilaginous fishes, bony fishes often rely heavily on vision to locate prey. Additionally, their gills are covered by a protective flap, called the **operculum**, which allows them to ventilate their gills without needing to swim. Another key adaptation in this group is the **swim bladder**, a gas-filled organ that helps regulate buoyancy.

Bony fishes are divided into two groups:

- **Ray-finned fishes**: This group includes the most familiar fishes such as tuna, trout, bass, and salmon. Their fins are supported by long, flexible rays.

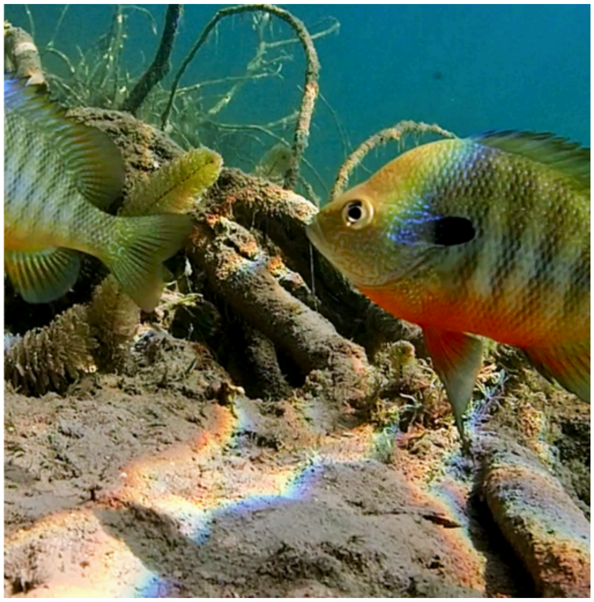

Figure 7.2.5 Rainbow Trout (left) by pashaefface, CC BY 4.0, Plains Longear Sunfish (right) by kjhurme, CC BY 4.0

- **Lobe-finned fishes**: These fishes have fleshy, lobed fins supported by bones. Living examples include the less familiar fishes, such as **lungfishes**. These fishes are especially important in evolutionary history, as they gave rise to the first land vertebrates.

Figure 7.2.6 "West African Lungfish" by bahleman, CC BY-NC 4.0

# Amphibians

**Amphibians** are vertebrate **tetrapods**, meaning they typically have four limbs. This group includes frogs and salamanders. The name *amphibian* means "dual life," referring to their life cycle, which often includes both aquatic and terrestrial stages.

Amphibian reproduction typically occurs in moist environments**,** where eggs are fertilized externally. The eggs hatch into larvae, commonly called **tadpoles**, that are usually herbivorous**,** gilled, and limbless. As they mature, tadpoles undergo a metamorphosis, a transformation where they develop lungs, limbs, and a carnivorous diet. This process allows them to transition from an aquatic to a terrestrial lifestyle. Some species also exhibit parental care, such as carrying eggs or tadpoles on their backs or legs.


Figure 7.2.7 (a) "Tadpole", (b) "Wood Frog Tadpole" and (c) "The Pickerel Frog (c)" by Brian Gratwicke, CC BY 2.0,

Modern amphibians have moist, permeable skin that contains mucus-secreting glands. This skin plays a vital role in **cutaneous respiration**, allowing for gas exchange directly with the environment. All adult amphibians are carnivorous, and many terrestrial species use a sticky tongue to capture prey.

Major groups of amphibians include:

Salamanders

**Salamanders** typically have elongated bodies, tails, and four limbs. There are around 500 species**,** with some living in water, others on land, and some transitioning between the two.

Figure 7.2.8 "Eastern Red-backed Salamander"(left) by andreakautz, Public Domain, "Spotted Salamander" (middle) by andreakautz, Public Domain, "Eastern Newt" (right) by tniernberger, Public Domain

### Frogs

**Frogs** are the most diverse amphibian group, with about 5000 species. They have a body plan specialized for jumping, with long, muscular hind limbs. Frogs use various strategies to avoid predators, including camouflage and poisonous skin secretions.

Figure 7.2.9 Green Frog (top left) by deberly, Public Domain, Strawberry Posion Dart Frog (bottom left) by jujuwild, Public Domain, Disc Robber Frog (bottom middle) by oecophylla, Public Domain, Northern Leopard Frog (right) by paulypod, Public Domain

Amphibians were the earliest vertebrates to adapt to life on land. They evolved from lobe-finned fishes over 360 million years ago. These early amphibians developed key adaptations such as limbs for movement on land, lungs for breathing air, and stronger skeletal structures to support their bodies outside of water. The emergence of amphibians represents a major evolutionary milestone that bridges the gap between fully aquatic fishes and the later emergence of fully terrestrial reptiles.

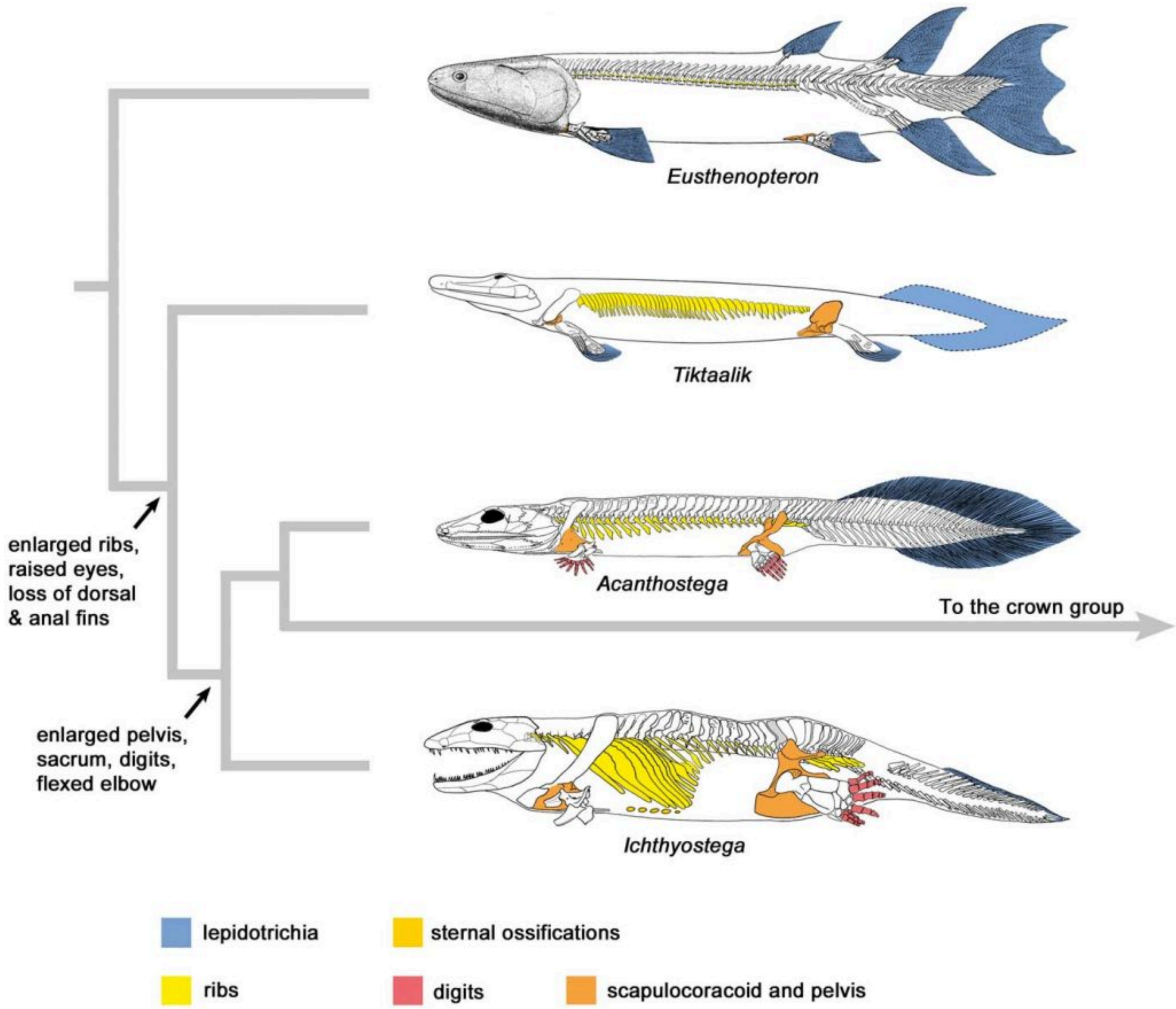


Figure 7.2.10: Simplified phylogeny spanning the fish-tetrapod transition. Image by Per E AHLBERG, CC BY 4.0

## Reptiles and Birds

The **amniotes**—which include reptiles, birds, and mammals—are distinguished from amphibians by their **amniotic egg**, an evolutionary adaptation that allowed vertebrates to reproduce away from water. The amniotic membranes within the egg create a self-contained aquatic environment, enabling gas exchange, waste storage, and water retention. This adaptation reduced dependence on moist habitats and allowed amniotes to colonize drier environments. The shells of reptile eggs are more leathery and flexible. The shells of bird eggs are composed of calcium carbonate and are hard and brittle, but possess pores for gas exchange. Most mammals do not lay eggs, but even with internal development (gestation), amniotic membranes are still present.

Although birds are now understood to be a lineage of reptiles, they are often discussed separately due to their many unique adaptations. In this section, we will explore reptiles and birds as distinct groups, while recognizing their shared evolutionary history.

## Reptiles

**Reptiles** are tetrapods, although some, like snakes, have lost their limbs through evolution. All reptiles reproduce using shelled, amniotic eggs, which are laid on land—even by aquatic species like sea turtles. Most reproduce sexually with internal fertilization.

A key adaptation for life on land is their scaly skin, which prevents water loss. Unlike amphibians, reptiles cannot breathe through their skin and must rely entirely on lungs for respiration.

Reptiles are **ectotherms** – animals whose main source of body heat comes from the environment. They use behaviours like basking in the sun or seeking shade to regulate their body temperature.

Major groups of reptiles include:

### Crocodilians

**Crocodilians** ("small lizard") include alligators and crocodiles. They have long snouts and powerful tails. They live in tropical regions and are found in freshwater habitats, such as rivers and lakes. Some species are able to move on land, but they spend most of their time in water. Unlike most reptiles, many crocodilian species do show parental care. Females guard their nests and protect their young from predators.

Figure 7.2.11 "Morelet's Crocodile" (left) by davidhernandeze, Public Domain, "American Alligator" (right) by jd_flores, Public Domain

## Lizards and Snakes

Figure 7.2.12 "Eastern Hognose Snake" (left) by philipvanbergen, CC BY 4.0, "Eastern Milksnake" (middle) by wildreturn, Public Domain, "Common Garter Snake" (right) by raffib128, Public Domain

Lizards and Snakes are the most diverse group of reptiles. **Lizards** typically have four limbs, eyelids, and external ears, while snakes lack these features. Lizards range in size from chameleons and geckos that are a few centimetres in length to the Komodo dragon, which is about 3 meters in length. **Snakes** evolved from lizard-like ancestors and range in size from 10 10-centimetre-long thread snakes to 7.5-meter-long pythons and anacondas. They are entirely carnivorous, feeding on a variety of prey including small mammals, birds, and insects.

## Turtles

**Turtles** are characterized by a bony or cartilaginous shell (carapace) made from modified ribs. Turtles lay eggs on land, even if they live in aquatic environments. They range in size from a few centimetres to the massive leatherback sea turtles (over 2m). The term "turtle" is often used to describe those that live in aquatic environments, whereas "tortoise" refers to those that live on land.

Figure 7.2.13 "Painted Turtle" (left) by efalquet, Public Domain, "Common Snapping Turtle" (middle) by rangersara, Public Domain, "Green Sea Turtle" (right) by kylenessen, Public Domain

### Birds

**Birds** are a specialized group of reptiles that evolved from theropod dinosaurs. Unlike reptiles, birds are **endothermic**, generating their own body heat through metabolism. Their most distinctive feature is **feathers**, which are modified scales. Birds have several different types of feathers that are specialized for specific functions, like contour feathers that streamline the bird's exterior and loosely structured down feathers that insulate.

Birds have evolved numerous adaptations for **flight**:

- Feathers that streamline the body and provide lift
- Hollow bones to reduce weight while maintaining strength
- A fused skeleton for stability during flight
- The absence of teeth and the presence of only one ovary to reduce body mass

To help keep their feathers in top condition, birds engage in a maintenance behaviour known as **preening**. This involves using their beak to clean, realign, and waterproof their feathers by spreading oil from a gland near the base of the tail. This oil helps maintain feather flexibility and water resistance, which is especially important for flight and insulation.

**Migration** is an important and widespread behaviour among birds, allowing them to exploit seasonal resources and favourable climates. Many bird species travel thousands of kilometres between breeding and wintering grounds, often navigating with remarkable precision using environmental cues like the sun, stars, and Earth's magnetic field. Migration helps birds avoid harsh conditions, access abundant food, and find suitable nesting sites.

Figure 7.2.14 Northern Cardinal (top left) by kcthetc1, Public Domain, Bald Eagle,(top middle) wildreturn, Public Domain, American Goldfinch, (top right) smays, Public Domain, Great Blue Heron, (bottom, left) quillipede, Public Domain, Wood Duck, (bottom middle) quillipede, Public Domain, Northern Flicker, (bottom right) erikschiff, Public Domain

## Mammals

**Mammals** are a diverse group of vertebrates characterized by the presence of hair and mammary glands. Mammals are endothermic, and **hair** provides insulation by trapping a layer of air close to the body to retain metabolic heat. Some hairs, called **whiskers**, are connected to nerves and function as sensory tools. Hair can also provide protective coloration.

Mammalian skin includes secretory glands with various functions. **Sebaceous glands** produce a lipid mixture called sebum that is secreted onto the hair and skin for water resistance and lubrication. **Sudoriferous glands** produce sweat for thermoregulation and scent for communication. **Mammary glands** produce milk that is used to feed newborns.

Mammals are classified into three major groups: **monotremes**, **marsupials**, and **eutherians** (placental mammals).

### Monotremes

**Monotremes** are the most primitive group of living mammals and include just three species: the platypus and two species of echidnas. Monotremes are unique among mammals, as they lay leathery eggs, similar to those of reptiles, rather than giving birth to live young. However, the eggs are retained within the mother's reproductive tract until they are almost ready to hatch. Once the young hatch, the female begins to secrete milk from pores in a ridge of mammary tissue along the ventral side of her body.

Figure 7.2.15 "Tasmanian Echidna" (left)by jason_graham, Public Domain, "Duck-billed platypus" (right) by Charles J. Sharpe, CC BY-SA 4.0

## Marsupials

**Marsupials** give birth to underdeveloped young, which then continue to grow and nurse inside a pouch on the mother's body. While they do form a placenta, it is less complex than that of placental mammals. Well-known marsupials include kangaroos**,** koalas**,** bandicoots, and the Tasmanian devil**.** Marsupials are found primarily in Australia and nearby islands, with a few species in the Americas, such as opossums.

Figure 7.2.16 Marsupial mammals. Clockwise from upper left: Koala, Mahogany Glider, Young Eastern Grey Kangaroo, and Sulawesi Bear Cuscus. Image by Daniele Pugliesi, CC BY-SA 3.0

## Eutherians

**Eutherians**, or **placental mammals**, are the most widespread and diverse group of mammals. They are distinguished by a complex **placenta** that supports the developing fetus by facilitating the exchange of nutrients, gases, and wastes between mother and offspring. This allows for a longer gestation period and more fully developed young at birth. Eutherians include a wide range of groups. Some examples include:

- **Rodents** – Have continuously growing incisors adapted for gnawing (e.g. mice, squirrels)
- **Bats** – Only mammals capable of true powered flight, with wings formed from elongated fingers and a thin membrane (e.g. big brown bats, vampire bats)
- **Carnivorans** – Have specialized teeth (canines) for capturing and slicing meat (e.g. dogs, cats, bears)
- **Hoofed animals** – Herbivorous mammals with hooves (e.g. horses, deer, pigs, whales)
- **Primates** – Have large brains, forward-facing eyes, and grasping hands adapted for complex behaviours (e.g. monkeys, apes, humans)

Figure 7.2.17 "Bornean Orangutan" (top left), by myrmecophil, CC BY-NC 4.0, "Common Raccoon" (top right) by jacksonkusack, Public Domain, "Eastern Chipmunk" (middle right) by glennberry, Public Domain, "Big Brown Bat" (bottom left) jacksonkusack, Public Domain, "White-tailed Deer" (bottom right) by glennberry, Public Domain

## Knowledge Check

**Text Description**

**1. Multiple Choice Activity #1**

Which of the following features is found in all vertebrates?

a. Open circulatory system
b. Exoskeleton
c. External fertilization
d. Backbone made of vertebrae

**2. Multiple Choice Activity #2**

What adaptation allows reptiles, birds, and mammals to reproduce away from water?

a. Swim bladder
b. Operculum
c. Amniotic egg
d. External fertilization

**3. Multiple Choice Activity #3**

Which group of fishes is characterized by a cartilaginous skeleton and the presence of paired fins?

a. Hagfishes
b. Ray-finned fishes
c. Cartilaginous fishes
d. Lobe-finned fishes

**4. Multiple Choice Activity #4**

Which of the following is a derived trait that first appears in the primate lineage?

a. Scaly skin
b. Opposable thumbs
c. Swim bladder

d. Amniotic egg

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Answers:

1. C. Backbone made of vertebrae
2. C. Amniotic egg
3. D. Cartilaginous fishes
4. C. Opposable thumbs

OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Create 4 multiple-choice questions using the following content

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# 7.3 PRIMATES

**Primates** are a group of mammals that includes lemurs, tarsiers, monkeys, and apes, including humans. Humans are the only primates found worldwide. Non-human primates primarily live in tropical and subtropical regions of South America, Africa, and Asia. They vary greatly in size, from the tiny mouse lemur (about 30 grams) to the massive mountain gorilla (up to 200 kg).

Understanding primates is key to understanding ourselves. Because humans are primates, studying their characteristics and evolution helps us trace the roots of our own species. Primates evolved from small, tree-dwelling mammals over 65 million years ago. This arboreal ancestry shaped many of their defining traits, including hands and feet adapted for climbing and swinging through trees. While not all modern primates today live in trees, these adaptations remain a core part of their evolutionary legacy.

These adaptations include:

- Rotating shoulder joints: Allow for a wide range of arm movement, useful for climbing and swinging
- Grasping hands and feet: Most primates have opposable thumbs and big toes (except humans), which help grip branches
- Stereoscopic vision: Overlapping fields of vision from forward-facing eyes provide depth perception necessary to gauge distances
- Flattened nails instead of claws: Helps in manipulation and tactile sensitivity
- Larger brains: Especially in areas related to vision and social behaviour
- Fewer offspring: Typically one at a time, allowing for extended parental care

Primates are generally divided into two broad groups:

Wet-nosed primates

Wet-nosed primates are generally smaller, **nocturnal** (more active at night), have a stronger sense of smell, and relatively smaller brains. They are found in Africa, Madagascar and parts of Asia. This group includes lemurs, lorises and bush babies.

Dry-nosed primates

**Dry-nosed primates** tend to have larger brains compared to other primates. They tend to rely more on vision rather than smell in their perception of the world. These primates also exhibit more complex social structures, often living in large, interactive groups with intricate communication and social bonds. Most dry-nosed primates are **diurnal** (active during the day), which aligns with their reliance on visual cues. This group includes:

- **Tarsiers** are small primates found in Southeast Asia. They have enormous eyes for night vision and are known for their powerful leaping abilities.
- **Monkeys** are divided into two major groups:
    - **New World monkeys** (found in the Americas): Many have prehensile tails and are highly arboreal (e.g. spider monkeys)
    - **Old World monkeys** (found in Africa and Asia): They are generally larger, more terrestrial, and lack prehensile tails (e.g. baboons, macaques)
- **Apes** are our closest living relatives and share many traits with humans, such as large brains and complex social behaviours (e.g. gibbons, orangutans, gorillas, chimpanzees, and humans)

## Human Evolution

Humans are the result of millions of years of evolutionary change. By studying fossils, anatomy, and genetics, scientists have pieced together a story of how several of our ancestral species, known as **hominins**, gradually developed traits that define us today. These traits, called **derived traits**, are new characteristics that evolved in a particular group, distinguishing them from their ancestors. As hominins evolved, several derived traits emerged that help set humans apart from our closest relatives, the great apes. These traits include:

## Bipedalism:

- One of the earliest and most important derived traits in human evolution is **bipedalism**, or walking on two legs. This shift freed the hands for carrying objects and using tools, and it changed the shape of the spine, pelvis, and legs.

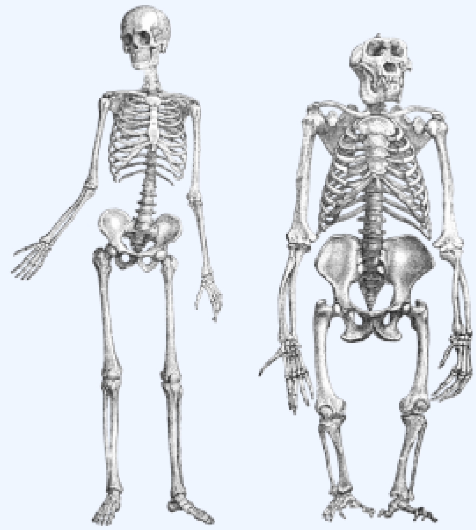

Figure 7.3.1 Compared to gorillas (right) and other apes, humans (left) have highly specialized adaptations to facilitate bipedal locomotion. Image by unknown from Brehms Tierleben, Small Edition 1927, Public Domain.

## Changes in Teeth and Diet:

- As early hominins adapted to new environments, their teeth changed too. Compared to apes, they had smaller canines and thicker tooth enamel, which suggests a shift to a more varied diet that included tough plant materials. The shift to cooking food and using tools to cut up and tear meat also reduced the need for large jaws and teeth, which resulted in a flatter face.

## Bigger Brains

- Over time, hominins developed larger and more complex brains, especially in areas related to problem-solving, language, and social behaviour.

## Tool Use

- Early humans began making and using tools, which allowed them to hunt, gather, and process food more effectively.

## Complex Culture

- Cultural behaviours eventually emerged, such as burying the dead, making art, and possibly using language.

Our species, *Homo sapiens*, did not appear suddenly but emerged through a long process involving many ancestral species. These ancestral species did not evolve in a straight line but more like a branching tree, with many species that lived, adapted, and sometimes went extinct

There are many key hominin species that help us understand the path to modern humans. Let's take a look at just a few:

Figure 7.3.2 Image (left) "Lucy" skeleton *Australopithecus afarensis*, cast from *the Muséum national d'histoire naturelle*, Paris. Image by Lucy blackbg, CC BY-SA 3.0 License, Image (right): An artistic reconstruction of *Australopithecus africanus* by John Gurche. Image by the Smithsonian, Smithsonian License

## ***Australopithecus afarensis*** **(3.9–2.9 million years ago)**

A well-documented early biped, *A. afarensis*, walked upright but still had adaptations for climbing. It bridges the gap between more primitive hominins and the genus *Homo*, showing how bipedalism evolved before large brains. Best known for the famous fossil "Lucy."

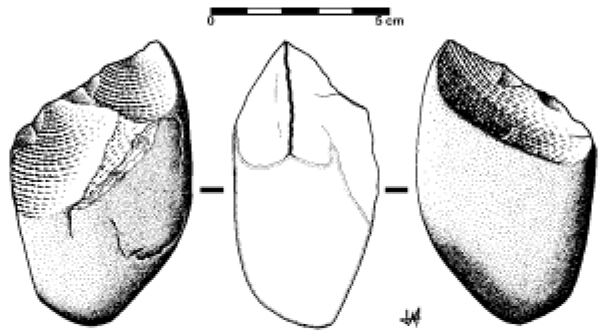


Figure 7.3.3 " Chopping tool" by José-Manuel Benito Álvarez, CC BY-SA 2.5

## *Homo habilis* (2.4–1.4 million years ago)

*H. habilis* is associated with the earliest known stone tools and is often called the "handyman". It had a larger brain than earlier hominins and marks the beginning of more advanced cognitive abilities.

7.3.4 Left: Skeleton of a young male *Homo erectus* "Nariokotome Boy" by Smithsonian, Smithsonian License, Right: an artist's depiction of how he may have looked during his life. "Homo-erectus Turkana-Boy" by Neanderthal Museum, CC BY-SA 4.0

## *Homo erectus* (1.9 million–110,000 years ago)

*H. erectus* was the first hominin to leave Africa and spread across Asia and Europe. It had a modern body shape, used fire, and made more sophisticated tools, showing increased adaptability and intelligence.

Figure 7.3.5 Reconstruction of a Neanderthal man butchering a goat, Image by Neanderrthal Museum, CC BY-SA 4.0

## *Homo neanderthalensis* (400,000–40,000 years ago)

Neanderthals lived in Europe and western Asia and were close relatives of modern humans. They had large brains, made complex tools, buried their dead, and may have used symbolic communication. Genetic evidence shows they interbred with early *Homo sapiens*.

## *Homo sapiens* (emerged around 300,000 years ago)

Our own species, *H. sapiens*, is defined by a high forehead, a rounded skull, and advanced cognitive abilities. We developed language, art, agriculture, and complex societies. Fossil and genetic evidence shows we originated in Africa and spread globally.

## Knowledge Check

**Text Description**

**1. Multiple Choice Activity #1**

Which of the following traits is shared by all primates?

a. Bony plates instead of nails
b. Grasping hands and feet
c. Hooved feet
d. External fertilization

**2. Multiple Choice Activity #2**

Which characteristic is typical of wet-nosed primates?

a. Strong sense of smell
b. Diurnal activity patterns
c. Highly developed vision
d. Prehensile tails

**3. Multiple Choice Activity #3**

What evolutionary adaptation is most strongly associated with bipedalism in early hominins?

a. Flattened fingernails
b. Reshaping of the pelvis and spine
c. Development of stereoscopic vision
d. Use of prehensile tails

**4. Multiple Choice Activity #4**

Which hominin species is best known for being the first to leave Africa and for using fire?

a. Homo habilis
b. Homo sapiens
c. Homo erectus
d. Homo neanderthalensis

**5. Multiple Choice Activity #5**

Which of the following is true about dry-nosed primates?

a. They are mostly nocturnal and rely heavily on smell.
b. They include only lemurs and bush babies.
c. They tend to live in small, solitary groups.
d. They have larger brains and more complex social behaviour

---

Answers:

1. C. Grasping hands and feet
2. B. Strong sense of smell
3. C. Reshaping of pelvis and spine
4. D. *Homo erectus*
5. C. They have larger brains and more complex social behaviour

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Prompt: Create 5 multiple-choice questions using the following content

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# CHAPTER 7 SUMMARY

## Key Takeaways

- **Vertebrates share common anatomical features**, including a backbone made of vertebrae, a cranium to protect the brain, and advanced organ systems such as a closed circulatory system and complex nervous system. They belong to the phylum Chordata and are divided into five major groups: fishes, amphibians, reptiles, birds, and mammals.
- **Fishes were the first vertebrates to evolve**, starting with jawless forms like hagfishes and lampreys. The evolution of jaws and paired fins gave rise to cartilaginous fishes (e.g., sharks and rays) and later to bony fishes, which are now the most diverse group of vertebrates.
- **Amphibians represent a transitional group**, having evolved from lobe-finned fishes. They typically have a dual life cycle (aquatic larvae and terrestrial adults), permeable skin for gas exchange, and were the first vertebrates to adapt to life on land.
- **Reptiles and birds are amniotes**, a group defined by the presence of an amniotic egg that allows reproduction away from water. Reptiles are ectothermic with scaly skin and internal fertilization. Birds, which evolved from reptiles, are endothermic, feathered, and highly adapted for flight and long-distance migration.
- **Mammals are endothermic vertebrates with hair and mammary glands**, and are divided into monotremes (egg-laying), marsupials (pouched), and eutherians (placental). Mammals have complex behaviours and specialized glands for thermoregulation, communication, and reproduction.
- **Primates—including humans—are characterized by traits such as stereoscopic vision, grasping limbs, and large brains**. Human evolution involved key developments like bipedalism, changes in teeth and diet, tool use, and the emergence of culture. Notable

hominin species include *Australopithecus afarensis*, *Homo habilis*, *Homo erectus*, *Homo neanderthalensis*, and *Homo sapiens*.

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Prompt: Summarize the following content into six key takeaways.

## Flashcards

Text Description
Front of card

1. Amniotes
2. Amniotic Egg
3. Amphibians
4. Apes
5. Australopithecus afarensis
6. Bats
7. Bipedalism
8. Birds
9. Bony Fishes
10. Carnivorans
11. Cartilage
12. Cartilaginous Fishes
13. Closed Circulatory System
14. Crocodilians
15. Cutaneous Respiration
16. Derived Traits
17. Diurnal

18. Dry-nosed Primates
19. Ectotherms
20. Electroreception
21. Endoskeleton
22. Endothermic
23. Eutherians
24. Feathers
25. Fishes
26. Frogs
27. Grasping Hands and Feet
28. Hagfishes
29. Hair
30. Hominins
31. Homo erectus
32. Homo habilis
33. Homo neanderthalensis
34. Homo sapiens
35. Hoofed animals
36. Jawed Fishes
37. Jawless Fishes
38. Lamprey
39. Lateral Line
40. Lizards
41. Lobe-finned Fishes
42. Lungfishes
43. Mammals
44. Mammary Glands
45. Marsupials
46. Migration
47. Monotremes
48. New World Monkeys
49. Nocturnal
50. Old World monkeys
51. Operculum
52. Placenta

53. Preening
54. Primates
55. Ray-finned Fishes
56. Rays
57. Reptiles
58. Rodents
59. Rotating Shoulder Joints
60. Salamanders
61. Scaly Skin
62. Sebaceous glands
63. Sharks
64. Snakes
65. Stereoscopic Vision
66. Sudoriferous glands
67. Swim Bladder
68. Tadpoles
69. Tarsiers
70. Tetrapods
71. Tool Use
72. Turtles
73. Vertebrae
74. Vertebrates
75. Wet-nosed Primates
76. Whiskers
77. Features of vertebrates
78. 5 groups of vertebrates
79. 2 groups of jawless fishes
80. 2 groups of jawed fishes
81. 2 groups of amphibians
82. 4 groups of reptiles
83. 2 key features of mammals
84. 3 groups of mammals
85. Adaptations to living in trees
86. 3 groups of dry-nosed primates
87. Derived traits of hominins

Back of card

1. A group of tetrapods that produce amniotic eggs, enabling reproduction on land; e.g. reptiles, birds, and mammals
2. A type of egg produced by reptiles, birds, and mammals that contains specialized membranes to support and protect the embryo, allowing reproduction away from water.
3. A group of vertebrates that typically begin life in water with gills and undergo metamorphosis to develop lungs for life on land
4. Dry-nosed primates with large brains and complex social behaviours; closest living relatives to humans; e.g. gibbons, orangutans, gorillas, chimpanzees, and humans
5. An early hominin species known for walking upright; represented by the famous fossil "Lucy"
6. Only mammals capable of true powered flight, with wings formed from elongated fingers and a thin membrane (e.g. big brown bats, vampire bats)
7. A mode of locomotion involving walking on two legs, a key evolutionary trait in humans and their ancestors
8. Endothermic reptiles with feathers, hollow bones, and adaptations for flight; evolved from theropod dinosaurs
9. Fishes with skeletons made of bone, a swim bladder for buoyancy, and an operculum covering their gills
10. Eutherians with specialized teeth (canines) for capturing and slicing meat (e.g. dogs, cats, bears)
11. A firm, flexible connective tissue found in various parts of the body; in some vertebrates (e.g. sharks), it makes up the entire skeleton
12. Jawed fishes with skeletons made of cartilage rather than bone; includes sharks and rays
13. A circulatory system in which blood is enclosed within vessels and pumped by a heart through a looped circuit
14. Large, aquatic reptiles with long snouts and powerful tails
15. Gas exchange through the skin; used by amphibians in addition to lungs or gills
16. New features or characteristics that evolved in a particular group, distinguishing them from ancestors
17. active during the day
18. A group of primates with larger brains and greater reliance on vision rather than smell; includes monkeys, apes, and humans
19. Animals that rely on external heat sources to regulate their body temperature (e.g. reptiles)
20. The ability to detect electrical fields generated by other organisms; used by sharks to locate prey

21. An internal skeleton made of bone or cartilage that supports and protects the body's organs
22. The ability of an organism to regulate its own body temperature using internal metabolic processes (e.g. birds and mammals)
23. Also called placental mammals; mammals that nourish developing offspring through a complex placenta and give birth to relatively developed young
24. Modified scales that cover birds' bodies; used for flight, insulation, and display
25. Aquatic vertebrates that use gills for respiration; includes jawless, cartilaginous, and bony fishes
26. Amphibians with smooth skin and strong hind legs for jumping; they undergo metamorphosis from aquatic tadpoles to terrestrial adults
27. A trait of primates that allows them to hold objects or cling to branches; often includes opposable thumbs or toes
28. Jawless, eel-like marine animals that produce slime for defense; they have a skull but no vertebral column
29. A defining feature of mammals; used for insulation, camouflage, and sensory functions
30. The group that includes modern humans and their direct ancestors
31. An early human species that was the first to leave Africa, use fire, and show modern body proportions
32. An early human species known for using tools, often called the "handy man"
33. Also called Neanderthals, they were close relatives of humans who lived in Europe and western Asia; they made tools, buried their dead, and possibly used symbolic communication
34. The species name for modern humans, characterized by large brains, language, art, and advanced social structures
35. Herbivorous mammals with hooves (e.g. horses, deer, pigs, whales)
36. Vertebrates with hinged jaws that allow for more efficient feeding; includes cartilaginous and bony fishes
37. Primitive fishes without jaws; includes hagfishes and lampreys
38. Jawless vertebrates with a toothed, funnel-like mouth; some are parasitic and attach to other fish to feed on their blood
39. A sensory organ in fishes that detects movement and vibrations in the water
40. Scaly reptiles with movable eyelids and external ears; most have four legs and are ectothermic
41. Bony fishes with fleshy, lobed fins supported by bones; ancestors of amphibians and other land vertebrates
42. Lobe-finned fishes that can breathe air using lungs

43. Endothermic vertebrates with hair and mammary glands; nourish young with milk
44. Glands found in mammals that produce milk to feed offspring
45. Mammals that give birth to underdeveloped young, which then continue developing in a pouch (e.g. kangaroos, koalas)
46. The seasonal movement of animals (especially birds) from one region to another for feeding or breeding
47. Egg-laying mammals, such as the platypus and echidna, that also nurse their young
48. Dry-nosed primates with prehensile tails; highly arboreal; found in the Americas; e.g. spider monkeys
49. active at night
50. Large, terrestrial, dry-nosed primates that lack prehensile tails; found in Africa and Asia; e.g. baboons, macaques
51. A bony flap that covers and protects the gills in bony fishes and helps with breathing without constant swimming
52. A complex organ in eutherians that facilitates nutrient, gas, and waste exchange between the mother and developing fetus
53. A behavior in birds where they use their beak to clean and maintain their feathers
54. A group of mammals with traits like grasping hands, stereoscopic vision, and large brains; includes monkeys, apes, and humans
55. Bony fishes with fins supported by long, flexible rays; includes most familiar fish species
56. Cartilaginous fishes with flattened bodies and enlarged pectoral fins
57. Ectothermic vertebrates with scaly skin and shelled, amniotic eggs; includes crocodilians, lizards, snakes, turtles, and birds
58. Eutherians with continuously growing incisors adapted for gnawing (e.g. mice, squirrels)
59. A primate trait that allows for a wide range of arm movement, useful for climbing and swinging
60. Amphibians with elongated bodies and tails
61. A protective covering made of keratin that prevents water loss; characteristic of reptiles.
62. Glands in mammals that secrete oil (sebum) to lubricate and waterproof the skin and hair
63. Cartilaginous fishes with streamlined bodies, multiple rows of teeth, and keen senses like electroreception
64. Legless reptiles with elongated bodies and flexible jaws; carnivorous
65. Vision in which both eyes have overlapping fields of view, allowing for depth perception; common in primates
66. Glands in mammals that produce sweat for thermoregulation and scent for communication

67. A gas-filled organ in many bony fishes that helps regulate buoyancy
68. The aquatic larval stage of frogs; they have gills, a tail, and no legs; undergo metamorphosis into adults
69. Small, nocturnal primates with large eyes and strong leaping ability, found in Southeast Asia
70. Vertebrates with four limbs; includes amphibians, reptiles, birds, and mammals
71. The practice of using objects to perform tasks, a behavior seen in early hominins and modern humans
72. Reptiles with a bony or cartilaginous shell developed from their ribs; found in aquatic and terrestrial environments
73. The individual bones that make up the backbone or spinal column of vertebrates
74. Animals with a backbone and an internal skeleton; includes fishes, amphibians, reptiles, birds, and mammals
75. Primates with a strong sense of smell and smaller brains, often nocturnal; includes lemurs and lorises
76. Specialized sensory hairs found in many mammals
77. endoskeleton with skull and backbone, closed circulatory systems, well-developed nervous systems, complex internal organs
78. Fishes, amphibians, reptiles, birds, mammals
79. hagfishes and lampreys
80. cartilaginous fishes and bony fishes
81. salamanders and frogs
82. crocodilians, lizards and snakes, turtles, birds
83. hair and mammary glands
84. monotremes, marsupials, eutherians
85. rotating shoulder joints, grasping hands and feet, stereoscopic vision, flattened nails, larger brains, fewer offspring
86. tarsiers, monkeys, apes
87. bipedalism, changes in teeth, bigger brains, tool use, complex culture

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Provide definitions for all the bolded terms in the shared content and list all the terms in alphabetical order.

# CHAPTER 8: ECOLOGY AND THE BIOSPHERE

## Chapter Overview

## Learning Objectives

By the end of this chapter, you will be able to:

- Define ecology and explain its central goal of understanding the distribution and abundance of organisms through interdisciplinary approaches.
- Identify and describe the four major levels of ecological study—organism, population, community, and ecosystem—and explain the types of questions ecologists ask at each level.
- Differentiate between biotic and abiotic factors in an organism's habitat and describe how both influence survival, growth, and reproduction.
- Explain the role of adaptations in organismal ecology, using examples such as the woodland caribou's physiological and behavioural traits for survival in boreal forests.
- Analyze population-level ecological concepts, including factors influencing population dynamics, such as habitat fragmentation and human activity.
- Interpret the interactions between species and organisms and their environment, especially in community and ecosystem contexts, including energy flow, nutrient cycling, and predator-prey dynamics.

OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat Prompt: Provide six learning objectives for the shared content.

# 8.1 WHAT IS ECOLOGY?

**Ecology** is the study of the interactions of living organisms with their environment. A central goal of ecology is to understand the distribution and abundance of organisms across the Earth. Achieving this goal requires integrating knowledge from many scientific disciplines, both within and beyond biology – including biochemistry, physiology, evolution, biodiversity science, molecular biology, geology, and climatology. Some ecological research even incorporates chemistry and physics, and frequently relies on mathematical models.

## Levels of Ecological Study

When studying biology, it is often helpful to subdivide it into smaller, related areas. For instance, cell biologists interested in cell signalling need to understand the chemistry of the signal molecules (which are usually proteins) as well as the result of cell signalling. Ecologists interested in the factors that influence the survival of an endangered species might use mathematical models to predict how current conservation efforts affect endangered organisms. To produce a sound set of management options, a conservation biologist needs to collect accurate data, including current population size, factors affecting reproduction, habitat requirements, and potential human influences on the endangered population and its habitat.

A **habitat** is the natural environment in which an organism lives. It includes all the resources and conditions the organism needs to survive, grow, and reproduce. These conditions are shaped by both **biotic factors** (the living components of the environment, such as plants, animals, fungi, and microbes) and **abiotic factors** (the non-living components like temperature, sunlight, water, soil, and air).

Within the discipline of ecology, researchers work at four specific levels, sometimes discretely and sometimes with overlap: organism, population, community, and ecosystem (Figure 8.1.1)

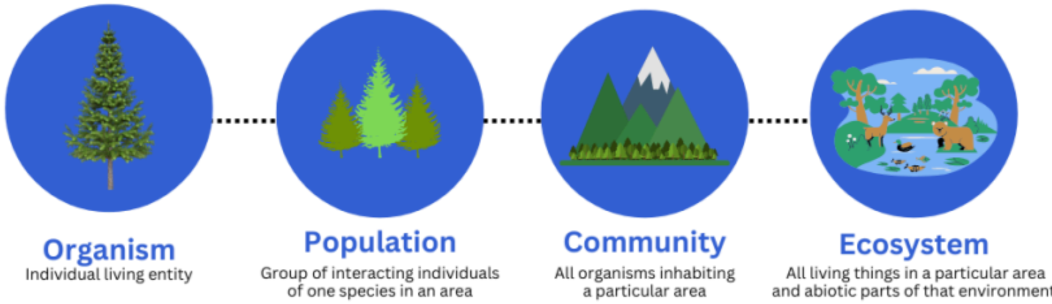


Figure 8.1.1 Ecology is often studied at one of these four levels of life. Graphic by Shauna Roch, CC BY-NC-SA 4.0

## Organismal Ecology

Figure 8.1.2 Mountain Woodland Caribou, Jasper National Park, Alberta. Photo by ThartmannWiki, CC BY-SA 4.0

Organismal ecology focuses on the adaptations that enable individuals to live in specific habitats. The distribution of organisms is limited by the abiotic conditions they can tolerate.

For example, the woodland caribou (*Rangifer tarandus caribou*) is specially adapted to life in Canada's boreal forests. These caribou have large, fur-covered hooves that help grip the ice and dig through snow for food. They rely heavily on lichens, which are slow-growing and found in mature forests. Their seasonal migrations and calving behaviours are also shaped by environmental conditions.

An ecologist studying woodland caribou at the organismal level might ask:

- *What are the limits of temperature that woodland caribou can tolerate?*
- *What is the maximum snow depth that woodland caribou can tolerate before their movement or foraging is significantly affected?*
- *What environmental factors do woodland caribou use to select calving sites to reduce predation?*

### Population Ecology

A **population** is a group of interbreeding individuals of the same species living in the same area at the same time. Population boundaries may be natural (like rivers or mountains) or artificial (such as roads or buildings). **Population ecology** focuses on the number of individuals in a population and how and why that number changes over time.

Woodland caribou populations have declined in many parts of Canada due to habitat fragmentation, industrial development, and increased predation. Because they are listed as threatened under Canada's Species at Risk Act, ecologists monitor their numbers closely. Researchers might also use mathematical models to predict population trends under various conditions.

An ecologist studying woodland caribou at the population level might ask:

- *How has the population size of woodland caribou changed over the past several decades in different regions of Canada?*
- *What impact does road construction have on the movement patterns and connectivity between caribou populations?*
- *How does habitat fragmentation affect the genetic diversity of isolated caribou populations?*

### Community Ecology

A **community** includes all the different species living in a particular area and the interactions among them. **Community ecology** focuses on **interspecific interactions**, which are interactions that occur between different species. In Canada's boreal forest, woodland caribou share their habitat with species such as moose, wolves, and black bears. Human activities like logging and road construction have altered these landscapes, creating younger forests that are more suitable for moose. The growing moose population supports a larger wolf population. These wolves also prey on caribou. Community ecologists might study how these predator-prey dynamics influence caribou survival and how restoring natural forest patterns could help rebalance these interactions.

An ecologist studying woodland caribou at the community level might ask:

- *How does the presence of moose influence wolf population density and predation rates on woodland caribou?*
- *What are the effects of increased predator abundance on caribou behaviour and habitat use?*

### Ecosystem Ecology

An **ecosystem** is a community of living organisms (biotic components) interacting with the non-living elements (abiotic components) of their environment. **Ecosystem ecology** focuses on how energy flows and nutrients cycle through these biotic and abiotic systems. Abiotic factors include elements such as air, water, soil, temperature, and sunlight.

Woodland caribou live in ecosystems dominated by coniferous forests, peatlands, and wetlands. These ecosystems store large amounts of carbon and play a role in regulating the climate. The slow decomposition rates in these cold, wet environments affect nutrient cycling and plant growth.

Ecosystem ecologists might study how climate change and industrial development alter the carbon balance of boreal forests, or how changes in soil moisture affect lichen availability for caribou.

An ecologist studying woodland caribou at the ecosystem level might ask:

- *What impact does industrial development have on nutrient availability in caribou habitats?*
- *How do changes in permafrost associated with global warming affect hydrology in caribou habitats?*
- *How does atmospheric pollution (e.g., acid rain or nitrogen deposition) influence the growth and distribution of lichen species?*

## Knowledge Check

**Text Description**

**1. Multiple Choice Activity #1**

Which of the following questions would most likely be asked in organismal ecology?

a. How does road construction impact gene flow between caribou populations?
b. How do caribou choose calving sites to reduce predation risk?
c. What is the effect of nitrogen deposition on lichen growth?
d. How do moose populations affect wolf densities?

**2. Multiple Choice Activity #2**

Which of the following best describes a focus of population ecology?

a. Studying how wolves interact with caribou and moose.
b. Examining how lichens respond to climate change.
c. Monitoring caribou numbers and predicting future population trends.
d. Exploring how caribou select habitats based on snow depth.

**3. Multiple Choice Activity #3**

What human activity has indirectly increased predation pressure on woodland caribou in boreal forests?

a. Overharvesting of lichens
b. Introduction of invasive species
c. Logging and road construction
d. Air pollution from mining

**4. Multiple Choice Activity #4**

Which of the following is an example of an ecosystem ecology research question?

a. What is the snow depth tolerance of woodland caribou?
b. How does permafrost thaw impact wetland hydrology?
c. How many caribou inhabit a given forest region?
d. How do moose compete with caribou for space?

**5. Multiple Choice Activity #5**

How do woodland caribou demonstrate adaptation to their environment, as described in organismal ecology?

a. By adjusting migration routes in response to wolf populations
b. By relying on mature forests with slow-growing lichens and using fur-covered hooves to navigate snowy terrain
c. By increasing birth rates in response to declining populations
d. By forming larger herds to confuse predators

**6. Drag and Drop Activity #6**

Match the phrase to its corresponding definition

Answer options: Community Ecology, Population Ecology, Ecosystem Ecology, Organismal Ecology

1. Level of ecology concerned with the adaptations of individuals
2. Level of ecology concerned with groups of individuals of the same species
3. Level of ecology concerned with groups of different species living together
4. Level of ecology concerned with both the biotic and abiotic factors influencing things living together

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**Answers:**

1. b
2. c
3. c
4. b
5. b
6. 1 = Organismal Ecology, 2 = Population Ecology, 3 = Community Ecology, 4 = Ecosystem Ecology

OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Create 5 multiple-choice questions using the following content

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# 8.2 DISTRIBUTION OF LIFE

The **biosphere** is the global sum of all ecosystems—it includes every region of Earth where life exists, from the deepest ocean trenches to the upper atmosphere. Many **abiotic factors** play a crucial role in determining where life can exist and what types of organisms are found in different regions. The major abiotic factors include: **energy source**, **temperature**, **water availability**, and **inorganic nutrients**.

## Energy Source

Figure 8.2.1 "Virginia Springbeauty" by blkillin, Public Domain

Most life on Earth ultimately depends on energy from the **sun**. This solar energy is captured by photosynthetic organisms (including green plants, algae, cyanobacteria, and some protists), which convert sunlight into chemical energy through photosynthesis. These organisms form the base of most food webs, which supply energy to all other living things, either directly or indirectly.

The availability of light is a key abiotic factor that influences where photosynthetic organisms can thrive. It also drives the evolution of specialized adaptations that help organisms capture and use light efficiently.

For example, in temperate forests, light availability changes dramatically with the seasons. In early spring, before the trees in the canopy fully leaf out, sunlight reaches the forest floor. This brief window of high light availability is critical for plants that grow, flower, and reproduce quickly before being shaded by the canopy above (spring ephemerals). One such plant is the spring beauty, which completes most of its life cycle in early spring. Its rapid growth and early blooming are adaptations to the seasonal pattern of light availability in the forest understory.

In aquatic ecosystems, light availability decreases with depth, so photosynthesis is limited to the upper layers of water. This creates a vertical structure in aquatic food webs, with photosynthetic organisms concentrated near the surface and other organisms distributed according to their energy needs and feeding strategies.

## Temperature

Figure 8.2.2 "Wood Frog", by nottawasaga , CC0 1.0 . Modification: cropped

**Temperature** also plays a major role in determining where species can live. It affects the rate of biochemical reactions, the state and density of water, and the efficiency of metabolism. Most organisms can only survive within a relatively narrow temperature range. Temperatures below 0 °C can cause water in cells to freeze, damaging tissues, while temperatures above 45 °C can lead to enzyme breakdown and metabolic failure.

Because of these constraints, organisms must either regulate their internal temperature or live in environments that naturally support their physiological needs. Some species have evolved remarkable adaptations to cope with temperature extremes. For example, wood frogs can survive freezing temperatures by producing antifreeze-like chemicals that protect their cells.

### Water

Figure 8.2.3 "Fernandina Marine Iguana", by simonjpierce , CC BY-NC 4.0

**Water** is essential for all life on Earth. It plays a central role in cellular processes, including nutrient transport, chemical reactions, and temperature regulation. Because of its importance, the availability of water is a major factor influencing where organisms can live and how they function.

On land, terrestrial organisms constantly lose water to the environment through processes like evaporation and transpiration. To survive, they have evolved a variety of adaptations to conserve water. For example, many plants have waxy cuticles and leaf hairs that reduce water loss by slowing the rate of transpiration. These features are especially important in dry environments where water is scarce.

In aquatic environments, the challenge is not water loss, but maintaining internal solute balance. Freshwater organisms live in environments where water tends to enter their bodies by osmosis. To prevent their cells from swelling and bursting, they excrete dilute urine and actively regulate solute levels. In contrast, marine organisms are surrounded by salty water that draws water out of their bodies. These organisms have adaptations to retain water and excrete excess salts. For example, the marine iguana (Amblyrhynchus cristatus) sneezes out salt-rich water vapour to maintain internal balance while feeding in the ocean.

## Inorganic Nutrients

Figure 8.2.4 "northern purple pitcher plant", by valeriedupee , CC0 1.0

**Inorganic nutrients**, such as nitrogen, phosphorus, and potassium, are essential for the growth and survival of all living organisms. These nutrients are required for building proteins, nucleic acids, and other vital cellular components. The availability of these nutrients in the environment plays a major role in determining the distribution and abundance of life.

Plants absorb inorganic nutrients along with water from the soil. As a result, the structure, pH, and nutrient content of the soil are critical factors influencing where different plant species can grow. For example, sandy soils drain quickly and may lack nutrients, while clay-rich soils retain water and nutrients but may limit root penetration. Some plants are adapted to nutrient-poor soils, while others require rich, fertile conditions to thrive. For example, **pitcher plants** grow in nutrient-poor soils in bogs and wetlands. Because the soil lacks sufficient nitrogen and phosphorus, these plants have evolved the ability to trap and digest insects to supplement their nutrient intake. This carnivorous strategy allows them to thrive in environments where most other plants would struggle to survive.

Animals, on the other hand, obtain inorganic nutrients by consuming plants or other animals. Therefore, their distribution is closely tied to the availability of their food sources. In some ecosystems, animals may migrate or shift their range in response to changes in the abundance or location of nutrient-rich food.

Other Abiotic Factors

Figure 8.2.5 "Jack pine", by alexisgodin , CC BY 4.0

There are many other abiotic factors that shape ecosystems.

In aquatic ecosystems, oxygen availability is a critical factor for survival. Unlike terrestrial animals that breathe air, aquatic organisms rely on dissolved oxygen in the water. The concentration of dissolved oxygen is influenced by water temperature and movement—cold, fast-moving water holds more oxygen than warm, still water. Other important abiotic factors in aquatic systems include salinity (salt concentration), currents, and tides, all of which affect the types of organisms that can live in different aquatic habitats.

On land, wind plays a significant role in shaping ecosystems. It can increase evaporation and transpiration rates, which influence water availability for plants. Wind also acts as a physical force, moving soil, seeds, pollen, and even small organisms, thereby affecting patterns of plant growth and species dispersal. Another powerful terrestrial factor is fire. While often seen as destructive, fire is a natural disturbance that plays a vital role in many ecosystems. Some species are adapted to fire and even depend on it for reproduction. For example, the jack pine produces cones that only open and release seeds in response to the high heat of a fire. Fires can also recycle nutrients like nitrogen back into the soil and reduce competition by clearing dense undergrowth, allowing sunlight to reach the forest floor and promoting new growth.

## Responding to Changing Abiotic Conditions

Abiotic factors such as temperature, light, and moisture are not constant. They can change seasonally, daily, or even suddenly due to weather events or natural disturbances like fires or floods. These fluctuations can significantly affect the survival and activity of organisms. To cope with these changes, organisms have evolved a variety of strategies that allow them to adjust to changing environments.

There are three main types of responses organisms use to adjust to changing abiotic conditions:

### Physiological Responses

**Physiological responses** involve short-term or reversible changes in how an organism's body *functions*. These changes help maintain **homeostasis** (the internal balance of body systems) even when external conditions shift.

When conditions are unfavourable, some animals enter a state of **torpor** where their metabolic rate drops significantly to conserve energy. **Hibernation** is a longer-term form of torpor used by some animals to survive cold winters when food is scarce. During hibernation, body temperature, heart rate, and breathing slow dramatically.

Another common physiological response is acclimation. **Acclimation** refers to gradual, reversible adjustments to a new environmental condition. For example, a fish moved from cooler to warmer water may gradually adjust its metabolism to function efficiently at the new temperature.

In humans, a notable physiological response occurs at high altitudes. When people travel or move to mountainous regions where oxygen levels are lower, their bodies respond by producing more red blood cells. This increases the blood's oxygen-carrying capacity to help them function better in the thinner air.

### Anatomical Responses

**Anatomical responses** are physical changes in an organism's body *structure* that help it cope with environmental changes. For instance, animals in cold climates often grow thicker fur or develop fat layers for insulation during winter. This is also an example of acclimation because these anatomical changes reverse when the temperatures rise again.

### Behavioural Responses

**Behavioural responses** are *actions or movements* that organisms perform to avoid or reduce exposure to unfavourable conditions. One of the most well-known behavioural responses is **migration**. Many animals migrate long distances to find more suitable climates, food sources, or breeding grounds. Humans also rely heavily on behavioural responses – we wear different clothing depending on the weather, use heating or air conditioning to regulate indoor temperatures, and modify our daily routines to avoid extreme conditions.

## Knowledge Check

**Text Description**

**1. Multiple Choice Activity #1**

What is the main reason spring ephemerals, such as the spring beauty, bloom early in temperate forests?

a. To avoid insect herbivores
b. To take advantage of sunlight before the canopy trees fully leaf out
c. Because their seeds only germinate in cold soil
d. To compete with evergreen plants for nutrients

**2. Multiple Choice Activity #2**

How do marine iguanas maintain internal water and salt balance in a salty ocean environment?

a. They excrete salt through their skin
b. They have water-tight scales to prevent water loss
c. They sneeze out salt-rich water vapour
d. They only feed in freshwater areas

**3. Multiple Choice Activity #3**

Which of the following is an anatomical response to cold temperatures?

a. Migration to warmer regions
b. Hibernation during winter
c. Growing thicker fur for insulation
d. Producing more red blood cells

**4. Multiple Choice Activity #4**

What abiotic factor primarily limits photosynthesis in deeper aquatic ecosystems?

a. Lack of nitrogen
b. Cold water temperatures
c. Limited dissolved oxygen
d. Decreased light availability

**5. Multiple Choice Activity #5**
Why are jack pine cones an adaptation to fire-prone ecosystems?

a. They grow only in moist soil created by fire
b. They contain seeds that require fire heat to germinate
c. They drop seeds before a fire begins
d. They are resistant to decay and rot

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**Answers:**

1. b
2. c
3. c
4. d
5. b

OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Create 5 multiple-choice questions using the following content

# 8.3 TERRESTRIAL BIOMES

A **biome** is a large geographic region characterized by a distinct climate and vegetation, which in turn determines the types of animals that can live there. Biomes are classified into two broad categories: terrestrial biomes (occur on land) and aquatic biomes (include marine and freshwater).

The major terrestrial biomes on Earth are distinguished by their typical **climate** (the long-term pattern of temperature and precipitation in a region). Annual totals and fluctuations of precipitation and temperature variation on a daily and seasonal basis affect the kinds of vegetation and animal life that can exist in broad geographical regions. Since a biome is defined by climate rather than location, the same biome can occur in geographically distinct areas with similar climates.

Some parts of the planet, such as Antarctica, Greenland, and high mountain ranges, are covered by permanent ice and glaciers. These areas experience extreme cold and receive very little precipitation. While they support limited life, they are not typically classified as biomes due to their harsh, uninhabitable conditions.

## What Controls Climate on Earth?

Climate is the most important factor in determining the types of organisms that can live in a particular biome. Several key factors work together to control Earth's climate patterns:

## Latitude

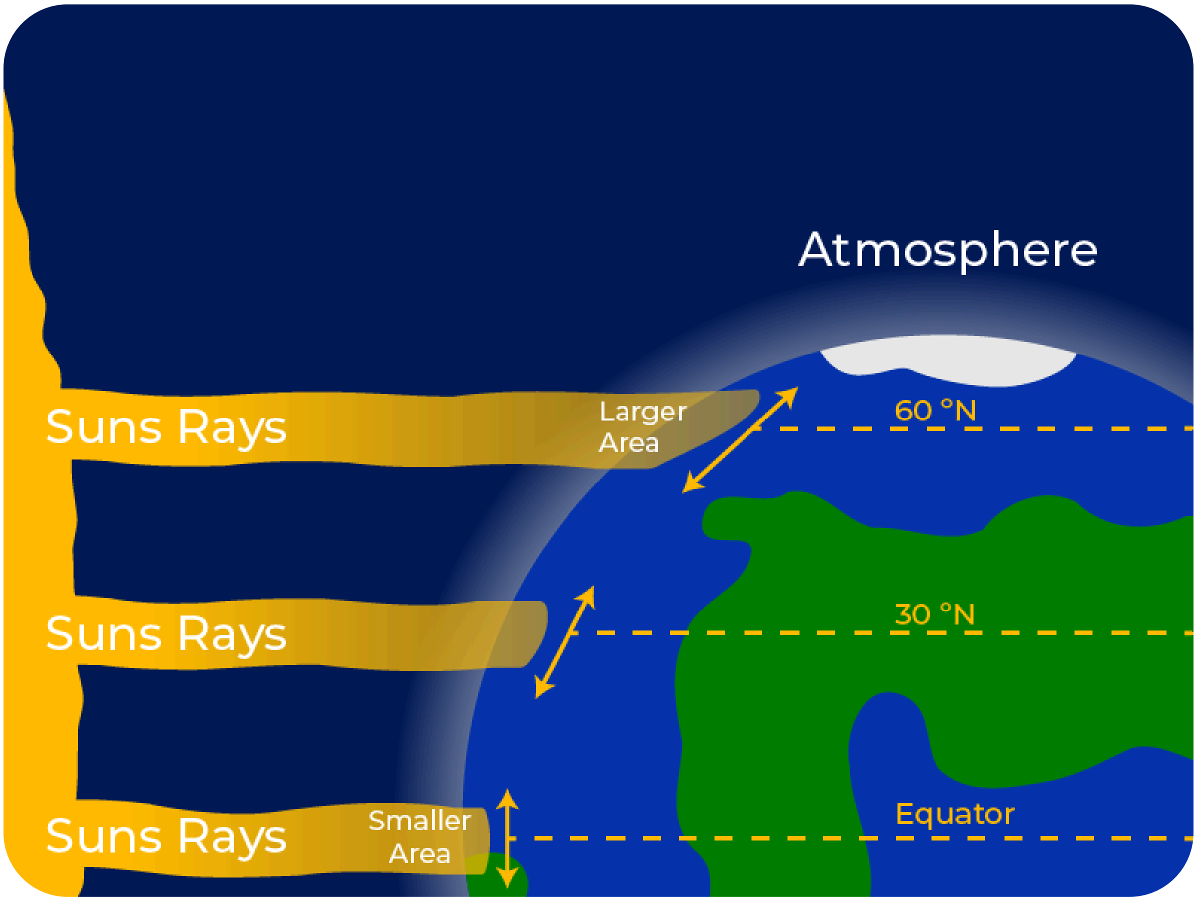


Figure 8.3.1 “Latitude and climate” by Koen Liddiard, CC BY-NC-SA 4.0

**Figure 8.3.1 Image Description**

A diagram showing how the Sun’s rays strike Earth differently depending on latitude. On the left, the Sun emits parallel rays that reach Earth’s curved surface. At the equator, rays hit directly, concentrating on a smaller area, resulting in more intense solar energy. At higher latitudes (30°N and 60°N), the rays strike at an angle, spreading over a larger area and passing through more atmosphere, which reduces their intensity. Labels indicate “Smaller Area” near the equator and “Larger Area” near 60°N, with the atmosphere depicted as a glowing blue arc around Earth.

**Latitude** refers to how far a location is from the equator. The equator receives direct sunlight year-round, resulting in consistently warm temperatures and high solar energy. As you move toward the poles, sunlight strikes Earth at a lower angle, spreading the energy over a larger area and reducing the intensity of heat. This creates a gradient of climate zones: tropical near the equator, temperate in the mid-latitudes, and polar near the poles. These broad temperature zones are the foundation for the distribution of biomes across the globe.

## Earth's Tilt

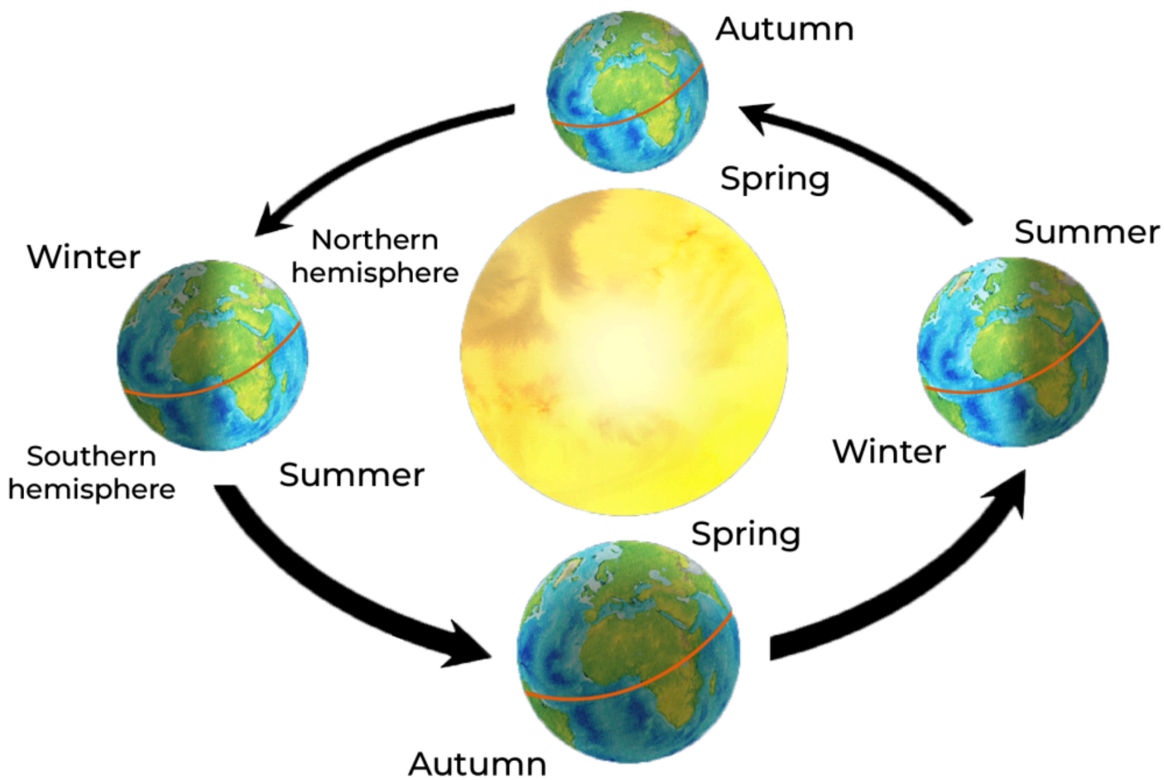


Figure 8.3.2 "Earth Revolving around Sun_2" by Siyavula Education, CC BY 2.0. Modification: Background removed

Earth is tilted at an angle of about 23.5 degrees relative to its orbit around the Sun. Because the Earth tilts on its axis, different parts of the planet get different amounts of sunlight throughout the year. This tilt creates the seasons. In the Northern Hemisphere, summer happens when the North Pole leans toward the Sun. Days are longer, and sunlight is more direct. In winter, the North Pole tilts away from the Sun, leading to shorter days and weaker sunlight. These seasonal shifts affect temperature and rainfall, which in turn influence plant growth and animal activity.

## Global Air Circulation Patterns

Precipitation is a key factor in determining the types of vegetation and animals that can survive in a region. Global air circulation patterns help explain why some areas are consistently wet while others are dry. Warm air rises near the equator, cools as it rises, and releases moisture—creating the wet conditions typical of tropical rainforests. Around 30° latitude, the now-dry air descends, warming and absorbing moisture from the land, which leads to the formation of deserts. These large-scale wind and pressure systems, such as the trade winds and westerlies, help distribute heat and moisture around the planet and are essential in shaping the world's biomes.

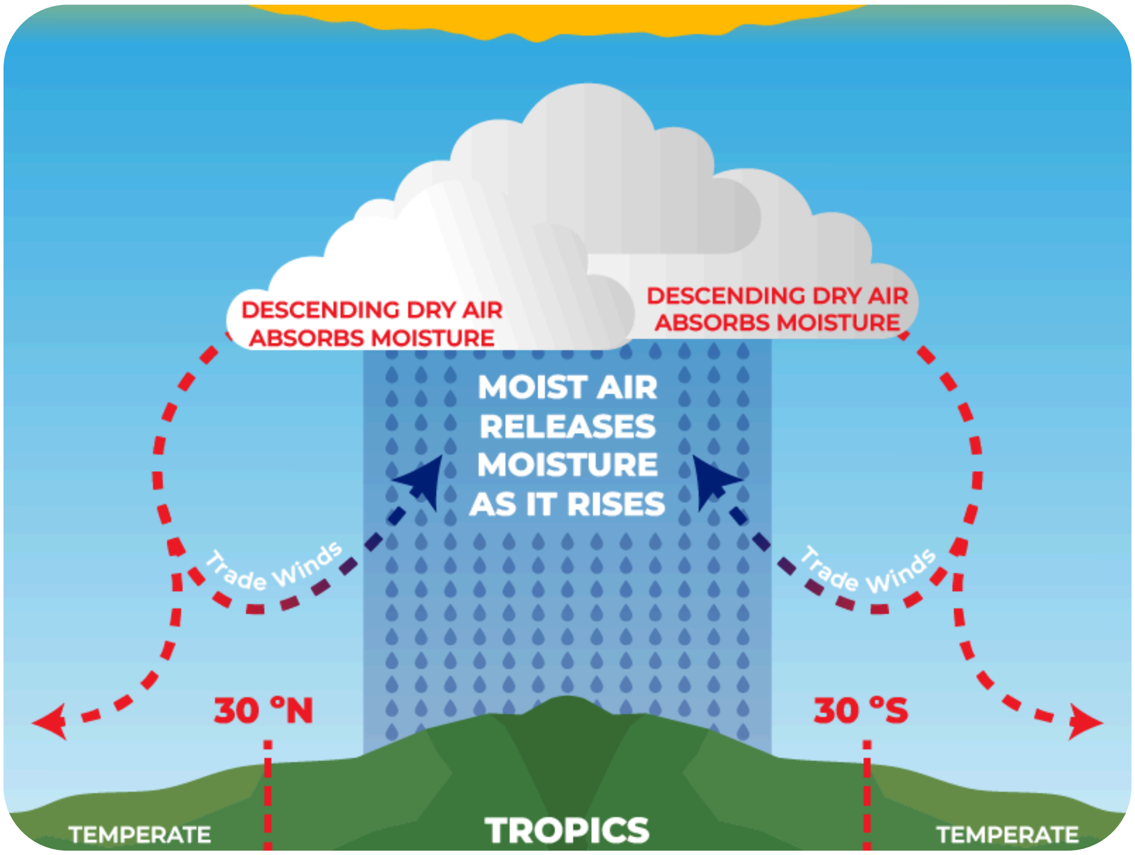


Figure 8.3.3 "Precipitation and Air Circulation" by Koen Liddiard, CC BY-NC-SA 4.0

**Figure 8.3.3 Image Description**

A diagram illustrating the global circulation of moist and dry air. In the center, moist air rises from the tropics, releasing moisture as rainfall. At higher altitudes, the air becomes dry and moves outward toward 30°N and 30°S. The descending dry air absorbs moisture, creating arid conditions. Red dashed arrows show the circulation of trade winds, curving back toward the tropics. The diagram labels the Tropics in the center, flanked by Temperate zones on either side.

## Proximity to Water

Water has a high heat capacity, meaning it warms and cools more slowly than land. As a result, areas near oceans or large lakes tend to have milder climates with smaller temperature fluctuations. Coastal regions often receive more precipitation and experience less extreme seasonal changes than inland areas at the same latitude.

## Other Influences on Climate

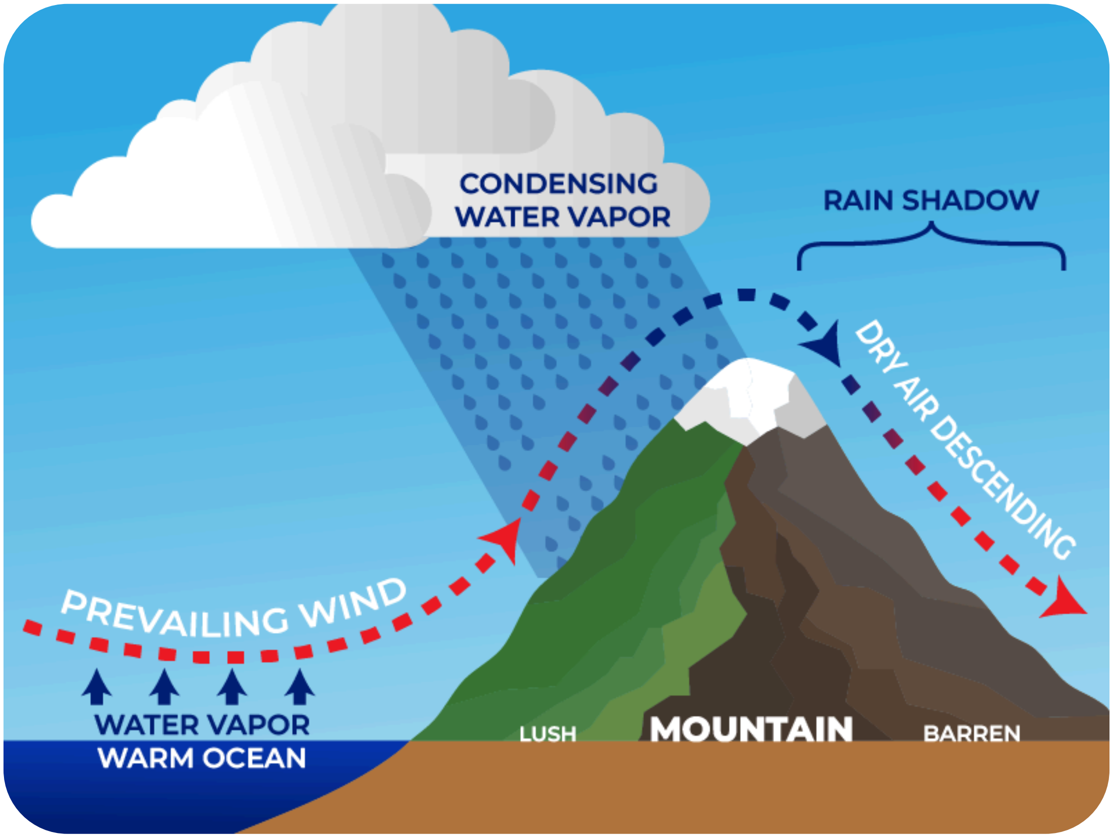


Figure 8.3.4 "Topography and Climate" by Koen Liddiard, CC BY-NC-SA 4.0

**Figure 8.3.4 Image Description**

A diagram illustrating the rain shadow effect. Moist air from a warm ocean rises with prevailing winds, carrying water vapour toward a mountain. As the air ascends, it cools and condenses into water vapour, producing rainfall on the lush, green windward side of the mountain. At the peak, the air loses most of its moisture and descends on the leeward side as dry air. This creates a rain shadow, resulting in a barren, brown landscape on the mountain's opposite side.

There are many other factors that also play a role in global climate patterns. Altitude affects temperature—higher elevations are generally cooler than lower ones. Topography, such as mountain ranges, can block air masses and create rain shadows, leading to dry conditions on one side of a mountain. Additionally, local wind patterns, cloud cover, and human activities can influence regional climates.

# Major Terrestrial Biomes

**Terrestrial biomes** are land-based ecosystems classified by their climate, dominant vegetation, and characteristic animal life.

### Tropical Rainforests

**Tropical rainforests** are found near the equator and are the most biologically diverse terrestrial biome. They have warm, stable temperatures year-round (20°C to 34°C) and receive 250 to over 450 cm of rainfall annually. Even in drier months, rainfall remains high compared to other biomes. The consistent warmth and sunlight support year-round plant growth, so these forests are highly productive.

Rainforests are structured in vertical layers, which creates a wide range of habitats. Common plants include broadleaf trees, vines, ferns, and epiphytes (plants that grow on other plants). Animals include jaguars, sloths, toucans, monkeys, frogs, and countless insect species. Many animals live in the canopy and rarely descend to the ground (OpenCurriculum, n.d.).

Tropical rainforests are vital for global biodiversity and climate regulation, but they face serious threats from deforestation and habitat loss.

Figure 8.3.5 Primary virgin tropical rainforest in Palawan, Philippines. The remainder of the tropical rainforest in the Philippines is found on the island of Palawan. The flora and fauna in Palawan are quite unique to the island, and are said to have more in common with those of Borneo than with the rest of the Philippines. "Palawan, Tropical jungle rainforest" by Vyacheslav Argenberg, CC BY 4.0

### Savannas

**Savannas** are grasslands with scattered trees, and they are located in Africa, South America, and Northern Australia. Savannas are hot, tropical areas with temperatures averaging from 24°C to 29°C and an annual rainfall of 50-120 cm. Savannas have an extensive dry season, so trees do not grow well. The open landscape allows sunlight to reach the ground, supporting a rich layer of grasses and herbaceous plants. Since fire is an important source of disturbance in this biome, plants have evolved well-developed root systems that allow them to quickly re-sprout after a fire.

Savannas support a wide variety of large herbivores, including elephants, giraffes, zebras, antelope, and wildebeest. These animals are often migratory, moving in herds in search of water and fresh grazing areas. The biome also supports many predators, such as lions, cheetahs, hyenas, and vultures, which rely on the abundance of herbivores for food. Smaller animals like meerkats, ground birds, and insects also thrive in this environment (OpenCurriculum, n.d.).

Figure 8.3.6 "Savanna Elephants (Loxodonta africana) crossing the Sabie River" by Bernard DUPONT, CC BY-SA 2.0

## Deserts

**Deserts** are dry biomes that receive less than 30 cm of precipitation per year. Most desserts are subtropical and found around 30° latitude north and south of the equator. These regions are known for their extreme heat, low humidity, and sparse vegetation.

Temperatures in deserts can exceed 40°C during the day but drop sharply at night due to the lack of cloud cover. The intense sunlight and dry air create harsh conditions for life, yet many organisms have evolved remarkable adaptations to survive. Plants in deserts are typically succulents, such as cacti and other plants that store water to help them during dry seasons. These plants often have thick, waxy cuticles, spines instead of leaves, and shallow but widespread roots to quickly absorb water from light rains. Animals in deserts are also well-adapted to conserve water and avoid heat. Many are nocturnal, active only at night when temperatures are cooler. Typical desert animals include lizards, snakes, and rodents (OpenCurriculum, n.d.).

In addition to subtropical deserts, there are cold deserts that experience freezing temperatures during the winter, and any precipitation is in the form of snowfall.

Figure 8.3.7 "Saguaro Cactus near Organ Pipe National Park", by Art Ivankin, CC BY 2.0

### Chaparral

The **chaparral** is a shrubland biome found in California, along the Mediterranean Sea, and along the southern coast of Australia. These areas experience hot, dry summers and mild, wet winters. Annual precipitation typically ranges from 65 to 75 centimetres, most of which falls during the winter months.

Temperatures in the chaparral can vary widely. Summer temperatures often exceed 30 °C, while winter temperatures are usually mild, ranging from 10 to 15°C. The long dry season and frequent droughts make fire a natural and important part of the chaparral ecosystem. Many plants are adapted to survive and even regenerate after periodic wildfires. The chaparral is a fragile biome that can be easily damaged by human activity like fire suppression, which disrupts natural fire cycles and leads to more intense wildfires.

Vegetation in the chaparral is dominated by dense, woody shrubs and small trees with tough, leathery leaves that reduce water loss. Some species have seeds that only germinate after exposure to fire (OpenCurriculum, n.d.).

Animals in the chaparral are adapted to the dry conditions and often avoid the heat by being active at night or during cooler parts of the day. They include rodents, lizards, and a variety of birds and insects. Most chaparral animals are small because the densely growing shrubs make it difficult for very large animals to move through. The largest animals are deer, which browse on the leaves of chaparral shrubs and trees (OpenCurriculum, n.d.).

Figure 8.3.8 The chaparral is dominated by shrubs. Photo by CNX OpenStax, CC BY 4.0

## Temperate Grasslands

**Temperate grasslands** are found in the interiors of continents, including the prairies of North America and the steppes of Eurasia. Annual precipitation typically ranges from 25 to 90 cm, which is enough to support grasses but not large stands of trees.

Temperate grasslands experience seasonal temperature extremes. Summers are often hot, with temperatures above 30°C, while winters can be very cold, with temperatures well below freezing.

Periodic droughts and fires are common and play an important role in maintaining the grassland ecosystem by preventing the growth of woody plants.

The dominant vegetation consists of grasses that are adapted to survive grazing, fire, and dry conditions. Many have deep root systems that help them access water and recover quickly after disturbances. Temperate grasslands support a variety of grazing animals and their predators. Common animals include bison, antelope, and small mammals such as prairie dogs and rabbits. Predators like wolves, coyotes, and foxes are also found in these ecosystems. Many animals are adapted to open landscapes and use burrows for shelter and protection (OpenCurriculum, n.d.).

Because of their rich, fertile soils, temperate grasslands have been heavily converted to agriculture, especially for growing grains like wheat and corn. As a result, much of the original grassland habitat has been lost, and many native species are now threatened (OpenCurriculum, n.d.).

Figure 8.3.9 "Pawnee Buttes Cloudscape" by MichaelKirsh, CC BY 3.0

## Temperate Forests

**Temperate forests** are the most common biome in eastern North America, Western Europe, Eastern Asia, Chile, and New Zealand. These areas experience four distinct seasons (spring, summer, autumn, and winter) with temperatures that range between –30 °C and 30 °C throughout the year. Precipitation is relatively constant throughout the year and ranges between 75 cm and 150 cm.

The dominant vegetation in temperate forests includes deciduous trees, such as oak, maple, beech, and birch, which lose their leaves each fall. In some mixed forests, coniferous trees like pine, spruce and fir are also common. The trees of the temperate forests leaf out and shade much of the ground; however, more sunlight reaches the ground in this biome than in tropical rainforests because trees in temperate forests do not grow as tall. As a result, the understory contains mosses, ferns, various herbaceous plants, and shrubs. The forest floor is often rich in organic material due to the seasonal leaf drop. As the thick layer of leaf litter decays, nutrients are returned to the soil. The leaf litter also protects soil from erosion, insulates the ground, and provides habitats for invertebrates and their predators (OpenCurriculum, n.d.).

Temperate forests support a wide variety of animal life. Common mammals include deer, raccoons, squirrels, and black bears. There are also insects, amphibians, reptiles, and birds. Many animals in this biome are adapted to seasonal changes, with some hibernating or migrating during the winter months (OpenCurriculum, n.d.).

Figure 8.3.10 Northern hardwood forest near Fritz Run, State Game Land 127, Monroe County. Photo by Nicholas_T, CC BY 2.0

## Boreal Forests

**Boreal forests**, or coniferous forests, are found in the high northern latitudes just below the Arctic Circle, stretching across Canada, Alaska, Russia, and Scandinavia. These forests experience long, cold winters and short, cool summers. Annual precipitation ranges from 40 to 100 cm and usually takes the form of snow.

Temperatures in boreal forests are cold for most of the year. Winter temperatures often drop well below freezing, while summer temperatures are mild, typically ranging from 10 to 20°C. The growing season is short, usually lasting only a few months.

The vegetation is dominated by coniferous trees such as spruce, fir, pine, and cedar, which are well adapted to cold conditions. These trees retain their needle-like leaves and can begin photosynthesis earlier in the spring than deciduous trees. It also takes less energy to warm a narrow needle than a broad leaf, which further allows evergreens to start growing during cooler temperatures. The forest floor is often covered with mosses, lichens, and low shrubs (OpenCurriculum, n.d.).

Animal life in the boreal forest includes species adapted to cold and seasonal changes. Common mammals include moose, wolves, snowshoe hares, and bears. Through the summer, there are also many insects and birds. Caribou spend their winters there. The boreal forest is too cold for amphibians or reptiles (OpenCurriculum, n.d.).

Boreal forests store large amounts of carbon because these slow-growing tree species are long-lived. This makes them important for climate regulation; however, they are often affected by human activities like logging and mining.

Figure 8.3.11 "Northern forest" by peupleloup, CC BY-SA 2.0

## Arctic Tundra

The **Arctic tundra** is found in the far northern regions of the world, including parts of Alaska, Canada, Greenland, and northern Russia. It is the coldest of all biomes and is characterized by long, harsh winters and short, cool summers. Temperatures can drop below -30 °C in winter and rarely rise above 10°C in summer. Annual precipitation is typically less than 25 cm and mostly falls as snow. The growing season is very short and lasts only about 2 months.

Plants in the Arctic tundra are generally low to the ground and include low shrubs, grasses, mosses, lichens, and small flowering plants. A defining feature of the tundra is **permafrost**, a layer of permanently frozen soil beneath the surface. The top layer of soil thaws in the summer, but deeper layers do not, so water cannot soak into the ground. This leaves the soil soggy and creates many bogs, lakes, and streams (OpenCurriculum, n.d.).

Few animals live in the tundra year-round. Those that remain have adapted to the extreme cold, including polar bears, arctic foxes and arctic hares. Insects such as mosquitoes can survive the winter as pupae and are very numerous in summer. Many species of birds and large herds of caribou migrate to the Arctic tundra each summer. There are no amphibians or reptiles. The Arctic tundra is a fragile ecosystem that is highly sensitive to climate change. Warming temperatures are causing permafrost to thaw, which can release stored carbon and further accelerate global warming (OpenCurriculum, n.d.).

Figure 8.3.12 "Nunavut tundra" by ADialla, CC BY 2.0

## Knowledge Check

**Text Description**

**1. Multiple Choice Activity #1**

What is the primary factor that defines the distribution of Earth's major terrestrial biomes?

a. Soil composition
b. Altitude and proximity to cities
c. Climate patterns of temperature and precipitation
d. The types of animals present in an area

**2. Multiple Choice Activity #2**

Which biome is characterized by long, cold winters, needle-leaved coniferous trees, and a forest floor covered with mosses and lichens?

a. Temperate forest
b. Boreal forest
c. Temperate grassland
d. Chaparral

**3. Multiple Choice Activity #3**

What climatic condition explains the location of most subtropical deserts around 30° latitude?

a. Heavy rainfall caused by ocean currents
b. Dry air descending from global air circulation patterns
c. Frequent monsoons caused by seasonal winds
d. Cold air trapped by high mountain ranges

**4. Multiple Choice Activity #4**

Which of the following adaptations is most common among plants in desert environments?

a. Broad leaves to maximize photosynthesis
b. Shallow root systems to collect water from dew
c. Water storage in thick tissues and waxy cuticles
d. Large surface area for faster transpiration

**5. Multiple Choice Activity #5**

Why do tundra soils often remain soggy during the summer months?

a. The soil is naturally very rich in clay
b. Rainfall increases drastically in the summer
c. Permafrost prevents water from draining into deeper layers
d. High winds constantly blow water into depressions

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**Answers:**

1. c
2. b
3. b
4. c
5. c

OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Create 5 multiple-choice questions using the following content

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# 8.4 AQUATIC BIOMES

**Aquatic biomes** are water-based biomes defined by factors such as water depth, temperature, salinity, and the amount of sunlight that penetrates the water. Aquatic ecosystems support a wide variety of life and play a crucial role in global processes like climate regulation, oxygen production, and nutrient cycling. Aquatic biomes are divided into two main types: marine and freshwater.

## Marine Biomes

**Marine biomes** include all saltwater environments, such as oceans, coral reefs, and estuaries. These ecosystems are the largest on Earth and support a vast diversity of organisms, from microscopic plankton to the largest animals on the planet.

### Ocean

The ocean is categorized by several zones (Figure 8.4.1). All of the ocean's open water is referred to as the **pelagic realm** (or zone). The **benthic realm** (or zone) extends along the ocean bottom from the shoreline to the deepest parts of the ocean floor. From the surface to the bottom or the limit to which photosynthesis occurs is the **photic zone** (approximately 200 m). At depths greater than 200 m, light cannot penetrate; thus, this is referred to as the **aphotic zone**. The majority of the ocean is aphotic and lacks sufficient light for photosynthesis. The deepest part of the ocean, the Challenger Deep (in the Mariana Trench, located in the western Pacific Ocean), is about 11,000 m deep. To give some perspective on the depth of this trench, the ocean is, on average, 4267 m deep.

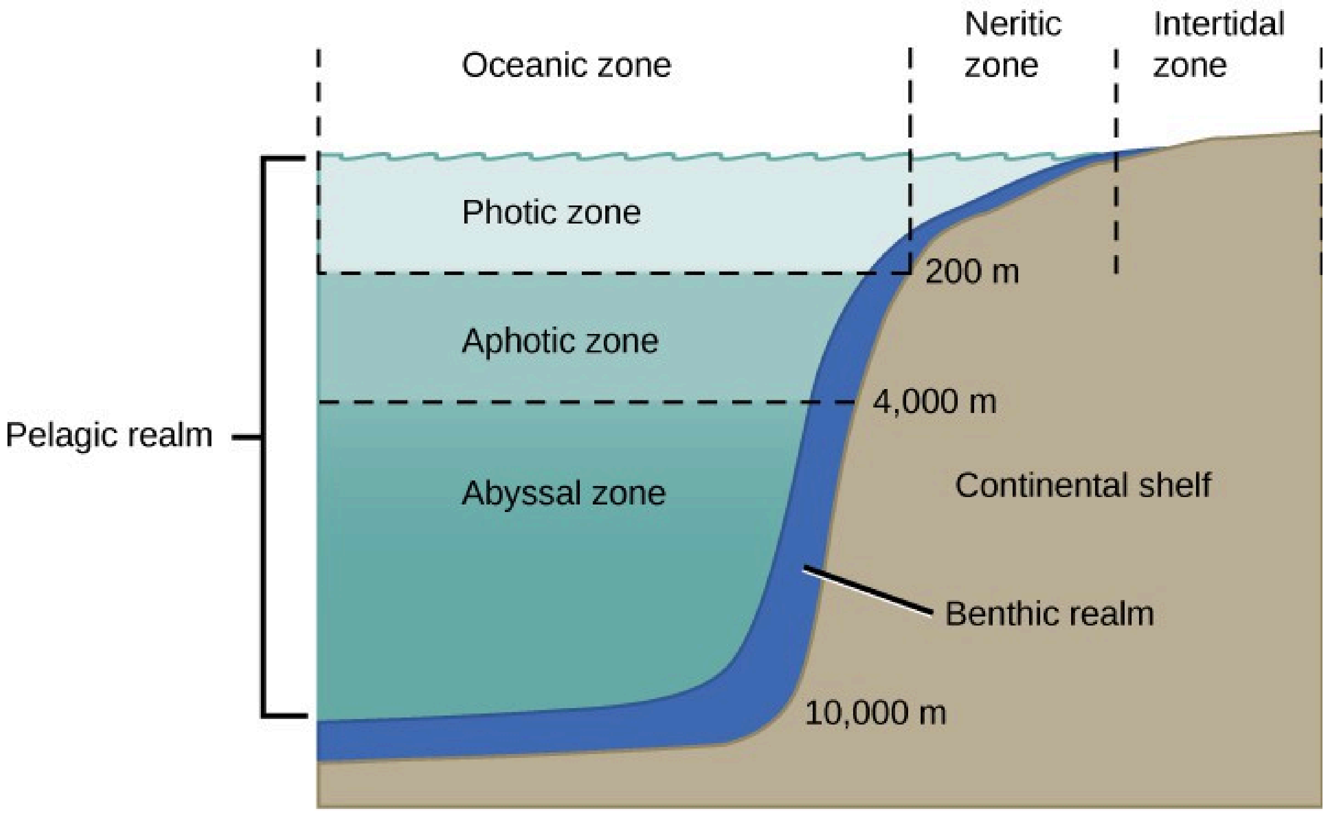


Figure 8.4.1 The ocean is divided into different zones based on water depth, distance from the shoreline, and light penetration. Illustration by OpenStax, CC BY 4.0

**Figure 8.4.1 Image Description**

A cross-sectional diagram of the ocean showing its ecological zones by depth and distance from shore. The intertidal zone lies at the shoreline, followed by the neritic zone over the continental shelf, and the deeper oceanic zone beyond. Vertically, the pelagic realm is divided into layers: the photic zone (surface to ~200 m), where light penetrates, the aphotic zone (200 m to ~4,000 m), where no light reaches, and the abyssal zone (below 4,000 m to ~10,000 m). The benthic realm refers to the seafloor, spanning from shallow continental shelves to the deepest ocean trenches.

The physical diversity of the ocean has a significant influence on the diversity of organisms that live within it. The ocean is categorized into different zones based on how far light reaches into the water. Each zone has a distinct group of species adapted to the biotic and abiotic conditions particular to that zone.

The **intertidal zone** is the oceanic region closest to land. With each tidal cycle, the intertidal zone alternates between being inundated with water and left high and dry. Generally, most people think of this portion of the ocean as a sandy beach. In some cases, the intertidal zone is indeed a sandy beach, but it can also be rocky, muddy, or dense with tangled roots in mangrove forests. The intertidal zone is an extremely variable environment because of tides. Organisms may be exposed to air at low tide and are underwater during high tide. Therefore, living things that thrive in the intertidal zone are often adapted to being dry for long periods of time. The shore of the intertidal zone is also repeatedly struck by waves, and the organisms found there are adapted to withstand damage from the pounding action of the waves. The exoskeletons of shoreline crustaceans (such as the shore crab, *Carcinus maenas*) are tough and protect them from desiccation (drying out) and wave damage. Another consequence of the pounding waves is that few algae and plants establish themselves in constantly moving sand or mud.

Figure 8.4.2 Sea stars, sea urchins, and mussel shells are often found in the intertidal zone, shown here in Kachemak Bay, Alaska. Photo by NOAA, Public Domain

The **neritic zone** extends from the margin of the intertidal zone to depths of about 200 m at the edge of the continental shelf. When the water is relatively clear, photosynthesis can occur in the neritic zone. The water contains silt and is well-oxygenated, low in pressure, and stable in temperature. These factors all contribute to the neritic zone having the highest productivity and biodiversity of the ocean. Phytoplankton, including photosynthetic bacteria and larger species of algae, are responsible for the bulk of this primary productivity. Zooplankton, protists, small fishes, and shrimp feed on the producers and are the primary food source for most of the world's fisheries. The majority of these fisheries exist within the neritic zone.

Beyond the neritic zone is the open ocean area known as the **oceanic zone**. Within the oceanic zone, there is thermal stratification. Abundant phytoplankton and zooplankton support populations of fish and whales. Nutrients are scarce, and this is a relatively less productive part of the marine biome. When photosynthetic organisms and the organisms that feed on them die, their bodies fall to the bottom of the ocean, where they remain; the open ocean lacks a process for bringing the organic nutrients back up to the surface.

Beneath the pelagic zone is the benthic realm, the deepwater region beyond the continental shelf. The bottom of the benthic realm is comprised of sand, silt, and dead organisms. Temperature decreases as water depth increases. This is a nutrient-rich portion of the ocean because of the dead organisms that fall from the upper layers of the ocean. Because of this high level of nutrients, a diversity of fungi, sponges, sea anemones, marine worms, sea stars, fishes, and bacteria exists.

The deepest part of the ocean is the **abyssal zone**, which is at depths of 4000 m or greater. The abyssal zone is very cold and has very high pressure, high oxygen content, and low nutrient content. There are a variety of invertebrates and fishes found in this zone, but the abyssal zone does not have photosynthetic organisms. Chemosynthetic bacteria use the hydrogen sulphide and other minerals emitted from deep hydrothermal vents. These chemosynthetic bacteria use hydrogen sulphide as an energy source and serve as the base of the food chain found around the vents.

## Coral Reefs

**Coral reefs** are ocean ridges formed by marine invertebrates living in warm shallow waters within the photic zone of the ocean. They are found within 30° north and south of the equator. The Great Barrier Reef is a well-known reef system located several miles off the northeastern coast of Australia. Other coral reefs are fringing islands, which are directly adjacent to land, or atolls, which are circular reefs surrounding a former island that is now underwater. The coral-forming colonies of organisms (members of the phylum Cnidaria) secrete a calcium carbonate skeleton. These calcium-rich skeletons slowly accumulate, thus forming the underwater reef (Figure 8.4.3). Corals found in shallower waters (at a depth of approximately 60 m) have a mutualistic relationship with photosynthetic unicellular protists. The relationship provides corals with the majority of the nutrition and the energy they require. The waters in which these corals live are nutritionally poor, and without this mutualism, it would not be possible for large corals to grow because there are few planktonic organisms for them to feed on. Some corals living in deeper and colder water do not have a mutualistic relationship with protists; these corals must obtain their energy exclusively by feeding on plankton using stinging cells on their tentacles.

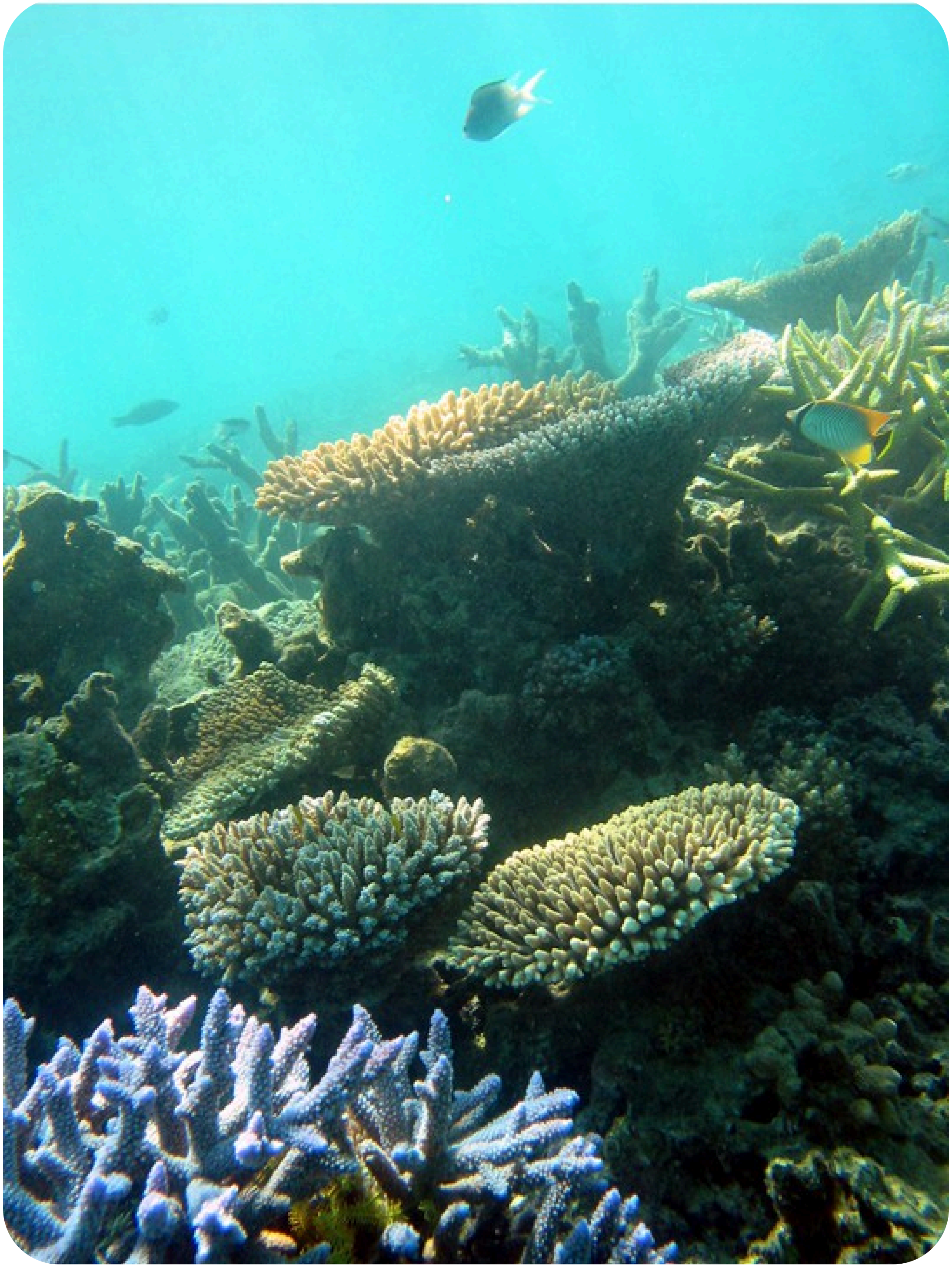

Figure 8.4.3 Coral reefs are formed by the calcium carbonate skeletons of coral organisms, which are marine invertebrates in the phylum Cnidaria. Photo by Terry Hughs, CC BY 2.5

Coral reefs are one of the most diverse biomes. It is estimated that more than 4000 fish species inhabit coral reefs. These fishes can feed on coral, the cryptofauna (invertebrates found within the calcium carbonate structures of the coral reefs), or the seaweed and algae that are associated with the coral. These species include predators, herbivores, or planktivores. Predators are animal species that hunt and are carnivores or "flesh eaters." Herbivores eat plant material, and planktivores eat plankton.

It takes a long time to build a coral reef. The animals that create coral reefs do so over thousands of years, continuing to slowly deposit the calcium carbonate that forms their characteristic ocean homes. Bathed in warm tropical waters, the coral animals and their symbiotic protist partners evolved to survive at the upper limit of ocean water temperature.

Together, climate change and human activity pose dual threats to the long-term survival of the world's coral reefs. The main cause of the killing of coral reefs is warmer-than-usual surface water. As global warming raises ocean temperatures, coral reefs are suffering. The excessive warmth causes the coral organisms to expel their endosymbiotic, food-producing protists, resulting in a phenomenon known as bleaching. The colours of corals are a result of the particular protist endosymbiont, and when the protists leave, the corals lose their colour and turn white, hence the term "bleaching."

Rising levels of atmospheric carbon dioxide further threaten the corals in other ways; as carbon dioxide dissolves in ocean waters, it lowers pH, thus increasing ocean acidity. As acidity increases, it interferes with the calcification that normally occurs as coral animals build their calcium carbonate homes.

When a coral reef begins to die, species diversity plummets as animals lose food and shelter. Coral reefs are also economically important tourist destinations, so the decline of coral reefs poses a serious threat to coastal economies.

Human population growth has damaged corals in other ways, too. As human coastal populations increase, the runoff of sediment and agricultural chemicals has increased, causing some of the once-clear tropical waters to become cloudy. At the same time, overfishing of popular fish species has allowed the predator species that eat corals to go unchecked.

Although a rise in global temperatures of 1°C–2°C (a conservative scientific projection) in the coming decades may not seem large, it is very significant to this biome. When change occurs rapidly, species can become extinct before evolution leads to newly adapted species. Many scientists believe that global warming, with its rapid (in terms of evolutionary time) and inexorable increases in temperature, is tipping the balance beyond the point at which many of the world's coral reefs can recover.

## Estuaries

**Estuaries** are biomes that occur where a river, a source of fresh water, meets the ocean. Therefore, both fresh water and salt water are found in the same vicinity; mixing results in a diluted (brackish) salt water. Estuaries form protected areas where many of the offspring of crustaceans, mollusks, and fish begin their lives. Salinity is an important factor that influences the organisms and their adaptations found in estuaries. The salinity of estuaries varies and is based on the rate of flow of its freshwater sources. Once or twice a day, high tides bring salt water into the estuary. Low tides occurring at the same frequency reverse the current of salt water.

Figure 8.4.4 An estuary is where fresh water and salt water meet, such as the mouth of the Klamath River in California, shown here. Photo by US Army Corps of Engineers, Public Domain

The daily mixing of fresh water and salt water is a physiological challenge for the plants and animals that inhabit estuaries. Many estuarine plant species are halophytes, plants that can tolerate salty conditions. Halophytic plants are adapted to deal with saltwater spray and saltwater on their roots. In some halophytes, filters in the roots remove the salt from the water that the plant absorbs. Animals, such as mussels and clams (phylum Mollusca), have developed behavioural adaptations that expend a lot of energy to function in this rapidly changing environment. When these animals are exposed to low salinity, they stop feeding, close their shells, and switch from aerobic respiration (in which they use gills) to anaerobic respiration (a process that does not require oxygen). When high tide returns to the estuary, the salinity and oxygen content of the water increases, and these animals open their shells, begin feeding, and return to aerobic respiration.

# Freshwater Biomes

**Freshwater biomes** include lakes, ponds, and wetlands (standing water) as well as rivers and streams (flowing water). Humans rely on freshwater biomes to provide aquatic resources for drinking water, crop irrigation, sanitation, recreation, and industry. These various roles and human benefits are referred to as ecosystem services. Lakes and ponds are found in terrestrial landscapes and are therefore connected with abiotic and biotic factors influencing these terrestrial biomes.

## Lakes and Ponds

Figure 8.4.5 The Great Lakes account for 21% of the world's freshwater. Photo by NASA, Public Domain

Lakes and ponds can range in area from a few square meters to thousands of square kilometres. Temperature is an important abiotic factor affecting living things found in lakes and ponds. During the summer in temperate regions, thermal stratification of deep lakes occurs when the upper layer of water is warmed by the Sun and does not mix with deeper, cooler water. The process produces a sharp transition between the warm water above and the cold water beneath. The two layers do not mix until cooling temperatures and winds break down the stratification, and the water in the lake mixes from top to bottom. During the period of stratification, most of the productivity occurs in the warm, well-illuminated upper layer, while dead organisms slowly rain down into the cold, dark layer below, where decomposing bacteria and cold-adapted species such as lake trout exist. Like the ocean, lakes and ponds have a photic layer in which photosynthesis can occur. Phytoplankton (algae and cyanobacteria) are found here and provide the base of the food web of lakes and ponds. Zooplankton, such as rotifers and small crustaceans, consume these phytoplankton. At the bottom of lakes and ponds, bacteria in the aphotic zone break down dead organisms that sink to the bottom.

## Rivers and Streams

Rivers and the narrower streams that feed into the rivers are continuously moving bodies of water that carry water from the source, or headwater, to the mouth at a lake or ocean. The largest rivers include the Nile River in Africa, the Amazon River in South America, and the Mississippi River in North America (Figure 8.4.6).

Figure 8.4.6 Rivers range from (a) narrow and shallow to (b) wide and slow-moving. Photo (a) by Marta Wave, Pexels License, Photo (b) by David DeHetre, CC BY 2.0

Abiotic features of rivers and streams vary along the length of the river or stream. Streams begin at a point of origin referred to as source water. The source water is usually cold, low in nutrients, and clear. The channel (the width of the river or stream) is narrower here than at any other place along the length of the river or stream. Headwater streams are of necessity at a higher elevation than the mouth of the river and often originate in regions with steep grades, leading to higher flow rates than lower elevation stretches of the river.

Faster-moving water and the short distance from its origin results in minimal silt levels in headwater streams; therefore, the water is clear. Photosynthesis here is mostly attributed to algae that are growing on rocks; the swift current inhibits the growth of phytoplankton. Photosynthesis may be further reduced by tree cover reaching over the narrow stream. This shading also keeps temperatures lower. An additional input of energy can come from leaves or other organic material that falls into a river or stream from the trees and other plants that border the water. When the leaves decompose, the organic material and nutrients in the leaves are returned to the water. The leaves also support a food chain of invertebrates that eat them and are in turn eaten by predatory invertebrates and fish. Plants and animals have adapted to this fast-moving water. For instance, leeches (phylum Annelida) have elongated bodies and suckers on both ends. These suckers attach to the substrate, keeping the leech anchored in place. In temperate regions, freshwater trout species (phylum Chordata) may be an important predator in these fast-moving and colder rivers and streams.

As the river or stream flows away from the source, the width of the channel gradually widens, the current slows, and the temperature characteristically increases. The increasing width results from the increased volume of water from more and more tributaries (stream or river that flows into a larger river or a lake). Gradients are typically lower farther along the river, which accounts for the slowing flow. With increasing volume can come increased silt, and as the flow rate slows, the silt may settle, thus increasing the deposition of sediment. Phytoplankton can also be suspended in slow-moving water. Therefore, the water will not be as clear as it is near the source. The water is also warmer as a result of longer exposure to sunlight and the absence of tree cover over wider expanses between banks. Worms (phylum Annelida) and insects (phylum Arthropoda) can be found burrowing into the mud. Predatory vertebrates (phylum Chordata) include waterfowl, frogs, and fishes. In heavily silt-laden rivers, these predators must find food in the murky waters, and, unlike the trout in the clear waters at the source, these vertebrates cannot use vision as their primary sense to find food. Instead, they are more likely to use taste or chemical cues to find prey.

When a river reaches the ocean or a large lake, the water typically slows dramatically, and any silt in the river water will settle. Rivers with high silt content discharging into oceans with minimal currents and wave action will build deltas, low-elevation areas of sand and mud, as the silt settles onto the ocean bottom. Rivers with low silt content or in areas where ocean currents or wave action are high create estuarine areas where the fresh water and salt water mix.

## Wetlands

**Wetlands** are environments in which the soil is either permanently or periodically saturated with water. Wetlands are different from lakes and ponds because wetlands exhibit a near continuous cover of emergent vegetation. Emergent vegetation consists of wetland plants that are rooted in the soil but have portions of leaves, stems, and flowers extending above the water's surface. There are several types of wetlands, including marshes, swamps, bogs, mudflats, and salt marshes (Figure 8.4.7).

Figure 8.4.7 Located in southern Florida, Everglades National Park is a vast array of wetland environments, including sawgrass marshes, cypress swamps, and estuarine mangrove forests. Here, a great egret walks among cypress trees. Photo by NPSPhoto, Public Domain

Freshwater marshes and swamps are characterized by slow and steady water flow. Bogs develop in depressions where water flow is low or nonexistent. Bogs usually occur in areas where there is a clay bottom with poor percolation. Percolation is the movement of water through the pores in the soil or rocks. The water found in a bog is stagnant and oxygen-depleted because the oxygen that is used during the decomposition of organic matter is not replaced. As the oxygen in the water is depleted, decomposition slows. This leads to organic acids and other acids building up and lowering the pH of the water. At a lower pH, nitrogen becomes unavailable to plants. This creates a challenge for plants because nitrogen is an important limiting resource. Some types of bog plants (such as sundews, pitcher plants, and Venus flytraps) capture insects and extract the nitrogen from their bodies. Bogs have low net primary productivity because the water found in bogs has low levels of nitrogen and oxygen.

## Knowledge Check

**Text Description**

**1. Multiple Choice Activity #1**

Which of the following ocean zones contains the highest biodiversity and productivity due to its shallow depth, high oxygen, and light availability?

a. Abyssal zone
b. Oceanic zone
c. Neritic zone
d. Aphotic zone

**2. Multiple Choice Activity #2**

What causes coral bleaching, a phenomenon that threatens coral reef ecosystems?

a. Overgrowth of algae blocking sunlight
b. Excessive sediment from rivers
c. Expulsion of symbiotic protists due to high water temperatures
d. A decrease in salinity caused by rainfall

**3. Multiple Choice Activity #3**

What percentage of the world's surface freshwater is contained in the Great Lakes?

a. 47%
b. 21%
c. 13%
d. 5%

**4. Multiple Choice Activity #4**

Which adaptation allows estuarine mussels and clams to survive fluctuating salinity levels?

a. Use of tentacles to regulate salt content
b. Switching between aerobic and anaerobic respiration
c. Producing salt through excretion
d. Photosynthesis for salt metabolism

**5. Multiple Choice Activity #5**

What is a key characteristic of bogs that leads to low plant productivity?

a. High oxygen levels and high nitrogen availability
b. Fast-flowing water and high pH
c. Stagnant, acidic water with low oxygen and nitrogen
d. Continuous light exposure and low humidity

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**Answers:**

1. c
2. c
3. b
4. b
5. c

OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Create 5 multiple-choice questions using the following content

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# CHAPTER 8 SUMMARY

## Key Takeaways

- **Ecology Studies Interactions Across Multiple Levels:** Ecology examines how organisms interact with their environment and each other, with research conducted at four main levels: organismal, population, community, and ecosystem. Each level helps explain species survival, distribution, and environmental relationships, like how woodland caribou are affected by predators, food sources, and habitat conditions.
- **Abiotic Factors Shape Life's Distribution:** The distribution of life on Earth is heavily influenced by abiotic (non-living) factors such as solar energy, temperature, water availability, and inorganic nutrients. These factors determine where photosynthesis can occur, how organisms regulate body temperature or retain water, and the fertility of soils for plant growth.
- **Organisms Adapt in Three Main Ways to Changing Environments:** To cope with environmental fluctuations (e.g., seasonal changes or extreme weather), organisms respond through:
    - Physiological responses (e.g., hibernation, acclimation)
    - Anatomical changes (e.g., thicker fur)
    - Behavioural strategies (e.g., migration or altering activity times)
- **Climate Controls Biome Formation and Distribution:** Biomes are large regions defined by climate, which influences vegetation and the animals that live there. Key climate drivers include latitude, Earth's axial tilt, air circulation patterns, proximity to water, and topography (e.g., rain shadows). These variables create predictable patterns, such as rainforests near the equator and deserts around 30° latitude.
- **Terrestrial Biomes Are Characterized by Climate, Flora, and Fauna:** Each biome supports species uniquely adapted to its temperature, precipitation, and growing conditions. Major terrestrial biomes include:

- Tropical rainforests (biodiverse, warm, wet)
  - Savannas (grasslands with seasonal drought)
  - Deserts (dry, extreme temperatures)
  - Chaparral (shrubland with fire-adapted species)
  - Temperate grasslands and forests (seasonal climates)
  - Boreal forests (cold-adapted evergreens)
  - Tundra (frozen, low productivity)
- **Human Activity and Climate Change Impact Ecosystems:** Human actions—such as deforestation, urbanization, industrial development, and climate change—are significantly altering ecosystems. Examples include boreal forest carbon storage loss, tundra permafrost thawing, and habitat fragmentation, which reduce biodiversity and affect species survival.

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Summarize the following content into six key takeaways.

## Flashcards

Click on the flashcards to review key terms discussed in this chapter.

**Text Description**

**Front of Card:**

1. Abiotic factors
2. Acclimation
3. Anatomical responses
4. Atmospheric pollution
5. Behavioural responses

6. Biomes
7. Biosphere
8. Biotic factors
9. Carbon balance
10. Community
11. Community ecology
12. Conservation biologist
13. Distribution
14. Ecosystem
15. Ecosystem ecology
16. Energy source
17. Endangered species
18. Evolution
19. Habitat
20. Homeostasis
21. Inorganic nutrients
22. Latitude
23. Migration
24. Nutrient cycling
25. Organismal ecology
26. Permafrost
27. Photic zone
28. Photosynthesis
29. Physiological responses
30. Population
31. Population ecology
32. Precipitation
33. Rain shadow
34. Species
35. Temperature
36. Torpor
37. Water availability

**Back of Card:**

1. The non-living components of the environment, such as temperature, sunlight, water, soil,

and air.

2. A gradual, reversible physiological adjustment to a new environmental condition.
3. Physical changes in an organism's body structure that help it adapt to environmental changes (e.g., growing thicker fur in winter).
4. Airborne pollutants, such as acid rain or nitrogen deposition, which can alter ecosystems.
5. Actions or movements organisms perform to reduce or avoid exposure to unfavourable environmental conditions (e.g., migration).
6. Large geographic regions characterized by distinct climate, vegetation, and animal life.
7. The global sum of all ecosystems, anywhere life exists on Earth.
8. The living components of the environment, such as plants, animals, fungi, and microbes.
9. The relationship between the amount of carbon stored and released in an ecosystem.
10. All the different species living in a particular area and the interactions among them.
11. The study of interspecific interactions between species within a community.
12. A scientist who studies and develops methods to protect biodiversity and endangered species.
13. The geographical area over which organisms are found.
14. A community of living organisms interacting with the non-living elements of their environment.
15. The study of how energy flows and nutrients cycle through biological communities and their physical environments.
16. A basic abiotic factor required for life; most commonly, solar energy captured through photosynthesis.
17. A species that is at serious risk of extinction.
18. The process through which species change over time through genetic variation and natural selection.
19. The natural environment in which an organism lives, including all the resources and conditions it needs to survive.
20. Maintaining stable internal conditions in an organism despite changes in the external environment.
21. Essential minerals (e.g., nitrogen, phosphorus, potassium) are required for the growth and survival of organisms.
22. A measure of how far a location is from the equator, affecting climate and biome distribution.
23. The movement of organisms from one region to another, often seasonally, in response to environmental conditions.
24. The movement and exchange of organic and inorganic matter back into the production of

living matter.
25. The study of how individual organisms adapt to their environments.
26. A layer of permanently frozen soil found in tundra regions that affects drainage and plant growth.
27. The upper layer of a body of water that receives enough sunlight for photosynthesis to occur.
28. The process by which photosynthetic organisms convert sunlight into chemical energy.
29. Short-term or reversible changes in an organism's body function in response to environmental conditions.
30. A group of interbreeding individuals of the same species living in the same area.
31. The study of the number of individuals in a population and how and why that number changes over time.
32. Rain, snow, sleet, or hail that falls to the ground influences biome types and plant life.
33. A dry area on the leeward side of a mountain range is created when mountains block the passage of rain-producing weather systems.
34. A group of organisms that can interbreed and produce fertile offspring.
35. An abiotic factor that influences the range of environments in which organisms can survive and thrive.
36. A state of decreased physiological activity in an animal, usually by a reduced body temperature and metabolic rate.
37. The presence of water in an ecosystem is a critical factor for life.

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Provide definitions for all the bolded terms in the shared content and list all the terms in alphabetical order.

# CHAPTER 9: POPULATION ECOLOGY

## Chapter Overview

## Learning Objectives

By the end of this chapter, you will be able to:

- Define and explain key population ecology concepts, including population size, density, distribution, growth, survivorship curves, and reproductive strategies (r- and K-selection).
- Compare and contrast exponential and logistic population growth models, and describe how carrying capacity and limiting factors influence population dynamics.
- Differentiate between density-dependent and density-independent limiting factors and analyze how they regulate population size in various environmental contexts.
- Evaluate the ecological principles used in conservation efforts, such as the protection and recovery of endangered species and the sustainable management of natural resources like fisheries and forests.
- Analyze the impact of invasive species on ecosystems, and explain how population ecology informs the development of control strategies, including biological control methods.
- Interpret human population trends and their ecological implications, including age structure, ecological footprints, and the concept of ecological overshoot and carrying capacity.

OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat Prompt: Provide six learning objectives for the shared content.

# 9.1 OVERVIEW OF POPULATION ECOLOGY

A population is a group of individuals of the same species living in the same area at the same time. Population ecology focuses on how these groups change over time – how many individuals are born, how many die, and how they interact with their environment. Scientists study population size, density, distribution, and growth to understand how species survive and adapt.

## Population Size and Density

Two basic ways to describe a population are by its size and density.

**Population size** refers to the total number of individuals in a population at a specific time. For example, if there are 500 deer in a forest, the population size is 500. This number is always changing due to births, deaths, immigration, and emigration. Births and immigration increase the population, while deaths and emigration decrease it. For example, the population will grow if more individuals are born or move into an area than die or leave. These changes can happen gradually or rapidly, depending on environmental conditions, food availability, disease, natural disasters, or human activity. Understanding how and why population size changes helps scientists monitor species health, predict future trends, and make decisions about conservation and resource management.

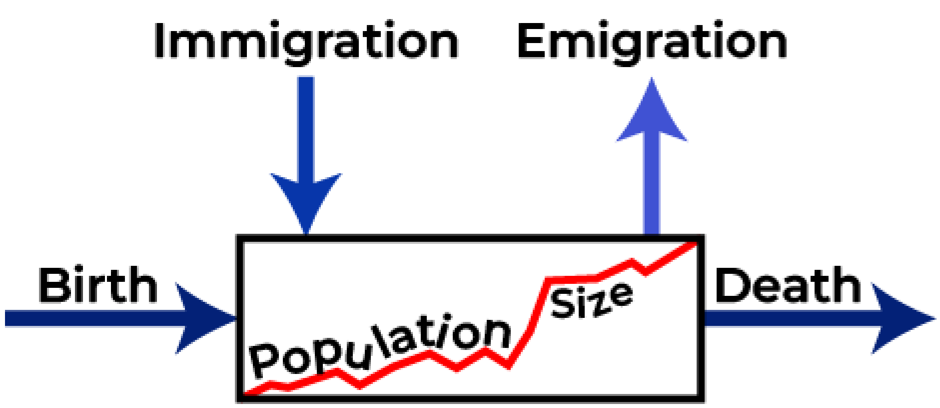


Figure 9.1.1 Diagram showing how population size changes: births and immigration increase population, while deaths and emigration decrease population. Image by Koen Liddiard, CC BY-NC-SA 4.0

The most accurate way to determine population size is to count all of the individuals within the area;

however, this method is usually not logistically or economically feasible, especially when studying large areas. Thus, scientists usually study populations by sampling a representative portion of each habitat and use this sample to make inferences about the population as a whole.

Figure 9.1.2 London Wildlife Trust Ecologist Tony Wileman and an assistant carrying out a transect survey of the anthill meadow in Gunnersbury Triangle local nature reserve. The quadrats are placed every 2 metres along the transect line, and all the plants in the sample areas are listed. Image by Ian Alexander, CC BY-SA

One common method is **quadrant sampling**, where researchers mark off small, square plots in a habitat and count the number of individuals within each one. They then use these counts to estimate the total population in the larger area. This method works well for plants or slow-moving animals. For more mobile species, scientists often use the **mark-recapture method**. In this technique, a group of individuals is captured, marked in a harmless way, and released back into the environment. Later, another group is captured, and researchers count how many of them are marked. Using this data, they can estimate the total population using a simple formula. These sampling methods help ecologists make informed estimates without needing to observe every single organism.

**Population density** is the number of individuals per unit area or volume. If those 500 deer live in a 100-square-kilometre forest, the density is five deer per square kilometre.

Density tells us how crowded a population is. High-density populations may face more competition for limited resources like food, water, or nesting sites. They may also spread diseases more easily. In contrast, low-density populations might have trouble finding mates or may be more vulnerable to predators.

# Species Distribution

**Species distribution** describes how individuals in a population are spaced out across their habitat. Even if two populations have the same size and density, the way individuals are spread out can be very different.

There are three main types of distribution:

1. **Uniform distribution**: Individuals are spaced evenly. This can happen when there is competition for resources like sunlight or territory. For example, some desert plants grow at regular distances to avoid competing for water. It is also seen in territorial animal species, such as penguins, that maintain a defined territory for nesting.
2. **Random distribution:** Individuals are spread unpredictably. This is rare in nature but can occur when resources are plentiful and evenly distributed. Dandelions growing in a field might show this pattern.

3. **Clumped distribution**: Individuals group together in patches. This is the most common pattern in nature. Animals may clump around food sources, water, or shelter. For example, elephants often travel in herds, and mussels cluster on rocks in the ocean. It may also be seen in plants that drop their seeds straight to the ground, such as oak trees.

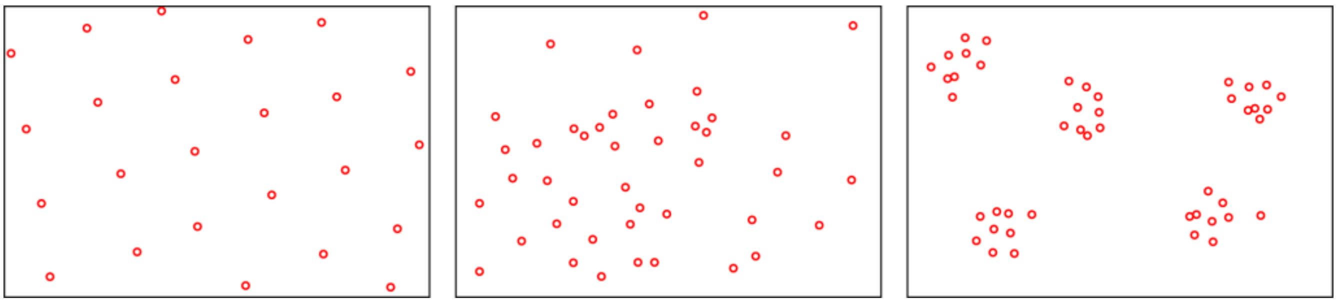

Figure 9.1.3 Uniform distribution (left), random distribution (middle) and clumped distribution (right). Image by Yerpo, CC BY-SA 4.0 Modified to horizontal layout

The distribution of the individuals within a population provides more information about how organisms interact with each other than does a simple density measurement. Just as lower-density species might have more difficulty finding a mate, solitary species with a random distribution might have a similar difficulty when compared to social species clumped together in groups.

## Survivorship Curves

A **survivorship curve** is a graph that shows the number of individuals in a population that survive at each age. It helps ecologists understand patterns of survival and death over the lifespan of a species. There are three main types of survivorship curves, each representing a different life strategy:

1. **Type I** – Most individuals survive to old age. Death usually occurs later in life. This pattern is common in large mammals like humans and elephants, which tend to have fewer offspring and invest heavily in their care.
2. **Type II** – Individuals have an equal chance of dying at any age. This straight-line curve is seen in some birds, reptiles, and small mammals, where the risk of death is fairly constant throughout life.
3. **Type III** – Most individuals die young, but those who survive early life tend to live much longer. This curve is typical of species like insects, fish, and many plants, which produce large numbers of offspring but provide little or no parental care.

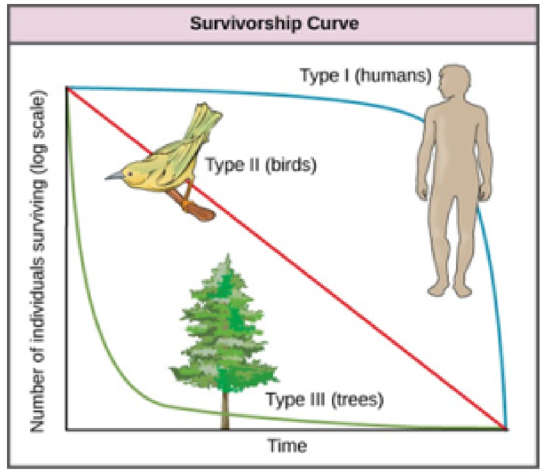


Figure 9.1.4 A survivorship curve graph showing three types of survival patterns across time. The x-axis represents time, and the y-axis represents the number of individuals surviving. Humans show a high survival until late in life, followed by a steep decline. Birds show a constant death rate throughout life. Trees show a drop early in life, with few individuals surviving to old age. "Survivorship Curve" by OpenStax, CC BY-SA 4.0

## Life History Strategies

Different species have different life history strategies for survival and reproduction. Ecologists describe these strategies using the terms r-selected and K-selected species. These terms come from variables used in population growth models: *r* represents the growth rate, and *K* represents the carrying capacity of the environment.

**r-selected species** focus on rapid growth and reproduction. They tend to:

- Produce many offspring at once
- Invest little or no care in each individual
- Mature quickly and have short lifespans
- Have a small body size
- Thrive in unpredictable or changing environments

Examples of r-selected species include insects, bacteria, and many types of plants. These species often experience boom-and-bust population cycles, where numbers rise quickly and then crash when resources run out.

**K-selected species**, on the other hand, grow more slowly and invest more in each offspring. They tend to:

- Produce fewer offspring
- Provide more parental care
- Mature slowly and live longer
- Are larger in body size
- Compete well in stable environments near the carrying capacity

Examples include elephants, whales, and humans.

While r- and K-selection represent two ends of a spectrum, many species fall somewhere in between. Understanding these strategies helps ecologists predict how populations respond to environmental changes and human impacts.

## Knowledge Check

**Text Description**

**1. Multiple Choice Activity #1**

Which of the following best describes population density?

a. The total number of species in an ecosystem
b. The number of individuals per unit area or volume
c. The rate at which a population grows over time
d. The maximum population an environment can support

**2. Multiple Choice Activity #2**

What type of species distribution is most common in nature and typically forms around resources like food or shelter?

a. Random distribution
b. Uniform distribution
c. Clumped distribution
d. Linear distribution

**3. Multiple Choice Activity #3**

Which survivorship curve is characterized by high mortality in early life, with a few individuals surviving to old age?

a. Type I
b. Type II
c. Type III
d. Type IV

**4. Multiple Choice Activity #4**

Which of the following traits is not typically associated with r-selected species?

a. Rapid maturity and short lifespan
b. High number of offspring
c. High parental investment
d. Small body size

**5. Multiple Choice Activity #5**

Why might low-density populations be at a disadvantage compared to high-density populations?

a. They experience more disease outbreaks
b. They face more competition for resources
c. They may have difficulty finding mates
d. They are more likely to be r-selected species

---

**Answers:**

1. b
2. c
3. c
4. c
5. c

---

# 9.2 POPULATION GROWTH AND REGULATION

Populations grow and change over time. Ecologists study these changes to make predictions about the future. This information is especially important in real-world situations. For example, a conservation manager might want to know whether an endangered species is recovering, or a game warden might need to estimate how many fish can be safely caught during a season without harming the population. To explore these patterns, scientists often use mathematical models. The two simplest models of population growth are exponential growth and logistic growth.

### Exponential Growth

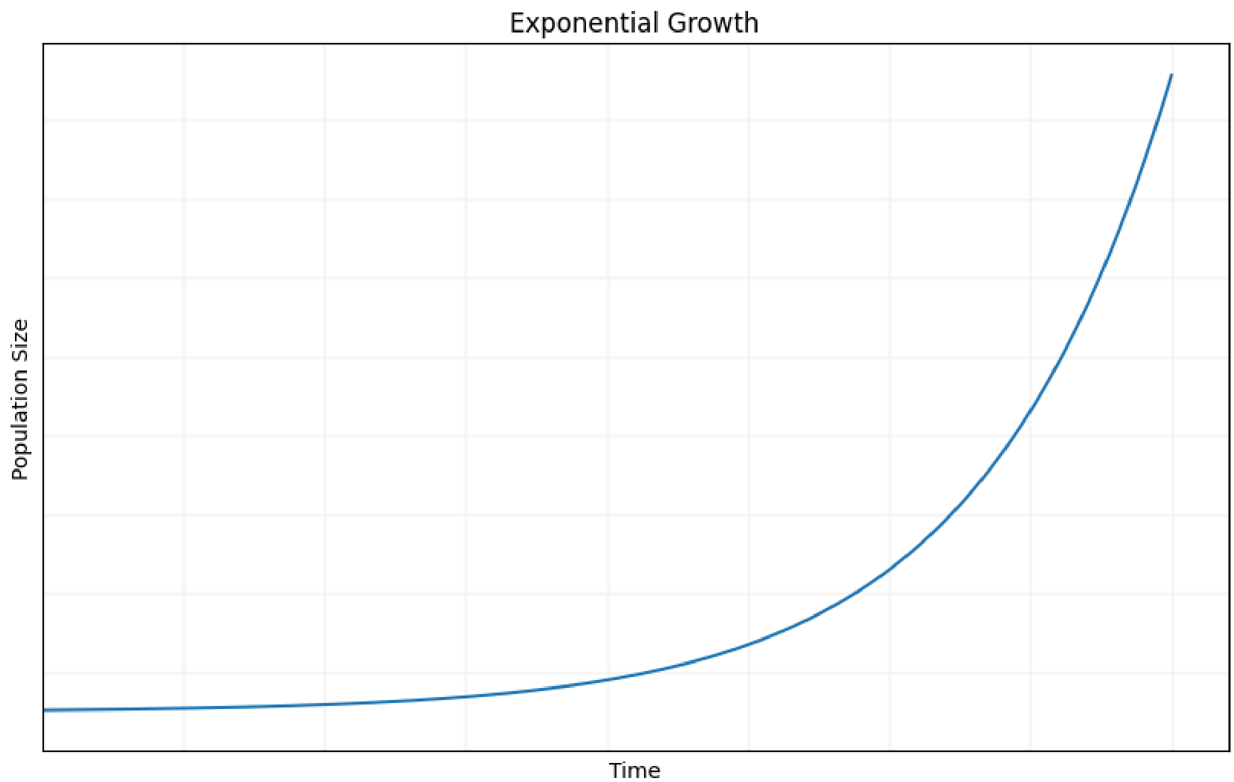


Figure 9.2.1. "Exponential Growth" plotted by Aaron Po using Matplotlib 3.10.3 and NumPy 2.3.1, CC0 1.0

**Exponential growth** happens when a population increases at a constant rate over time, without any limits. In this model, the larger the population gets, the faster it grows—because more individuals are reproducing. This creates a **J-shaped curve** when graphed. For example, if a population of bacteria doubles every hour, it might start with just a few cells, but quickly grow into millions.

This kind of growth can happen in nature, but usually only for short periods—such as when a species enters a new environment with plenty of resources and no predators. However, in the real world, resources like food, space, and water are limited, so exponential growth can't continue forever. Eventually, something will slow the growth down.

In many cities, raccoon populations have grown exponentially due to easy access to food and shelter.

Figure 9.2.2. "Common Raccoon" by jacksonkusack , CC0 1.0

## Logistic Growth

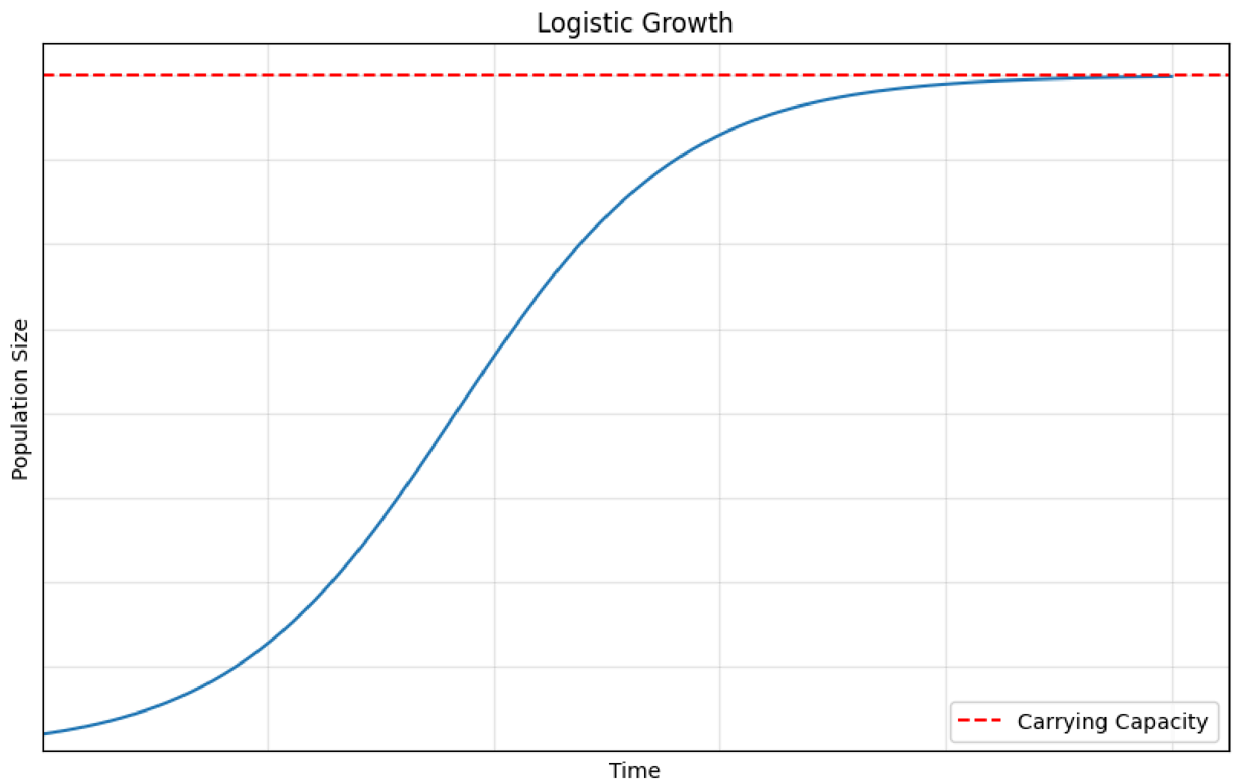


Figure 9.2.3. "Logistic Growth." Created by Aaron Po using Matplotlib 3.10.3 and NumPy 2.3.1, CC0 1.0

**Logistic growth** describes a more realistic pattern of population growth. In this model, a population starts off growing quickly, but then the growth slows down as resources become limited. Eventually, the population levels off when it reaches the **carrying capacity (K)**, the maximum number of individuals that the environment can support over time.

This creates an **S-shaped curve** on a graph. At first, when the population is small and resources are abundant, growth is fast. However, as the population increases, **intraspecific competition** (competition among individuals of the same species) intensifies. They begin to compete for food, space, mates, and other limited resources. As a result, birth rates may decline and death rates may rise, causing the population growth to slow and eventually stabilize around the carrying capacity. Logistic growth is common in nature because no environment has unlimited resources. It helps ecologists understand how populations are regulated and how they respond to environmental pressures.

After being nearly wiped out by the fur trade, beavers (*Castor canadensis*) slowly returned to suitable habitats. Their numbers grew quickly at first, but as space and food became limited, growth slowed and eventually levelled off.

Figure 9.2.4. "American Beaver" by ryan_griffiths CC0 1.0

While real populations are more complex, these models provide useful starting points for understanding how populations behave.

## Population Dynamics and Regulation

The logistic model of population growth, while valid in many natural populations and a useful model, is a simplification of real-world population dynamics. Implicit in the model is the assumption that the carrying capacity of the environment remains constant, but in reality, it often changes. For example, some summers are hot and dry while others are cold and wet. In many areas, the carrying capacity during the winter is also much lower than it is during the summer. Natural events such as earthquakes, wildfires, and floods can also dramatically alter an environment and reduce its ability to support life. Additionally, populations rarely exist in isolation. They share their environment with other species, leading to **interspecific competition** – competition between different species for the same limited resources. These factors all influence how a population grows and survives over time.

Population growth is regulated by a variety of **limiting factors** – environmental conditions that restrict the size, growth, or distribution of a population. These factors determine the carrying capacity of an ecosystem and help explain why populations don't grow indefinitely.

Limiting factors are typically grouped into two categories:

### Density-Dependent Limiting Factors

**Density-dependent limiting factors** affect a population more strongly as its size increases. These factors help keep populations in balance by slowing growth when numbers get too high. The more crowded a population becomes, the more individuals compete for limited resources like food, water, shelter, and mates. This intraspecific competition can lead to lower birth rates, higher death rates, or both. For example, Tree Swallows (*Tachycineta bicolor*) are cavity-nesting birds that rely on natural tree holes or nest boxes to raise their young. In a dense population, limited nesting sites can prevent some individuals from reproducing, reducing the overall birth rate. Similarly, in an overpopulated deer (*Odocoileus virginianus*) herd, food shortages can lead to malnutrition and increased death rate.

Figure 9.2.5: "Tree Swallow" by wfpetrie, CC BY 4.0

Figure 9.2.6: "White-tailed Deer" by djs39, CC BY 4.0

Other density-dependent factors include the spread of disease and increased predation. In dense populations, diseases can spread more easily from one individual to another. Predators may also find it easier to hunt when prey are more concentrated. These pressures naturally limit population growth and help stabilize numbers near the environment's carrying capacity.

Density-dependent regulation is one of the key mechanisms that shapes logistic growth and helps maintain ecological balance in natural systems.

### Density-Independent Limiting Factors

**Density-independent limiting factors** affect populations regardless of their size or density. These are usually abiotic factors that can cause sudden and dramatic changes in population size. Examples include natural disasters (wildfires, floods, droughts, and hurricanes), extreme temperatures (heatwaves or cold snaps), and pollution (chemical spills, air or water contamination, and pesticide use). These events can drastically reduce population numbers in a short time.

Density-independent factors impact large and small populations equally. For instance, a sudden late-spring frost in Southwestern Ontario can kill large numbers of insect pollinators, regardless of how many individuals were present in the population.

Figure 9.2.7 Mining Bees *(Andrena spp)* are solitary ground-nesting bees that emerge early in spring and are vulnerable to cold snaps. Photo by wildbeewatcher, CC BY-NC-SA 4.0

Density-independent factors do not regulate populations in a predictable way. They are random and often severe, which can make population recovery difficult, especially for species already under stress from other environmental pressures. While density-independent factors don't shape population growth patterns like density-dependent ones do, they are still important to consider, especially in the face of climate change, which is increasing the frequency and intensity of extreme weather events.

In real-life situations, population regulation is very complicated, and density-dependent factors can interact with density-independent factors. A dense population that suffers mortality from a density-independent cause will likely recover differently than a sparse population. For example, a population of deer affected by a harsh winter will usually recover faster if there are more deer remaining, compared with a population of deer living within the same area but with fewer individuals surviving the density-independent cause.

## Knowledge Check

**Text Description**

**1. Multiple Choice Activity**

If the major food source of seals declines due to pollution or overfishing, which of the following would likely occur?

a. The carrying capacity of seals would remain the same, but the population of seals would decrease
b. The carrying capacity of seals would decrease, but the seal population would remain the same
c. The carrying capacity of seals would decrease, as would the seal population
d. The number of seal deaths would increase, but the number of births would also increase, so the population size would remain the same

**2. Drag and Drop**

Move the terms into the correct category, “Density Independent” or “Density Dependent” factors.

Temperature, Fire, Earthquake, Predation, Disease, Pollution, Food, Flood, Parasitism, Competition

**3. Multiple Choice Activity**

A population can exhibit logistic growth when which of the following occurs?

a. There is intraspecific competition for den sites
b. There are only a certain number of females that are reproductively active
c. All of these are true
d. There is a limited amount of food available

**4. Multiple Choice Activity**

K-selected species have which of the following characteristics?

a. They become reproductively mature quickly (early in life)
b. They have a high fecundity
c. They exhibit Type II survivorship curves

d. They have a long lifespan

**5. True or False Activity**

r-selected species often exhibit little or no parental care for their offspring, allowing them to allocate more energy towards producing more offspring. (True/False)

**6. Blanks Activity**

A population that has a ________ distribution may be seen in plants that drop their seeds straight to the ground, such as oak trees; it can also be seen in animals that live in social groups (schools of fish or herds of elephants).

---

Correct Answers:

1. c. The carrying capacity of seals would decrease, as would the seal population
2. Density Independent Factors: Floods, Pollution, Earthquake, Temperature, Fire, Density Dependent Factors: Competition, Parasitism, Disease, Predation, Food
3. c. all of these are true
4. d. they have a long lifespan
5. True
6. clumped

OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Create 5 multiple-choice questions using the following content

# 9.3 APPLICATIONS OF POPULATION ECOLOGY

## Conservation of Endangered Species

Figure 9.3.1: "Bald Eagle", by davidfbird, CC0 1.0

Population ecology plays a vital role in the conservation of **endangered species** by helping scientists understand the factors that influence population size, growth, and survival. In Canada, over 850 wildlife species are currently listed as at risk of extinction. Conservation biologists use population models to identify threats, such as habitat loss, low reproductive rates, or high mortality, and to design strategies that support population recovery.

A powerful example of successful conservation in Ontario is the bald eagle (*Haliaeetus leucocephalus*), which was once nearly extirpated (locally extinct) from southern Ontario due to habitat loss, hunting, and especially the widespread use of the pesticide DDT. DDT caused eggshell thinning, leading to reproductive failure. By the 1980s, bald eagles had disappeared from much of their former range in Ontario. Thanks to decades of conservation work, including the ban on DDT, protection of nesting sites, and monitoring programs, bald eagle populations have rebounded. In 2023, the Ontario government officially removed the bald eagle from the province's list of at-risk species.

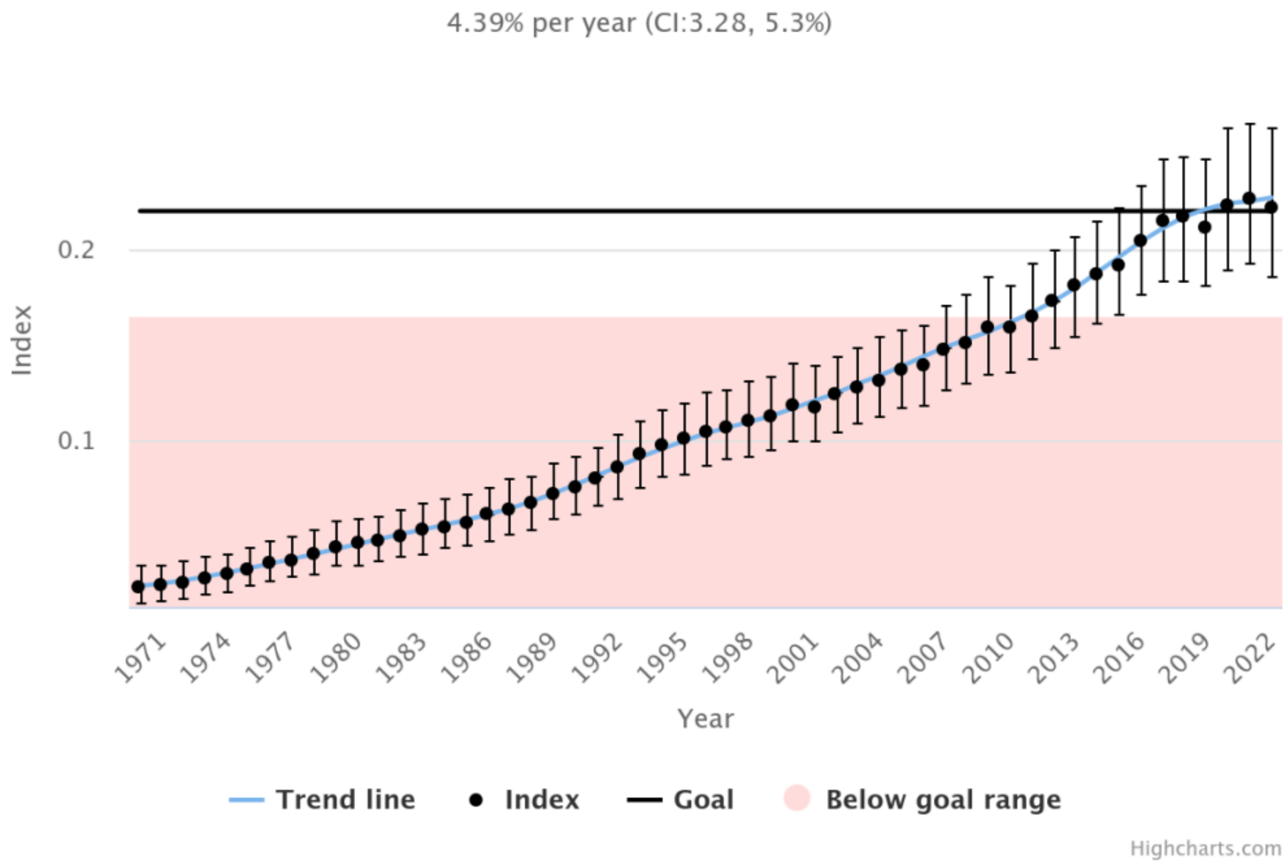


Figure 9.3.2 "Breeding Bird Survey: Canada, 1970-2022", NatureCounts, FDEd (CAN).

### Figure 9.3.2 Image Description

A line graph showing the increase in an index from 1971 to 2022. The x-axis represents years (1971–2022), and the y-axis represents the index value. Black dots with error bars mark index values, while a blue trend line indicates steady growth.

- In 1971, the index starts below 0.02 and increases consistently over time.
- By the mid-1990s, the index surpassed 0.1, continuing to climb through the 2000s.
- Around 2015, the index rises above 0.2 and approaches the black horizontal goal line.
- By 2022, the index is near 0.22 with wider error bars.

A shaded pink area marks the below goal range (index values under 0.2). The trend shows an average annual growth of 4.39% per year (CI: 3.28%, 5.3%).

# Sustainable Resource Management

Population ecology is essential for **sustainable resource management**, managing natural resources in a way that meets human needs while preserving ecosystem health. This approach uses ecological data, such as population size, reproductive rates, and harvest pressure, to ensure that resources like forests, fisheries, and wildlife can regenerate over time.

Figure 9.3.3: "American Lobster", by ninalaflamme, CC BY-NC 4.0

A strong example of this in Canada is the Atlantic lobster (*Homarus americanus*) fishery, one of the country's most economically valuable and sustainably managed fisheries. Fisheries and Oceans Canada (DFO) applies population ecology principles to monitor lobster stocks, set science-based catch limits, and regulate fishing seasons. Conservation measures include:

- Trap limits to prevent overharvesting
- Minimum size regulations to allow lobsters to reproduce before being caught
- Protection of egg-bearing females to support future generations

These strategies have helped maintain healthy lobster populations while supporting the livelihoods of thousands of coastal fishers. The lobster fishery demonstrates how population ecology can guide resource use that is both economically viable and environmentally responsible.

## A Cautionary Tale: Atlantic Cod

In contrast, the collapse of the Atlantic cod (*Gadus morhua*) fishery in the early 1990s shows what can happen when ecological warnings are ignored. Despite declining stock assessments, cod continued to be overfished for decades which ultimately led to a population crash and a federal moratorium that remains in place for many cod stocks. This slow recovery highlights the importance of using population data to guide sustainable practices before it's too late.

Figure 9.3.4: "Atlantic Cod", by janbomb123 , CC BY-NC 4.0

## Invasive Species Management

Figure 9.3.5 "common reed", by brendanboyd, CC BY 4.0

**Invasive species** are non-native organisms (those introduced outside their natural range) that spread rapidly and cause harm to native ecosystems, economies, or human health. Population ecology helps scientists understand how invasive species grow, reproduce, and spread to provide information necessary to develop effective control strategies.

Ontario is home to hundreds of invasive species, including plants, animals, insects, and pathogens that threaten the province's biodiversity. One of the most aggressive invasive species in Ontario is Phragmites (common reed, *Phragmites australis*), a tall, fast-growing grass native to Eurasia. It has spread rapidly through wetlands, roadside ditches, and shorelines. Phragmites form dense stands (up to 200 stems per square metre) that crowd out native plants, reduce habitat for frogs, turtles, and birds, and block access to waterways.

General control measures for invasive species include early detection and rapid response to prevent establishment, mechanical removal such as cutting or digging, and targeted herbicide application where appropriate. In some cases, biological control (see next section) can help suppress invasive populations. Additionally, public education is essential to limit the unintentional spread of invasive species through human activity.

Conservation groups like the Nature Conservancy of Canada (NCC), in partnership with the Ontario Ministry of Natural Resources and Forestry, have used population ecology to map infestations, monitor spread, and evaluate control methods. These efforts have led to the gradual recovery of native wetland vegetation and improved habitat for wildlife in some areas.

Invasive species cost the Canadian economy an estimated $3.6 billion annually. By applying ecological principles, scientists and land managers can slow the spread of invasive species and reduce their impact on local ecosystems.

## Other Invasive Species in Ontario

Here are some other examples of invasive species that you are likely to encounter in Ontario:

### Common Buckthorn (*Rhamnus cathartica*)

Introduced as a hedge plant, this shrub invades forests and fields, outcompeting native plants and altering soil chemistry, making it harder for native species to grow.

Figure 9.3.6 "common buckthorn", by elacroix-carignan , CC0 1.0

### Garlic Mustard (*Alliaria petiolata*)

A biennial herb that spreads aggressively in forests, displacing native wildflowers and releasing chemicals into the soil that inhibit the growth of other plants.

Figure 9.3.7. "garlic mustard", by alec_mcclay , CC BY 4.0

European Starling (*Sturnus vulgaris*)

Introduced to North America in the late 1800s, European Starlings are now widespread across Ontario. They compete aggressively with native birds for nesting sites. Their large flocks can also damage crops and create sanitation issues in urban areas.

Figure 9.3.8 "European Starling", by glennberry , CC0 1.0

Emerald Ash Borer (*Agrilus planipennis*)

A metallic green beetle native to Asia that has devastated ash tree populations across Ontario. Larvae feed under the bark, cutting off water and nutrient flow, killing trees within a few years.

Figure 9.3.9 "Emerald Ash Borer", by broacher , CC BY 4.0

Zebra Mussel (*Dreissena polymorpha*)

A small freshwater mussel from Eurasia that clogs water intake pipes, damages infrastructure, and outcompetes native mussels. It spreads rapidly through ballast water and recreational boating.

Figure 9.3.10 "Zebra Mussel", by noskcaj55 , CC BY 4.0

## Biological Control of Pests

**Biological control**, or bio-control, is the use of natural enemies (such as predators, parasites, or pathogens) to manage pest populations. This method is rooted in population ecology, which helps scientists understand how pest and control species interact, how their populations grow and fluctuate, and how environmental factors influence their success. Biocontrol offers a sustainable alternative to chemical pesticides, aiming to reduce pest populations while minimizing harm to native species and ecosystems.


Figure 9.3.11 Tetrastichus planipennisi (Chalcidoid Wasp). A natural enemy of the Emerald Ash Borer. Image by andrewsonea, CC BY-NC 4.0

Effective bio-control relies on detailed ecological research. Scientists must identify natural enemies that are specific to the target pest and assess their potential impact on non-target species. Before introducing a biocontrol agent, researchers conduct extensive testing in controlled environments to ensure it will not become invasive or disrupt local ecosystems. Population models help predict how the bio-control agent will establish, spread, and affect pest populations over time.

In Ontario, bio-control has been used to control the emerald ash borer (*Agrilus planipennis*). Researchers have introduced several species of parasitic wasps from the beetle's native range, which lay their eggs inside emerald ash borer larvae and eventually kill them. Population ecology models help determine the best release sites, timing, and expected impact of these wasps on beetle populations. Early results show that these bio-control agents are establishing in Ontario forests and contributing to the suppression of emerald ash borer populations.

Another promising bio-control effort is underway to manage invasive common reed (*Phragmites australis*). After over a decade of international research, two species of stem-boring moths were approved for release in 2019. These moths lay eggs on Phragmites stems; their larvae bore into the stalks, weakening the plant and reducing its ability to spread. The moths are highly specific to invasive Phragmites and pose no threat to native plants. Since their release, tens of thousands of moths have been introduced at dozens of sites across southern Ontario. Early results show promising signs of damage to Phragmites, suggesting the moths are establishing and beginning to suppress the invasive grass.

Figure 9.3.12 Larva being used as bio-control by boring into stalks of the invasive common reed, Photo (left) by Claire Schon, Used under Fair Dealing for Educational Purposes (Canada), Photo (right) by Michael McTavish, Used under Fair Dealing for Educational Purposes

Bio-control does not aim to eradicate invasive species entirely but to restore ecological balance by reuniting pests with their natural enemies. That being said, bio-control is not without risks. Scientists must carefully evaluate potential bio-control agents to ensure they do not harm native species or become invasive themselves.

## A Cautionary Tale: Asian Lady Beetle

The Asian lady beetle (*Harmonia axyridis*) was introduced in North America to control crop pests like aphids. While initially effective, it became invasive, out-competing native lady beetles and becoming a household nuisance. This example highlights the risks of bio-control when species are introduced without thorough ecological testing and long-term monitoring.

Figure 9.3.13 "Asian Lady Beetle", by chaumps , CC BY-NC 4.0 .

## Knowledge Check

**Text Description**

**1. Multiple Choice Activity #1**

What helped the bald eagle population recover in Ontario after near extirpation?

a. Introduction of new predators
b. Legalization of DDT
c. Conservation efforts, including banning DDT and protecting nesting sites
d. Increased hunting of invasive species

**2. Multiple Choice Activity #2**

Which of the following is an example of sustainable resource management guided by population ecology in Canada?

a. Overfishing of Atlantic cod
b. Urban development of wetland areas
c. Regulated lobster fishing with size limits and egg-bearing protections
d. Introduction of non-native species for biodiversity

**3. Multiple Choice Activity #3**

What is a major characteristic of invasive species?

a. They always improve soil quality
b. They are native and help stabilize ecosystems
c. They outcompete native species and disrupt local ecosystems
d. They reproduce slowly and are easily contained

**4. Multiple Choice Activity #4**

How does biological control help manage pest populations?

a. By genetically modifying the pest species
b. By introducing natural enemies like predators or parasites
c. By increasing pesticide use
d. By removing all native competitors

**5. Multiple Choice Activity #5**

What ecological lesson is highlighted by the introduction of the Asian lady beetle for biocontrol?

a. Biocontrol always eradicates the target pest
b. Biocontrol agents never affect native species
c. Poorly tested biocontrol agents can become invasive and cause new problems
d. Lady beetles are not effective against crop pests

---

**Answers:**

1. c
2. c
3. c
4. b
5. c

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Prompt: Create 5 multiple-choice questions using the following content

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# 9.4 HUMAN POPULATION GROWTH

## Historical Patterns and Future Projections

Human population growth has changed dramatically over time. For most of history, populations grew slowly due to high death rates from disease, famine, and limited medical knowledge. The Agricultural Revolution (~10,000 years ago) allowed for more stable food supplies, leading to gradual growth. The Industrial Revolution in the 18th and 19th centuries brought advances in medicine, sanitation, and food production, causing death rates to fall and triggering exponential growth. The global population now exceeds 8 billion.

The following link contains a human population growth graph from 1 CE to 2050 and the years that we reached each billion: World Population Growth Graph.

However, growth is slowing. The global population growth rate peaked in 1963 at about 2.3% per year. Since then, it has steadily declined due to falling fertility rates worldwide. The annual growth rate is now below 1%, the slowest rate since 1950 (United Nations, 2024). This decline is largely driven by women having fewer children and by increasing access to education, healthcare, and family planning. UN projections estimate that the global population will peak at around 10.3 billion in the mid-2080s. This peak is 700 million lower than projections made a decade ago, largely due to declining fertility rates. Over half of all countries now have fertility rates below the replacement level of 2.1 children per woman.

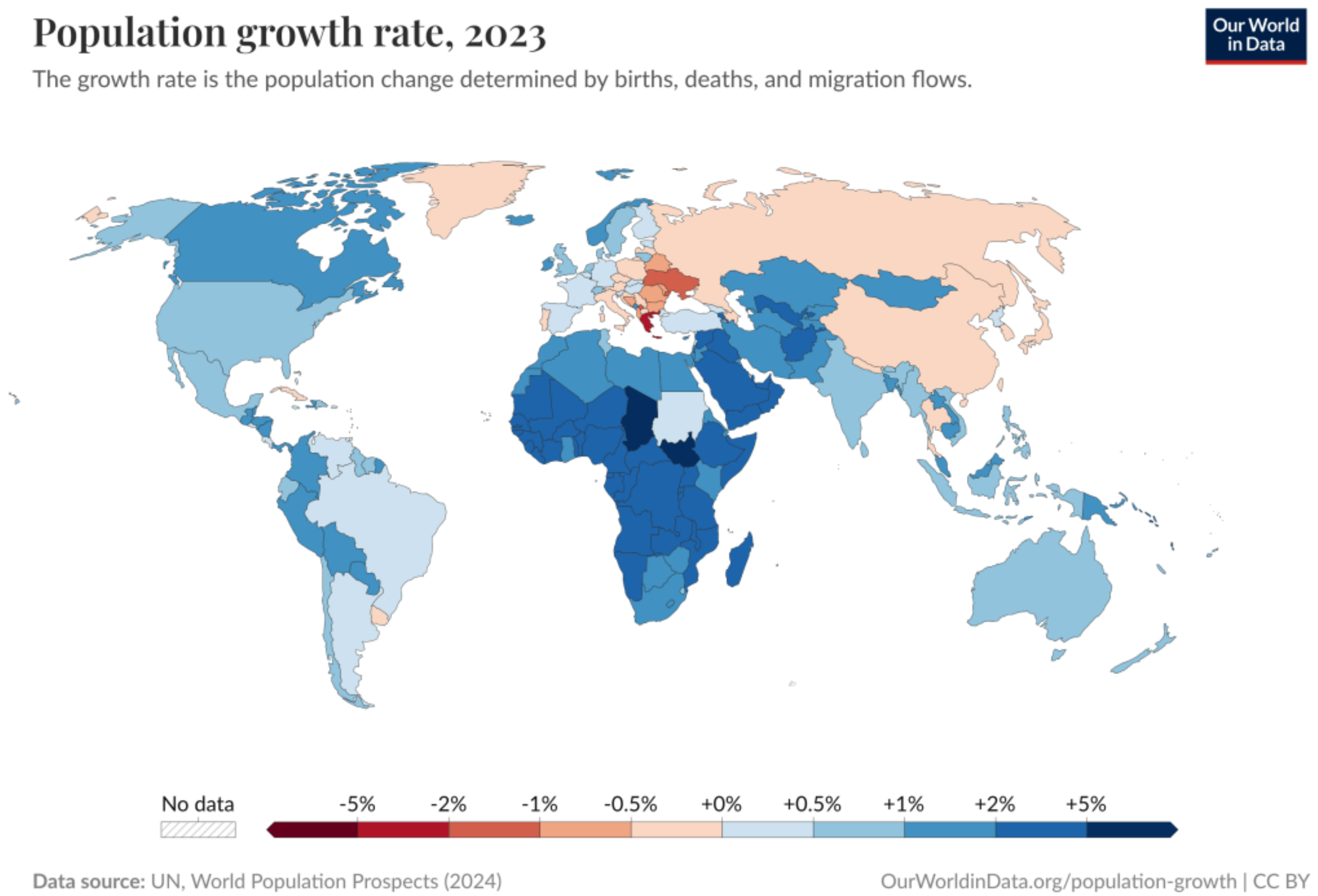


Figure 9.4.1 "Population Growth Rate, 2023" by Our World In Data, CC BY 4.0

**Figure 9.4.1 Image Description**

A world map titled "Population growth rate, 2023" showing the annual percentage change in population across countries, determined by births, deaths, and migration. Countries are shaded from dark red (population decline of –5% or more) to dark blue (population growth of +5% or more).

- High growth (dark blue): Concentrated in sub-Saharan Africa, including countries like Niger, Chad, and the Democratic Republic of the Congo.
- Moderate growth (light to medium blue): Found in most of Africa, South Asia, and parts of the Middle East.
- Low or near zero growth (light beige to pale blue): Includes much of North America, South America, and Oceania.
- Population decline (red to orange): Observed in Eastern Europe, Russia, parts of Central Europe, and East Asia (including Japan).
- No data: Marked with gray diagonal stripes for a few small countries or territories.

# Age Structure and Economic Development

**Age structure** is the distribution of individuals across age groups. Age structure diagrams visually represent the number of individuals in different age groups, typically separated by sex. These diagrams help illustrate whether a population is growing, stable, or declining. A wide base indicates a high proportion of young people and potential for rapid growth, while a narrow base and wider top suggest an aging population and potential population decline.

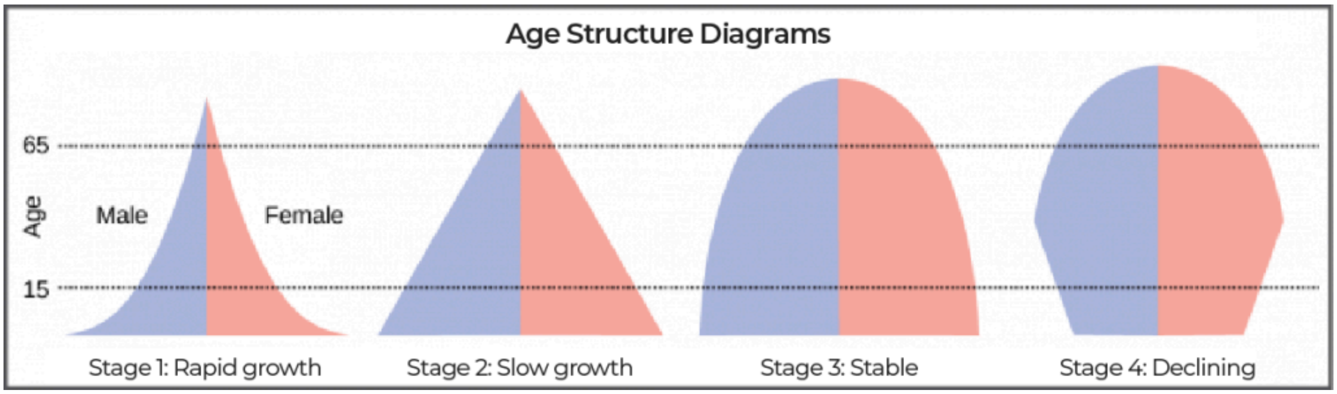


Figure 9.4.2 Image by OpenStax, CC BY 4.0 Modifications made to text labels

**Figure 9.4.2 Image Description**

A set of four population age structure diagrams comparing males (blue) and females (red) across different growth stages. Dashed horizontal lines mark ages 15 and 65, showing the proportion of youth and elderly in each stage.

- Stage 1: Rapid growth – Pyramid shape with a wide base and narrow top, indicating many young people and few older individuals.
- Stage 2: Slow growth – Triangle shape with a broader base but less steep sides, showing a slower population increase.
- Stage 3: Stable – Bell shape with a more even distribution across ages, indicating little overall growth.
- Stage 4: Declining – Barrel shape with a narrower base than the middle, showing fewer young people and an aging population.

Age structure has major implications for economic development and social planning. Countries with a young population face challenges in providing education, jobs, and healthcare for a growing youth population. In contrast, countries with an aging population must support a shrinking workforce and increasing healthcare needs for the elderly.

# Carrying Capacity of Humans

Calculating the carrying capacity for humans is particularly complex because it depends not only on population size, but also on consumption patterns, technology, and lifestyle choices.

One way to measure our impact is through the **ecological footprint**, which calculates how much biologically productive land and water area a population requires to produce the resources it consumes and absorb its waste. This is compared to **biocapacity**, the Earth's ability to regenerate those resources and absorb waste, especially carbon emissions.

According to the Global Footprint Network (n. d.), the global ecological footprint is about 2.5 global hectares (gha) per person. The Earth's biocapacity is only about 1.6 gha per person. This means that humanity is using resources at a rate that would require 1.7 Earths to sustain long-term. This condition is known as **ecological overshoot** – when demand exceeds nature's ability to regenerate. Overshoot leads to deforestation, soil erosion, biodiversity loss, and climate change.

The gap between ecological footprint and biocapacity is not evenly distributed. High-income countries tend to have much larger footprints per person, while low-income countries often live within or below their biocapacity. For Canada, the average ecological footprint per person is 8.7 gha. If everybody on Earth lived like Canadians, we would need over 5 Earths to stay within biocapacity.

> The following link contains the map of Ecological Footprints per Person in the world: Global Footprint Map

This highlights the importance of addressing not just population size, but also inequities in consumption and resource use. To live within Earth's carrying capacity, we must:

- Reduce overconsumption and waste
- Transition to renewable energy
- Protect and restore ecosystems
- Shift toward sustainable food systems and urban planning

Ultimately, the planet's ability to support human life depends not just on how many people there are, but on how sustainably we live.

## Knowledge Check

**Text Description**

**1. Multiple Choice Activity #1**

What major global shift began around 10,000 years ago and contributed to gradual human population growth?

a. The Industrial Revolution
b. The Medical Revolution
c. The Agricultural Revolution
d. The Digital Revolution

**2. Multiple Choice Activity #2**

What is the primary reason the global population growth rate has declined since its peak in 1963?

a. An increase in global conflict
b. Higher infant mortality rates
c. Falling fertility rates and greater access to education and healthcare
d. Decrease in agricultural productivity

**3. Multiple Choice Activity #3**

In an age structure diagram, what does a wide base typically indicate about a population?

a. A declining population with high life expectancy
b. A stable population with balanced age groups
c. A growing population with many young people
d. An aging population with low birth rates

**4. Multiple Choice Activity #4**

What does it mean when humanity is in ecological overshoot?

a. There is too much unused land on the planet
b. Resource use is equal to the Earth's ability to regenerate
c. Human demand exceeds Earth's capacity to regenerate resources
d. The global population is below replacement level

**5. Multiple Choice Activity #5**

Which of the following best explains why calculating human carrying capacity is especially complex?

a. It changes weekly due to weather patterns
b. It depends on age structure alone
c. It is based solely on population density
d. It includes variables like consumption, technology, and lifestyle

---

**Answers:**

1. c
2. c
3. c
4. c
5. d

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Prompt: Create 5 multiple-choice questions using the following content

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# CHAPTER 9 SUMMARY

## Key Takeaways

- **Population Ecology:** Examines how populations change over time, focusing on population size, density, distribution, birth and death rates, and environmental interactions to understand species survival and adaptation.
- **Population Size and Density:** These are influenced by birth, death, immigration, and emigration, and are typically estimated using sampling methods such as quadrant sampling and mark-recapture techniques due to practical constraints.
- **Species Distribution Patterns (Clumped, Uniform, and Random):** These reveal important ecological interactions, such as resource availability, competition, and social behaviour, which influence survival and reproductive success.
- **Survivorship Curves (Types I, II, III)**: These illustrate species' life history strategies, while r- and K-selection explain reproductive patterns ranging from high-output, low-care species to low-output, high-care species.
- **Exponential and Logistic Models:** These describe population growth, with exponential growth showing unchecked increases and logistic growth incorporating environmental limits, stabilizing populations around carrying capacity.
- **Population Regulation**: This is shaped by both density-dependent and density-independent limiting factors, such as competition, disease, predation, natural disasters, and climate, all of which interact to influence population dynamics and recovery potential.

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Summarize the following content into six key takeaways.

# Flashcards

Click on the flashcards to review key terms discussed in this chapter.

**Text Description**

**Front of Card:**

1. Agricultural Revolution
2. Age structure
3. Biocapacity
4. Biological control
5. Carrying capacity (K)
6. Clumped distribution
7. Competition
8. Conservation of endangered species
9. Density-dependent limiting factors
10. Density-independent limiting factors
11. Ecological footprint
12. Ecological overshoot
13. Endangered species
14. Exponential growth
15. Immigration
16. Interspecific competition
17. Intraspecific competition
18. Invasive species
19. K-selected species
20. Limiting factors
21. Logistic growth
22. Mark-recapture method
23. Population density
24. Population ecology
25. Population size
26. Quadrant sampling

27. R-selected species
28. Random distribution
29. Species distribution
30. Survivorship curve
31. Sustainable resource management
32. Type I survivorship curve
33. Type II survivorship curve
34. Type III survivorship curve
35. Uniform distribution
36. 3 types of species distribution
37. 3 types of survivorship curves
38. 2 types of life history strategies
39. 2 types of population growth
40. 2 types of limiting factors
41. 4 applications of population ecology

**Back of Card:**

1. A historical shift about 10,000 years ago when humans began farming and domesticating animals, leading to food stability and population growth.
2. The distribution of individuals among age groups in a population is used to predict trends and plan for future needs.
3. The Earth's ability to regenerate resources and absorb waste over time.
4. The use of predators, parasites, or pathogens to control pest species naturally and sustainably.
5. The maximum number of individuals an environment can support based on resource availability.
6. A pattern where individuals gather in groups, usually near resources.
7. When organisms compete for the same limited resources, affecting population growth.
8. Actions to protect species from extinction using legal protection, habitat restoration, and ecological strategies.
9. Factors like disease or competition that intensify as population density increases.
10. Factors like natural disasters that impact populations regardless of size.
11. The land and water area required by a person or group to produce resources and absorb waste.
12. Occurs when human consumption exceeds Earth's ability to regenerate resources, causing

environmental damage.

13. Species at risk of extinction due to threats like habitat loss or disease.
14. Population growth at a constant rate without limits, forming a J-shaped curve.
15. The arrival of individuals into a population, increasing its size.
16. Competition between different species for shared resources.
17. Competition within the same species for limited resources.
18. Non-native species that spread rapidly, harming ecosystems and economies.
19. Species that grow slowly, produce few offspring, and invest in parental care; adapted to stable environments.
20. Environmental conditions that restrict population size and growth.
21. Growth that slows as resources become limited, stabilizing at carrying capacity; S-shaped curve.
22. A method of estimating population size using captured, marked, and recaptured individuals.
23. The number of individuals per unit area or volume.
24. The study of population dynamics and interactions with the environment.
25. The total number of individuals in a specific area at a given time.
26. Estimating population size by counting individuals in small plots and scaling up.
27. Species that reproduce quickly, have many offspring, and little parental care; suited for unstable environments.
28. A distribution where individuals are spread randomly across a habitat.
29. How individuals are spatially arranged in their habitat—clumped, uniform, or random.
30. A graph showing how many individuals survive at each age level; Types I, II, and III.
31. The practice of using natural resources in a way that maintains ecosystem health for future generations.
32. Most individuals survive to old age (e.g., humans).
33. Equal chance of dying at any age (e.g., birds).
34. High death rate early in life, with survivors living long (e.g., fish, plants).
35. Individuals are evenly spaced due to competition or territoriality.
36. Clumped, uniform, and random.
37. Type I, Type II, and Type III.
38. r-selected and k-selected species.
39. Exponential and logistic growth.
40. Density-dependent and density-independent.
41. Conservation of endangered species, sustainable resource management, invasive species management, and biological control.

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Prompt: Provide definitions for all the bolded terms in the shared content and list all the terms in alphabetical order.

# CHAPTER 10: COMMUNITY AND ECOSYSTEM ECOLOGY

## Chapter Overview

## Learning Objectives

By the end of this chapter, you will be able to:

- Describe key interspecific interactions within biological communities (e.g., competition, predation, herbivory, parasitism, mutualism, and commensalism) and explain how they impact the survival and reproduction of species.
- Analyze the role of coevolution in shaping species traits and behaviours, providing examples of how evolutionary pressures from interactions such as predation and mutualism drive adaptive changes.
- Interpret the structure of trophic levels and food webs in an ecosystem, including the roles of producers, consumers (primary to quaternary), detritivores, and decomposers in the flow of energy and cycling of matter.
- Explain the concepts of energy flow and ecological pyramids, including how energy is transferred through trophic levels and why energy availability limits food chain length and top predator populations.
- Illustrate the processes and significance of biogeochemical cycles (water, carbon, nitrogen, and phosphorus), identifying the main reservoirs, pathways, and human impacts on each cycle.
- Evaluate the ecological consequences of human activities such as deforestation, fossil fuel combustion, agriculture, and fertilizer use on biodiversity, nutrient cycling, and ecosystem stability.

OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat Prompt: Provide six learning objectives for the shared content.

# 10.1 COMMUNITY ECOLOGY

## Interspecific Interactions

In nature, populations of a single species rarely exist in isolation. Instead, they share their habitat with many other species, forming what ecologists call a **community**. The variety of species in a community, along with their relative abundance, is referred to as **species diversity**. Some environments, like the icy landscapes of Antarctica, have relatively low species diversity but still support a surprising range of life. In contrast, tropical rainforests are so rich in species that scientists have yet to fully catalogue their biodiversity.

Ecologists study communities to understand how species interact with one another – these relationships are known as **interspecific interactions**. Such interactions can take many forms. For instance, a bee pollinating a flower benefits both species, while a lion hunting a zebra benefits one species at the expense of the other. Even seemingly minor relationships, like moss growing on the bark of a tree, can have ecological importance.

To better understand these dynamics, ecologists classify interspecific interactions based on whether they benefit, harm, or have no effect on the species involved. The major types of interspecific interactions include **competition, predation, herbivory, parasitism, mutualism,** and **commensalism**.

## Competition (-/-)

**Competition** occurs when individuals of different species compete for the same limited resources in an ecosystem, such as food, water, space, or sunlight. Because these resources are in short supply, the presence of one species can reduce the availability of the resource for another. This makes competition a negative interaction for both species involved.

Each species has a **niche**, which refers to its role in the ecosystem – how it uses resources, where it lives, and how it interacts with other organisms. To avoid direct competition, many species undergo **niche differentiation**. This means they evolve to use different parts of the habitat or different types of resources. For example, several species of birds can live in the same tree by feeding in different parts of the canopy or at different times of day.

The **competitive exclusion principle** states that two species that compete for exactly the same resources cannot stably coexist (Figure 10.1.1). Eventually, one species will outcompete the other, leading to the local extinction of the less competitive species or forcing it to adapt by using different resources.

An experimental example of this principle is shown with two *Paramecium* species – *Paramecium aurelia* and *Paramecium caudatum* (types of protists). When grown individually in the laboratory, they both thrive. But when they are placed together in the same test tube (habitat), *P. aurelia* outcompetes *P. caudatum* for food, leading to the latter's eventual extinction.

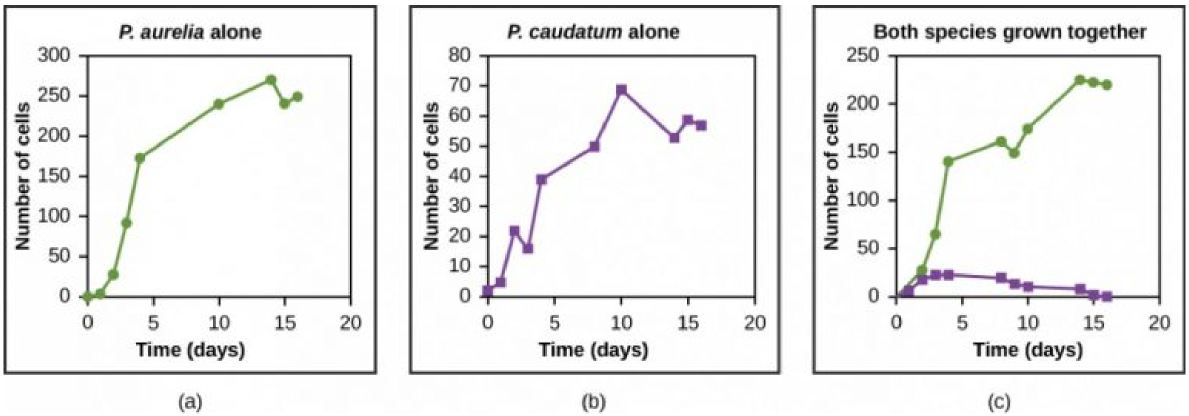


Figure 10.1.1 Paramecium aurelia and Paramecium caudatum grow well individually, but when they compete for the same resources, the P. aurelia outcompetes the P. caudatum. Image by OpenStax, CC BY 4.0

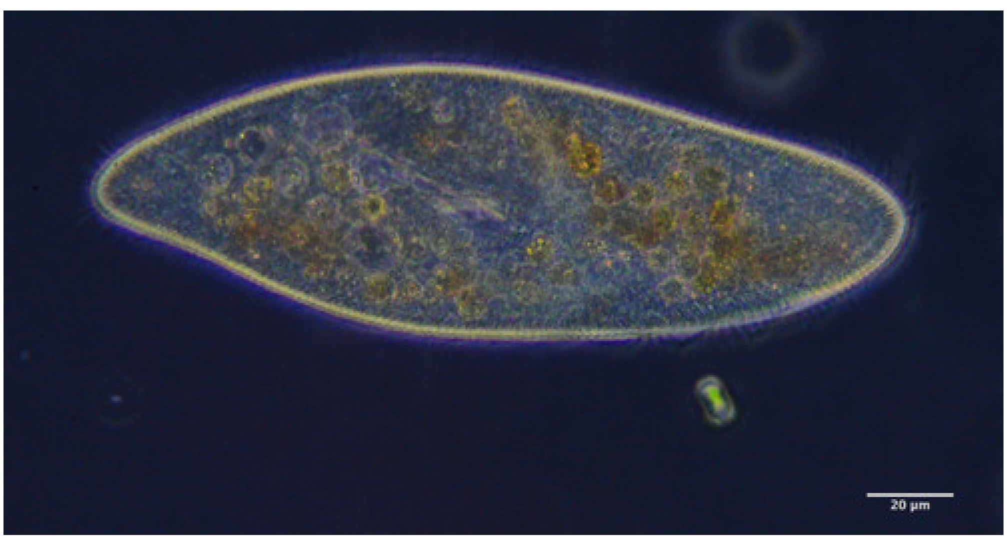


Figure 10.1.2 "Paramecum caudatum" by Don Loarie, CC BY 4.0

## Herbivory (+/–)

**Herbivory** is an interaction in which an animal feeds on a plant or algae. It benefits one species (the herbivore) and harms the other (the plant), making it a positive/negative interaction**.** Herbivores often consume parts of a plant without killing it entirely.

Herbivores come in many forms. Some, like deer and rabbits, feed on leaves and stems. Others, like caterpillars and beetles, chew through foliage. Still others, such as aphids, pierce plant tissues and suck out fluids. Grazing animals like bison and elk can shape entire ecosystems by influencing which plant species dominate a landscape.

Plants, in turn, have evolved a wide range of defences to reduce damage from herbivores:

### Mechanical Defenses

**Mechanical defences** include structures like thorns, spines, and tough leaves that make plants harder to eat. For example, the thorns on a hawthorn tree discourage browsing (eating) by deer.

Figure 10.1.3 "hawthorns", by thomasstan, CC BY-NC 4.0

### Chemical Defenses

**Chemical defences** involve the production of compounds that deter herbivores. Some plants produce toxins, bitter-tasting chemicals, or substances that interfere with digestion. For example, milkweed contains toxic compounds that can harm or kill many insects.

Figure 10.1.4 "common milkweed", by johnslowry, CC BY-NC 4.0

Indirect Defenses

**Indirect defences** include strategies that attract predators or parasites of herbivores. For example, some plants are able to produce extrafloral nectar, a sugary secretion that attracts ants. Ants then patrol the plant and will attack or chase away herbivores to defend their food source. When plants get damaged by herbivores, they can increase the amount of nectar production to enhance ant recruitment and reduce further herbivory.

In another form of indirect defence, tall goldenrod (Solidago altissima) can detect pheremones released by male gall-inducing flies. This early warning system allows the plant to prime its defences and prepare for attack before damage occurs.

Figure 10.1.5 "Golden Rod Gall Fly" Photo by jyhmml, CC BY-NC 4.0

Figure 10.1.6 "Goldenrod Gall" Photo by t-massey, CC BY-NC 4.0

## Predation (+/-)

**Predation** is an interaction in which one species, the **predator**, kills and eats another species, the **prey**. This relationship benefits the predator but harms the prey, making it a positive/negative interaction.

Predators have evolved a wide range of adaptations that help them locate, capture, and consume their prey. These include sharp teeth and claws, keen senses, speed, and stealth. At the same time, prey species have developed defences to avoid being eaten:

Behavioural Defenses

**Behavioural defences** help prey avoid detection or escape attacks. These include fleeing, hiding, forming groups, or startling predators. For example, some animals live in herds or flocks to reduce the chance of any one individual being caught.

Figure 10.1.7 "Snowshoe Hare"by jhskevington, CC BY-NC 4.0

### Mechanical Defenses

**Mechanical defences** include physical structures that make prey harder to eat. Examples include the hard shells of turtles, the spines of porcupines, and the tough exoskeletons of many insects.

Figure 10.1.8: "Reddish-brown Stag Beetle" by mikedufour, CC BY-NC 4.0

Camouflage

**Camouflage** allows prey to blend into their surroundings and avoid being seen. A walking stick insect looks like a twig, while a flounder can match the colour and texture of the ocean floor.

Figure 10.1.9 "Northern Walkingstick" by mikecowlard, CC BY-NC 4.0

Chemical Defenses

**Chemical defences** involve the production of toxins or distasteful substances that can deter or even kill predators. These chemical defences are often paired with warning coloration – bright colours or bold patterns that signal danger to potential predators. For example, the monarch butterfly caterpillar sequesters poisons from its food (milkweeds) to make itself poisonous or distasteful to potential predators. The caterpillar is bright yellow and black to advertise its toxicity. The caterpillar is also able to pass the sequestered toxins on to the adult monarch, which is also dramatically colored black and red as a warning to potential predators.

Figure 10.1.10 "Monarch" by roxanefilion  CC BY-NC 4.0

Figure 10.1.11 "Monarch" by birdsnbug5, CC BY-NC 4.0

## Mimicry

**Mimicry** is when a harmless species resembles a harmful or unpalatable one. The viceroy mimics the monarch butterfly. Although the viceroy is not poisonous, this resemblance helps the viceroy avoid being eaten.

Figure 10.1.12 “Viceroy” by jimroberts1, CC BY-SA 4.0

These predator-prey interactions can also cause population cycles. A classic example is the relationship between the Canada lynx and the snowshoe hare. As hare populations increase, lynx have more food and their numbers grow. But as lynx numbers rise, they consume more hares, causing the hare population to decline. This, in turn, leads to a drop in lynx numbers, allowing the hare population to recover – and the cycle begins again.

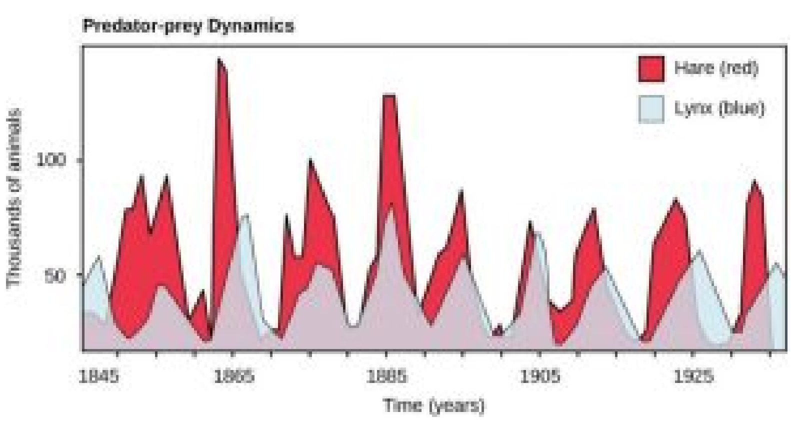


Figure 10.1.13 The cycling of snowshoe hare and lynx populations in Northern Ontario is an example of predator-prey dynamics. Image by OpenStax, CC BY 4.0

**Figure 10.1.13 Image Description**

The image is a line and area graph titled "Predator-prey Dynamics." The x-axis represents time (years) ranging from 1845 to 1935, while the y-axis represents the number of animals (in thousands), ranging from 0 to 150. Two populations are shown: hares (red) and lynx (blue).

The red shaded area represents hare populations, which fluctuate dramatically over time, showing repeated peaks and crashes. The blue shaded area represents lynx populations, which also rise and fall but slightly lag behind the hare populations. Peaks in hare populations are followed by peaks in lynx populations, while hare declines coincide with lynx declines. This illustrates the cyclical relationship between prey and predator populations over the 90-year span, where lynx numbers depend on hare abundance.

## Parasitism (+/–)

A **parasite** is an organism that feeds off another organism called the **host.** In **parasitism**, the parasite benefits, but the host is harmed. This makes parasitism a positive/negative interaction. The host is usually weakened by the parasite as it siphons resources the host would normally use to maintain itself. Parasites may kill their hosts, but there is usually selection to slow down this process to allow the parasite time to complete its reproductive cycle before it or its offspring are able to spread to another host.

Parasites come in many forms. **Endoparasites**, like tapeworms and roundworms, live inside the bodies of animals and absorb nutrients. **Ectoparasites**, like ticks and lice, attach to the outside of the host and feed on blood or skin. For example, the winter tick (*Dermacentor albipictus*) infests moose. In some cases, a single moose can carry tens of thousands of ticks, leading to severe hair loss, blood loss, and even death.

Figure 10.1.14 "Winter Ticks" Photos by hereinthewild, 

## Mutualism (+/+)

**Mutualism** is a type of interspecific interaction in which both species benefit. This makes it a positive/positive interaction. Mutualistic relationships are common in nature and can involve the exchange of food, protection, or other services that help both species survive or reproduce.

One of the most familiar examples is the relationship between flowering plants and their pollinators. Bees, butterflies, and hummingbirds feed on nectar while helping the plant reproduce by transferring pollen from one flower to another.

Another example is lichen, which is formed by a mutualistic relationship between a fungus and photosynthetic algae or cyanobacteria. The algae produce glucose through photosynthesis, which nourishes both organisms. In return, the fungus provides a protective structure that shields the algae from the environment and helps absorb nutrients from the air.

Figure 10.1.15 "Common Sunburst Lichen" by data_nerd, CC BY 4.0

Figure 10.1.16 "Powder-headed Tube Lichen" by hansritter, CC BY-NC 4.0

Figure 10.1.17 "beard lichens" by jfbienentreu, CC BY-NC 4.0

## Commensalism (+/0)

**Commensalism** is an interspecific interaction in which one species benefits while the other is neither helped nor harmed. This makes it a positive/neutral interaction. These relationships can be difficult to study because it's often hard to prove that one species is truly unaffected.

Commensal relationships often involve one species gaining shelter, transportation, or access to food without impacting the other. For example, barnacles attach themselves to the shells of whales or turtles. The barnacles benefit by gaining access to nutrient-rich waters as the host moves, while the whale or turtle is generally unaffected.

Another example is a bird nesting in trees. The tree is not harmed by the presence of the nest among its branches. The nests are light and produce little strain on the structural integrity of the branch, and most of the leaves, which the tree uses to get energy by photosynthesis, are above the nest, so they are unaffected. The bird, on the other hand, benefits greatly. If the bird had to nest in the open, its eggs and young would be vulnerable to predators.

Figure 10.1.18 "American Robin Nest with Eggs" by Laslovarga, CC BY SA 3.0

## Coevolution

Due to all of these interspecific interactions, species often influence each other's evolution in a process known as **coevolution**.

In positive/negative interactions, such as predation, herbivory, or parasitism, one species evolves new ways to exploit another, prompting the other to evolve defences in response. This ongoing back-and-forth can lead to an evolutionary "arms race". For example, prey animals may evolve better camouflage or faster escape behaviours, while predators become more skilled hunters. Plants may develop toxins or tougher leaves, while herbivores evolve resistance. Hosts may strengthen their immune systems, while parasites evolve ways to hide or suppress those defences.

Mutualistic relationships also drive coevolution. In these cases, traits evolve in both partners that improve the effectiveness of the interaction. You can see this in the relationship between flowers and their pollinators. For example, wild bergamot (also called beebalm**,** *Monarda fistulosa***)**, a native Canadian wildflower with a tubular shape, has coevolved with Beebalm Shortface bees (*Dufourea monardae*), which have long tongues that can reach the nectar.

Figure 10.1.19 "wild bergamot" by david3865, CC BY-NC 4.0

Figure 10.1.20 "Beebalm Shortface" by bob15noble, CC BY-NC 4.0

Coevolution can even occur in competitive relationships, where species evolve in response to each other to reduce overlap in resource use. This often leads to **character displacement**, where competing species evolve differences in traits like body size, feeding behaviour, or habitat use to minimize direct competition. In areas with high bee diversity, species like bumblebees and sweat bees have evolved different foraging times, flower preferences, and tongue lengths to reduce direct competition.

These close interactions are often the result of thousands of years of evolutionary pressure, which shapes the traits and behaviours of both species involved.

## Trophic Structure

Now that we've explored how populations interact within a community, we can take a broader look at how energy and nutrients move through that community. The **trophic structure** of a community refers to the feeding relationships among its species. These relationships shape the pathways through which energy and matter flow – from photosynthetic organisms to herbivores, and then to various levels of predators. The step-by-step transfer of energy between these groups is known as a **food chain**, which illustrates how each organism depends on others for nourishment and survival.

At the base of food chains are **producers** – organisms that can make their own food, mostly using energy from the sun. On land, these are typically plants. In aquatic environments, producers include **phytoplankton**, such as photosynthetic protists and cyanobacteria, as well as algae and aquatic plants.

All other levels in the food chain are referred to as consumers because they consume other organisms. Organisms that feed directly on producers are called **primary consumers.** They are typically **herbivores** (plant-eating animals) like insects, birds, deer, or rabbits. In the water, primary consumers are **zooplankton** (microscopic heterotrophic organisms like protists and larvae).

The next level consists of **secondary consumers**, which are **carnivores** that eat herbivores. Examples include frogs, small fish, or insect-eating birds. **Tertiary consumers** are carnivores that feed on other carnivores, and some ecosystems even include **quaternary consumers**, such as hawks or killer whales, which sit at the top of the food chain. Quaternary consumers are often, but not always, the final consumers, meaning the ones that sit at the top of the food chain.

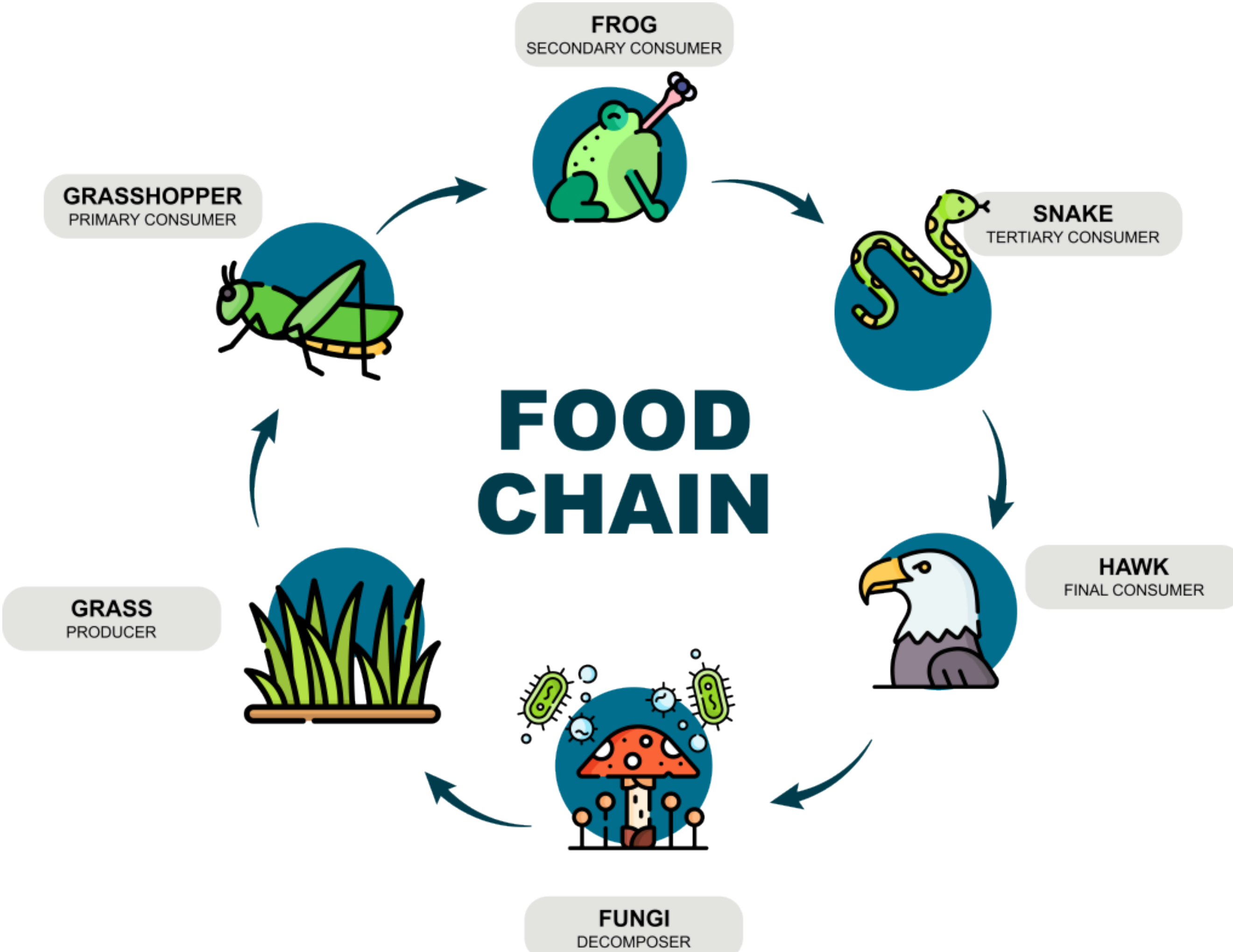


Figure 10.1.21 "Food Chain" by Sanaz Habibi CC BY-NC-SA

Another important level in food chains is the consumers that get their energy from waste and dead bodies, collectively known as **detritus. Detritivores**, such as earthworms, millipedes, and some insects, feed on dead organic matter in its early stages of decay. **Decomposers**, including fungi and many bacteria, break down this material further by secreting enzymes that digest complex molecules into simpler inorganic compounds. These nutrients are then recycled back into the ecosystem, where they can be taken up again by producers. Without decomposers and detritivores, ecosystems would quickly become overwhelmed with waste and dead matter, and the flow of nutrients would grind to a halt.

While food chains help illustrate feeding structure in a community, they are simplified models that don't fully capture the complexity of real ecosystems. In nature, most organisms feed on more than one species and may be eaten by multiple predators. This means that a single species can occupy more than one trophic level, depending on what it eats and what eats it. To better represent these intricate feeding relationships, ecologists use food webs. A **food web** is a more realistic and holistic model that maps out all the interconnected feeding interactions within a community. It shows how energy and nutrients move through multiple pathways, often crossing several trophic levels. Food webs highlight the complexity and interdependence of species in an ecosystem, and they help us understand how changes to one part of the system, such as the loss of a species, can ripple through the entire community.

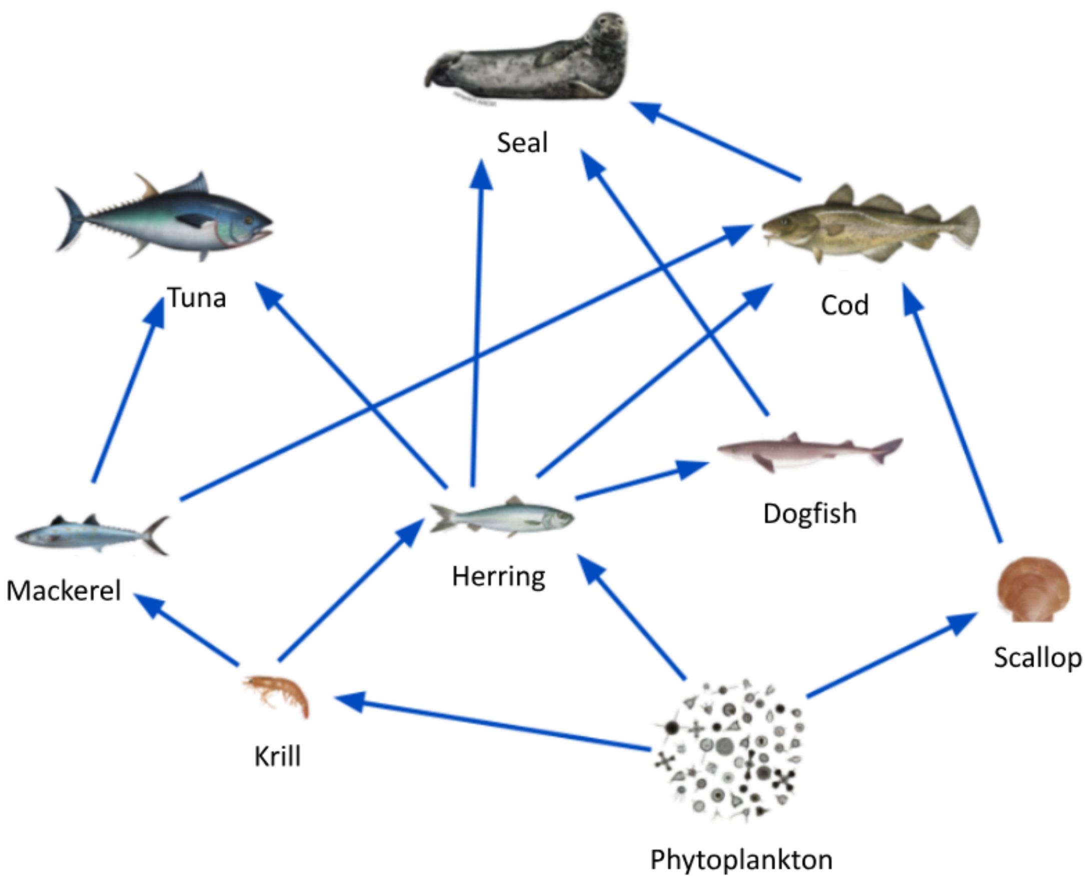


Figure 10.1.22 Food Web Diagram for the Monterey Bay Habitat. Image by NOAA, License

## Knowledge Check

**Text Description**

**1. Multiple Choice Activity #1**

Which of the following interactions is classified as (+/−), where one species benefits and the other is harmed?

a. Mutualism
b. Commensalism
c. Predation
d. Neutralism

**2. Multiple Choice Activity #2**

What does the competitive exclusion principle state?

a. Two species can share the same niche indefinitely
b. Predators and prey evolve together to maintain balance
c. Two species competing for the exact same resources cannot stably coexist
d. Herbivores will always be outcompeted by carnivores

**3. Multiple Choice Activity #3**

Which of the following best illustrates mutualism?

a. A tick feeding on a moose
b. A butterfly pollinating a flower while collecting nectar
c. A lion preying on a zebra
d. Barnacles hitching a ride on a whale

**4. Multiple Choice Activity #4**

In a food chain, which of the following is a primary consumer?

a. Hawk
b. Deer
c. Mushroom
d. Algae

**5. Multiple Choice Activity #5**

What role do decomposers play in an ecosystem?

a. They consume only live animals
b. They compete for light with producers
c. They break down dead material, recycling nutrients back to the ecosystem
d. They produce their own energy through photosynthesis

---

**Answers:**

1. c
2. c
3. b
4. b
5. c

OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Create 5 multiple-choice questions using the following content

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# 10.2 ENERGY FLOW THROUGH ECOSYSTEMS

Ecosystem ecology is an extension of organismal, population, and community ecology. The ecosystem comprises all the biotic components (living things) and abiotic components (non-living things) in a particular geographic area. Some of the abiotic components include air, water, soil, and climate. Ecosystem biologists study how nutrients and energy are stored and moved among organisms and the surrounding atmosphere, soil, and water. Ecosystems are powered by two fundamental processes: energy flow and nutrient cycling. These processes are essential for maintaining life and ecosystem stability. **Energy flow** begins when solar energy is captured by producers through photosynthesis. This energy is then transferred through the ecosystem as organisms consume one another, moving from producers to herbivores, and then to carnivores and decomposers. Unlike nutrients, which are recycled within ecosystems, energy flows in a one-way stream: it enters as sunlight and exits as heat. **Nutrient cycling**, on the other hand, involves the continuous movement of elements like carbon, nitrogen, and phosphorus between the biotic (living) and abiotic (non-living) components of the ecosystem. Together, these processes link all organisms to each other and to their physical environment, forming the foundation of ecosystem ecology.

## Primary Productivity and Energy Budgets

Nearly all life on Earth depends on energy from the sun. In ecosystems, this energy is first captured by **producers** through the process of photosynthesis. These producers convert sunlight into chemical energy, which becomes the starting point for energy flow through the rest of the ecosystem.

However, only about 1% of the sunlight that reaches Earth's surface is actually turned into usable energy by producers. This is because most of the sunlight is either reflected, absorbed as heat, or made up of wavelengths that plants can't use. Producers also use some of the energy they capture to power their own life processes, like growth and repair.

**Primary productivity** is the amount of energy that producers make available to the rest of the ecosystem. This energy forms the base of the food web and determines how much life an ecosystem can support. Ecosystems like tropical rainforests and wetlands are highly productive, while deserts and the open ocean have much lower productivity per unit area. Despite its low productivity, the open ocean contributes significantly to global primary production because of its vast size.

Understanding primary productivity helps ecologists estimate how much energy is available to support life and how ecosystems respond to changes in the environment.

## Energy Transfer and Ecological Pyramids

As energy flows through an ecosystem, it moves from one trophic level to the next – from producers to herbivores, then to carnivores and eventually to decomposers. But this transfer is not very efficient. On average, only about **10% of the energy** at one level is passed on to the next. The remaining 90% is lost in various ways – much of it is released as heat during metabolic processes, some is used for movement and other life activities, some is invested in growth, and some is left behind in waste or undigested material.

This pattern of energy loss can be visualized using an **ecological pyramid**, where each level represents the energy available to organisms at that trophic level. The base of the pyramid is wide, representing the large amount of energy captured by producers. As you move up to herbivores, then to carnivores, the pyramid narrows because less energy is available at each step.

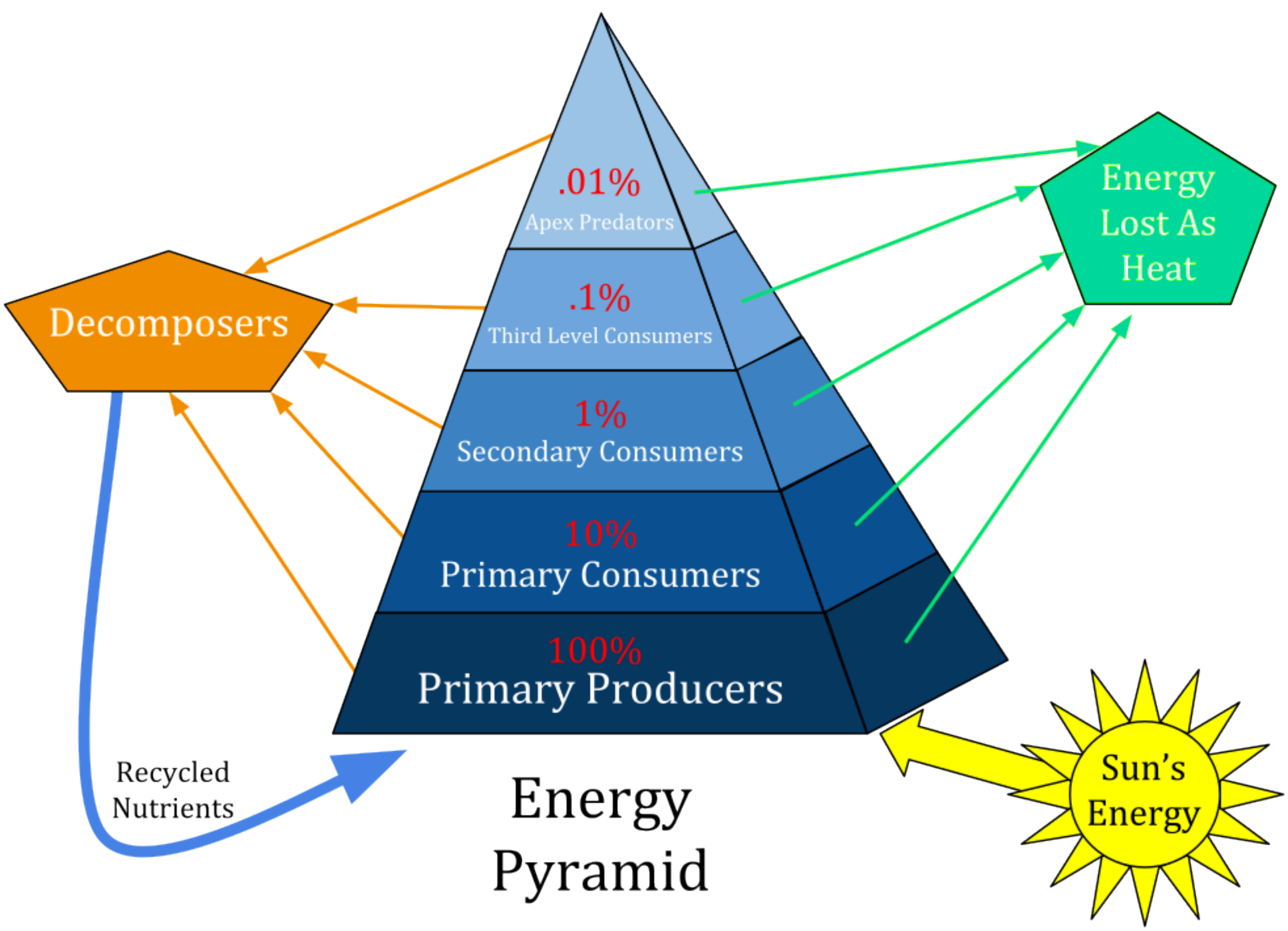


Figure 10.2.1 [Image](#) by [Swiggity.Swag.YOLO.Bro](#), [CC BY-SA 4.0](#)

**Figure 10.2.1 Image Description**

The diagram shows an ecological pyramid of energy flow. At the base are Primary Producers (100%), such as plants, which capture the sun's energy. Above them are Primary Consumers (10%), like herbivores, followed by Secondary Consumers (1%), and then Third Level Consumers (0.1%). At the very top are Apex Predators (0.01%), representing the smallest amount of available energy. Green arrows point outward to show energy lost as heat at each trophic level. On the left, Decomposers recycle nutrients from all levels back to the ecosystem. A large yellow sun at the bottom right highlights the role of solar energy as the foundation of the system.

This explains why ecosystems can only support a few top-level predators, like hawks or wolves. There simply isn't enough energy to support large populations at the top. It also helps explain why food chains are usually limited to **three to five levels** – there's simply not enough energy left to support another level beyond that.

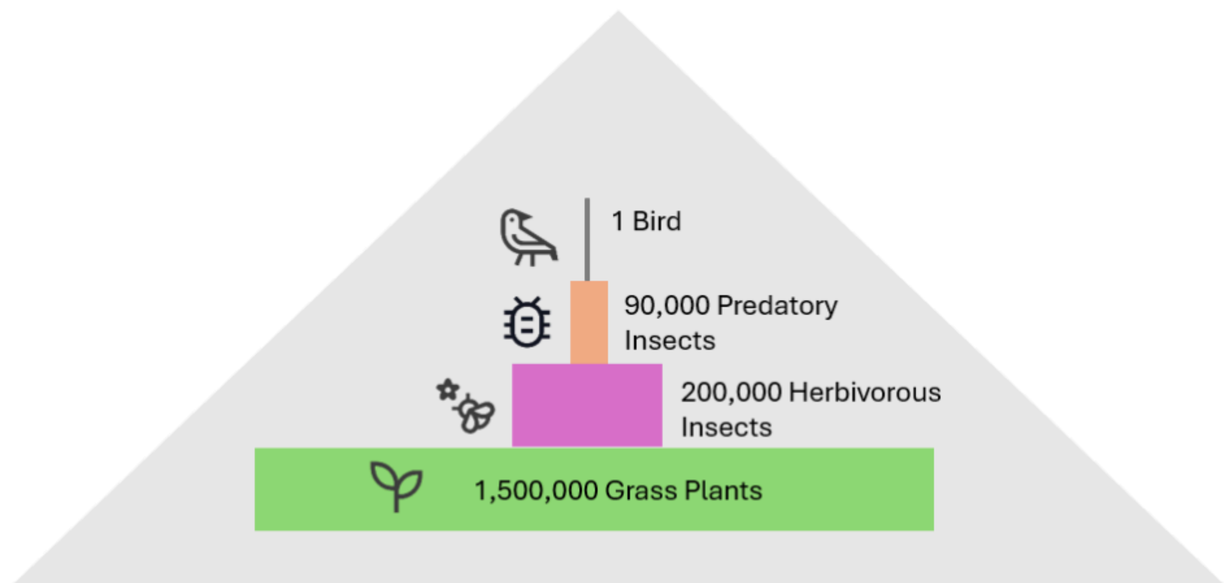


Figure 10.2.2 Example of an ecological pyramid depicting the number of organisms per 0.1 hectare in a summer grassland. Image by saudette, 

**Figure 10.2.2 Image Description**

The image is a pyramid of numbers showing the population sizes at different trophic levels in an ecosystem. At the base are 1,500,000 grass plants (producers). Above them are 200,000 herbivorous insects that feed on the grass. The next level includes 90,000 predatory insects that consume the herbivores. At the top of the pyramid is 1 bird, representing the highest trophic level. The pyramid illustrates how population numbers decrease as energy flows upward through the food chain.

## Knowledge Check

**Text Description**

**1. DragText Activity**

Drag the words into the correct boxes.
_____ ecology is an extension of _____ ecology. The ecosystem comprises all the _____ components (living things) and _____ components (non-living things) in a particular geographic area. Some of the abiotic components include _____, water, _____, and climate. Ecosystem biologists study how _____ and _____ are _____ and _____ among organisms and the surrounding _____, soil, and _____.
Possible answers:

- soil
- moved
- air
- atmosphere
- Ecosystem
- water
- nutrients
- abiotic
- stored
- biotic
- energy
- organismal, population, and community

**2. MultiChoice Activity**

What is the main source of energy that drives most ecosystems on Earth?

a. Wind energy
b. Tidal movement

c. Geothermal heat
d. Solar energy

**3. MultiChoice Activity**

How much of the sunlight that reaches Earth's surface is typically converted into usable energy by producers?

a. About 10%
b. About 25%
c. About 1%
d. About 50%

**4. MultiChoice Activity**

What happens to most of the energy as it moves from one trophic level to the next?

a. It is recycled back to producers
b. It increases at each level
c. It is stored in predators for long-term use
d. It is lost as heat, movement, or waste

**5. MultiChoice Activity**

Which of the following ecosystems has *low productivity per unit area* but contributes significantly to global primary production due to its vast size?

a. Tropical rainforest
b. Desert
c. Wetland
d. Open ocean

**6. MultiChoice Activity**

Why are food chains usually limited to only three to five trophic levels?

a. Herbivores cannot digest producers efficiently
b. Too many predators compete for limited prey
c. Ecosystems run out of physical space
d. Energy is lost at each level, limiting how many levels can be supported

---

Correct Answers:

1. ***Ecosystem*** ecology is an extension of ***organismal, population, and community*** ecology. The ecosystem comprises all the ***biotic*** components (living things) and ***abiotic*** components (non-living things) in a particular geographic area. Some of the abiotic components include ***air***, water, ***soil***, and climate. Ecosystem biologists study how ***nutrients*** and ***energy*** are ***stored*** and ***moved*** among organisms and the surrounding ***atmosphere***, soil, and ***water***.
2. d. Solar energy
3. c. About 1%
4. d. It is lost as heat, movement, or waste
5. d. Open ocean.

OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Create 5 multiple-choice questions using the following content

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# 10.3 NUTRIENT CYCLES IN ECOSYSTEMS

While energy flows through ecosystems in a one-way stream, matter is continuously recycled. The elements that make up living organisms, such as carbon, nitrogen, phosphorus, and water, move through the environment in complex cycles that connect the atmosphere, land, water, and living things. These are known as **biogeochemical cycles**, which are the natural pathways by which essential elements circulate through both the living (bio-) and non-living (geo-) parts of the Earth. Along the way, elements are stored in **abiotic reservoirs** (non-living parts of the environment such as the atmosphere, oceans, soil, and rocks) before being taken up again by organisms. These cycles are essential for life, as they ensure that nutrients are reused and made available across generations.

## The Water Cycle

Water is essential for all living things. It plays a critical role in biological processes such as digestion, circulation, and temperature regulation. The average adult human body is about 60% water. Most land animals, including humans, require a steady supply of fresh water to survive.

Despite its importance, fresh water is surprisingly scarce. While about 2.5% of Earth's water is freshwater, nearly all of it is locked away in glaciers, ice caps, or underground aquifers. Only about 0.5% of Earth's total water is accessible for human use, including both surface water and groundwater that can be reached through wells. This small fraction supports most terrestrial life and ecosystems. A lack of access to this limited supply can have major effects on ecosystem dynamics and human societies. To meet growing demands, humans have developed technologies such as wells, rainwater collection, and desalination to increase water availability.

The **water cycle** (or hydrologic cycle) describes how water moves continuously through the environment, connecting the atmosphere, land, and bodies of water. The water cycle begins with **evaporation**, where heat from the sun causes water from oceans, lakes, and rivers to change into water vapour and rise into the atmosphere. Plants also contribute through **transpiration**, releasing water vapour from their leaves.

As water vapour rises, it cools and condenses into clouds in a process known as **condensation**. Eventually, the water returns to Earth as **precipitation** in the form of rain, snow, sleet, or hail. Some of this water flows over the land as runoff, entering rivers, lakes, and oceans. Some soaks into the ground, replenishing groundwater supplies that plants and animals depend on.

The water cycle is powered by solar energy and does not have a beginning or end. It plays a vital role in regulating climate, supporting plant growth, and shaping ecosystems. Human activities, such as deforestation, urban development, and climate change, can alter the natural flow of water and disrupt local and global ecosystems.

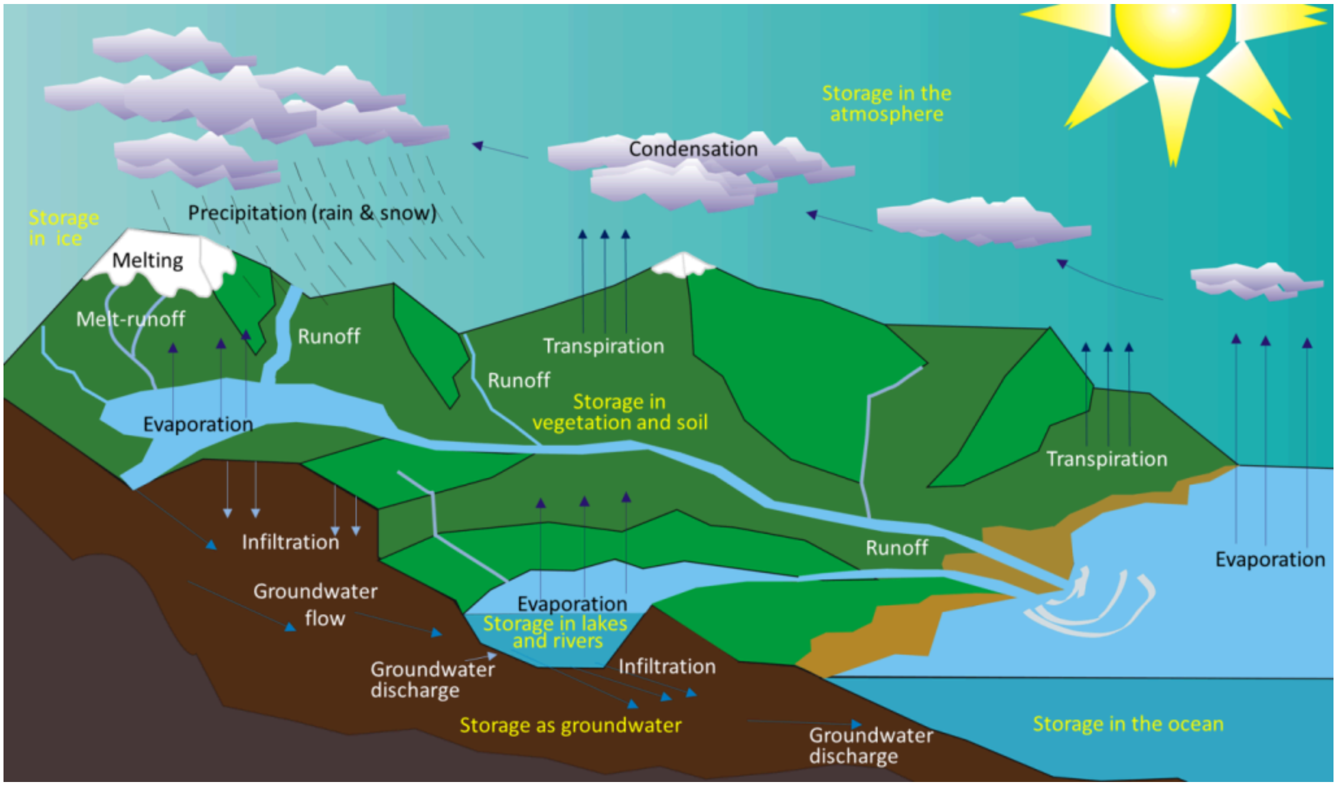


Figure 10.3.1. The various components of the water cycle. Black or white text indicates the movement or transfer of water from one reservoir to another. Yellow text indicates the storage of water. Image by Ingwik, CC BY-SA 3.0, Modifications: Text added

### Figure 10.3.1 Image Description

The diagram illustrates the water cycle, showing how water moves through the atmosphere, land, and oceans. Starting with evaporation from oceans, lakes, and rivers, and transpiration from plants, water vapour rises into the atmosphere. It condenses into clouds (condensation) and returns to Earth as precipitation (rain or snow). In mountainous areas, snow and ice undergo melting and produce melt-runoff. Water then flows as runoff into rivers, lakes, and oceans, or infiltrates into the ground, becoming groundwater. Groundwater can move through groundwater flow and discharge back into rivers, lakes, and oceans. Water is stored in various reservoirs: ice, vegetation and soil, lakes and rivers, groundwater, oceans, and the atmosphere. The sun drives the entire process by providing energy for evaporation and transpiration.

## The Carbon Cycle

Carbon is a key building block of life. It forms the backbone of important biological molecules like carbohydrates, proteins, fats, and DNA. The **carbon cycle** describes how carbon moves between the atmosphere, living organisms, oceans, and the Earth's surface.

Carbon enters the ecosystem primarily through **photosynthesis**, when plants, algae, and some bacteria absorb carbon dioxide ($CO_2$) from the atmosphere and use it to build organic molecules. These molecules are then passed through the food web as organisms eat plants and each other. When organisms release energy through **cellular respiration**, they return $CO_2$ to the atmosphere. When organisms die, decomposers break down their bodies, releasing carbon back into the soil and air.

The main abiotic reservoirs for carbon are the atmosphere (as $CO_2$ gas), the ocean (where carbon is dissolved in water and stored in marine sediments), and fossil fuels (such as coal, oil, and natural gas, formed from ancient biological material). Carbon can remain in these reservoirs for varying lengths of time – from days to millions of years.

Human activities have significantly altered the carbon cycle. The burning of fossil fuels like coal, oil, and natural gas releases large amounts of $CO_2$ into the atmosphere. Deforestation also reduces the number of plants available to absorb carbon. These changes have led to rising levels of atmospheric $CO_2$, contributing to climate change and affecting ecosystems around the world.

### The Carbon Cycle

**Text Description**

A diagram of the carbon cycle showing how carbon moves through the environment.

1. Photosynthesis: Plants, algae, and some bacteria absorb carbon dioxide ($CO^2$) from the atmosphere and use it to make food through photosynthesis.
2. Consumption: Animals eat plants (and other animals), transferring carbon through the food web.
3. Cellular Respiration: Organisms release $CO^2$ back into the atmosphere as a byproduct of cellular respiration.
4. Decomposition: When organisms die, decomposers break down their bodies, returning carbon to the soil and air.
5. Combustion: Carbon stored in fossil fuels is released into the atmosphere through human activities (like burning coal and oil).

The diagram highlights the continuous cycling of carbon between the atmosphere, plants, animals, soil, and human activities.

## The Nitrogen Cycle

Nitrogen is an essential element for all living things. It is a key component of amino acids, proteins, and DNA. Although nitrogen gas ($N_2$) makes up about 78% of Earth's atmosphere, most organisms cannot use it in this form. The **nitrogen cycle** describes how nitrogen moves between the atmosphere, soil, water, and living organisms.

The cycle begins with **nitrogen fixation**, a process in which certain bacteria (often found in soil or in the roots of legumes) convert atmospheric nitrogen gas into forms that plants can absorb, such as ammonium ($NH_4^+$). Other bacteria in the soil carry out nitrification, converting ammonium into nitrates ($NO_3^-$), which plants can use more easily.

Plants take up these nitrogen compounds from the soil and use them to build proteins and other important molecules. When animals eat plants (or other animals), nitrogen moves through the food web. When organisms excrete waste or die, decomposers break down the organic material, returning nitrogen to the soil in the form of ammonium.

Other soil bacteria perform **denitrification**, converting nitrates back into nitrogen gas, which is released into the atmosphere and completes the cycle.

The main **abiotic reservoirs** for nitrogen include the atmosphere (as $N_2$ gas), soil (containing ammonium and nitrate compounds), and water bodies (where nitrogen can accumulate from runoff). Human activities (such as the use of synthetic fertilizers and large-scale agriculture) have significantly altered the nitrogen cycle. Excess nitrogen from fertilizers can run off into waterways, leading to **eutrophication**, a process in which nutrient overload causes rapid algal growth (called algal blooms). As the algae multiply, they eventually exhaust the available nutrients and sunlight, especially in dense blooms where light can't penetrate the water. Once the algae die, their decomposition by bacteria consumes large amounts of oxygen from the water, leading to low-oxygen conditions that can suffocate fish and other aquatic organisms.

## The Nitrogen Cycle

**Text Description**

A diagram of the nitrogen cycle showing the movement of nitrogen through the atmosphere, soil, plants, and animals. At the top, atmospheric nitrogen ($N^2$). The cycle contains the following steps:

- Nitrogen Fixation: Nitrogen-fixing bacteria (in soil or root nodules of legumes) convert nitrogen gas ($N^2$) from the atmosphere into ammonium ($NH^{4+}$), a form plants can use.
- Nitrification: Nitrifying bacteria convert ammonium into nitrites ($NO^{2-}$) and then into nitrates ($NO^{3-}$), which are more easily absorbed by plants.
- Assimilation: Plants absorb nitrates from the soil and use them to build proteins and other nitrogen-containing molecules.
- Animals obtain nitrogen by eating plants or other animals, moving nitrogen through the food web.
- Decomposition: Decomposers break down nitrogen-rich waste and dead organisms, returning nitrogen to the soil as ammonium
- Denitrification: Denitrifying bacteria convert nitrates in the soil back into nitrogen gas ($N^2$), which is released into the atmosphere.

## The Phosphorus Cycle

Phosphorus is a vital nutrient for all living organisms. It is a key component of DNA, RNA, ATP, and cell membranes. Unlike carbon and nitrogen, phosphorus does not cycle through the atmosphere. Instead, it moves through the environment via rocks, soil, water, and living things.

The phosphorus cycle begins when phosphate-containing rocks are broken down by weathering. This releases phosphate ions ($PO_4^{3-}$) into the soil and water, where they can be absorbed by plants. Plants use phosphorus to build important biological molecules, and animals obtain it by eating plants or other animals.

When organisms excrete waste or die, decomposers return phosphorus to the soil or sediments. Some of this phosphorus may be carried by runoff into rivers, lakes, and oceans, where it can settle and become part of new sedimentary rock over long periods of time.

The main abiotic reservoirs for phosphorus are rocks, soil, and sediments. Human activities, such as the use of phosphate-based fertilizers and detergents, can add excess phosphorus to waterways. Similar to the nitrogen cycle, this can lead to eutrophication and harm aquatic ecosystems.

## The Phosphorus Cycle

**Text Description**

A diagram illustrating the phosphorus cycle in an ecosystem.

- Weathering: Phosphate is released from rocks through weathering and erosion and enters the soil and water.
- Sedimentation: Phosphorus in water can settle and become part of sediments, eventually forming new rock.
- Absorption by Plants: Plants absorb phosphate from the soil and use it to build DNA, ATP, and other molecules.
- Consumption: Animals obtain phosphorus by eating plants or other animals.
- Decomposition: Decomposers break down waste and dead organisms, returning phosphorus to the soil or water.
- Human Impact: Fertilizers and detergents add phosphorus to ecosystems, often leading to water pollution and eutrophication.

The cycle shows continuous movement of phosphorus between rocks, water, soil, plants, and animals.

## Knowledge Check

**Text Description**

**1. Multiple Choice Activity #1**

Which of the following statements best distinguishes energy flow from nutrient cycling in ecosystems?

a. Energy is recycled while nutrients are lost
b. Both energy and nutrients flow in one direction only
c. Energy flows in one direction; nutrients are continuously recycled
d. Nutrients flow through decomposers first; energy does not

**2. Multiple Choice Activity #2**

What is the main process by which plants remove carbon dioxide from the atmosphere in the carbon cycle?

a. Cellular respiration
b. Photosynthesis
c. Combustion
d. Decomposition

**3. Multiple Choice Activity #3**

Which process in the nitrogen cycle converts atmospheric nitrogen gas into a form that plants can absorb and use?

a. Denitrification
b. Assimilation
c. Nitrogen fixation
d. Nitrification

**4. Multiple Choice Activity #4**

Why is the phosphorus cycle unique compared to the carbon and nitrogen cycles?

a. It does not involve living organisms
b. It does not cycle through the soil
c. It does not cycle through the atmosphere
d. It is not affected by human activities

**5. Multiple Choice Activity #5**

Which environmental problem is commonly associated with excess nitrogen or phosphorus entering aquatic ecosystems?

a. Acid rain
b. Eutrophication
c. Greenhouse effect
d. Ozone depletion

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**Answers:**

1. c
2. b
3. c
4. c
5. b

OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Create 5 multiple-choice questions using the following content

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# CHAPTER 10 SUMMARY

## Key Takeaways

- **Interspecific interactions shape community structure:** Species within a community interact in diverse ways—such as competition, predation, herbivory, parasitism, mutualism, and commensalism—which influence population dynamics, biodiversity, and evolutionary adaptations.
- **Species evolve to reduce competition and survive environmental pressures:** Through niche differentiation and the competitive exclusion principle, species adapt to avoid direct competition. Coevolution further drives reciprocal adaptations between interacting species, from predators and prey to mutualistic partners.
- **Energy flows through trophic levels but is inefficiently transferred:** Energy enters ecosystems via producers through photosynthesis and flows to herbivores, carnivores, and decomposers. Due to the 10% rule, only a small fraction of energy is passed on at each level, limiting food chain length and top predator populations.
- **Food webs better represent complex ecological relationships than food chains:** While food chains show linear feeding relationships, food webs reveal how species often occupy multiple trophic levels, emphasizing the interconnectedness and resilience or vulnerability of ecosystems.
- **Biogeochemical cycles recycle essential nutrients:** The carbon, nitrogen, phosphorus, and water cycles move matter through living and non-living components of ecosystems. These cycles sustain life by replenishing nutrients that organisms need to grow, reproduce, and function.
- **Human activities disrupt ecosystem balance:** Practices like burning fossil fuels, deforestation, and overuse of fertilizers introduce excess nutrients or pollutants, leading to ecosystem imbalances such as climate change, eutrophication, and biodiversity loss.

OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Summarize the following content into six key takeaways.

## Flashcards

**Text Description**

This activity contains a set of dialogue cards, which are described below.

**Key Terms:**

1. Phosphorus cycle
2. Coevolution
3. Predation
4. Nutrient cycling
5. Commensalism
6. Carnivore
7. Detritus
8. Nitrification
9. Competition
10. Main abiotic reservoirs for phosphorus
11. Denitrification
12. Tertiary consumers
13. Mimicry
14. Host
15. Parasitism
16. Warning coloration
17. Parasite
18. Mechanical defences
19. Competitive exclusion principle
20. Primary productivity
21. Ecological pyramid
22. Camouflage
23. Ectoparasites

24. Prey
25. Predator
26. Assimilation
27. Trophic structure
28. Biogeochemical cycles
29. Condensation
30. Primary consumers
31. Chemical defenses
32. Producers
33. Decomposers
34. Mutualism
35. 6 types of interspecific interactions
36. Quaternary consumers
37. Abiotic reservoirs
38. Herbivores
39. Food web
40. Consumers
41. Water cycle
42. Energy flow
43. Indirect defenses
44. Interspecific interactions
45. Secondary consumers
46. Precipitation
47. Zooplankton
48. Community
49. Carbon cycle
50. Behavioral defenses
51. Transpiration
52. 5 types of defenses against predation
53. Main abiotic reservoirs for nitrogen
54. Main abiotic reservoirs for carbon
55. Phytoplankton
56. Detritivores
57. Niche differentiation
58. Nitrogen fixation

59. 3 types of defenses against herbivory
60. Niche
61. Decomposition
62. Evaporation
63. Species diversity
64. Nitrogen cycle
65. Food chain
66. Herbivory
67. Endoparasites

**Solution:**

1. The movement of phosphorus through rocks, water, soil, and living organisms; Mainly driven by weathering and sedimentation
2. The process by which two or more species influence each other's evolutionary pathways over time through close ecological interactions
3. An interaction where one organism (the predator) kills and eats another (the prey); benefits the predator and harms the prey (+/−)
4. The continuous movement of nutrients such as nitrogen, phosphorus, and carbon through the environment and organisms
5. An interspecific interaction in which one species benefits while the other is neither helped nor harmed (+/0)
6. An animal that feeds on other animals
7. Dead organic matter including the remains of organisms and waste products
8. A process in the nitrogen cycle where bacteria convert ammonium ($NH^{4+}$) to nitrate ($NO^{3-}$)
9. An interspecific interaction in which individuals of different species compete for the same limited resources; Negative interaction for both species involved (-/-)
10. rocks, soil, sediments, water (from human activities)
11. The conversion of nitrates in the soil back into nitrogen gas by bacteria, releasing it into the atmosphere
12. Carnivores that eat other carnivores (secondary consumers)
13. An adaptation in which one species evolves to resemble a harmful or distasteful species
14. The organism that a parasite lives on or in and from which it obtains nourishment
15. An interspecific interaction where one organism (parasite) feeds off another (host); benefits the parasite and harms the host (+/−)
16. Bright colors or patterns that signal to predators that an organism is toxic or unpalatable

17. An organism that lives in or on another organism (host) and benefits by deriving nutrients at the host's expense
18. Physical features of an organism, like thorns or shells, that deter herbivores or predators
19. The idea that two species competing for the exact same resources cannot stably coexist; one will outcompete the other
20. The amount of energy that producers make available to the rest of the ecosystem through photosynthesis; Forms the base of the food web
21. A graphical representation that shows the amount of energy or organisms at each trophic level in an ecosystem; Only about 10% of the energy at one level is passed on to the next
22. A defense mechanism that allows organisms to blend into their surroundings to avoid detection by predators
23. Parasites that live on the surface of the host, such as ticks or lice
24. An organism that is hunted and consumed by another species (predator)
25. An organism that kills and eats another species (prey)
26. The process by which plants absorb nitrates or ammonium from the soil and incorporate them into organic molecules such as proteins and DNA
27. The feeding relationships in an ecosystem, organized by trophic levels
28. Natural processes that recycle elements like carbon, nitrogen, phosphorus, and water through the living and non-living parts of ecosystems
29. The process by which water vapor in the air is changed into liquid water; The reverse of evaporation and is a key part of the water cycle
30. Herbivores that feed directly on producers
31. The use of toxic, distasteful, or harmful chemical compounds by organisms to deter herbivores or predators
32. Organisms, typically plants or algae, that make their own food using sunlight through photosynthesis; Form the base of food chains
33. Organisms, such as fungi and bacteria, that break down dead matter and waste into simpler substances, recycling nutrients into the ecosystem
34. An interspecific interaction in which both species benefit (+/+)
35. competition (-/-), herbivory (+/-), predation (+/-), parasitism (+/-), mutualism (+/+), commensalism (+/0)
36. Top-level predators in a food chain that feed on tertiary consumers
37. Non-living parts of the environment where elements are stored, such as the atmosphere, oceans, soil, and rocks
38. Plant-eating animals, like insects, birds, deer, or rabbits

39. A complex network of interconnected food chains that shows the feeding relationships in an ecosystem
40. Organisms that obtain energy by feeding on other organisms (producers or other consumers)
41. Describes how water moves continuously through the environment, connecting the atmosphere, land, and bodies of water
42. The one-way movement of energy through an ecosystem from the sun to producers and then to various levels of consumers
43. Strategies used by plants to attract predators or parasitoids of herbivores to reduce herbivory
44. Relationships between individuals of different species in a community, such as predation, competition, and mutualism
45. Carnivores that eat herbivores (primary consumers)
46. The movement of water from the atmosphere to the Earth's surface in the form of rain, snow, sleet, or hail
47. Microscopic aquatic animals or heterotrophic protists that feed on phytoplankton and other small organisms
48. All the different populations of species that live together and interact in a particular area
49. The movement of carbon through atmosphere, oceans and living organisms; Carbon is exchanged among organisms and the environment through processes like photosynthesis and cellular respiration
50. Actions or behaviors that help prey avoid predators, such as fleeing, hiding, living in groups, or startling predators
51. The evaporation of water from plant leaves, which contributes to the movement of water through the water cycle
52. behavioural defenses, mechanical defenses, camouflage, chemical defenses, mimicry
53. atmosphere (as $N^2$ gas), soil (ammonium and nitrate), and water bodies (where nitrogen can accumulate from runoff)
54. Atmosphere ($CO^2$ gas), the ocean, and fossil fuels
55. Microscopic photosynthetic organisms found in aquatic environments that serve as producers
56. Organisms that consume dead organic matter, especially in early stages of decay; e.g. earthworms, millipedes
57. The process by which competing species use the environment differently to minimize competition
58. A process by which certain bacteria convert atmospheric nitrogen gas ($N^2$) into forms (like

ammonium) that plants can absorb

59. mechanical defenses, chemical defenses, indirect defenses
60. The role an organism plays in its ecosystem, including how it uses resources and interacts with other organisms
61. The breakdown of dead organisms and waste by decomposers, returning nutrients to the environment
62. The process by which water changes from a liquid to a gas or vapor, typically from surfaces like lakes, rivers, and soil
63. The variety and relative abundance of different species in a community
64. The movement of nitrogen through the atmosphere, soil, water, and living organisms; Includes processes like nitrogen fixation, nitrification, assimilation, and denitrification
65. A linear sequence of organisms through which energy and nutrients flow as one organism eats another
66. A interspecific interaction where an animal (herbivore) feeds on a plant or algae; benefits the herbivore and harms the plant (+/−)
67. Parasites that live inside the host's body, such as tapeworms or roundworms

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Provide definitions for all the bolded terms in the shared content and list all the terms in alphabetical order.

# CHAPTER 11: BIODIVERSITY AND CONSERVATION

## Chapter Overview

## Learning Objectives

By the end of this chapter, you will be able to:

- Define biodiversity and explain its three levels—genetic, species, and ecosystem diversity—along with their roles in supporting ecosystem stability and resilience.
- Describe the importance of biodiversity in providing ecosystem services, cultural value, and human well-being.
- Identify and explain the major drivers of biodiversity loss, including habitat destruction and fragmentation, overexploitation, pollution, climate change, and invasive species, with examples from local and global contexts.
- Explain key conservation strategies, including legislative frameworks, protected areas, species-level conservation approaches, and ecosystem restoration, and evaluate their effectiveness in protecting biodiversity.
- Demonstrate how individuals can contribute to biodiversity conservation through sustainable lifestyle choices, citizen science, advocacy, volunteering, and integrating sustainability into career paths.
- Assess the potential for biodiversity recovery by recognizing successful conservation efforts and understanding the importance of collective responsibility and long-term commitment to environmental stewardship.

OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Provide 6 learning objectives for the shared content.

# 11.1 BIODIVERSITY

## Types of Biodiversity

**Biodiversity**, short for biological diversity, refers to the variety of life on Earth, ranging from the smallest microorganisms to the largest plants and animals. Understanding biodiversity is required to appreciate the complexity and interconnectedness of life on Earth.

Biodiversity is often explored through three main levels:

### Genetic Diversity

Figure 11.1.1. Genetic variations allow for the differences in the body size, shape, colour intensity, and stripe patterns in this group of zebras. Photo by Magda Ehlers, Pexels License

**Genetic diversity** is the variation in the genes of organisms within a population. Genes determine an organism's traits, such as size, colour, or resistance to disease, so genetic diversity means that individuals in a population are not all the same. This variation is essential for the survival of species because it allows populations to adapt to changes in their environment.

For example, imagine a viral outbreak affecting a population of plants. If all the plants are genetically identical, the virus could wipe out the entire population. But in a genetically diverse population, some individuals might carry genes that make them naturally resistant to the virus. These resistant plants are more likely to survive and reproduce, passing on their beneficial traits to the next generation. Over time, this helps the population adapt and persist despite environmental challenges.

### Species Diversity

**Species diversity** refers to the variety of different species in a particular region or ecosystem. It includes two key components:

- **Species richness:** The number of different species present.
- **Species evenness:** How evenly individuals are distributed among those species.

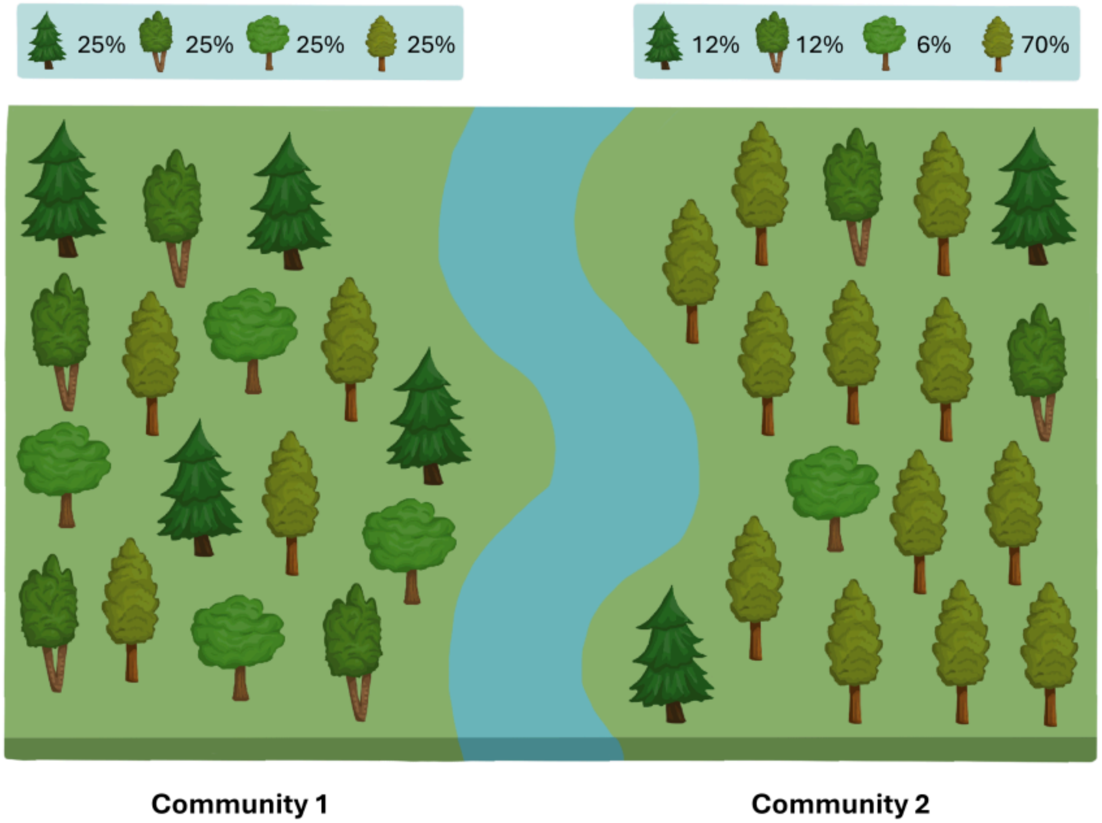


Figure 11.1.2. Both of these communities have the same species richness, but they have different species evenness. Community 1 has greater species evenness, so it has higher species diversity. Image by Avery Audette, CC BY-NC-SA 4.0

High species diversity is important because it contributes to the stability and resilience of ecosystems. A diverse ecosystem is better able to withstand disturbances, such as disease outbreaks or environmental changes.

Consider a forest facing an invasion by a pest that kills pine trees. If the forest is made up mostly of pine trees, the pest could destroy most of the forest, leaving little habitat for animals and causing many species to die or leave. However, in a more diverse forest with many types of trees, the loss of pine trees would be less devastating. Other tree species would remain to provide food and shelter, helping the ecosystem recover and continue to support wildlife.

## Ecosystem Diversity

Figure 11.1.3 The lake, wetland and forest are all different ecosystems in this particular area. Photo by Pixnio, Pixnio License

**Ecosystem diversity** refers to the variety of ecosystems in a given area. An ecosystem includes all the living organisms in a particular area, along with the abiotic (non-living) components like air, water, and soil. Forests, wetlands, grasslands, deserts, coral reefs, and tundra are all examples of different ecosystems. Each ecosystem supports unique communities of organisms and plays a role in global ecological processes like nutrient cycling and climate regulation.

## Importance of Biodiversity

Biodiversity is essential for maintaining the health of the planet and the well-being of all living things. One of its most critical roles is supporting **ecosystem services**, the natural processes performed by ecosystems that directly or indirectly benefit people. These services include:

- **Pollination** of crops by insects like bees and butterflies.
- **Purification of air and water** by plants and wetlands.
- **Decomposition** of waste and recycling of nutrients by fungi and bacteria.
- **Climate regulation** through forests and oceans that absorb carbon dioxide.

Without biodiversity, these services would be less effective or could collapse entirely.

Biodiversity is also a vital source of food, lumber, and medicine. Many modern drugs are derived from compounds found in plants, fungi, and animals. Biodiversity holds cultural, spiritual, and recreational value. It is even important in mental health and well-being. Research shows that exposure to biodiverse natural environments (rich in plant, bird, and insect life) can reduce stress, lower the risk of depression and anxiety, and improve cognitive function.

Finally, diverse ecosystems are more resilient to disturbances such as disease outbreaks, extreme weather, or invasive species. This resilience is crucial in our rapidly changing world, helping ecosystems recover and continue to support life even under stress.

## The Biodiversity Crisis

Earth is facing a **biodiversity crisis**. Across the globe, species are disappearing at an unprecedented rate, and ecosystems are being pushed beyond their limits. This crisis is not just about the loss of rare animals or plants, but it's about the unravelling of the natural systems that support all life, including our own.

The **Living Planet Index** tracks the population trends of thousands of vertebrate species around the world. According to the [2024 Living Planet Report [PDF]] (WWF, 2024, p. 24), monitored populations of mammals, birds, amphibians, reptiles, and fish have declined by an average of 73% since 1970. This means that over 50 years, the size of monitored wildlife populations has reduced, on average, by almost three-quarters.

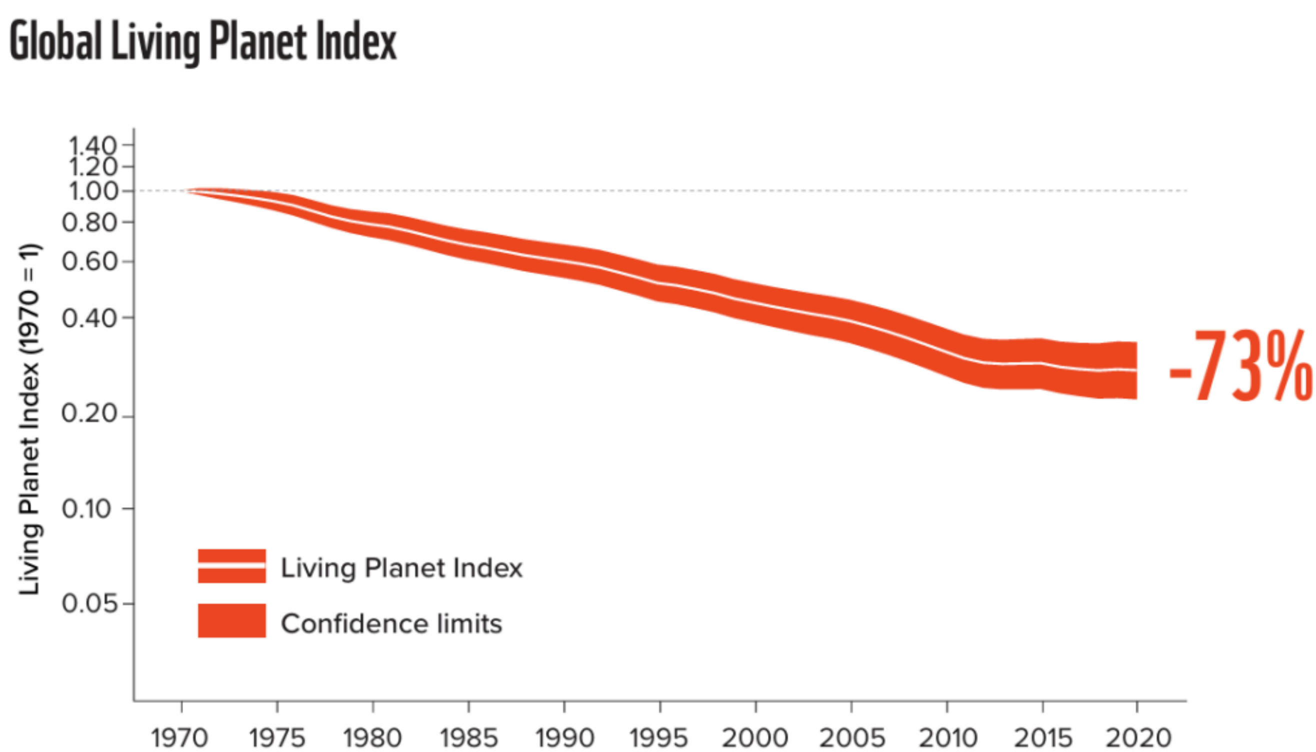


Figure 11.1.4 The global Living Planet Index from 1970 to 2020 based on 34,836 monitored populations of 5,495 vertebrate species. The white line represents the index value, and the shaded areas represent the statistical uncertainty surrounding the value. Image © 2024 WWF All rights reserved. Used under FDEd (CAN).

**Figure 11.1.4 Image Description**

A line graph titled *Global Living Planet Index* displays the change in the Living Planet Index from 1970 to 2020, with 1970 set as the baseline value of 1.0 on the vertical axis. The horizontal axis shows years in increments of five, from 1970 to 2020. The solid red line represents the Living Planet Index, showing a steady decline over time, while the shaded red band around it indicates confidence limits. The index drops by approximately 73% over the 50-year period, as highlighted by a large red "-73%" on the right side of the graph.

Figure 11.1.5 "Biodiversity Jenga", Martin Sharman, CC BY-NC-SA 2.0.

One way to understand the biodiversity crisis is through the Jenga analogy. Imagine an ecosystem as a tower built from Jenga blocks, where each block represents a species. As species are lost, blocks are removed from the tower. At first, the structure may remain standing, but as more blocks are taken away, the tower becomes unstable and eventually collapses. Similarly, ecosystems can tolerate some loss of biodiversity, but beyond a certain point, their ability to function breaks down. This analogy highlights how even the loss of seemingly minor or obscure species can have cascading effects, threatening the stability of entire ecosystems.

The biodiversity crisis is driven by a combination of human activities:

## Habitat Destruction and Fragmentation

The leading cause of biodiversity loss is the destruction of natural habitats. Forests are cleared for agriculture, wetlands are drained for development, and grasslands are converted into urban areas. When habitats are broken into smaller, isolated patches, it becomes harder for species to find food, reproduce, and migrate. This **fragmentation** can lead to population declines and local extinctions.

Figure 11.1.6 The clearing of forests destroyed by logging. Photo by H.-J. Sydow, CC BY-SA 3.0

In Canada, the boreal forest, one of the largest intact forest ecosystems in the world, is being fragmented and destroyed by logging, mining, and oil extraction. This deforestation threatens species such as the woodland caribou, which depend on large areas of old-growth forest for their survival. Habitat fragmentation isolates caribou populations, making it difficult for them to find food and escape predators.

Ontario contains 25% of Canada's remaining wetlands, which account for about 6% of the world's total wetland area. Yet, these wetlands are being fragmented and drained for agricultural expansion and urban development. Southern Ontario has lost about 72% of its original wetlands, with some areas in southwestern Ontario losing over 85%. This loss threatens biodiversity but also reduces ecosystem services like flood control, water purification, and carbon storage.

## Overexploitation

**Overexploitation** involves harvesting species from the wild at rates faster than their populations can recover. This includes overfishing, hunting and logging. Overfishing has depleted many fish stocks, driving some species to the brink of extinction. The illegal wildlife trade targets animals like elephants, rhinos, and tigers for their ivory, horns, and skins, drastically reducing their populations. Forests are heavily impacted by unsustainable logging, which threatens tree species but also destroys habitats for countless other organisms that depend on healthy forest ecosystems to survive.

Figure 11.1.7 Elephant ivory seized from poachers in Garamba. Photo by Enough Project, CC BY-NC-ND 2.0

Overexploitation can also include using natural resources at rates that exceed ecological recovery. For example, freshwater is withdrawn from lakes, rivers, and aquifers for agriculture, industry, and urban use at unsustainable rates. This can lower water levels, degrade aquatic habitats, and concentrate pollutants.

In parts of the United States, such as California and Arizona, prolonged drought and overuse have led to severe water shortages. In Canada, parts of British Columbia and the Prairies are also experiencing increasing water stress due to drought and growing demand.

## Pollution

**Pollution** from human activities harms species and ecosystems in many ways. Pesticides and fertilizers can poison soil and water, harming insects, amphibians, and aquatic life. Plastic waste can entangle or be ingested by marine animals. Air pollution can damage forests and acidify lakes. Light and noise pollution disrupt animal behaviour and migration.

Figure 11.1.8 "Fort McMurray, Alberta" by Kris Krüg, CC BY-NC-ND 2.0

Mining generates more pollutants than any other industry in North America. The extraction of oil from the Alberta oil sands has significantly contributed to environmental pollution. Tailings ponds, which store the toxic by-products of this extraction process, have contaminated local water sources, harming aquatic life. Air pollution from oil sands operations releases substances that can lead to acid rain, adversely affecting both terrestrial and aquatic ecosystems.

Figure 11.1.9 Algae Bloom on Lake Erie. Microcystis blooms have become a regular occurrence on the lake. In 2014, the bloom was especially intense around the water intake for Toledo, Ohio, causing managers to warn residents not to consume public drinking water for several days. NASA image courtesy Jeff Schmaltz, LANCE/EOSDIS MODIS Rapid Response Team at NASA GSFC. Caption by Mike Carlowicz.

Having too many nutrients can also be harmful. When there is a large input of nitrogen and phosphorus (e.g., from sewage and runoff from fertilized lawns and farms), the growth of algae skyrockets, resulting in a large accumulation of algae called an **algal bloom**. Algal blooms (Figure 8.4.5) can become so extensive that they reduce light penetration in water. As a result, the lake or pond becomes aphotic and photosynthetic plants cannot survive. When the algae die and decompose, severe oxygen depletion occurs in the water. Fishes and other organisms that require oxygen are then more likely to die.

Some toxic chemicals don't break down easily, so they persist in the environment and build up in organisms over time. **Biomagnification** is the process by which toxic chemicals become more concentrated in organisms at each successive trophic level. These substances are typically fat-soluble, meaning they accumulate in body fat rather than being excreted in water-based waste.

One of the most well-known examples of biomagnification involves the pesticide DDT, which was widely used in the mid-20th century. Although it was effective at controlling insects, DDT entered aquatic ecosystems and accumulated in fish. Birds that ate those fish, such as bald eagles, ended up with high concentrations of DDT in their bodies (as mentioned in 16.3). This caused their eggshells to become thin and fragile, leading to widespread reproductive failure. The issue was brought to public attention by Rachel Carson's influential book *Silent Spring*, and DDT was eventually banned in many countries, including Canada.

Other substances known to biomagnify include **PCBs** (polychlorinated biphenyls), once used in industrial coolants, and heavy metals like mercury, lead, and cadmium. Biomagnification is a powerful reminder of how pollution can move through ecosystems and affect species far removed from the original source. It also highlights the importance of monitoring and regulating persistent pollutants to protect both wildlife and human health.

## Climate Change

**Climate change** refers to long-term shifts in global temperatures and weather patterns, primarily caused by human activities. The main driver is the increased concentration of greenhouse gases in the atmosphere, such as carbon dioxide ($CO_2$) and methane ($CH_4$). These gases trap heat from the sun, creating a "**greenhouse effect**" that warms the planet. Most of these emissions come from burning fossil fuels and from deforestation. As the climate changes, it disrupts ecosystems by altering temperature and rainfall patterns, shifting growing seasons, melting ice, and increasing the frequency of extreme weather events. These changes pose serious challenges for many species, especially those with narrow habitat ranges or limited ability to adapt or migrate.

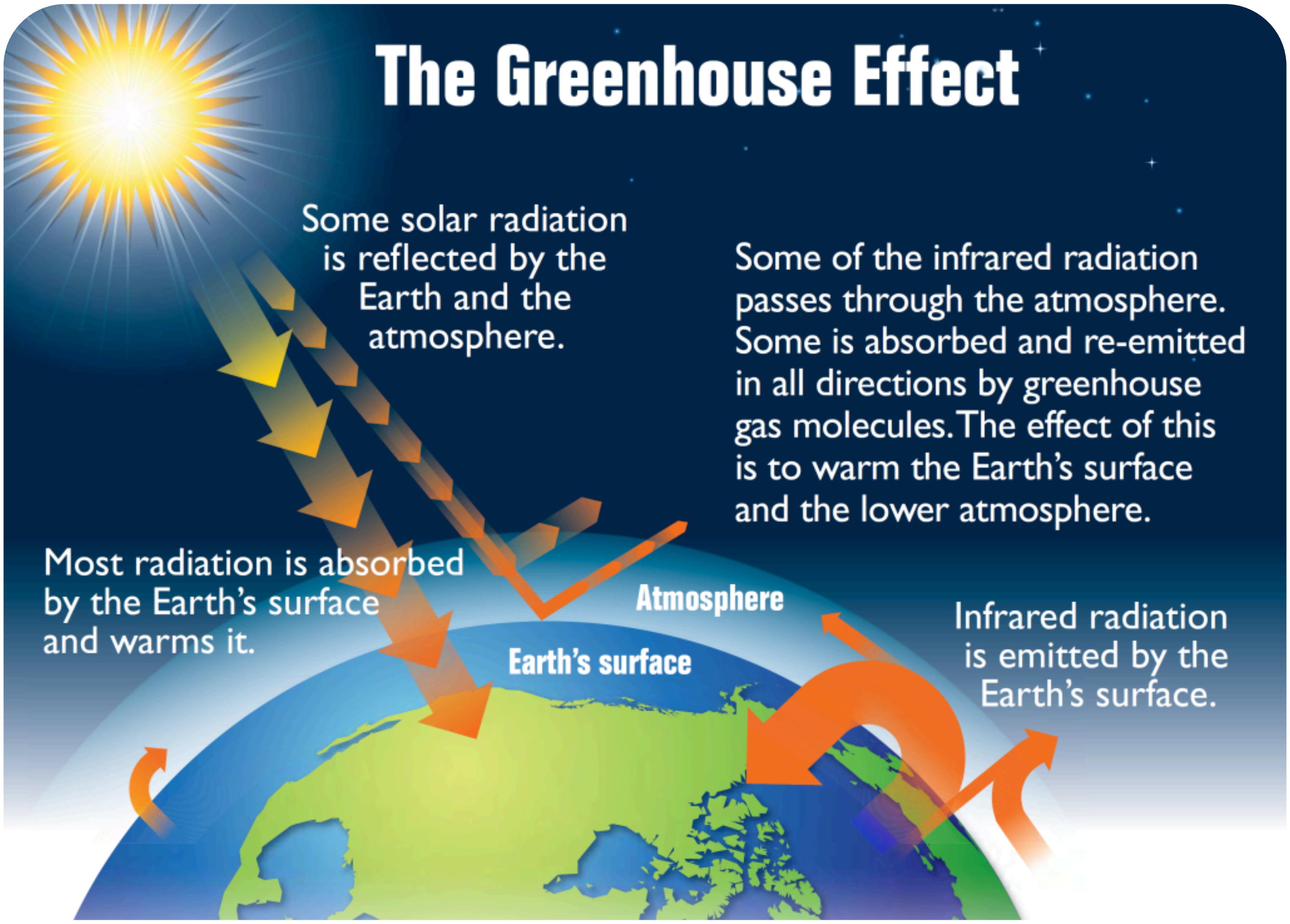


Figure 11.1.10 "Earth's Greenhouse Effect" by US EPA, Public Domain

**Figure 11.1.10 Image Description**

An educational diagram titled The Greenhouse Effect illustrates how solar and infrared radiation interact with Earth's surface and atmosphere. On the left, yellow arrows from the Sun show incoming solar radiation; some is reflected by Earth and the atmosphere, while most is absorbed by Earth's surface, warming it. Orange arrows depict infrared radiation emitted by the Earth's surface. Some infrared radiation passes through the atmosphere, while some is absorbed and re-emitted in all directions by greenhouse gas molecules, warming the surface and lower atmosphere. Labels identify "Atmosphere" and "Earth's surface," and explanatory text is placed near each set of arrows to describe the processes. The image uses a combination of bright colors against a dark blue background to distinguish radiation types and energy flows.

Wildfires are becoming more frequent and intense worldwide, driven by rising temperatures, prolonged droughts, and shifting weather patterns associated with climate change. These fires pose a significant threat to biodiversity by destroying habitats and displacing wildlife.

Coral reefs are highly sensitive to warming oceans and are experiencing widespread bleaching and die-offs.

Figure 11.1.11 "Dying Coral Reef" (photo, left) by Cesar Jung-Harada, CC BY-NC-SA 2.0, "Vibrant-coloured coral reef" (photo right) by Tom Fisk, Pexels License

## Invasive Species

As previously discussed, invasive species are plants, animals, or other organisms introduced to new environments that end up causing harm. Once established, they can spread quickly, outcompeting native species for resources, altering habitats, spreading disease, or preying on native wildlife. Because they often have no natural predators in their new environment, invasive species can grow unchecked and become a serious threat to biodiversity.

Invasive species can spread in many ways, but one of the most common (and preventable!) is through human activity. Global trade and travel move organisms around the world in shipping containers, on boats, or in soil stuck to tires and equipment. But invasives also spread in more everyday ways, including through our homes, gardens, and even our pets.

One major pathway is the release of pets into the wild. In Florida, Burmese pythons are now thriving in the Everglades after being released by pet owners who could no longer care for them. These massive snakes have no natural predators in the region and have caused dramatic declines in native mammal populations. Closer to home, in Ontario, goldfish released from aquariums have become a growing problem in ponds and lakes. In the wild, goldfish can grow much larger than in tanks, stir up sediment, uproot aquatic plants, and compete with native fish for food and space.

Figure 11.1.12 "Burmese Python" by chloetheexplorer, CC BY-NC 4.0, "Goldfish" by Ioqan, CC BY-NC 4.0

Gardens and landscaping can also be a source of invasive species. Many ornamental plants sold at garden centers are non-native, and some can escape cultivation and spread into nearby natural areas. Periwinkle, Japanese knotweed, and Norway maple are just a few examples of garden plants that have become invasive in parts of Canada.

Figure 11.1.13 "Lesser Periwinkle" by emmayetman, 

## Knowledge Check

**Text Description**

**1. MultiChoice Activity #1**

Which of the following best describes *genetic diversity*?

a. The even distribution of individuals among different species.
b. The variety of ecosystems in a given region.
c. The total number of species in a given ecosystem.
d. The variation in the genes of organisms within a population.

**2. MultiChoice Activity #2**

A forest with high species diversity is more likely to:

a. Have only one dominant species.

b. Recover more effectively from disturbances such as pests or disease.
c. Be completely destroyed if one tree species is lost.
d. Lack the ability to provide ecosystem services.

**3. MultiChoice Activity #3**

Which of the following is an example of an *ecosystem service* provided by biodiversity?

a. Pollination of crops by bees and butterflies
b. Coral bleaching due to climate change.
c. The illegal wildlife trade.
d. The spread of invasive species.

**4. MultiChoice Activity #4**

The *Jenga analogy* in biodiversity studies is used to illustrate:

a. The competition between invasive and native species.
b. How genetic variation increases within a population.
c. How species loss can destabilize ecosystems over time.
d. How climate change affects ocean currents.

**5. MultiChoice Activity #5**

Which of the following is NOT a primary driver of biodiversity loss mentioned in the content?

a. Natural selection.
b. Pollution.
c. Overexploitation.
d. Habitat destruction and fragmentation.

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Answers:

1. d. The variation in the genes of organisms within a population.
2. b. Recover more effectively from disturbances such as pests or disease.
3. a. Pollination of crops by bees and butterflies
4. c. How species loss can destabilize ecosystems over time.

5. a. Natural selection.

OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Create 5 multiple-choice questions using the following content

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# 11.2 CONSERVATION

**Conservation biology** is the science of protecting biodiversity. It responds to the growing imbalance caused by human activities – species are going extinct much faster than new ones can naturally evolve. Conservation is not just about saving individual species but aims to preserve the ecological relationships that sustain ecosystems.

## Conservation Strategies

Effective conservation depends on ecological knowledge. Today, the main efforts to preserve biodiversity involve legislative approaches to regulate human and corporate behaviour, setting aside protected areas, conserving individual species and ecosystem restoration.

### Legislation

Laws and international agreements play a critical role in protecting biodiversity by regulating human activities that threaten species and ecosystems. These legal tools help prevent extinction, support species recovery, and promote sustainable interactions with nature.

Canada's **Species at Risk Act (SARA)** provides a legal framework for identifying and protecting species at risk, developing recovery strategies, and conserving critical habitat. At the international level, the most comprehensive agreement for biodiversity is the Convention on Biological Diversity (CBD), established in 1992. Its current framework, the Kunming-Montreal Global Biodiversity Framework, includes ambitious goals such as protecting 30% of the planet's lands and waters by 2030 and restoring 30% of degraded ecosystems (30×30).

Climate-related agreements also play a role in biodiversity protection. The United Nations Framework Convention on Climate Change (UNFCCC) and its associated COP (Conference of the Parties) meetings bring countries together to assess progress and strengthen commitments to climate action. The Paris Agreement, adopted under the UNFCCC, aims to limit global warming to well below 2°C above pre-industrial levels. Scientific findings from the Intergovernmental Panel on Climate Change (IPCC) show that exceeding 1.5°C would lead to significantly more severe climate impacts, so there is a strong global push to limit warming to 1.5°C. The IPCC supports these efforts by providing scientific assessments that guide policy decisions and emphasize the role of ecosystems in climate mitigation.

## Protected Areas


Figure 11.2.1 Algonquin Provincial Park is Ontario's oldest and most iconic protected area, known for its vast forests, scenic lakes, and popular recreational activities like hiking, canoeing, and wildlife viewing. Photo by Wladyslaw, CC BY-SA 3.0

**Protected areas** are regions set aside to preserve biodiversity. These areas include national parks, wildlife areas, marine reserves, and other conservation zones where human activities are regulated or restricted. By limiting development, resource extraction, and other disturbances, protected areas allow ecosystems to function with minimal human interference and provide safe habitats for species to thrive.

In Canada, protected areas are a cornerstone of conservation efforts. They include National Parks, which are managed by Parks Canada to protect representative examples of the country's different natural regions. In Ontario, the protected areas system includes provincial parks and conservation areas, covering approximately 11% of the province's land area (Environment and Climate Change Canada, 2025). These areas are designed to protect significant natural and cultural features while supporting recreation, education, and scientific research.

## Species-Level Conservation

**Species-level conservation** focuses on protecting individual species through targeted actions such as captive breeding, reintroduction, and habitat restoration.

- **Captive breeding** involves raising individuals of a species in controlled environments (zoos, research facilities, or conservation centers) with the goal of increasing population numbers. Once stable populations are established, individuals may be released into the wild to help restore or reinforce natural populations. This approach is especially useful for species with critically low numbers or those that have disappeared from parts of their historical range.
- **Reintroduction** is the process of returning individuals to areas where the species once lived but has disappeared. Successful reintroduction depends on suitable habitat, genetic diversity, and long-term monitoring.
- **Habitat restoration** involves repairing or recreating natural environments that have been degraded or destroyed. This can include planting native vegetation, removing invasive species, restoring water flow, and improving soil conditions. Restored habitats provide the necessary conditions for species to survive and reproduce.

These various conservation strategies often work hand-in-hand. For example, the recovery of the **Vancouver Island Marmot** (*Marmota vancouverensis*) has relied on all three approaches (Sustayn, 2024). In the early 2000s, the wild population had dropped to fewer than 30 individuals. Conservationists began a captive breeding program at facilities like the Toronto Zoo and the Calgary Zoo to increase numbers. Once marmots were successfully bred, they were reintroduced into carefully selected alpine meadows on Vancouver Island. At the same time, habitat restoration efforts were undertaken to improve meadow conditions, reduce human disturbance, and ensure the marmots had access to food and shelter. With these combined efforts, the marmot population has seen a notable resurgence, with more than 380 individuals now thriving across the island.

Figure 11.2.2 "Vancouver Island Marmot" by marmota_taylor, CC BY-NC 4.0

Canada has had several other successful species-level conservation efforts, including the whooping crane, black-footed ferret, the swift fox, and others. In addition to these successes, many species are currently undergoing active conservation efforts. One example is the **mottled duskywing** (*Erynnis martialis*), a small butterfly once thought to be extirpated from Ontario. Conservationists have launched a multi-year recovery program involving captive breeding, reintroduction, and oak savanna habitat restoration. Early releases have taken place in protected areas such as Pinery Provincial Park and Norfolk County, and ongoing monitoring is helping refine strategies to support long-term survival.

Species-level conservation efforts are especially impactful when directed toward **keystone species**, organisms that have a disproportionately large influence on the structure and function of their ecosystems. Protecting a keystone species can lead to widespread ecological benefits, supporting many other organisms that depend on the same habitat.

The **Canadian beaver** (*Castor canadensis*) is a classic example of a keystone species. By building dams, beavers transform streams into wetlands, creating rich and diverse habitats that support amphibians, fish, aquatic plants, birds, and mammals. These wetlands also improve water quality, reduce erosion, and help regulate water flow, making them valuable for both biodiversity and ecosystem services. Conservation efforts that protect beavers, such as safeguarding riparian zones, regulating trapping, and promoting coexistence, have cascading benefits. In areas where beavers have returned or been protected, researchers have observed increases in species richness and improvements in ecosystem resilience.

Figure 11.2.3 "North American Beaver" by Steve, CC BY-SA 2.0, "Beaver Dam" by Wsiegmund, CC BY-SA 3.0

## Ecosystem Restoration

**Ecosystem restoration** is the process of repairing and revitalizing ecosystems that have been degraded or destroyed. Restoration efforts aim to reestablish native species, rebuild ecological processes, and recover the ecosystem services that nature provides, such as water purification, carbon storage, pollination, and flood control.

Restoration can take many forms, including:

- **Replanting native vegetation** to stabilize soil and provide habitat.
- **Removing invasive species** that outcompete native flora and fauna.
- **Restoring natural water flow** in rivers, wetlands, and floodplains.

In Southern Ontario, wetland restoration projects have reversed decades of habitat loss caused by agriculture, urban development, and pollution. One notable example is the restoration of farmland on Pelee Island at the Florian Diamante Nature Reserve, where former soybean fields were transformed back into functioning wetland habitat (Nature Conservancy of Canada, 2023). Restoration efforts included breaking drainage tiles, constructing berms (mounds of dirt used to redirect water), installing water control structures, and planting native vegetation. The restored wetlands now help regulate water levels, reduce nutrient runoff, and store carbon. They also support a wide range of species, including amphibians, waterfowl, fish, and rare plants.

These wetlands also provide critical stopover habitat for migratory birds, making them an important link in continental flyways and a favourite destination for birders.

You can learn more about this restoration project on the Nature Conservancy Canada Website: From Marsh to farm and back again: A wetland restoration story.

## Everyday Actions for Biodiversity

Preserving biodiversity requires changes in human behaviour and beliefs. Human activities are major drivers of biodiversity loss. But individuals (even students!) can make a meaningful impact through everyday choices.

At the heart of these efforts is the principle of **sustainability,** meeting the needs of the present without compromising the ability of future generations to meet their own. Sustainability connects conservation to everyday life, encouraging people to live in ways that support ecological balance, protect natural resources, and promote long-term well-being for both humans and wildlife. Even small actions can contribute to large-scale change.

## Lifestyle Choices

Figure 11.2.4 Photo by Yaroslav Shuraev, Pexels License

Everyday decisions about what we eat, buy, and use have direct impacts on the environment. Avoiding single-use plastics, choosing low-impact transportation (public transit, biking or walking), reducing energy use at home (turning off lights and using energy-efficient appliances) and supporting sustainable brands are all ways to lower your ecological footprint.

From an ecological perspective, food choices are especially important. Humans are biologically omnivores, capable of digesting both plant and animal matter. However, choosing more plant-based foods is a more energy-efficient and sustainable option. Producing plant-based meals generally requires less land, water, and energy, and results in fewer greenhouse gas emissions compared to meat production. As discussed in Section 10.2**,** only about 10% of energy is passed from one trophic level to the next. This means that eating higher on the food chain requires more energy and resources to produce compared to eating lower on the food chain, such as consuming plants directly. By shifting toward a diet that emphasizes fruits, vegetables, legumes, and grains, individuals can reduce their environmental impact while still meeting nutritional needs. This choice also supports biodiversity by reducing the demand for intensive livestock farming, which is a major driver of habitat loss and deforestation globally.

Sharing stories of your own lifestyle choices can motivate others to care and act. Whether through social media, art, writing, or classroom presentations, raising awareness helps build a culture of sustainability. Highlighting success stories shows that change is possible and encourages others to get involved.

## Community Science

**Community science** (also known as citizen science) is scientific research conducted in collaboration with the public. Individuals or groups who are not professional scientists contribute to data collection, analysis, and reporting, often in partnership with researchers or institutions. This approach helps expand the scope of scientific inquiry, fosters public engagement with science, and supports large-scale environmental monitoring and conservation efforts.

Figure 11.2.5 Photo by PNW Production, Pexels License

Participating in community science platforms like iNaturalist allows anyone to contribute valuable biodiversity data. By documenting plants, animals, and fungi in your area, you help researchers track species distributions, monitor population trends, and detect invasive species. Events like the City Nature Challenge and Great Canadian BioBlitz bring communities together to explore nature and contribute to global biodiversity databases.

## Advocacy

Figure 11.2.6 Photo by Kaboompics.com, Pexels License

Advocacy involves using your voice to support environmental protection. This can include signing petitions, contacting elected officials, attending public consultations, or promoting conservation issues on social media. On campus, students can start or join sustainability clubs, organize awareness campaigns, or push for greener policies.

Public engagement is essential for building the political will needed to fund conservation programs, enforce regulations, and support international cooperation. By staying informed and voting for leaders who value environmental protection, individuals help ensure that strong environmental legislation is in place to safeguard ecosystems for future generations.

## Volunteering

Figure 11.2.7 Photo by Kari Moreland, 

Volunteering offers hands-on opportunities to make a tangible difference in conservation efforts. Activities such as habitat cleanups, tree planting, and invasive species removal directly improve local ecosystems and help restore biodiversity. These experiences also build environmental awareness and connect people to nature in meaningful ways.

Many conservation organizations across Canada, such as Wildlife Preservation Canada, Nature Conservancy of Canada, and local conservation authorities, offer volunteer programs where individuals can assist with species monitoring, habitat restoration, and public education. By volunteering, students gain practical experience, contribute to real-world recovery efforts, and become part of a broader community working to protect wildlife and ecosystems.

## Career Pathways

Whether you're studying science, business, art, or healthcare, you can integrate sustainability into your career. Environmental sciences and conservation biology are obvious paths, but sustainability is increasingly relevant in fields like urban planning, education, law, and marketing. Choosing a career that supports or aligns with environmental values helps build a future where biodiversity is protected.

## Hope for the Future

Nature is resilient. With informed action, ecosystems and species can recover. Across the globe, youth-led movements, Indigenous stewardship, and scientific innovation are driving meaningful change. These efforts remind us that conservation is not just a scientific challenge, but that it's a human one, rooted in care, responsibility, and connection.

Every person has the power to make a difference. Whether through research, restoration, education, or everyday choices, our collective actions shape the future of life on Earth. The path ahead may be complex, but it is filled with possibilities.

**No one can do everything, but everyone can do something for biodiversity.**

## Knowledge Check

**Quiz Text Description**

**1. MultiChoice Activity #1**

Which of the following is the primary goal of conservation biology?

a. To prevent all human interaction with nature.
b. To focus exclusively on restoring plant species.
c. To preserve ecological relationships that sustain ecosystems.
d. To breed endangered species in captivity only.

**2. MultiChoice Activity #2**

What is the main objective of the Kunming-Montreal Global Biodiversity Framework's "30×30" goal?

a. Increase global biodiversity awareness by 30% by 2030.
b. Protect 30% of the planet's lands and waters and restore 30% of degraded ecosystems by

2030.

c. Reduce global meat consumption by 30% by 2030.
d. Lower greenhouse gas emissions by 30% by 2030.

**3. MultiChoice Activity #3**

Which of the following best describes a *keystone species*?

a. A species introduced to restore degraded habitats.
b. A species with the largest population in an ecosystem
c. A species that has a disproportionately large impact on ecosystem structure and function.
d. A species that is endangered due to overexploitation.

**4. MultiChoice Activity #4**

The restoration of farmland to wetland habitat on Pelee Island included all of the following EXCEPT:

a. Breaking drainage tiles to restore water flow.
b. Planting native vegetation.
c. Introducing invasive species to increase biodiversity.
d. Constructing berms and water control structures.

**5. MultiChoice Activity #5**

Which everyday action would most directly help reduce habitat loss caused by livestock farming?

a. Choosing more plant-based meals.
b. Volunteering for invasive species removal.
c. Using public transportation instead of driving.
d. Participating in citizen science projects.

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Answers:

1. c. To preserve ecological relationships that sustain ecosystems.
2. b. Protect 30% of the planet's lands and waters and restore 30% of degraded ecosystems by 2030.
3. c. A species that has a disproportionately large impact on ecosystem structure and function.

4. c. Introducing invasive species to increase biodiversity.
5. a. Choosing more plant-based meals.

OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Create 5 multiple-choice questions using the following content

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# CHAPTER 11 SUMMARY

## Key Takeaways

- **Three Levels of Biodiversity**: Biodiversity encompasses genetic diversity (variation within species that supports adaptation), species diversity (variety and distribution of species within ecosystems), and ecosystem diversity (range of distinct ecosystems and their ecological roles). Each level contributes to the resilience and stability of life on Earth.
- **Importance of Biodiversity for Ecosystem Services:** Biodiversity underpins essential ecosystem services such as pollination, air and water purification, nutrient recycling, climate regulation, and food and medicine production. It also supports cultural, recreational, and mental health benefits, while enabling ecosystems to recover from disturbances
- **Drivers of the Biodiversity Crisis:** Global biodiversity is in sharp decline—wild vertebrate populations have dropped by an average of 73% since 1970—due to habitat destruction and fragmentation, overexploitation of species and resources, pollution (including biomagnification of toxins), climate change, and the spread of invasive species.
- **Conservation Strategies:** Conservation biology employs legislative measures (e.g., Canada's Species at Risk Act, global agreements like the CBD's 30×30 target), establishment of protected areas, species-level interventions (captive breeding, reintroduction, habitat restoration), and ecosystem restoration to preserve and recover biodiversity.
- **Everyday Actions to Support Biodiversity:** Individuals can contribute through sustainable lifestyle choices (e.g., reducing plastic use, shifting toward plant-based diets), participating in community science, advocating for conservation policies, volunteering for habitat and species recovery, and integrating sustainability into careers.
- **Hope and Collective Responsibility:** Despite current challenges, biodiversity can recover through informed, coordinated action. Indigenous stewardship, youth movements, scientific innovation, and community engagement demonstrate that everyone can play a role—no single person can do everything, but everyone can do something.

OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat
Prompt: Summarize the following content into six key takeaways.

## Flashcards

**Text Description**

This activity contains a set of dialog cards, which are described below.

**Key Terms:**

1. Ecosystem diversity
2. Overexploitation
3. Living Planet Index
4. Vancouver Island Marmot
5. Species diversity
6. Captive breeding
7. Protected areas
8. Ecosystem restoration
9. Advocacy
10. Habitat destruction
11. Conservation biology
12. Legislation
13. Invasive species
14. Jenga analogy
15. Species at Risk Act (SARA)
16. Species-level conservation
17. Biodiversity (biological diversity)
18. Genetic diversity
19. Ecosystem services
20. Pollination
21. Volunteering
22. Community science
23. Reintroduction

24. 4 conservation strategies
25. Pollution
26. Species evenness
27. Keystone species
28. Biomagnification
29. Lifestyle choices
30. Mottled duskywing
31. Fragmentation (Habitat fragmentation)
32. Sustainability
33. 3 levels of biodiversity
34. 5 human activities driving biodiversity crisis
35. Career pathways
36. Species richness
37. Climate change
38. 5 categories of action for biodiversity
39. Biodiversity crisis
40. PCBs (Polychlorinated biphenyls)
41. Greenhouse effect
42. Algal bloom
43. Canadian beaver

**Solution:**

1. The variety of different ecosystems found within a particular area
2. Harvesting species from the wild at rates faster than their populations can naturally recover, leading to population declines or extinction
3. A measure that tracks the population trends of thousands of vertebrate species globally and is used to indicate the health of ecosystems and biodiversity trends
4. A critically endangered species of marmot endemic to Vancouver Island; Conservation efforts, including captive breeding and habitat protection, helped to restore their population
5. The variety of different species within a particular region or ecosystem encompassing both species richness and evenness
6. Raising individuals of a species in controlled environments with the goal of increasing population numbers and potentially reintroducing them to the wild
7. Designated regions for the preservation of biodiversity, with restricted human activities to protect ecosystems and species

8. The process of repairing and revitalizing degraded or destroyed ecosystems to restore native species, ecological processes, and ecosystem services
9. Active support for a cause or proposal, often involving public campaigning, education, and influencing policy to promote conservation and biodiversity protection.
10. The process by which natural habitats are damaged or eliminated, often due to human activities like agriculture, urban development, or resource extraction
11. The science of protecting biodiversity by preserving ecological relationships and ecosystems
12. Laws or international agreements that are created to regulate human activities and protect biodiversity
13. Non-native species introduced to an area that cause harm by outcompeting native organisms, altering habitats, or disrupting ecosystems
14. A metaphor used to describe ecosystem stability – removing species (blocks) weakens the structure, and too many losses can cause the entire system to collapse
15. Canadian legislation aimed at preventing wildlife species from becoming extinct, protecting their habitats, and facilitating recovery strategies
16. Conservation efforts focused on protecting individual species through measures like legal protection, habitat management, captive breeding, and reintroduction
17. The variety of life on Earth includes genetic diversity, species diversity, and ecosystem diversity
18. Variation in the genetic composition of individuals within a species or population enables adaptation and survival
19. Natural processes performed by ecosystems that directly or indirectly benefit humans, such as pollination, air and water purification, nutrient cycling, and climate regulation
20. The transfer of pollen from one plant to another, enabling plant reproduction, and often facilitated by animals like insects, birds, and bats
21. Offering time and effort without financial compensation to support conservation initiatives, such as habitat restoration, species monitoring, and community science projects.
22. Scientific research conducted in collaboration with the public, where volunteers collect data, monitor species, and contribute to biodiversity studies (also known as citizen science)
23. Returning individuals of a species to areas where the species previously existed but have disappeared
24. Legislation, protected areas species-level conservation, ecosystem restoration
25. Harmful substances released into the environment by human activities negatively impacting ecosystems and species
26. How evenly individuals are distributed among the different species in an ecosystem

27. A species that has a disproportionately large influence on the structure and function of an ecosystem, where its removal significantly affects other species
28. The process by which toxic chemicals accumulate and become more concentrated in organisms at each successive trophic level of a food chain.
29. Personal decisions that impact the environment, such as diet, transportation, energy use, and consumption habits, which can contribute to or mitigate biodiversity loss
30. A species of butterfly native to Ontario, considered at risk due to habitat loss and fragmentation; a focus of conservation efforts including reintroduction and habitat restoration
31. Breaking habitats into smaller, isolated patches making it difficult for species to find food, reproduce, and migrate
32. Meeting the needs of the present without compromising the ability of future generations to meet their own needs, supporting ecological balance and long-term well-being
33. Genetic diversity, species diversity, ecosystem diversity
34. Habitat destruction and fragmentation, overexploitation, pollution, climate change, invasive species
35. Everybody can integrate sustainability into their own career to build a future where biodiversity is protected
36. The number of different species present in an ecosystem or region
37. Long-term shifts in global temperatures and weather patterns primarily caused by increased greenhouse gas concentrations due to human activities
38. Lifestyle choices, community science, advocacy, volunteering, career pathways
39. The rapid decline in global biodiversity due to human activities; leading to species extinction and ecosystem degradation
40. Toxic industrial chemicals that persist in the environment, contribute to pollution and biomagnification in food chains
41. The warming of Earth's surface is due to atmospheric gases (greenhouse gases like $CO^2$ and methane) trapping heat from the sun
42. A rapid increase or accumulation of algae in water systems, often resulting from high nutrient levels
43. A keystone species in Canadian ecosystems, known for building dams that create wetlands, which support biodiversity and regulate water systems

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OpenAI. (2025). ChatGPT. [Large language model]. https://chat.openai.com/chat

Prompt: Provide definitions for all the bolded terms in the shared content and list all the terms in alphabetical order.

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# INSTRUCTOR SLIDE DECKS

## Slide Decks

- Biology Essentials 2 – Chapter 1
- Biology Essentials 2 – Chapter 2
- Biology Essentials 2 – Chapter 3
- Biology Essentials 2 – Chapter 4
- Biology Essentials 2 – Chapter 5
- Biology Essentials 2 – Chapter 6
- Biology Essentials 2 – Chapter 7
- Biology Essentials 2 – Chapter 8
- Biology Essentials 2 – Chapter 9
- Biology Essentials 2 – Chapter 10
- Biology Essentials 2 – Chapter 11

# VERSION HISTORY

This page provides a record of changes made to the open textbook since its initial publication. If the change is minor, the version number increases by 0.1. If the change involves substantial updates, the version number increases to the next full number.

| Version | Date | Change | Affected Web Rage |
|---|---|---|---|
| 1.0 | October 27, 2025 | Publication | N/A |