INTRODUCTION TO ECOLOGY



Sara Kappus
Evergreen Valley College

LibreTexts™

Introduction to Ecology

Sara Kappus

This text is disseminated via the Open Education Resource (OER) LibreTexts Project (https://LibreTexts.org) and like the thousands of other texts available within this powerful platform, it is freely available for reading, printing, and "consuming."

The LibreTexts mission is to bring together students, faculty, and scholars in a collaborative effort to provide an accessible, and comprehensive platform that empowers our community to develop, curate, adapt, and adopt openly licensed resources and technologies; through these efforts we can reduce the financial burden born from traditional educational resource costs, ensuring education is more accessible for students and communities worldwide.

Most, but not all, pages in the library have licenses that may allow individuals to make changes, save, and print this book. Carefully consult the applicable license(s) before pursuing such effects. Instructors can adopt existing LibreTexts texts or Remix them to quickly build course-specific resources to meet the needs of their students. Unlike traditional textbooks, LibreTexts' web based origins allow powerful integration of advanced features and new technologies to support learning.



LibreTexts is the adaptable, user-friendly non-profit open education resource platform that educators trust for creating, customizing, and sharing accessible, interactive textbooks, adaptive homework, and ancillary materials. We collaborate with individuals and organizations to champion open education initiatives, support institutional publishing programs, drive curriculum development projects, and more.

The LibreTexts libraries are Powered by NICE CXone Expert and was supported by the Department of Education Open Textbook Pilot Project, the California Education Learning Lab, the UC Davis Office of the Provost, the UC Davis Library, the California State University Affordable Learning Solutions Program, and Merlot. This material is based upon work supported by the National Science Foundation under Grant No. 1246120, 1525057, and 1413739.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation nor the US Department of Education.

Have questions or comments? For information about adoptions or adaptions contact info@LibreTexts.org or visit our main website at https://LibreTexts.org.

This text was compiled on 05/03/2026

TABLE OF CONTENTS

Licensing

About the Book

Preface

1: Introduction to Ecology

- 1.1: Introduction to Ecology
- 1.2: Levels of Ecological Research
- 1.3: The Process of Science
- 1.4: Reporting and Evaluating Scientific Work

2: The Physical Environment

- 2.1: Climate
- 2.2: Differential Heating of Earth's Surface
- 2.3: Atmospheric Circulation
- 2.4: Global Winds and Precipitation
- 2.5: Oceanic Circulation

3: Terrestrial and Aquatic Biomes

- 3.1: Biogeography and Species Distributions
- 3.2: Terrestrial Biomes
- 3.3: Aquatic Biomes

4: Natural Selection and Evolution

- 4.1: Darwin, Wallace, and the Theory of Natural Selection
- 4.2: Evolution
- 4.3: Macroevolution and Speciation
- 4.4: Evidence of Evolution
- 4.5: Common Misconceptions about Evolution

5: Adaptations to the Environment

- 5.1: Tolerance Ranges of Species
- 5.2: Temperature, Water, and other Factors
- 5.3: Homeostasis and Regulation
- 5.4: Energy and Nutrients
- 5.5: Principle of Allocation and Evolutionary Trade-offs

6: Life History and Reproductive Strategies

- 6.1: Life History Theory and Natual Selection
- 6.2: Life Histories and Natural Selection
- 6.3: Life History Characteristics
- 6.4: Sexual Selection and Mate Choice
- 6.5: Mating Systems

7: Population Ecology

- 7.1: Characteristics of Popualtions
- 7.2: Population Growth and Regulation
- 7.3: The Human Population

8: Species Interactions in Communities

- 8.1: A summary of Interactions
- 8.2: Exploitative Interactions
- 8.3: Competition
- 8.4: Commensalism and Mutualism
- 8.5: Symbiosis

9: Community Structure and Dynamics

- 9.1: Community Structure
- 9.2: The Role of Species within Communities
- 9.3: Food Chains and Food Webs
- 9.4: Disturbance
- 9.5: Succession

10: Ecosystems

- 10.1: Introduction to Ecosystem Ecology
- 10.2: Energy Flow through Ecosystems
- 10.3: Biogeochemical Cycles
- 10.4: Ecosystem Services
- 10.5: Resistance, Resilience, and Stability

11: Landscape Ecology and Island Biogeography

- 11.1: What is Landscape Ecology?
- 11.2: Terminology
- 11.3: Applications of Landscape Ecology
- 11.4: Island Biogeography

12: Biodiversity and The Extinction Crisis

- 12.1: Value of Biodiversity
- 12.2: Patterns of Biodiversity
- 12.3: Extinction
- 12.4: Measures of Biodiversity Loss

13: Threats to Biodiversity

- 13.1: Habitat Loss and Fragmentation
- 13.2: Pollution
- 13.3: Invasive Species
- 13.4: Overexploitation
- 13.5: Climate Change

14: Protecting Biodiversity

- 14.1: Policies
- 14.2: Non-profit Organizations
- 14.3: Species-level Conservation
- 14.4: Protected Areas
- 14.5: Ecosystem Restoration
- 14.6: Economic Influences on Conservation
- 14.7: Individual Choices

Index

Glossary

Detailed Licensing

Detailed Licensing

Licensing

*A detailed breakdown of this resource's licensing can be found in **Back Matter/Detailed Licensing**.*

About the Book

An Open Educational Resource Initiative at Evergreen Valley College

The Evergreen Valley College Open Educational Resources Initiative (EVC-OER) was funded by President Tammeil Gilkerson beginning in 2022. As part of EVC's focused work advancing opportunity, equity, and social justice, the initiative aims to promote the development of a more robust collection of Open Educational Resources (OER) to support EVC's faculty instruction and student learning. In addition, we hope to build a faculty community of practice engaged in curating, developing, and publishing OER materials to sustainably transform their courses into zero-cost or low-cost courses, eliminating structural barriers that may impede students' success.

The information in this resource is intended solely for use by the user, who accepts full responsibility for its use. Although the author(s) and EVC-OER Support team at San José Evergreen Community College District (SJECCD) have made every effort to ensure that the information in this resource is accurate, openly licensed, and accessible at press time, the author(s) and EVC-OER Support team do not assume and hereby disclaim any liability to any party for any loss, damage, or disruption caused by errors or omissions, whether such errors or omissions result from negligence, accident, or any other cause.

EVC-OER Initiative

Evergreen Valley College

3095 Yerba Buena Road

San José, CA 95135

Please bring all such errors and changes to LibreTexts (info@libretext.org.)

Book Contributors

This book is written for a general education audience, EVC course BIOL 063 - Ecology.

This book by Sara Kappus (2023) is funded by the EVC President's OER initiative. It is licensed CC BY and is developed by the contributors below.

- Sara Kappus, Ph.D (All Chapters)

Preface

Introduction

Welcome to Introduction to Ecology. This book introduces you to Ecology, the branch of biology that deals with the relations of living organisms, including humans, to one another and to their physical surroundings. Interactions between organisms and the environment are considered at the organismal, population, community, ecosystem, and biosphere level. You will gain insights into how field, lab, and modeling experiments are utilized by Ecologists to reveal the nature of these interactions and develop an appreciation for the interconnectedness of life on Earth. You will discover how ecological relationships are changing under the immense pressure and demands of the human population and the growing need to conserve ecosystems from excessive rates of extinction and the erosion of ecological interactions.

Audience

This book is an introductory text for those with little or no experience with biology or ecology. It is intended to support general education courses in biology, ecology, and conservation biology at the level of a freshman or sophomore college student. This book covers key concepts in science and biology, (such as the scientific method and evolution) that will serve as the foundation for understanding more advanced ecological concepts. This book is intended to guide students to understanding the importance of ecological study in the face of the wide variety of ways that humans affect ecological systems.

Chapter Outline

The text is organized into fourteen chapters that follow the levels of Ecological understanding.

Chapter 1-3 are introductory and include information which introduces students to the science of ecology and patterns and processes found on planet Earth.

- Chapter 1: Introduction to Ecology - In this chapter we introduce the science of ecology including; the levels of study, the experimental nature of ecology and how the scientific method is utilized, and covers the broad applications of ecological study.
- Chapter 2: The physical Environment - This chapter covers patterns and processes which govern Earths climate including the green house effect, atmospheric, and oceanic circulation and emphasizes why an understanding of the physical environment is key to understanding all ecological phenomena.
- Chapter 3: Terrestrial and Aquatic Biomes - Basic patterns in the distribution and abundance of life on earth are covered. Emphasis is placed on how tolerance to the physical environment determines which types of organisms and ecosystems are found in various locations on Earth.

Chapters 4-6 focus on the biotic and abiotic factors which drive adaptations of individual organisms (organismal level of Ecology).

- Chapter 4: Natural Selection and Evolution - Students are introduced to the theory of natural selection, processes of microevolution (such as mutation, genetic drift, and sexual selection) and the macroevolutionary process which drive speciation.
- Chapter 5: Adaptations to the Environment - This chapter focuses on how tolerance to environmental variables (such as temperature, water, and nutrients) and evolutionary trade offs drives the adaptation of organisms to their physical environments. Also covered within this chapter are the diverse roles organisms play in their environments by acting as producers, consumers, and detritivores.
- Chapter 6: Life History and Reproductive Strategies - The concept of evolutionary trades-offs in again highlighted in this chapter by examining the many different ways organisms allocate energy over their life time to events important for an organism's fitness such as growth, reproductive development, lifespan, finding a mate, and raising offspring.

Chapters 7-11 cover increasing levels of ecology and the associated complexity.

- Chapter 7: Population Ecology - In this chapter students will learn how characteristics of populations (such as density or age structure) can inform us about the distribution of resources or population change. Population growth models and regulation is discussed while emphasizing how population studies hold the key to solving practical problems such as saving endangered species, controlling pest populations, and managing fish and game populations.

- Chapter 8: Species Interactions - Populations rarely, if ever, live in isolation from populations of other species. This chapter coverers the diverse ways that different species interact (such as a predator and its prey) and how the outcomes of such interactions can be positive, negative, or neutral for the species involved. The theme of the chapter focuses on how such interactions drive evolutionary outcomes such as competitive exclusion and resource partitioning.
- Chapter 9: Community Structure and Dynamics - Communities are complex systems that can be characterized by community structure (the number and size of populations and their interactions) and community dynamics (how the members and their interactions change over time). The role of species in their community, trophic interactions, disturbance, and succession are discussed.
- Chapter 10: Ecosystems - The chapter focuses on the transfer of energy and matter among living and non-living components within and between ecosystems. Productivity of ecosystems measured by the efficiency of energy transfer between trophic levels in discussed as well as the cycling of matter by biogeochemical cycles. The varied ways ecosystems provide benefits to humans (Ecosystems services) and concepts of Ecosystem stability are also discussed.
- Chapter 11: Landscape Ecology and Island Biogeography - This chapter introduces students to the new and emerging field of landscape ecology and its increasing importance in a human dominated global landscape. Concepts such as habitat fragmentation, edge effects, and species-area relationships are introduced. The chapter has an underlying theme which emphasized the links between landscape ecology and conservation biology.

Chapters 12-14 focus on conservation biology by emphasizing human impacts and the importance of protecting biodiversity.

- Chapter 12: Biodiversity and the Extinction Crisis - This chapter introduces students to the current biodiversity crisis on Earth. Measures of biodiversity loss, increasing extinctions rates, and the value and importance of biodiversity is discussed.
- Chapter 13: Threats to Biodiversity - The core threat to biodiversity on the planet is the combination of human population growth and the resources used by that population. This chapter covers the five main threats to biodiversity which are habitat loss, pollution, overexploitation, invasive species, and climate change.
- Chapter 14: Protecting Biodiversity - This final chapter of the text focuses on the many tools and solutions with which we may combat threats to biodiversity. It emphasizes how protecting biodiversity is key for maintaining the ecosystem services (food and clean water) and environmental stability that humans rely on for survival.

For the Student

Each chapter in this text begins with an attention grabbing case study, a chapter summary, and a list of relevant learning objectives. Found at the top of each section is a table of contents for ease of navigation. Chapter sections may also include green boxes with definitions of the most important ecological terms, supporting videos, and interactive concept checks. To get the best learning experience you should begin by reading the learning objective and chapter summaries,and use the concept checks to test your understanding. Pay close attention to (or make flashcards for) terms in the green boxes and bold text. Use the videos to enhance your understanding of challenging concepts.

For the Instructor

A Chapter Summary and Learning Objectives can be found at the beginning of each chapter and can be used to identify which chapters to include or omit for a course other than Introductory Ecology. Of course the chapters are intended to be viewed in order by the student, but some sections may stand alone as units. For instance, a general biology instructor covering ecology may choose to utilize chapters 7-10, while any instructor intending to cover the concept of conservation biology may want to include chapters 12-14.

Each chapter begins with specific example or case study to grab the students attention and highlight an application of the ecological concept covered within the chapter. Throughout each chapter are green boxes with definitions of the most important ecological terms, supporting videos, and interactive concept checks.

CHAPTER OVERVIEW

1: Introduction to Ecology



Figure 1.1: The western toad (*Bufo boreas*) is widespread throughout the western U.S and Canada and can be found in wetlands, ponds, and lakes which they use for breeding. Sharp declines in local populations have been recorded throughout their range, and the drivers of these declines are poorly understood. (image by Thompsma via Wikimedia Commons; CC BY 3.0)

Chapter Summary

Ecology is the study of the interactions of living organisms with their environment. Ecology addresses the full scale of life, from tiny bacteria to processes that span the entire planet. Ecologists study many diverse and complex relations among species, such as predation and pollination. One core goal of ecology is to understand the distribution and abundance of living things in the physical environment. Ecology is an experimental sciences that uses lab and field experiments, and models, to test hypothesis and predictions in an attempt to explain natural patterns on Earth.

Ecologists ask questions across four levels of biological organization—organismal, population, community, and ecosystem. At the organismal level, ecologists study individual organisms and how they interact with their environments. At the population and community levels, ecologists explore, respectively, how a population of organisms changes over time and the ways in which that population interacts with other species in the community. Ecologists studying an ecosystem examine the living species (the biotic components) of the ecosystem as well as the nonliving portions (the abiotic components), such as air, water, and soil, of the environment.

Learning Objectives

After reading this chapter you should be able to:

- Define ecology and provide examples of how ecological study contributes to society.
- List in order and describe the levels of ecological organization.
- List and explain the steps of the scientific method, emphasizing how hypothesis testing allows us to clarify relationships between organisms and their environment.
- Explain how controlled experiments are used to determine cause and effect.

1.1: Introduction to Ecology
1.2: Levels of Ecological Research
1.3: The Process of Science

This page titled 1: Introduction to Ecology is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

1.1: Introduction to Ecology

Have you ever hiked through a forest and noticed the incredible diversity of organisms living together, from ferns to trees to mushrooms the size of dinner plates? Or taken a road trip and watched the landscape change outside the window, shifting from oak forest to tall stands of pine to grassy plains? If so, you've gotten a classic taste of **ecology**, the branch of biology that examines how organisms interact with each other and with their physical environment.

Ecology isn't just about species-rich forests, pristine wilderness, or scenic vistas, though. Have you, for instance, ever found cockroaches living under your bed, mold growing in your shower, or even fungus creeping in between your toes? If so, then you've seen equally valid examples of ecology in action.

Definition: Ecology

Ecology is the study of the relationships between living organisms, including humans, and ther physical environment.

Some of the phenomena that ecologists study include adaptations of organisms to the physical environment, changes in populations over time, interactions between organisms (such as a predator and its prey), the flow of energy and recycling of matter, and the biodiversity of different ecosystems.

Ecology requires the integration of scientific disciplines inside and outside of biology, such as biochemistry, physiology, evolution, biodiversity, molecular biology, geology, and climatology. Some ecological research also applies aspects of chemistry and physics, and it frequently uses mathematical models. It is important to note that ecology is not synonymous with environment, environmentalism, natural history, or environmental science. It is also different from, though closely related to, the studies of evolutionary biology, genetics, and ethology.



Figure 1.1.1: Images illustrating interactions among organisms and between organisms and their physical environment. Upper left: mushrooms growing on a mossy log. Image by Upper right: rolling green hills covered with wildflowers, grasses, and occasional trees. Lower left: rolling fields of dry, yellow grass with scrub-covered hills and snowy mountains in the distance. Lower right: cockroach on floorboards. Image credit: upper left, Forest by Jens Hellermann, public domain; upper right, Konza Prairie Preserve by Kgwo1972, public domain; lower left, San Raphael Grasslands by Dominic Sherony, CC BY-SA 2.0; lower right, Cockroach closeup by 部秉宥, CC BY-SA 2.0

Biotic and Abiotic Factors

One core goal of ecology is to understand the distribution and abundance of living things in the environment. For instance, your backyard or neighborhood park probably has a very different set of plants, animals, and fungi than the backyard of another student on the opposite side of the globe. These patterns in nature are driven by interactions among organisms as well as between organisms and their physical environment. Thus, the distribution and abundance of organisms is driven by both living and nonliving factors. **Biotic factors** are living aspects of the environment. They consist of other organisms, including members of the same and different species. **Abiotic factors** are the nonliving aspects of the environment. They include factors such as sunlight, water, temperature, and nutrients.

As an example, let's go back to our shower mold. Mold is more likely to appear in your shower than, say, your sock drawer. Why might this be the case?

- Maybe the mold needs a certain amount of water to grow, and this amount of water is found only in the shower. Water availability is an example of an abiotic, or nonliving, factor that can affect distribution of organisms.
- Maybe mold feeds off of dead skin cells found in the shower, but not in the dresser. Availability of nutrients provided by other organisms is an example of a biotic, living-organism-related, factor that can influence distribution.

Why it Matters

The science of Ecology is diverse and has produced an immense body of knowledge about the world around us. It has yielded fascinating insights about the environment, our dependence upon it, and the impacts caused by human activities. There are many practical applications of ecology in conservation biology, wetland management, natural resource management (agriculture, forestry, fisheries), city planning (urban ecology), community health, economics, basic and applied science, and human social interaction (human ecology).

Organisms and resources comprise ecosystems which, in turn, maintain biophysical feedback mechanisms that moderate processes acting on living and nonliving components of the planet. Ecosystems sustain life-supporting functions and produce natural capital, such as biomass production (food, fuel, fiber and medicine), the regulation of climate, global biogeochemical cycles, water filtration, soil formation, erosion control, flood protection, and many other natural features of scientific, historical, economic, or intrinsic value. Ecology enriches our world and is crucial for human wellbeing and prosperity.

Attribution:

This article is a modified derivative of:

- "The scope of ecology." by OpenStax College, Biology, CC BY 3.0
- Why It Matters: Ecology of Living Things. Authored by: Shelli Carter and Lumen Learning. Provided by: Lumen Learning. License: *CC BY*

This page titled 1.1: Introduction to Ecology is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

1.2: Levels of Ecological Research

Levels of Ecology

When a discipline such as Ecology is studied, it is often helpful to subdivide it into smaller, related areas. 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 (like physiology and behavior), habitat requirements (such as plants and soils), and potential human influences on the endangered population and its habitat (which might be derived through studies in sociology and urban ecology). Within the discipline of ecology, researchers work at four specific levels, sometimes discretely and sometimes with overlap: organism, population, community, and ecosystem (Figure 1.2.1).

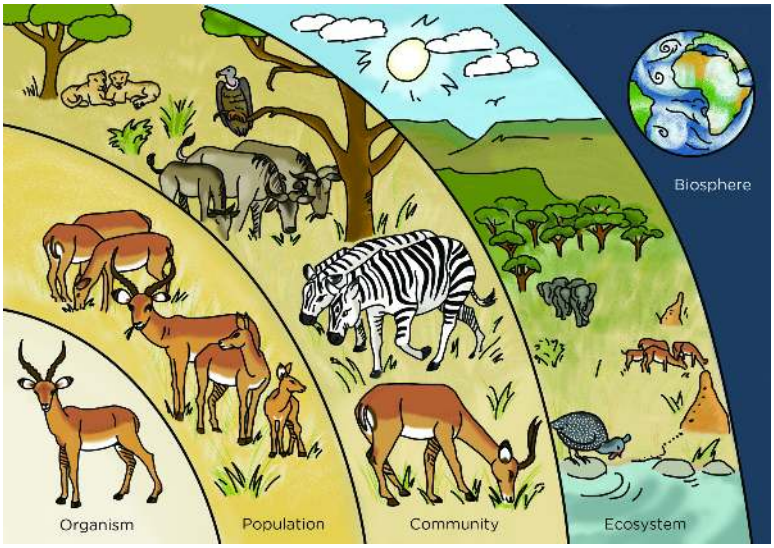


Figure 1.2.1:The study of ecology is organized at different levels from small to large. Each level can be studied discretely or with overlap. *(Image* by Siyavula Education via Flicker; CC BY 2.0)

Organismal Ecology

Researchers studying ecology at the **organismal** level are interested in the adaptations that enable individuals to live in specific habitats. These adaptations can be morphological, physiological, and behavioral. For instance, the Karner blue butterfly (*Lycaeides melissa samuelis*) (Figure 1.2.2) is considered a specialist because the females preferentially oviposit (that is, lay eggs) on wild lupine. This preferential adaptation means that the Karner blue butterfly is highly dependent on the presence of wild lupine plants for its continued survival.



Figure 1.2.2: The Karner blue butterfly (*Lycaeides melissa samuelis*) is a rare butterfly that lives only in open areas with few trees or shrubs, such as pine barrens and oak savannas. It can only lay its eggs on lupine plants. (Image Figure 44.3 by J & K Hollingsworth via OpenStax; CC BY 4.0)

After hatching, the larval caterpillars emerge and spend four to six weeks feeding solely on wild lupine (Figure 1.2.3). The caterpillars pupate (undergo metamorphosis) and emerge as butterflies after about four weeks. The adult butterflies feed on the

nectar of flowers of wild lupine and other plant species. A researcher interested in studying Karner blue butterflies at the organismal level might, in addition to asking questions about egg laying, ask questions about the butterflies' preferred temperature (a physiological question) or the behavior of the caterpillars when they are at different larval stages (a behavioral question).



Figure 1.2.3:The wild lupine (*Lupinus perennis*) is the host plant for the Karner blue butterfly. (Image by Joshua Mayer via Flickr; CC BY-SA 2.0)

Population Ecology

A **population** is a group of interbreeding organisms that are members of the same species living in the same area at the same time. (Organisms that are all members of the same species are called conspecifics.) A population is identified, in part, by where it lives, and its area of population may have natural or artificial boundaries: natural boundaries might be rivers, mountains, or deserts, while examples of artificial boundaries include mowed grass, manmade structures, or roads. The study of population ecology focuses on the number of individuals in an area and how and why population size changes over time. Population ecologists are particularly interested in counting the Karner blue butterfly, for example, because it is classified as federally endangered. However, the distribution and density of this species is highly influenced by the distribution and abundance of wild lupine. Researchers might ask questions about the factors leading to the decline of wild lupine and how these affect Karner blue butterflies. For example, ecologists know that wild lupine thrives in open areas where trees and shrubs are largely absent. In natural settings, intermittent wildfires regularly remove trees and shrubs, helping to maintain the open areas that wild lupine requires. Mathematical models can be used to understand how wildfire suppression by humans has led to the decline of this important plant for the Karner blue butterfly.

Community Ecology

A biological **community** consists of the different species within an area, typically a three-dimensional space, and the interactions within and among these species. Community ecologists are interested in the processes driving these interactions and their consequences. Questions about conspecific interactions often focus on competition among members of the same species for a limited resource. Ecologists also study interactions among various species; members of different species are called heterospecifics. Examples of heterospecific interactions include predation, parasitism, herbivory, competition, and pollination. These interactions can have regulating effects on population sizes and can impact ecological and evolutionary processes affecting diversity.

For example, Karner blue butterfly larvae form mutualistic relationships with ants. Mutualism is a form of a long-term relationship that has coevolved between two species and from which each species benefits. For mutualism to exist between individual organisms, each species must receive some benefit from the other as a consequence of the relationship. Researchers have shown that there is an increase in the probability of survival when Karner blue butterfly larvae (caterpillars) are tended by ants. This might be because the larvae spend less time in each life stage when tended by ants, which provides an advantage for the larvae. Meanwhile, the Karner blue butterfly larvae secrete a carbohydrate-rich substance that is an important energy source for the ants. Both the Karner blue larvae and the ants benefit from their interaction.

Ecosystem Ecology

Ecosystem ecology is an extension of organismal, population, and community ecology. The **ecosystem** is composed of all the biotic components (living things) in an area along with the abiotic components (non-living things) of that area. Some of the abiotic

components include air, water, and soil. Ecosystem biologists ask questions about how nutrients and energy are stored and how they move among organisms and the surrounding atmosphere, soil, and water.

The Karner blue butterflies and the wild lupine live in an oak-pine barren habitat. This habitat is characterized by natural disturbance and nutrient-poor soils that are low in nitrogen. The availability of nutrients is an important factor in the distribution of the plants that live in this habitat. Researchers interested in ecosystem ecology could ask questions about the importance of limited resources and the movement of resources, such as nutrients, through the biotic and abiotic portions of the ecosystem.

? Concept Check 1.2.1

What level of ecology is concerned with understanding the diversity and abundances of different kinds of organisms living together in the same place?

Answer

Community ecology

Attribution:

This page is a modified derivative of:

-

This page titled 1.2: Levels of Ecological Research is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

1.3: The Process of Science

Although each level in the hierarchy of ecological systems has a unique set of questions on which ecologists focus their research, studies at all ecological levels have one thing in common: they include the process known as the **scientific method**. The methods of science include careful observation, record keeping, logical and mathematical reasoning, experimentation, and submitting conclusions to the scrutiny of others.

Definition: The Scientific Method

The goal of all scientists is to better understand the world around them. The scientific method is an method for acquiring knowledge that has characterized the development of science since at least the 17th century. It can be applied to any scientific discipline such as geology, physics, chemistry, biology and ecology. The process in the scientific method involves making conjectures (hypothetical explanations), deriving predictions from the hypotheses as logical consequences, and then carrying out experiments or empirical observations based on those predictions.

The Nature of Science

Like other sciences, Ecology gathers knowledge about the natural world. Science is a very specific way of learning, or knowing, about the world. The history of the past 500 years demonstrates that science is a very powerful way of knowing about the world; it is largely responsible for the technological revolutions that have taken place during this time. There are however, areas of knowledge and human experience that the methods of science cannot be applied to. These include such things as answering purely moral questions, aesthetic questions, or what can be generally categorized as spiritual questions. Science cannot investigate these areas because they are outside the realm of material phenomena, the phenomena of matter and energy, and cannot be observed and measured.

The scientific method is a method of research with defined steps that include experiments and careful observation. The steps of the scientific method will be examined in detail, but one of the most important aspects of this method is the testing of hypotheses. A **hypothesis** is a suggested explanation for an event, which can be tested. Hypotheses, or tentative explanations, are generally produced within the context of a scientific theory. A **scientific theory** is a generally accepted, thoroughly tested and confirmed explanation for a set of observations or phenomena. Scientific theory is the foundation of scientific knowledge.

Scientific Inquiry

One thing is common to all forms of science: an ultimate goal “to know.” Curiosity and inquiry are the driving forces for the development of science. Scientists seek to understand the world and the way it operates. Two methods of logical thinking are used: inductive reasoning and deductive reasoning.

Inductive reasoning is a form of logical thinking that uses related observations to arrive at a general conclusion. This type of reasoning is common in descriptive science. A life scientist such as a biologist makes observations and records them. These data can be qualitative (descriptive) or quantitative (consisting of numbers), and the raw data can be supplemented with drawings, pictures, photos, or videos. From many observations, the scientist can infer conclusions (inductions) based on evidence. Inductive reasoning involves formulating generalizations inferred from careful observation and the analysis of a large amount of data. For instance, it is a common practice among amateur and professional ornithologists (bird scientists) to conduct bird counts at various geographical locations and seasons throughout the year. From this large pool of data, migration patterns of different bird species can be inferred.

Deductive reasoning or deduction is the type of logic used in hypothesis-based science. In deductive reasoning, the pattern of thinking moves in the opposite direction as compared to inductive reasoning. Deductive reasoning is a form of logical thinking that uses a general principle or law to predict specific results. From those general principles, a scientist can deduce and predict the specific results that would be valid as long as the general principles are valid. For example, a prediction would be that if the climate is becoming warmer in a region, the distribution of plants and animals should change. Comparisons have been made between distributions in the past and the present, and the many changes that have been found are consistent with a warming climate. Finding the change in distribution is evidence that the climate change conclusion is a valid one.

Both types of logical thinking are related to the two main pathways of scientific study: descriptive science and hypothesis-based science. Descriptive (or discovery) science aims to observe, explore, and discover, while hypothesis-based science begins with a specific question or problem and a potential answer or solution that can be tested. The boundary between these two forms of study is often blurred, because most scientific endeavors combine both approaches. Observations lead to questions, questions lead to forming a hypothesis as a possible answer to those questions, and then the hypothesis is tested. Thus, descriptive science and hypothesis-based science are in continuous dialogue.

Hypothesis Testing

Ecologists study the living world by posing questions about it and seeking science-based responses. This approach is common to other sciences as well and is often referred to as the scientific method. The scientific method is not exclusively used by ecologist and biologists but can be applied to almost anything as a logical problem-solving method.

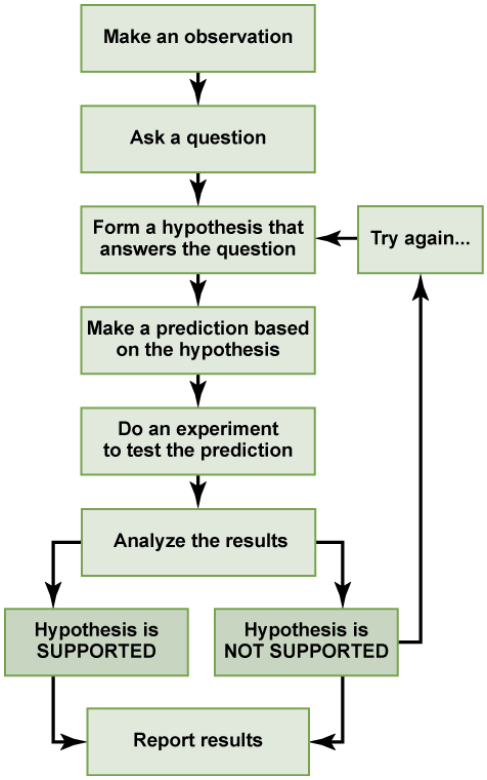


Figure 1.3.1: The scientific method is a series of defined steps that include experiments and careful observation. If a hypothesis is not supported by data, a new hypothesis can be proposed. (Figure 1.18 by OpenStax; CC BY 4.0)

The scientific process typically starts with an **observation** (often a problem to be solved) that leads to a question. Let's think about a simple problem that starts with an observation and apply the scientific method to solve the problem. For instance, on Florida beaches every year, tens of thousands of sea turtle hatchlings are found in roadways, pools, and porches of beachfront property. This observation is also a serious issue, because sea turtles are protected species under the Endangered Species Act. As biologists who are tasked with protecting these species, we need to ask a question: Why are the hatchling turtles moving toward land, and not toward the ocean when they emerge from their nests?"



Figure 1.3.2: Hatchling sea turtles emerging from their nest. (sea turtle hatchlings by Florida Fish and Wildlife via Flickr; CC BY-ND 2.0)

Recall that a hypothesis is a suggested explanation that can be tested. To solve a problem, several hypotheses may be proposed and tested. For example, one hypothesis might be, “The hatchlings moved toward the land because they are attracted to the lights on the shoreline.” But there could be other explainations for the turtles behavior and thus, it is often useful to propose and test more than one hypothesis. A second hypothesis might be, “The hatchlings are attracted to the road noise, which sounds similar to waves.” Each hypothesis may need to be tested sequentially with different sets of experiments and observations.

Once a hypothesis has been selected, a prediction may be made. A **prediction** is a logical statement which follows the hypothesis and typically has the format “If..., then....” For example, the prediction for the first hypothesis might be, “If the sea turtles are attracted to light, shining a light at one end of an enclosure will attract them to that side.”

A hypothesis must be testable to ensure that it is valid. For example, a hypothesis that depends on what a sea turtle thinks is not testable, because it can never be known what a sea turtle thinks. It should also be falsifiable, meaning that it can be disproven by experimental results. An example of an unfalsifiable hypothesis is “Sea turtle hatchlings are beautiful.” There is no experiment that might show this statement to be false. To test a hypothesis, a researcher will conduct one or more experiments designed to eliminate one or more of the hypotheses. This is important. A hypothesis can be disproven, or eliminated, but it can never be proven. Science does not deal in proofs like mathematics. If an experiment fails to disprove a hypothesis, then we find support for that explanation, but this is not to say that down the road a better explanation will not be found, or a more carefully designed experiment will be found to falsify the hypothesis.

Each experiment will have one or more variables and one or more controls. A **variable** is any part of the experiment that can vary or change during the experiment. A control is a part of the experiment that does not change. Look for the variables and controls in the example that follows. Following the example above, an experiment might be conducted to test the hypothesis that light attracts sea turtles. Two artificial enclosures with a layer of sand are placed in a facility in which the temperature, humidity, and other factors are all the same. One of the enclosures is kept dark, and in the other enclosure, a light is placed at one end. The enclosures are each stocked with ten hatchling turtles, and their movements are tracked for 10 minutes.

The **independent variable** in this experiment is the presence or absence of light, and the control is the dark enclosure. The **dependent variable** is the data the biologist is collecting, in this case, the movement of the turtles. If the enclosure with the light shows that the turtles move toward the light, then we have found support for our hypothesis. If they do not move differently in the lit tank than the dark tank, then we reject our hypothesis. Be aware that rejecting one hypothesis does not determine whether or not the other hypotheses can be accepted; it simply eliminates one hypothesis that is not valid. Using the scientific method, the hypotheses that are inconsistent with experimental data are rejected.

In practice, the scientific method is not as rigid and structured as it might at first appear. Sometimes an experiment leads to conclusions that favor a change in approach; often, an experiment brings entirely new scientific questions to the puzzle. The results above led to another question: What color lights affect hatchling turtles the most? Many times, science does not operate in a linear fashion; instead, scientists continually draw inferences and make generalizations, finding patterns as their research proceeds. Scientific reasoning is more complex than the scientific method alone suggests.

Basic and Applied Science

The scientific community has been debating for the last few decades about the value of different types of science. Is it valuable to pursue science for the sake of simply gaining knowledge, or does scientific knowledge only have worth if we can apply it to solving a specific problem or bettering our lives? This question focuses on the differences between two types of science: basic science and applied science.

Basic science or "pure" science seeks to expand knowledge regardless of the short-term application of that knowledge. It is not focused on developing a product or a service of immediate public or commercial value. The immediate goal of basic science is knowledge for knowledge's sake, though this does not mean that in the end it may not result in an application.

In contrast, **applied science** or "technology," aims to use science to solve real-world problems, making it possible, for example, to improve a crop yield, find a cure for a particular disease, or save animals threatened by human activity. In applied science, the problem is usually defined for the researcher.

Some individuals may perceive applied science as "useful" and basic science as "useless." A question these people might pose to a scientist advocating knowledge acquisition would be, "What for?" A careful look at the history of science, however, reveals that basic knowledge has resulted in many remarkable applications of great value. Many scientists think that a basic understanding of science is necessary before an application is developed; therefore, applied science relies on the results generated through basic science. Other scientists think that it is time to move on from basic science and instead to find solutions to actual problems. Both approaches are valid. It is true that there are problems that demand immediate attention; however, few solutions would be found without the help of the knowledge generated through basic science.

One example of how basic and applied science can work together to solve practical problems occurred after the discovery of DNA structure led to an understanding of the molecular mechanisms governing DNA replication. Strands of DNA, unique in every organism, are found in cells, where they provide the instructions necessary for life. During DNA replication, new copies of DNA are made, shortly before a cell divides to form new cells. Understanding the mechanisms of DNA replication enabled scientists to develop laboratory techniques that are now used to identify the source of poached elephant tusks, determine the breeding patterns of northern vs. southern albatross to better protect their roosts, and to determine the population structure of the invasive snake head. Without basic science, it is unlikely that applied science could exist.

While research efforts in both basic science and applied science are usually carefully planned, it is important to note that some discoveries are made by serendipity, that is, by means of a fortunate accident or a lucky surprise. Penicillin was discovered when biologist Alexander Fleming accidentally left a petri dish of Staphylococcus bacteria open. An unwanted mold grew, killing the bacteria. The mold turned out to be Penicillium, and a new critically important antibiotic was discovered. Even in the highly organized world of science, luck—when combined with an observant, curious mind focused on the types of reasoning discussed above—can lead to unexpected breakthroughs.

The Scientific Method is Flexible

The scientific method may seem too rigid and structured. It is important to keep in mind that, although scientists often follow this sequence, there is flexibility. Sometimes an experiment leads to conclusions that favor a change in approach. Often, an experiment brings entirely new scientific questions to the puzzle. Many times, science does not operate in a linear fashion. Instead, scientists continually draw inferences and make generalizations, finding patterns as their research proceeds. Scientific reasoning is more complex than the scientific method alone suggests. Notice, too, that we can apply the scientific method to solving problems that aren't necessarily scientific in nature.

Attribution

This page is modified from:

- The Process of Science by OpenStax; license CC BY 4.0

This page titled 1.3: The Process of Science is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

1.4: Reporting and Evaluating Scientific Work

Whether scientific research is basic science or applied science, scientists must share their findings for other researchers to expand and build upon their discoveries. Communication and collaboration within and between sub disciplines of science are key to the advancement of knowledge in science. For this reason, an important aspect of a scientist's work is disseminating results and communicating with peers. Scientists can share results by presenting them at a scientific meeting or conference, but this approach can reach only the limited few who are present. Instead, most scientists present their results in peer-reviewed articles that are published in scientific journals. Peer-reviewed articles are scientific papers that are reviewed, usually anonymously by a scientist's colleagues, or peers. These colleagues are qualified individuals, often experts in the same research area, who judge whether or not the scientist's work is suitable for publication. The process of peer review helps to ensure that the research described in a scientific paper or grant proposal is original, significant, logical, and thorough. Grant proposals, which are requests for research funding, are also subject to peer review. Scientists publish their work so other scientists can reproduce their experiments under similar or different conditions to expand on the findings.

There are many journals and the popular press that do not use a peer-review system. A large number of online open-access journals, journals with articles available without cost, are now available, many of which use rigorous peer-review systems, but some of which do not. Results of any studies published in these forums without peer review are not reliable and should not form the basis for other scientific work. In one exception, journals may allow a researcher to cite a personal communication from another researcher about unpublished results with the cited author's permission.

Careful attention is required to evaluate information presented as "scientifically supported" found on the internet, in general. Questions to ask about a source include:

- Who wrote the article? Who provided the information to the author? What are their qualifications?
- What's the author trying to get across or accomplish?
- Is the article peer reviewed before publication?
- When was it written? Is the information timely?
- Where does it apply? Local? Worldwide?
- Is the information accurate? Does it make sense? Is it supported by data? Do others find the same conclusions?

Answering these questions sometimes takes more research than just reading an article on its own, but is important for verifying information contained within.

Attribution:

Cropped and edited from

- Reporting Scientific Work by Open Stax CC-BY 4.0

This page titled 1.4: Reporting and Evaluating Scientific Work is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

CHAPTER OVERVIEW

2: The Physical Environment



Figure 2.1: One of the first images taken by humans of the whole Earth. Photographed by the crew of Apollo 8 (probably by Bill Anders) the photo shows the Earth at a distance of about 30,000 km."Earthrise" is now one of the most reproduced space photos of all time, appearing on US postage stamps, posters, and the cover of Time magazine in 1969. It is often cited as propelling the environmental movement that led to the first Earth Day in 1970. The photo highlighted Earth's fragility, since it was seen against the vast blackness of space.(Public Domain; U.S. govt via Wikimedia Commons)

Chapter Summary

The ultimate source of energy driving the motion of the atmosphere and the ocean is radiant energy from the sun, which falls on different parts of the Earth in differing amounts. The oceans are the recipient of most of this solar energy, and they are therefore a major factor in regulating Earth’s climate. Climate is the prevailing weather conditions in an area in general or over a long period (years, decades, etc.) and includes seasonal and daily changes. Descriptions of climate usually include average temperature, humidity, wind, precipitation, as well as seasonal variability.

Species distributions are limited by tolerance to abiotic conditions. Each species has a set of environmental conditions within which it can best survive and reproduce. Temperature is one of many abiotic forces influencing where life can exist and the types of organisms found in different parts of the biosphere. Therefore, an understanding of the physical environment is key to understanding all ecological phenomena.

Learning Objectives

After reading this chapter you should be able to:

- Describe how differential heating of Earth's surface creates 3 climate zones: tropical, temperate, and polar.
- Describe the green house effect.
- Explain the some of the ways the oceans contribute to climate regulation.
- Explain how the Coriolis effect contributes to global wind patterns.
- Describe the location and directions of earths major surface currents (gyres).
- Explain the causes and effects of ENSO.

2.1: Climate
2.2: Differential Heating of Earth's Surface
2.3: Atmospheric Circulation
2.4: Global Winds and Precipitation
2.5: Oceanic Circulation

This page titled 2: The Physical Environment is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

2.1: Climate

Many forces influence the communities of living organisms present in different parts of the biosphere (all of the parts of Earth inhabited by life). The biosphere extends into the atmosphere (several kilometers above Earth) and into the depths of the oceans. Species distributions are limited by tolerance to abiotic conditions. Each species has a set of environmental conditions within which it can best survive and reproduce. Many different physical, abiotic (non- living) factors influence where species live, including temperature, humidity, soil chemistry, pH, salinity and oxygen levels.

For example, the tropics have very high biodiversity. Many different types of species live in the tropics with overlapping distributions. Why? Well, the answer is complex, but one of the most important factors is temperature. The warm and stable temperatures of the tropics are ideal for the metabolic process (such as growth, digestion, and development) of most organisms. Temperature is one of many abiotic forces influencing where life can exist and the types of organisms found in different parts of the biosphere. Therefore, an understanding of the physical environment is key to understanding all ecological phenomena.

So why are the tropics warm, and polar regions cold? Why are some parts of earth dry and others wet? To answer the most basic ecological question: What controls the distribution and abundance of species on Earth? We must begin with understanding Earth's **climate**.

Definition: Climate

Climate is the prevailing weather conditions in an area in general or over a long period (years, decades, etc.) and includes seasonal and daily changes. Descriptions of climate usually include average temperature, humidity, wind, precipitation, as well as seasonal variability. Climate is largely influenced by heat energy absorbed and transported by Earth’s atmosphere and oceans.

The ultimate source of energy driving the motion of the atmosphere and the ocean is radiant energy from the sun, which falls on different parts of the Earth in differing amounts. The oceans are the recipient of most of this solar energy, and they are therefore a major factor in regulating Earth’s climate. Water has a very high heat capacity, so it can absorb a large amount of heat without much of an increase in temperature. Water can also release large amounts of heat back to the atmosphere without its temperature declining as much as land temperatures would.

In this chapter we will examine the ways that the oceans and atmosphere interact with solar radiation to influence wind and atmospheric circulation, global ocean currents, and three distinct climate zones; the polar, temperate, and the tropical zones.

Attribution:

This article is a modified derivative of:

-

This page titled 2.1: Climate is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

2.2: Differential Heating of Earth's Surface

Incoming Solar Radiation

If the Earth was a flat surface facing the sun, every part of that surface would receive the same amount of incoming solar radiation. However, because the Earth is a sphere, sunlight is not equally distributed over the Earth's surface, so different regions of Earth will be heated to different degrees. This differential heating of Earth's surface occurs for a number of reasons. First, because of the curvature of Earth, sunlight only falls perpendicularly to the surface at the center of the sphere (equatorial regions). At any other point on Earth, the angle between the surface and the incoming solar radiation is less than 90°. Because of this, the same amount of incoming solar radiation will be concentrated in a smaller area at the equator, but will be spread over a much larger area at the poles. Thus the tropics receive more intense sunlight and a greater amount of heating per unit of area than the polar regions.

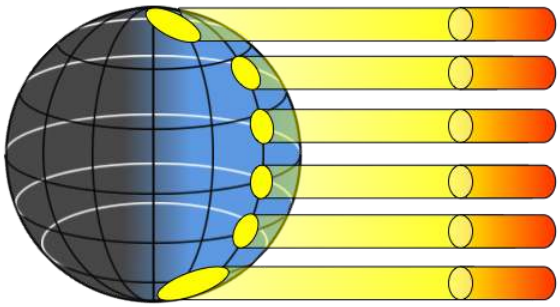


Figure 2.2.1: Because of the curvature of the Earth, the same amount of sunlight will be spread out over a larger area at the poles compared to the equator. The equator therefore receives more intense sunlight, and a greater amount of heat per unit of area (By Thebiologyprimer via Wikimedia; license CCO).

The angle at which sunlight strikes the Earth contributes to differential heating of the surface in an additional way. At the poles, because of the angle at which the solar energy strikes the surface, more of the light will glance off of the surface and the atmosphere and be reflected back into space. At the equator, the direct angle with which light reaches the surface results in more of the energy being absorbed rather than reflected. Finally, the poles reflect more solar energy than other parts of the Earth because the poles have a higher albedo. The albedo refers to the reflectivity of a surface. Lighter surfaces are more reflective than darker surfaces (which absorb more energy), and therefore have a higher albedo. At the poles, the ice, snow and cloud cover create a much higher albedo, and the poles reflect more and absorb less solar energy than the lower latitudes. Through all of these mechanisms, the poles absorb much less solar radiation than equatorial regions, which is why the poles are cold and the tropics are very warm.

Global Distribution of Heat

But there is an interesting twist to this global distribution of heat. The tropical regions actually receive more radiant heat than they emit, and the poles emit more heat than they receive. We should therefore expect that the tropics will be getting continually warmer, while the poles become increasingly cold. Yet this is not the case; so what is happening? Rather than the heat remaining isolated near the equator, about 20% of the heat from the tropics is transported to the poles before it is emitted. This large scale transport of energy moderates the climates at both extremes. The mechanisms for this heat transfer are ocean and atmospheric circulation.

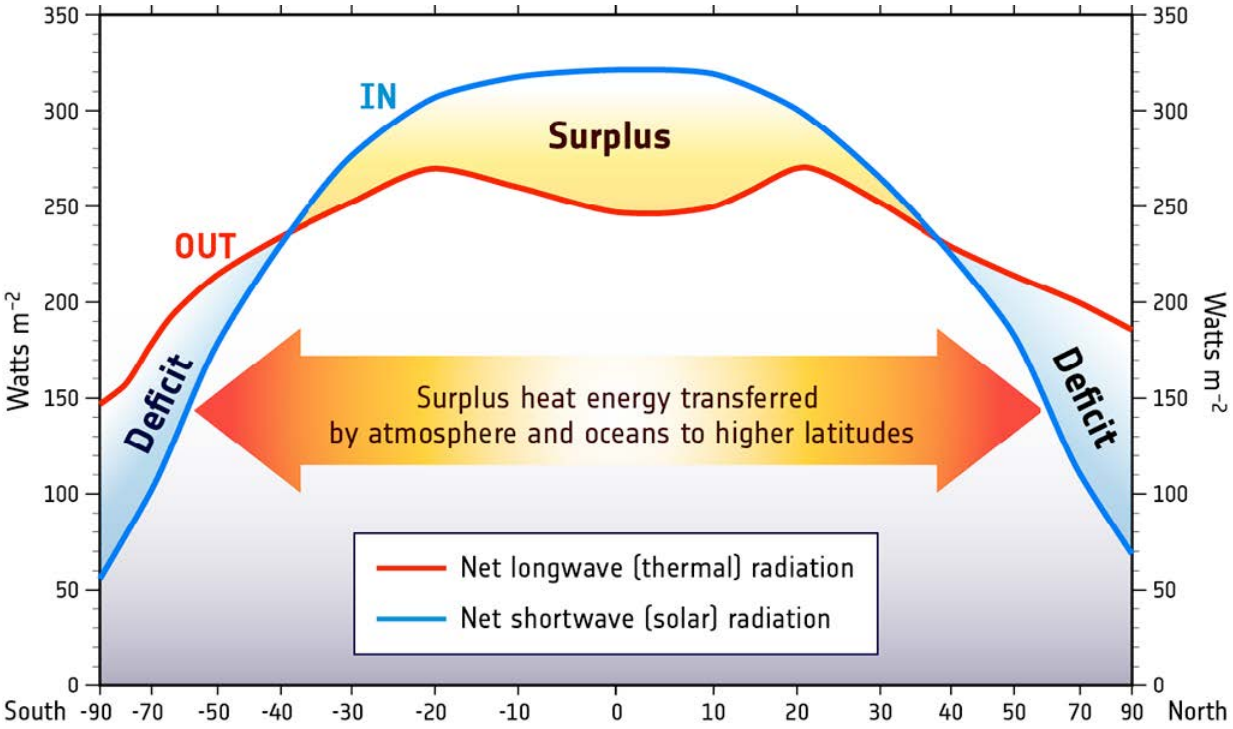


Figure 2.2.2: The balance between heat gain and heat loss as a function of latitude. Excess heat received near the equator is transferred towards the poles (by National Oceanography Centre (NOC); CC BY 3.0)

The idea of differential heating of the Earth's surface is fundamental to understanding a wide range of oceanographic and atmospheric processes. This differential heating leads to atmospheric convection, which creates winds, which blow over the water and create waves and surface currents, and these currents influence nutrient distribution, which promotes primary production, which then supports the rest of the ocean ecosystem. So there's a lot riding on the simple fact that more light reaches the tropics than the poles!

? Concept Check 2.2.1

According to Figure 2.2.2 at what latitude is there a transition from heat surplus to heat deficit?

Answer

The transition occurs around 40° North and 40° South.

Attribution

This article is a modified derivative of:

-

This page titled 2.2: Differential Heating of Earth's Surface is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

2.3: Atmospheric Circulation

Convection Cells

Because more solar energy hits the equator, the air warms and forms a low pressure zone. As the air rises, half moves toward the North Pole and half toward the South Pole. As it moves along the top of the troposphere it cools. The cool air is dense and when it reaches a high pressure zone it sinks to the ground. The air is sucked back toward the low pressure at the equator. This describes the convection cells north and south of the equator. If the Earth did not rotate, there would be one convection cell in the northern hemisphere and one in the southern with the rising air at the equator and the sinking air at each pole. But because the planet does rotate, the situation is more complicated. The planet's rotation means that the Coriolis Effect must be taken into account.

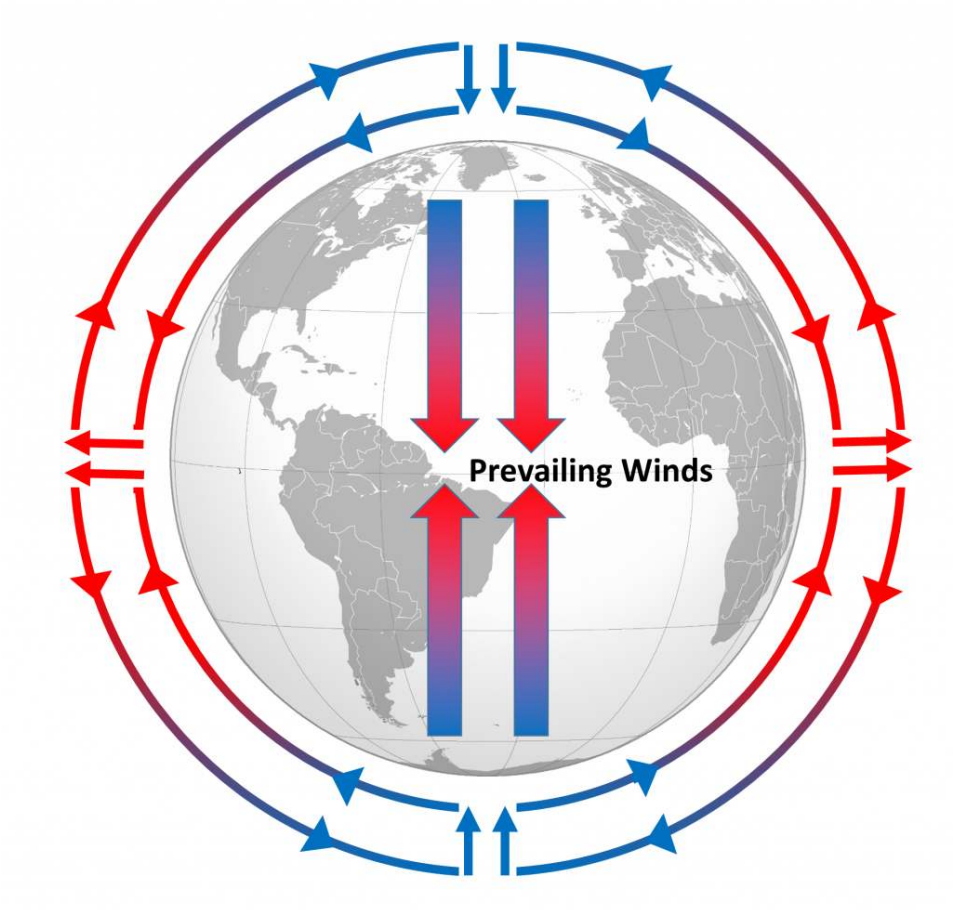


Figure 2.3.1: Hypothetical atmospheric convection cells on a non-rotating Earth. Air rises at the equator and sinks at the poles, creating a single convection cell in each hemisphere. The prevailing winds moving over the Earth's surface blow from the poles towards the equator in both hemispheres (by Paul Webb via Libretext; CC BY-SA 3.0).

Coriolis Effect

The non-rotating situation in Figure 2.3.1 is of course only hypothetical, and in reality the Earth's rotation makes this atmospheric circulation a bit more complex. The paths of the winds on a rotating Earth are deflected by the Coriolis Effect.

Definition: Coriolis Effect

An effect whereby a mass moving in a rotating system experiences a force (the *Coriolis force*) acting perpendicular to the direction of motion and to the axis of rotation. On the earth, the effect tends to deflect moving objects to the right in the northern hemisphere and to the left in the southern and is important in the formation of cyclonic weather systems.

The Coriolis Effect is a result of the fact that different latitudes on Earth rotate at different speeds. This is because every point on Earth must make a complete rotation in 24 hours, but some points must travel farther, and therefore faster, to complete the rotation in the same amount of time. In 24 hours a point on the equator must complete a rotation distance equal to the circumference of the Earth, which is about 40,000 km. A point right on the poles covers no distance in that time; it just turns in a circle. So the speed of rotation at the equator is about 1600 km/hr, while at the poles the speed is 0 km/hr. Latitudes in between rotate at intermediate speeds; approximately 1400 km/hr at 30^o and 800 km/hr at 60^o. As objects move over the surface of the Earth they encounter regions of varying speed, which causes their path to be deflected by the Coriolis Effect.

In the Northern hemisphere objects moving towards the equator from the north pole are moving from a low speed to a high speed. Imagine a cannon located at 60^o and facing the equator. It will be moving east at 800 km/hr and when its shell is fired towards the equator, the shell will be moving east at 800 km/hr. But, as it approaches the equator it will be moving over land that is traveling east faster than the projectile. So the projectile gets "behind" its target, and will land to the west of its destination. But from the point of view of the cannon facing the equator, the path of the shell still appears to have been deflected to the right (green arrow, Figure 2.3.2). Therefore, in the Northern Hemisphere, the apparent Coriolis deflection will always be to the right.

In the Southern Hemisphere the situation is reversed (Figure 2.3.2). Objects moving towards the equator from the south pole are moving from low speed to high speed, so are left behind and their path is deflected to the left. Movement from the equator towards the south pole also leads to deflection to the left. In the Southern Hemisphere, the Coriolis deflection is always to the left from the point of origin.

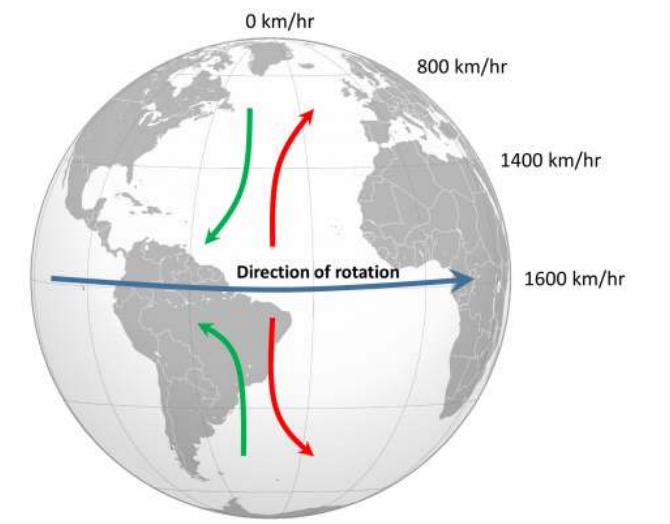


Figure 2.3.2: The Coriolis Effect. Objects moving from the equator towards the poles (red arrows) move into a region of slower rotational speed and their paths are deflected "ahead" of their point of origin. Movement from high latitudes to low latitudes (green arrows) goes from a region of low speed to a region of higher rotation speed, and there is deflection "behind" their point of origin. In the Northern Hemisphere this deflection is always to the right from the point of origin, and in the Southern Hemisphere the deflection is always to the left (by Paul Webb via Libretext; CC BY-SA 3.0).

Because of the rotation of the Earth and the Coriolis Effect, rather than a single atmospheric convection cell in each hemisphere, there are three major cells per hemisphere. Warm air rising at the equator cools as it moves through the upper atmosphere, and it descends at around 30^o latitude. The convection cells created by rising air at the equator and sinking air at 30^o are referred to as **Hadley Cells**, of which there is one in each hemisphere. The cold air that descends at the poles moves over the Earth's surface towards the equator, and by about 60^o latitude it begins to rise, creating a **Polar Cell** between 60^o and 90^o. Between 30^o and 60^o lie the **Ferrel Cells**, composed of sinking air at 30^o and rising air at 60^o (Figure 2.3.3). With three convection cells in each hemisphere that rotate in alternate directions, the surface winds no longer always blow from the poles towards the equator as in the non-rotating Earth in Figure 2.3.3. Instead, surface winds in both hemispheres blow towards the equator between 90^o and 60^o latitude, and between 0^o and 30^o latitude. Between 30^o and 60^o latitude, the surface winds blow towards the poles (Figure 2.3.3).

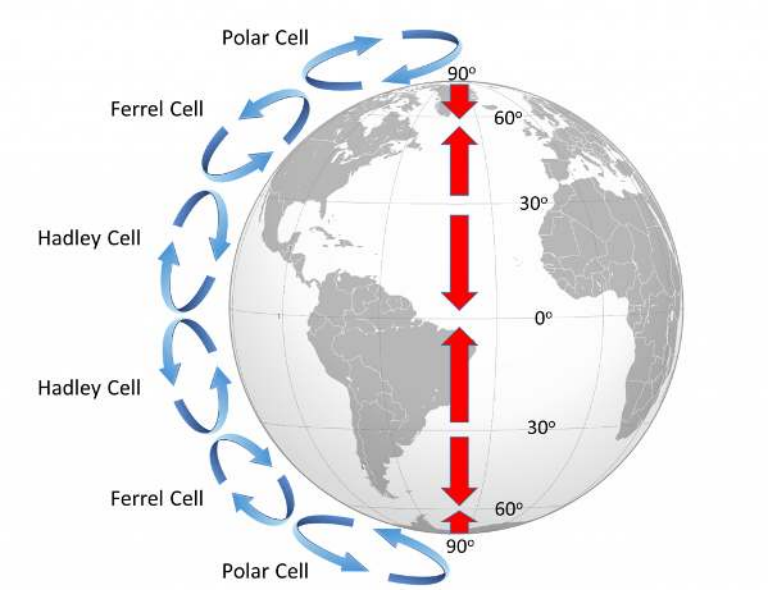


Figure 2.3.3: On a rotating Earth, there are three atmospheric convection cells in each hemisphere, leading to alternating bands of surface winds (red arrows) (by Paul Webb via Libretext; CC BY-SA 3.0)

Surface winds

The surface winds created by the atmospheric convection cells are also influenced by the Coriolis Effect as they change latitudes. The Coriolis Effect deflects the path of the winds to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. Adding this deflection leads to the pattern of prevailing winds illustrated in Figure \(\PageIndex{4}\. Between the equator and 30^o latitude are the **trade winds**; the northeast trade winds in the Northern Hemisphere and the southeast trade winds in the Southern Hemisphere (note that winds are named based on the direction from which they originate, not where they are going). The **westerlies** are the dominant winds between 30^o and 60^o in both hemispheres, and the polar easterlies are found between 60^o and the poles.

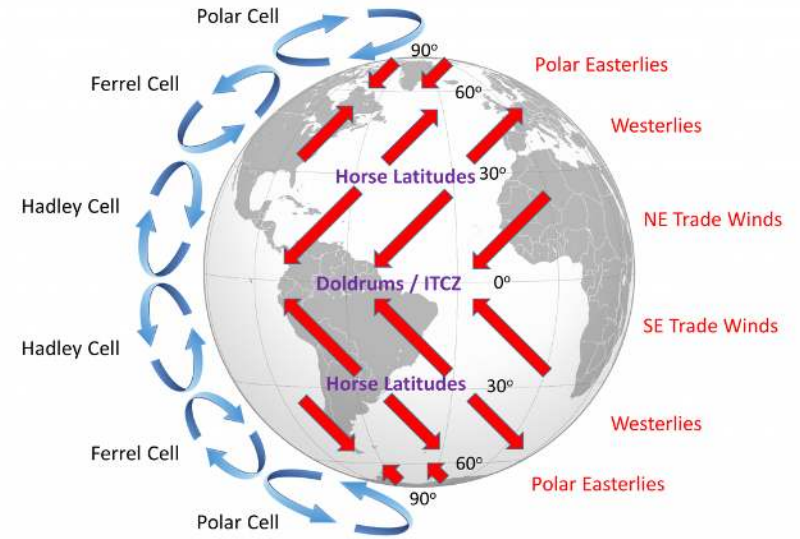


Figure 2.3.4: The prevailing wind patterns of Earth (by Paul Webb via Libretext; CC BY-SA 3.0)

Attribution

This article is a modified derivative of:

- Winds and the Coriolis Effect by Paul Webb license a CC BY 4.0

This page titled 2.3: Atmospheric Circulation is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

2.4: Global Winds and Precipitation

Precipitation

Besides their effect on the global wind belts, the high and low pressure areas created by the six atmospheric circulation cells determine in a general way the amount of **precipitation** a region receives.

Definition: Precipitation

Precipitation is any liquid or frozen water that forms in the atmosphere and falls back to the Earth.

In low pressure regions, where air is rising, rain is common. In high pressure areas, the sinking air causes evaporation and the region is usually dry.



Figure 2.4.1: Sand Dunes in the Emirate of Abu Dhabi (left) (Nepenthes via Wikimedia Commons; *CC BY-SA*) and Mountain Forests of Srilanka (right) (Faslan at en.Wikipedia; *CC BY-SA*)

Along the equator air is rising as it is warmed by solar radiation. Warm air contains more water vapor than cold air with the water content of air roughly doubling with every 10° C increase in temperature. So the air rising at the equator is warm and full of water vapor; as it rises into the upper atmosphere it cools. Cool air can no longer hold as much water vapor, so the water condenses and forms rain and we see wet habitats like tropical rainforests near the equator.

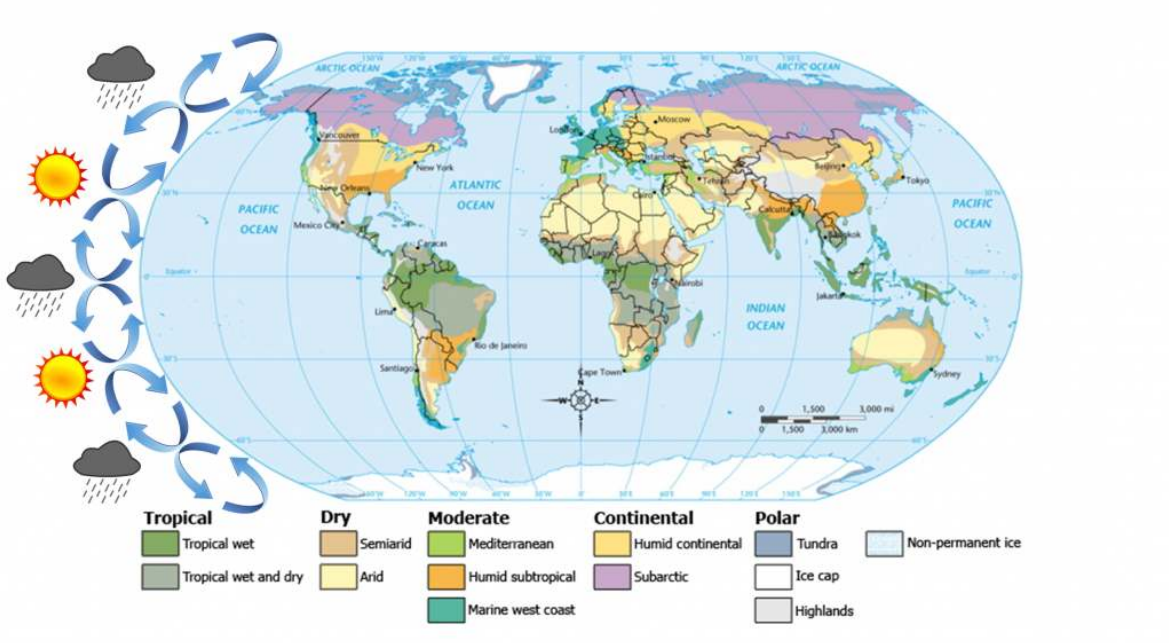


Figure 2.4.2: Major global climatic regions in relation to atmospheric convection cells. Rising air and low pressure creates rain and wet environments at 0° and 60° latitudes, while high pressure, sinking air creates drier conditions at 30° and 90° latitudes. (by Paul Web via 8.3: Winds and Climate; CC BY-SA 3.0).

? Concept Check 2.4.1

The amount of water vapor that air can hold _____ with temperature.

Answer

increases

After rising and producing rain near the equator, the air masses move towards 30º latitude and sink back towards Earth as part of the Hadley convection cells. This air has lost most of its moisture after producing the equatorial rains, so the sinking air is dry, resulting in arid climates near 30° latitude in both hemispheres. Many of the major desert regions on Earth are located near 30° latitude, including much of Australia, the Middle East, and the Sahara Desert of Africa .

The air also becomes compressed and heats up as it sinks, absorbing any moisture from the clouds and creating clear skies. Thus high pressure systems are associated with dry weather and clear skies. This cycle of high and low pressure regions continues with the Ferrel and Polar convection cells, leading to rain and the boreal forests at 60º latitude in the Northern Hemisphere (there are no corresponding large land masses at these latitudes in the Southern Hemisphere). At the poles, descending, dry air produces little precipitation, leading to the polar desert climate.

Attribution

This article is a modified derivative of:

-

This page titled 2.4: Global Winds and Precipitation is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

2.5: Oceanic Circulation

Surface Currents and Gyres

It is the prevailing winds that blow across the water surface to create the major ocean surface currents. However, wind-driven surface currents only affect the top 100-200m of water, meaning surface currents only involve about 10% of the world's ocean water. In contrast, the deep **thermohaline circulation** impacts around 90% of the ocean water.

Surface currents generally move in the same direction as the winds that created them. However, because of Coriolis deflection, the surface currents are offset approximately 45 degrees relative to the wind direction.

The **trade winds** create the equatorial currents that flow east to west along the equator; the North Equatorial and South Equatorial currents. If there were no continents, these surface currents would travel all the way around the Earth, parallel to the equator. However, the presence of the continents prevents this unimpeded flow. When these equatorial currents reach the continents, they are diverted and deflected away from the equator by the Coriolis Effect; deflection to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. These currents then become western boundary currents; currents that run along the western side of the ocean basin (i.e. the east coasts of the continents). Since these currents come from the equator, they are warm water currents, bringing warm water to the higher latitudes and distributing heat throughout the ocean.

At the same time, between 30-60º latitude the **westerlies** move surface water towards the east. The Coriolis Effect and the presence of the continents deflect the currents towards the equator, creating eastern boundary currents (on the eastern side of the ocean basins). These currents come from high latitude areas, so they deliver cold water to the lower latitudes. Together, these currents combine to create large-scale circular patterns of surface circulation called **gyres**. In the Northern Hemisphere the gyres rotate to the right (clockwise), while in the Southern Hemisphere the gyres rotate to the left (counterclockwise).

There are five major gyres in the oceans; the North Atlantic, South Atlantic, North Pacific, South Pacific, and Indian (Figure

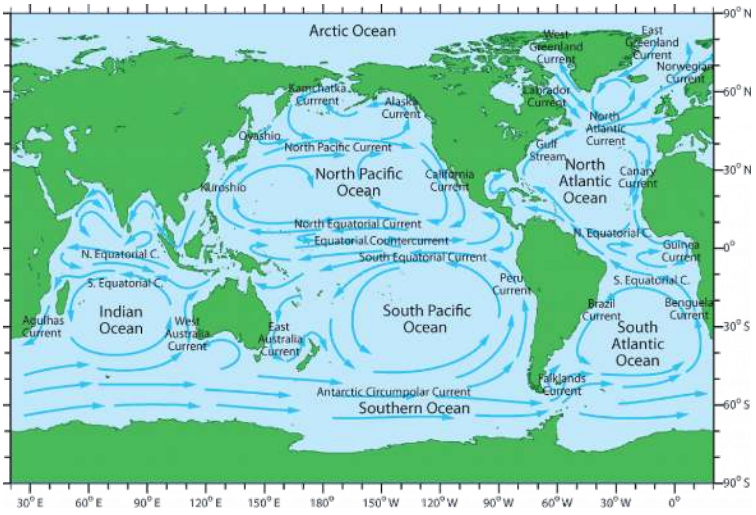


Figure 2.5.1: The major global surface currents (by oceaanstromen; CC BY-NC-SA 2.0)

Thermohaline Circulation

There are other significant ocean currents that are independent of the wind, and involve water movements in the other 90% of the ocean. These currents are driven by differences in water **density**. Waters of different densities tend to stratify themselves into layers, with the densest, coldest water on the bottom and warmer, less dense water on top. It is the movement of these density layers that create the deep water circulation. Since seawater density depends mainly on temperature and salinity, this circulation is referred to as **thermohaline circulation**.

The main processes that increase seawater density are cooling, evaporation, and ice formation. Evaporation and ice formation cause an increase in density by removing fresh water, leaving the remaining seawater with greater salinity. The main processes that decrease seawater density are heating, and dilution by fresh water through precipitation, ice melting, or freshwater runoff. Note that all of these processes exert their effects at the surface, but don't necessarily affect deeper water. However, changing the density of

the surface water causes it to sink or rise, and these vertical, density-driven movements create the deep ocean currents. These thermohaline currents are slow, on the order of 10-20 km per year compared with surface currents that move at several kilometers per hour.

The densest ocean water is formed in two primary locations near the poles (The North Atlantic near Greenland, and the South Pacific in the Weddle Sea), where the water is very cold and highly saline as a result of ice formation. This cold, dense water sinks and moves throughout the ocean as part of the thermohaline circulation. This bottom water circulates through the atlantic and eventually moves eastwards into the Indian and Pacific Oceans where it gradually mixes with warmer water and rises to the surface. As surface water, it makes its way back to the North Atlantic through the surface currents of the Pacific and Indian Oceans. Once back in the North Atlantic, it cools and once again forms a new mass of very cold highly saline dense water which sinks and starts the process anew.This cycle of rising and sinking water transporting water between the surface and deep circulation has been referred to as the global oceanic “conveyor belt”, and may take about 1000-2000 years to complete.

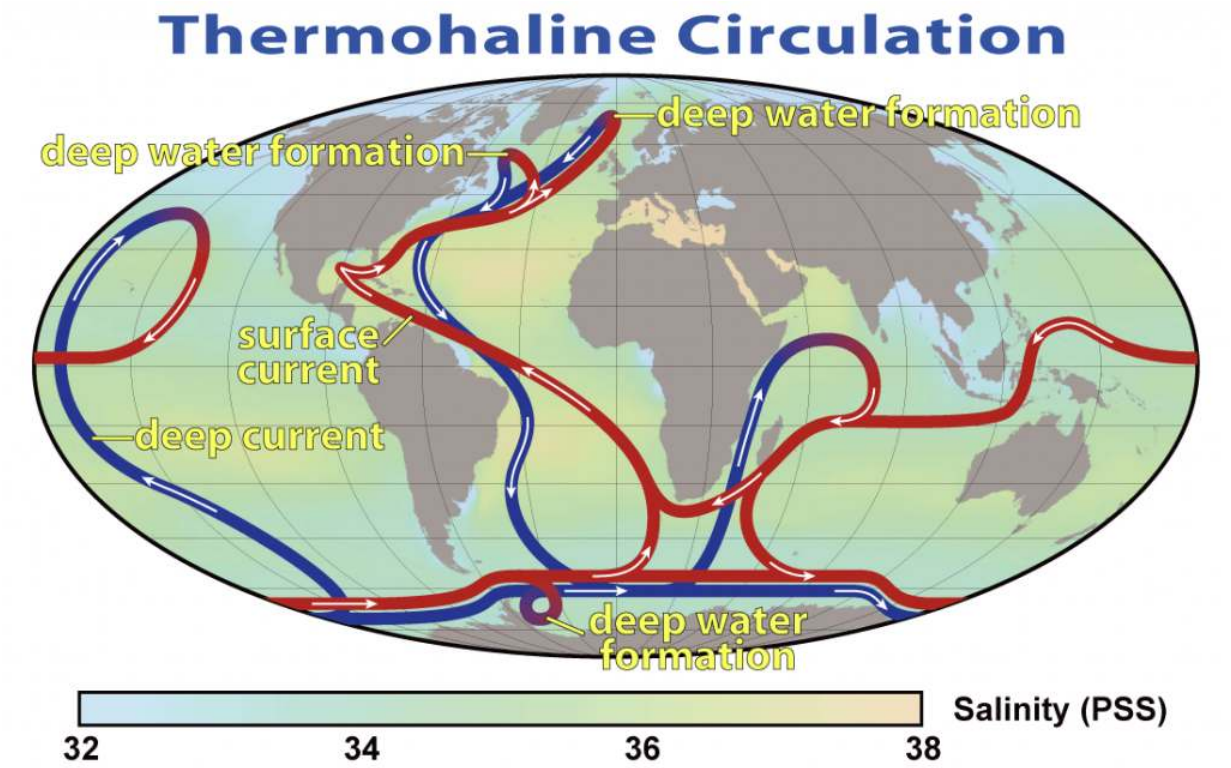


Figure 2.5.2: The global ocean “conveyor belt.” Cold, dense water sinks in the Greenland and Weddell Seas and circulates over the seafloor into the Indian and Pacific Oceans (blue paths). Eventually the water rises to the surface, and returns to the site of bottom water formation via surface currents (red paths), to start the cycle again (By Robert Simmon, NASA via Wikimedia Commons; Public domain).

This global circulation pattern has a number of important implications for Earth’s environment. For one, it is vital to the transport of heat around the globe, bringing warm water towards the poles, and cold water to the tropics, stabilizing temperature in both environments. The conveyor belt also helps deliver cold oxygen rich surface water to deep water habitats and the organisms within them. Once at the bottom of ocean basins deep water accumulates nutrients as organic matter sinks and decomposes.When this water eventually rises again in the Indian Ocean it brings an abundance of nutrients to the surface which support large and diverse communities of organisms.

The ocean conveyor belt may be significantly impacted by climate change disrupting thermohaline circulation. Increased warming, particularly in the Arctic, could lead to continuing melting of the polar ice caps, adding a large amount of fresh water to the polar surface water. This input of fresh water could create a low density, low salinity surface layer of water that no longer sinks, thus disrupting the deep circulation conveyor belt and preventing oxygen and nutrient transport to bottom communities.

The sinking of seawater in the Greenland Sea also helps drive the Gulf Stream; as water sinks, more surface water is pulled northwards in the Gulf Stream. If this polar water stops sinking the Gulf Stream could weaken, reducing heat transport to the poles

and cooling the northern climate. It seems counter intuitive, but global warming could lead to colder conditions in Europe and the freezing of ports and cities that are usually ice-free due to the warming effects of the Gulf Stream. Recent evidence has already shown that the strength of the Gulf Stream is waning, likely due to the increased melting of Arctic ice.

Attribution

This article is a modified derivative of:

-
-

This page titled 2.5: Oceanic Circulation is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

CHAPTER OVERVIEW

3: Terrestrial and Aquatic Biomes



Figure 3.1: Desert Bighorn Sheep are native to the deserts of the United States West and Southwest. A desert is a terrestrial biome that receives no more than 10 inches of rainfall per year. Deserts can be found on every continent and cover about one-fifth of Earth's land area. Water is scare and and, consequently, living conditions are hostile for plant and animal life. The desert bighorn sheep has adapted to this set of environmental conditions and unlike most mammals, their body temperature can safely fluctuate several degrees. They may go without visiting water for weeks or months, sustaining their body moisture from food and from rainwater collected in temporary rock pools. They may have the ability to lose up to 30% of their body weight and still survive. After drinking water, they quickly recover from their dehydrated condition. Wildlife ecologists are just beginning to study the importance of this adaptive strategy, which has allowed small bands of desert bighorns to survive in areas too dry for many of their predators.(CC-BY-SA 3.0; Andrew Barna via Wikimedia)

Chapter Summary

Earth’s biomes can be either terrestrial or aquatic. Terrestrial biomes are based on land, while aquatic biomes include both ocean and freshwater biomes. The location of Earth's major terrestrial biomes are determined by the average temperature and rainfall which affect the dominant type off vegetation and animal life that can exist in broad geographical regions. The aquatic biome is the largest of all the biomes, covering about 75 percent of Earth’s surface. Abiotic factors such as light, temperature, flow, and dissolved nutrients are important for determine the composition of plant and animal communities including estuaries, coral reefs, and kelp Forests.

Learning Objectives

After reading this chapter you should be able to:

- Explain the difference between abiotic and biotic factors that influence life.
- Explain why temperature and precipitation are the most influential abiotic factors.
- Define Biogeography and endemic species.
- Recognize distinguishing characteristics of each of the eight major terrestrial biomes.
- Describe important abiotic factors influencing aquatic biomes and characteristics of each biome.
- Compare and contrast the characteristics of the ocean zones.

3.1: Biogeography and Species Distributions
3.2: Terrestrial Biomes
3.3: Aquatic Biomes

This page titled 3: Terrestrial and Aquatic Biomes is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

3.1: Biogeography and Species Distributions

Biogeography

Biogeography is the study of the geographic distribution of living things and the abiotic factors that affect their distribution. Abiotic factors such as temperature and rainfall vary based mainly on latitude and elevation. As these abiotic factors change, the composition of plant and animal communities also changes. For example, if you were to begin a journey at the equator and walk north, you would notice gradual changes in plant communities. At the beginning of your journey, you would see tropical wet forests with broad-leaved evergreen trees, which are characteristic of plant communities found near the equator. As you continued to travel north, you would see these broad-leaved evergreen plants eventually give rise to seasonally dry forests with scattered trees. You would also begin to notice changes in temperature and moisture. At about 30 degrees north, these forests would give way to deserts, which are characterized by low precipitation.

Moving farther north, you would see that deserts are replaced by grasslands or prairies. Eventually, grasslands are replaced by deciduous temperate forests. These deciduous forests give way to the boreal forests found in the subarctic, the area south of the Arctic Circle. Finally, you would reach the Arctic tundra, which is found at the most northern latitudes. This trek north reveals gradual changes in both climate and the types of organisms that have adapted to environmental factors associated with ecosystems found at different latitudes. However, different ecosystems exist at the same latitude due in part to abiotic factors such as jet streams, the Gulf Stream, and ocean currents. If you were to hike up a mountain, the changes you would see in the vegetation would parallel those as you move to higher latitudes.

Ecologists who study biogeography examine patterns of species distribution. No species exists everywhere; for example, the Venus flytrap is endemic to a small area in North and South Carolina. An endemic species is one which is naturally found only in a specific geographic area that is usually restricted in size. Other species are generalists: species which live in a wide variety of geographic areas; the raccoon, for example, is native to most of North and Central America.

Species distribution patterns are based on biotic and abiotic factors and their influences during the very long periods of time required for species evolution; therefore, early studies of biogeography were closely linked to the emergence of evolutionary thinking in the eighteenth century. Some of the most distinctive assemblages of plants and animals occur in regions that have been physically separated for millions of years by geographic barriers. Biologists estimate that Australia, for example, has between 600,000 and 700,000 species of plants and animals. Approximately 3/4 of living plant and mammal species are endemic species found solely in Australia (Figure 3.1.1 ab).



Figure 3.1.1: Australia is home to many endemic species. The (a) wallaby (Wallabia bicolor), a medium-sized member of the kangaroo family, is a pouched mammal, or marsupial. The (b) echidna (Tachyglossus aculeatus) is an egg-laying mammal. (Figure 44.6 modification of work by Derrick Coetzee (a) and by Allan Whittome (b), via OpenStax; CC-BY 4.0)

Sometimes ecologists discover unique patterns of species distribution by determining where species are not found. Hawaii, for example, has no native land species of reptiles or amphibians, and has only one native terrestrial mammal, the hoary bat. Most of New Guinea, as another example, lacks placental mammals.

Attribution

This article is a modified derivative of:

-

This page titled 3.1: Biogeography and Species Distributions is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

3.2: Terrestrial Biomes

Earth's biomes can be either terrestrial or aquatic. Terrestrial biomes are based on land, while aquatic biomes include both ocean and freshwater biomes.

Definition: Biome

A biome is a biogeographic area characterized by similar climate and predominant type of vegetation. These regions may be vastly separated in space (for instance consider the similar chaparral communities of South Australia, South Africa, and California), but contain similar types of organisms because the similar physical environment leads to similar evolutionary solutions. As vegetation provides food and habitat for many other organisms we find that communities of animals also tend to be similar within a biome.

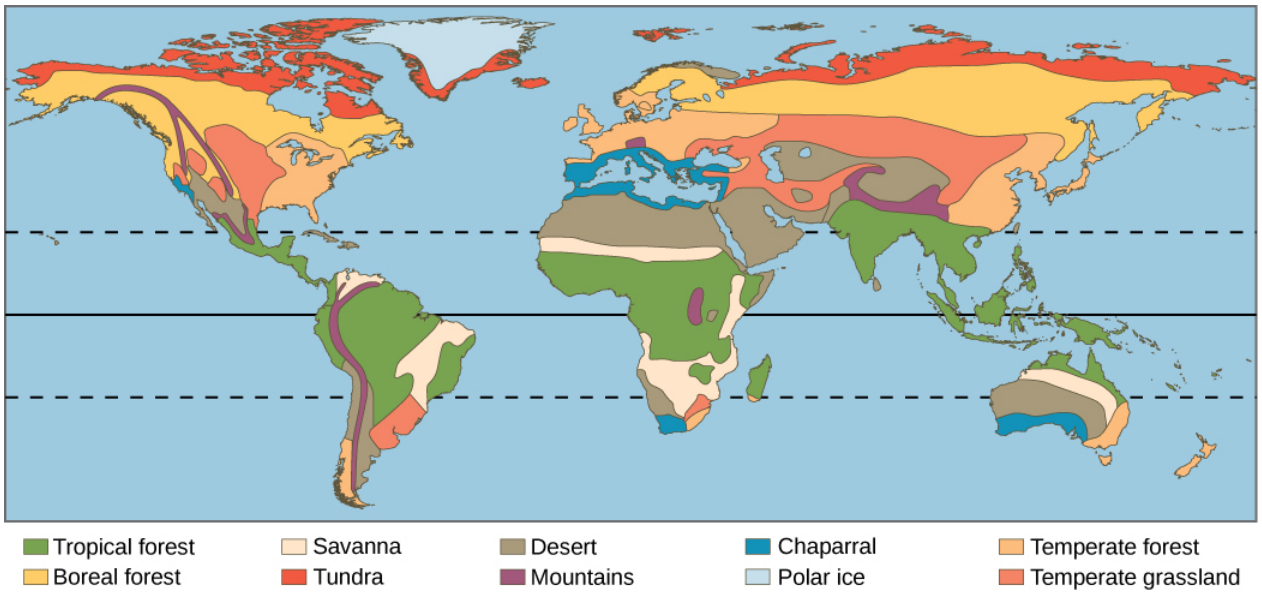


Figure 3.2.1: Each of the world's eight major biomes is distinguished by characteristic temperatures and amount of precipitation. Polar ice caps and mountains are also shown.

Temperature and Precipitation

The terrestrial biomes on Earth are each distinguished by characteristic **temperatures** and amount of **precipitation**. Annual totals and fluctuations of precipitation affect the kinds of vegetation that can exist in each region.

Low latitudes (near the equator) have high temperatures and low latitudes (near the poles) have low temperatures. Temperature also decreases with altitude. At high altitudes, the atmosphere is thinner and traps less heat energy from the sun. Because temperatures decline with altitude as well as latitude, similar biomes exist on mountains even when they are at low latitudes. As a rule of thumb, a climb of 1000 feet (about 300 m) is equivalent in changed flora and fauna to a trip northward of some 600 miles (966 km).

Latitude influences temperature, but it also affects precipitation. For example, deserts tend to occur at latitudes of around 30° and at the poles. Where precipitation is moderately abundant — 40 inches (about 1 m) or more per year — and distributed fairly evenly throughout the year, the major determinant is temperature. It is not simply a matter of average temperature, but includes such limiting factors as whether it ever freezes or length of the growing season. Biomes are thus characterized not only by average temperature and precipitation but also their seasonality.

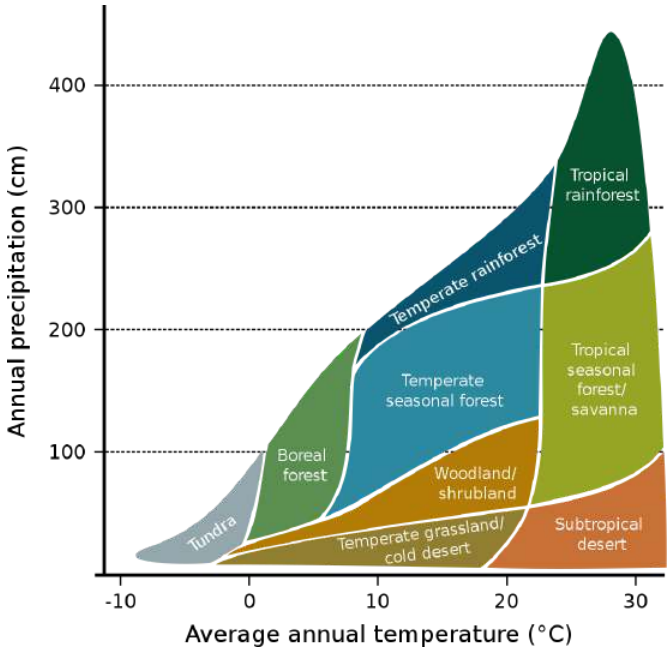


Figure 3.2.2:Average annual temperature and annual precipitation are two climatic factors that determine the distribution of biomes. This graph shows annual precipitation in centimeters on the y-axis and average annual temperature in degrees Celsius on the x-axis. Tropical rainforests have the highest temperatures and most precipitation. Tropical seasonal forests and savannas have high temperatures (20-30°C) with precipitation from approximately 50 to 270 centimeters. Subtropical deserts have similarly high temperatures but dry conditions. Temperate grasslands and cold deserts range in average annual temperature from below 0 to 22°C and have less than 50 centimeters of precipitation per year. Woodlands/shrublands (such as the chaparral) have the same temperature range as cold deserts but can receive a little over 100 cm of precipitation per year. Temperate forests have intermediate temperatures (approximately 16-22°C), but temperate rainforests receive more precipitation than temperate seasonal forests. Boreal forests receive a little less precipitation than temperate forests, but are colder (approximately 1-10°C). The tundra has the coldest temperatures and little precipitation. Deserts have a range of temperatures but low precipitation. Image by Navarras (public domain).

? Concept Check 3.2.1

What 2 abiotic variables are most important for determining the location of, and dominant vegetation found within, each Biome?

Answer

Temperature and Precipitation

Tropical Forest

Tropical rainforests are also referred to as tropical wet forests. This biome is found in equatorial regions (Figure 3.2.1). Tropical rainforests are the most diverse terrestrial biome. This biodiversity is still largely unknown to science and is under extraordinary threat primarily through logging and deforestation for agriculture. Tropical rainforests have also been described as nature's pharmacy because of the potential for new drugs that is largely hidden in the chemicals produced by the huge diversity of plants, animals, and other organisms. The vegetation is characterized by plants with spreading roots and broad leaves that fall off throughout the year, unlike the trees of deciduous forests that lose their leaves in one season. These forests are "evergreen," year-round.

The temperature and sunlight profiles of tropical rainforests are stable in comparison to that of other terrestrial biomes, with average temperatures ranging from 20°C to 34°C (68°F to 93°F). Month-to-month temperatures are relatively constant in tropical rainforests, in contrast to forests further from the equator. This lack of temperature seasonality leads to year-round plant growth, rather than the seasonal growth seen in other biomes. In contrast to other ecosystems, a more constant daily amount of sunlight (11–12 hours per day) provides more solar radiation, thereby a longer period of time for plant growth.

The annual rainfall in tropical rainforests ranges from 250 cm to more than 450 cm (8.2–14.8 ft) with considerable seasonal variation. Tropical rainforests have wet months in which there can be more than 30 cm (11–12 in) of precipitation, as well as dry months in which there are fewer than 10 cm (3.5 in) of rainfall. However, the driest month of a tropical rainforest can still exceed the annual rainfall of some other biomes, such as deserts.

Tropical rainforests have high net primary productivity because the annual temperatures and precipitation values support rapid plant growth (Figure 3.2.2). However, the high rainfall quickly leaches nutrients from the soils of these forests. Tropical rainforests are characterized by vertical layering of vegetation and the formation of distinct habitats for animals within each layer. On the forest floor is a sparse layer of plants and decaying plant matter. Above that is an understory of short, shrubby foliage. A layer of trees rises above this understory and is topped by a closed upper canopy—the uppermost overhead layer of branches and leaves. Some additional trees emerge through this closed upper canopy. These layers provide diverse and complex habitats for the variety of plants, animals, and other organisms within. Many species of animals use the variety of plants and the complex structure of the forests for food and shelter. Some organisms live several meters above ground, rarely ever descending to the tropical rainforest floor.

Rainforests are not the only forest biome in the tropics; there are also tropical dry forests, which are characterized by a dry season of varying lengths. These forests commonly experience leaf loss during the dry season to one degree or another. The loss of leaves from taller trees during the dry season opens up the canopy and allows sunlight to the forest floor that allows the growth of thick ground-level brush, which is absent in tropical rainforests. Extensive tropical dry forests occur in Africa (including Madagascar), India, southern Mexico, and South America.



Figure 3.2.3: Species diversity is very high in tropical wet forests, such as these forests of Madre de Dios, Peru, near the Amazon River. (credit: Roosevelt Garcia)

Savannas

Savannas are grasslands with scattered trees, and they are found in Africa, South America, and northern Australia (Figure 3.2.1). Savannas are hot, tropical areas with temperatures averaging from 24°C –29°C (75°F –84°F) and an annual rainfall of 51–127 cm (20–50 in). There is insufficient precipitation to support most species of trees and so grasses and forbs (herbaceous flowering plants) dominate the landscape. The savanna often has distinct wet and dry seasons. And fires act as important source of disturbance. As a result plants have evolved well-developed root systems that allow them to quickly re-sprout after a fire.



Figure 3.2.4: Mount Tambora National Park, a location with extraordinary natural panoramic charm, has savanna with various types of animals, as well as lowland forests to mountain forests located on the island of Sumbawa. (CC BY-SA 4.0; Budi Wasisto via Wikimedia Commons)

Deserts

Subtropical deserts exist between 15° and 30° north and south latitude and are centered on the Tropic of Cancer and the Tropic of Capricorn (Figure 3.2.1). Deserts are frequently located on the downwind side of mountain ranges, which create a rain shadow after prevailing winds drop their water content on the mountains. This is typical of the North American deserts, such as the Mohave and Sonoran deserts. Deserts in other regions, such as the Sahara Desert in northern Africa or the Namib Desert in southwestern Africa are dry because of the high-pressure, dry air descending at those latitudes. Subtropical deserts are very dry; evaporation typically exceeds precipitation. Subtropical hot deserts can have daytime soil surface temperatures above 60°C (140°F) and nighttime temperatures approaching 0°C (32°F). The temperature drops so far because there is little water vapor in the air to prevent radiative cooling of the land surface. Subtropical deserts are characterized by low annual precipitation of fewer than 30 cm (12 in) with little monthly variation and lack of predictability in rainfall. Some years may receive tiny amounts of rainfall, while others receive more. In some cases, the annual rainfall can be as low as 2 cm (0.8 in) in subtropical deserts located in central Australia (“the Outback”) and northern Africa.

The low species diversity of this biome is closely related to its low and unpredictable precipitation. Despite the relatively low diversity, desert species exhibit fascinating adaptations to the harshness of their environment. Very dry deserts lack perennial vegetation that lives from one year to the next; instead, many plants are annuals that grow quickly and reproduce when rainfall does occur, then they die. Perennial plants in deserts are characterized by adaptations that conserve water: deep roots, reduced foliage, and water-storing stems (Figure 20.21). Seed plants in the desert produce seeds that can lie dormant for extended periods between rains. Most animal life in subtropical deserts has adapted to a nocturnal life, spending the hot daytime hours beneath the ground. The Namib Desert, in southern Africa, is the oldest on the planet, and has probably been dry for more than 55 million years. It supports a number of endemic species (species found only there) because of this great age. For example, the unusual gymnosperm Welwitschia mirabilis is the only extant species of an entire order of plants. There are also five species of reptiles considered endemic to the Namib.

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. The largest of these deserts are the Gobi Desert in northern China and southern Mongolia, the Taklimakan Desert in western China, the Turkestan Desert, and the Great Basin Desert of the United States.




Figure 3.2.5: Many desert plants have tiny leaves or no leaves at all to reduce water loss. The leaves of ocotillo, shown here in the Chihuahuan Desert in Big Bend National Park, Texas, appear only after rainfall and then are shed. (credit “bare ocotillo”: "Leaflet"/Wikimedia Commons)

Chaparral

The chaparral is also called scrubland or woodland and is found in California, along the Mediterranean Sea, and along the southern coast of Australia (Figure 3.2.1). The annual rainfall in this biome ranges from 65 cm to 75 cm (25.6–29.5 in) and the majority of the rain falls in the winter. Summers are very dry and many chaparral plants are dormant during the summertime, springing back to life when the winter rains start. The chaparral vegetation is dominated by shrubs with tiny leaves, thick cuticles, and light coloring to reflect heat and deter herbivores. This vegetation is also adapted to periodic fires, and some plants actually require fire as part of their life cycle. Some chaparral plants store oils in their leaves that ensure the plant burns quickly, others produce seeds that will only germinate after a hot fire. The ashes left behind after a fire are rich in nutrients like nitrogen that fertilize the soil and promote plant regrowth. Fire is a natural part of the maintenance of this biome and frequently threatens human habitation in this biome in the U.S. Figure 3.2.6.



Figure 3.2.6: The chaparral is dominated by shrubs. (credit: Miguel Vieira)

Temperate Grasslands

Temperate grasslands are found throughout central North America, where they are also known as prairies, and in Eurasia, where they are known as steppes ((Figure 3.2.1)). Temperate grasslands have pronounced annual fluctuations in temperature with hot summers and cold winters. The annual temperature variation produces specific growing seasons for plants. Plant growth is possible when temperatures are warm enough to sustain plant growth, which occurs in the spring, summer, and fall.

Annual precipitation ranges from 25.4 cm to 88.9 cm (10–35 in). Temperate grasslands have few trees except for those found growing along rivers or streams. The dominant vegetation tends to consist of grasses. The treeless condition is maintained by low precipitation, frequent fires, and grazing (Figure 3.2.7). The vegetation is very dense and the soils are fertile because the subsurface of the soil is packed with the roots and rhizomes (underground stems) of these grasses. The roots and rhizomes act to anchor plants into the ground and replenish the organic material (humus) in the soil when they die and decay.



Figure 3.2.7: The American bison (Bison bison), more commonly called the buffalo, is a grazing mammal that once populated American prairies in huge numbers. (credit: Jack Dykinga, USDA ARS)

Fires, which are a natural disturbance in temperate grasslands, can be ignited by lightning strikes. It also appears that the lightning-caused fire regime in North American grasslands was enhanced by intentional burning by humans. When fire is suppressed in temperate grasslands, the vegetation eventually converts to scrub and dense forests. Often, the restoration or management of temperate grasslands requires the use of controlled burns to suppress the growth of trees and maintain the grasses.

Temperate Forests

Temperate forests are the most common biome in eastern North America, Western Europe, Eastern Asia, Chile, and New Zealand ((Figure 3.2.1). This biome is found throughout mid-latitude regions. Temperatures range between –30°C and 30°C (–22°F to 86°F) and drop to below freezing on an annual basis. These temperatures mean that temperate forests have defined growing seasons during the spring, summer, and early fall. Precipitation is relatively constant throughout the year and ranges between 75 cm and 150 cm (29.5–59 in).

Deciduous trees are the dominant plant in this biome with fewer evergreen conifers. Deciduous trees lose their leaves each fall and remain leafless in the winter. Thus, little photosynthesis occurs during the dormant winter period. Each spring, new leaves appear as temperature increases. Because of the dormant period, the net primary productivity of temperate forests is less than that of tropical rainforests. In addition, temperate forests show far less diversity of tree species than tropical rainforest biomes.

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 the trees in tropical rainforests. The soils of the temperate forests are rich in inorganic and organic nutrients compared to tropical rainforests. This is because of the thick layer of

leaf litter on forest floors and reduced leaching of nutrients by rainfall. As this 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 (Figure 20.24).



Figure 3.2.8: Deciduous trees are the dominant plant in the temperate forest. (credit: Oliver Herold)

Boreal Forests

The boreal forest, also known as taiga or coniferous forest, is found roughly between 50° and 60° north latitude across most of Canada, Alaska, Russia, and northern Europe (Figure 3.2.1). Boreal forests are also found above a certain elevation (and below high elevations where trees cannot grow) in mountain ranges throughout the Northern Hemisphere. This biome has cold, dry winters and short, cool, wet summers. The annual precipitation is from 40 cm to 100 cm (15.7–39 in) and usually takes the form of snow; little evaporation occurs because of the cold temperatures.

The long and cold winters in the boreal forest have led to the predominance of cold-tolerant cone-bearing plants. These are evergreen coniferous trees like pines, spruce, and fir, which retain their needle-shaped leaves year-round. The sap of evergreen trees is thick and sticky, and has a lower freezing point than the sap of deciduous trees. This enables them to stay active across the seasons. Evergreen trees can also photosynthesize earlier in the spring than deciduous trees because less energy from the Sun is required to warm a needle-like leaf than a broad leaf. Evergreen trees grow faster than deciduous trees in the boreal forest. In addition, soils in boreal forest regions tend to be acidic with little available nitrogen. Leaves are a nitrogen-rich structure and deciduous trees must produce a new set of these nitrogen-rich structures each year. Therefore, coniferous trees that retain nitrogen-rich needles in a nitrogen limiting environment may have had a competitive advantage over the broad-leafed deciduous trees.

The net primary productivity of boreal forests is lower than that of temperate forests and tropical wet forests. The aboveground biomass of boreal forests is high because these slow-growing tree species are long-lived and accumulate standing biomass over time. Species diversity is less than that seen in temperate forests and tropical rainforests. Boreal forests lack the layered forest structure seen in tropical rainforests or, to a lesser degree, temperate forests. The structure of a boreal forest is often only a tree layer and a ground layer. Additionally, relatively fewer understory plants are adapted to growing in the acidic soil. When conifer needles are dropped, they decompose more slowly than broad leaves; therefore, fewer nutrients are returned to the soil to fuel plant growth (Figure 3.2.9).



Figure 3.2.9: The boreal forest (taiga) has low lying plants and conifer trees. (credit: L.B. Brubaker, NOAA)

Arctic Tundra

The Arctic tundra lies north of the subarctic boreal forests and is located throughout the Arctic regions of the Northern Hemisphere (Figure 3.2.1). Tundra also exists at elevations above the tree line on mountains. The average winter temperature is –34°C (–29.2°F) and the average summer temperature is 3°C–12°C (37°F –52°F). Plants in the Arctic tundra have a short growing season of approximately 50–60 days. However, during this time, there are almost 24 hours of daylight and plant growth is rapid. The annual precipitation of the Arctic tundra is low (15–25 cm or 6–10 in) with little annual variation in precipitation. And, as in the boreal forests, there is little evaporation because of the cold temperatures.

Plants in the Arctic tundra are generally low to the ground and include low shrubs, grasses, lichens, and small flowering plants (Figure 3.2.10). There is little species diversity, low net primary productivity, and low aboveground biomass. The soils of the Arctic tundra may remain in a perennially frozen state referred to as permafrost. The permafrost makes it impossible for roots to penetrate far into the soil and slows the decay of organic matter, which inhibits the release of nutrients from organic matter. The melting of the permafrost in the brief summer provides water for a burst of productivity while temperatures and long days permit it. During the growing season, the ground of the Arctic tundra can be completely covered with plants or lichens.



Figure 3.2.10: Low-growing plants such as shrub willow dominate the tundra landscape during the summer, shown here in the Arctic National Wildlife Refuge. (credit: Arctic National Wildlife Refuge, USFWS)

Attribution Ch. 3.2:

This page is a modified derivative of

- Terrestrial Biomes by Open Stax CC-BY 4.0
- 22.2: Climate and Biomes by Melissa Ha CC BY-NC 4.0

This page titled 3.2: Terrestrial Biomes is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

3.3: Aquatic Biomes

Abiotic factors in Aquatic Biomes

Like terrestrial biomes, the **aquatic biome** is influenced by abiotic factors. In the case of this biome, the abiotic factors include light, temperature, flow, and dissolved nutrients.The aquatic medium—water— has different physical and chemical properties than air. Even if the water in a pond or other body of water is perfectly clear (there are no suspended particles), water, on its own, absorbs light. As one descends deep enough into a body of water, eventually there will be a depth at which the sunlight cannot reach. While there are some abiotic and biotic factors in a terrestrial ecosystem that shade light (like fog, dust, or insect swarms), these are not usually permanent features of the environment. The importance of light in aquatic biomes is central to the communities of organisms found in both freshwater and marine systems because it controls productivity through photosynthesis.

Definition: Aquatic Biome

The **aquatic biome** is the largest of all the biomes, covering about 75 percent of Earth's surface. This biome is usually divided into two categories: freshwater and marine. Typically, freshwater habitats are less than 1 percent salt. Marine life, however, has to be adapted to living in a habitat with a high concentration of salt. Freshwater habitats include ponds, lakes, rivers, and streams, while marine habitats include the ocean and salty seas.

In addition to light, solar radiation warms bodies of water and many exhibit distinct layers of water at differing temperatures. The water temperature affects the organisms' rates of growth and the amount of dissolved oxygen available for respiration.

The movement of water (flow) is also important in many aquatic biomes. In rivers, the organisms must obviously be adapted to the constant movement of the water around them, but even in larger bodies of water such as the oceans, regular currents and tides impact availability of nutrients, food resources, and the presence of the water itself.

Finally, all natural water contains dissolved salts. Fresh water contains low levels of such dissolved substances because the water is rapidly recycled through evaporation and precipitation. The oceans have a relatively constant high salt content. Aquatic habitats at the interface of marine and freshwater ecosystems have complex and variable salt environments that range between freshwater and marine levels. These are known as brackish water environments. Lakes located in closed drainage basins concentrate salt in their waters and can have extremely high salt content that only a few and highly specialized species are able to inhabit.

Dissolved nutrients such as nitrogen, phosphorus, and silica, occur in low amounts but are important for microscopic aquatic plants known as phytoplankton. Phytoplankton serve as the basis of the food chain in most marine systems. Phytoplankton growth is often limited by the availability of these, and other nutrients, and thus systems with high nutrients support rapid growth of phytoplankton who in turn support diverse communities of aquatic organisms. Nutrients availability in freshwater systems is often high. In marine systems, nutrient availability is highly variable and is influenced by wind, ocean depth, proximity to shore, and circulation of deep ocean currents.

Freshwater Systems

The aquatic (freshwater, or partly freshwater) biome include lakes, ponds, and wetlands (standing water) as well as rivers and streams (flowing water). Freshwater biomes are found in terrestrial landscapes and are therefore connected with abiotic and biotic factors influencing these terrestrial biomes.

Lakes and Ponds

Lakes and **ponds** can range in area from a few square meters to thousands of square kilometers. A lake is an area filled with water, localized in a basin, surrounded by land, and distinct from any river or other outlet that serves to feed or drain the lake. Lakes are typically larger and deeper than ponds, which also lie on land, though there are no official or scientific definitions. Most lakes are fed and drained by rivers and streams.

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 (Figure 3.3.1). The process produces a sharp transition between the warm water above and cold water beneath

and has a large influence on the animal and plant life inhabiting the lake. 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.

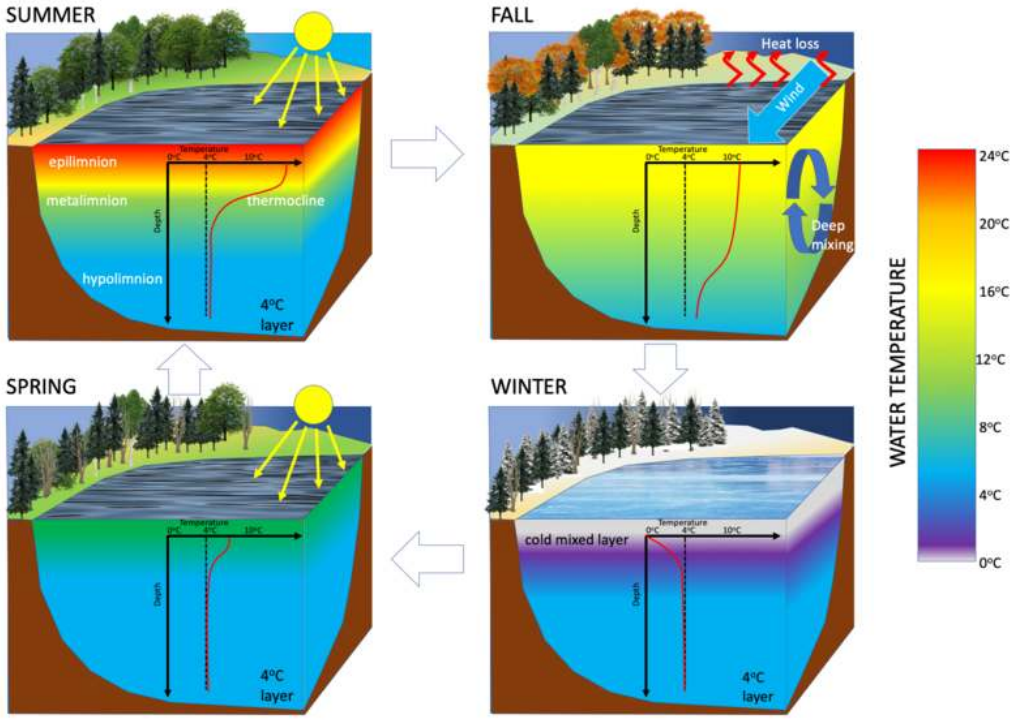


Figure 3.3.1: The effect of seasons on mixing and stratification of large freshwater lakes. (CC-BY-SA 4.0: Dimictic lake by wikimedia Commons)

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 3.3.2).



(a) (b)

Figure 3.3.2: Rivers range from (a) narrow and shallow to (b) wide and slow moving. (modification of work by Cory Zanker; credit b: modification of work by David DeHetre)

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.

Headwater streams are often clear because they are closer to their origin and fast moving, resulting in minimal siltation. Photosynthesis here is mostly attributed to algae that are growing on rocks; the swift current inhibits the growth of phytoplankton. While photosynthesis in the water may be partially blocked by overhead tree branches and leaves, those same leaves add energy to the stream. 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, some species of mayfly (phylum Arthropoda) have flattened bodies and legs with modified claws to help them cling to the underside of submerged rocks. This body form reduces drag and allows these species to benefit from the high oxygen concentrations in fast-moving currents without being dislodged. Freshwater trout species are an important predator in these fast-moving 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. 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 and insects can be found burrowing into the mud. Predatory vertebrates 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 freshwater and saltwater 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 they are shallower. Because of this, they 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 3.3.3).



Figure 3.3.3: Located in southern Florida, Everglades National Park is vast array of wetland environments, including sawgrass marshes, cypress swamps, and estuarine mangrove forests. Here, a great egret walks among cypress trees. (credit: NPS)

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.

Estuaries

Estuaries are biomes that occur where a river, a source of freshwater, meets the ocean. Therefore, both freshwater and saltwater 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 the adaptations of the organisms 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 3.3.4).



Figure 3.3.4: As estuary is where fresh water and salt water meet, such as the mouth of the Klamath River in California. (credit: U.S. Army Corps of Engineers)

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 salt water spray and salt water 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 behavioral 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.

Marine Systems

The ocean is a continuous body of saltwater that is relatively uniform in chemical composition. It is a weak solution of mineral salts and decayed biological matter. The ocean is categorized by several zones (Figure 3.3.5). 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 or 650 ft). At depths greater than 200 m, light cannot penetrate; thus, this is referred to as the aphotic zone. The ocean is, on average, 4267 m or 14,000 ft deep. Thus, the majority of the ocean is aphotic and lacks sufficient light for photosynthesis.

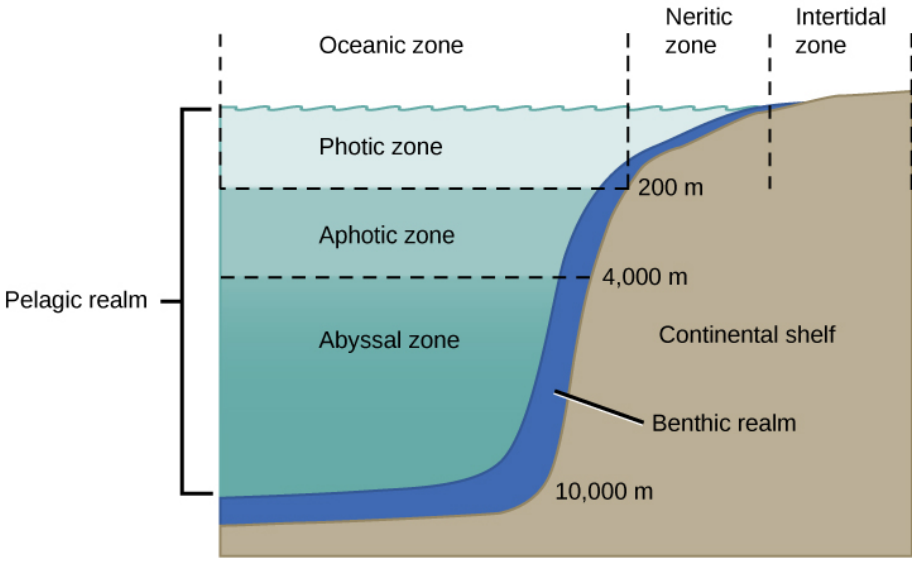


Figure 3.3.5: The ocean is divided into different zones based on water depth, distance from the shoreline, and light penetration. (CC BY; Open Stax)

Intertidal Zone

The **intertidal zone** (Figure 3.3.5) is the oceanic region that is 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 (Figure 3.3.6). 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. Thus in sandy or mud bottom intertidal communities many organisms burrow into the substrate.



Figure 3.3.6: Sea stars, sea urchins, and mussel shells are often found in the intertidal zone, shown here in Kachemak Bay, Alaska. (credit: NOAA)

Neritic Zone

The **neritic zone** is the relatively shallow part of the ocean above the drop-off of the continental shelf, approximately 200 meters (660 ft) in depth. From the point of view of marine biology it forms a relatively stable and well-illuminated environment for marine life, from plankton up to large fish and corals, while physical oceanography sees it as where the oceanic system interacts with the

coast. 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.

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. Corals are adapted to warm clear waters. The Great Barrier Reef is a well-known, and largest reef system in the world, 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 animals (related to jelly fish and sea anemones) secrete a calcium carbonate skeleton. These calcium-rich skeletons slowly accumulate, thus forming the underwater reef (Figure 3.3.7. Corals found in shallower waters (at a depth of approximately 60 m or about 200 ft) have a mutualistic relationship with photosynthetic algae. 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 algae; these corals must obtain their energy exclusively by feeding on plankton using stinging cells on their tentacles.

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.



Figure 3.3.7: Coral reefs are formed by the calcium carbonate skeletons of coral organisms, which are marine invertebrates in the phylum Cnidaria. (credit: Terry Hughes)

Kelp Forests

Kelp forests are underwater areas with a high density of kelp, which covers a large part of the world's coastlines. They are recognized as one of the most productive and dynamic ecosystems on Earth (Figure 3.3.8). Although algal kelp forest combined with coral reefs only cover 0.1% of Earth's total surface, they account for 0.9% of global primary productivity. Kelp forests occur worldwide throughout temperate and polar coastal oceans.

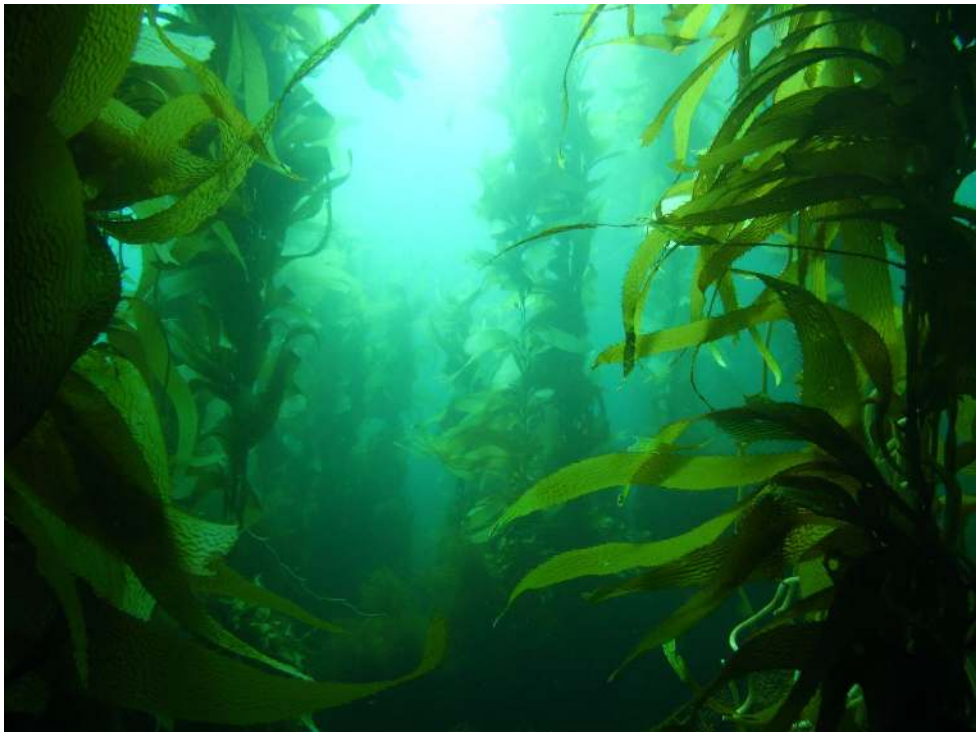


Figure 3.3.8: The kelp (a type of brown algae) of a kelp forest creates 3-dimensional structure and habitat for a diversity of fish, invertebrates, and mammals. (public domatin; Sara Kappus taken on Santa Catalina Island)

Kelp forests are mostly found in cool, shallow, nutrient-rich water near coasts. Kelp is a brown alga, which requires access to light in order to photosynthesize - this is the reason for their abundance in shallow coastal water, Kelp forests provide a unique habitat for marine organisms and are a source for understanding many ecological processes. Over the last century, they have been the focus of extensive research, particularly in trophic ecology, and continue to provoke important ideas that are relevant beyond this unique ecosystem. For example, kelp forests can influence coastal oceanographic patterns and provide many ecosystem services

Kelp forests often draw comparisons to terrestrial forests, however the two ecosystems are distinct in that kelp is an algae - not a member of the Plant Kingdom. The structure of all kelp bears three universal morphological characteristics: holdfasts, stipes, and fronds. The holdfasts, which serve as an anchor for kelp, must be attached to hard substrates such as rocks or sand. Although they resemble roots on terrestrial plants, holdfasts do not transport water or nutrients through their stipe. The stipe, analogous to the stem, gives structural support to the algae. Fronds are blades extending from the stipe. The blades serve as the photosynthetic and nutrient uptake center for the organism.

Kelp forests are an important foundation species, which provide large areas of habitat within the ocean. Kelp forests have a wide variety of inhabitants within their boundaries: invertebrates frequently graze on the blades, fish find shelter in the fronds, and invertebrates - such as brittle stars, sea stars, anemones, sponges and tunicates - live in the holdfast. Kelp is also the single largest source of fixed carbon within their ecosystems. Pieces of decomposing kelp sink deeper into the ocean, or wash up on beaches, providing nutrients organisms in other ecosystems. Thus, kelp derived particulate organic matter (POM) is an important food source for fauna both within and outside the kelp forest.

Since kelp is capable of attenuating waves and dampening their energy, many animals are able to seek refuge in the forests. Various species of kelp tolerate ocean storms differently. In fact, along the California coast giant kelp has been known to dominate in years with less turbulent sea conditions, while bull kelp is more dominant in open waters and years of turbulent conditions.

Oceanic zone

Photic Zone

Beyond the neritic zone is the open ocean area known as the oceanic zone, which is further divided into 3 layers based on sunlight availability (the photic zone, aphotic zone and abyssal zone) (Figure 3.3.5). Within the Photic zone there is sufficient light for net photosynthesis to occur. Abundant phytoplankton and zooplankton support populations of fish, sea birds, and marine mammals. Nutrients are scarce and this is a relatively less productive part of the marine biome when compared to the Neritic zone. When photosynthetic organisms and the organisms that feed on them die, their bodies fall to the bottom of the ocean and provide food for deep ocean scavengers.

Aphotic Zone

The depth at which less than one percent of sunlight reaches begins the aphotic zone. While most of the ocean's biomass lives in the photic zone, the majority of the ocean's water lies in the aphotic zone. Bioluminescence is more abundant than sunlight in this zone.

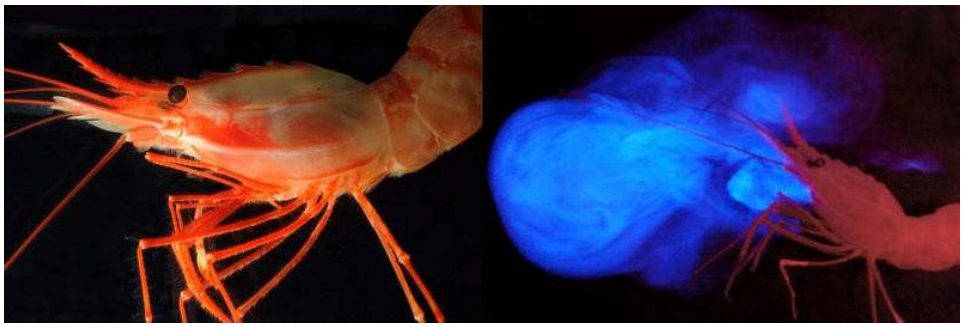


Figure 3.3.9: The deep-sea pandalid shrimp Heterocarpus ensifer and a photo of the same animal 'vomiting' light from glands located near its mouth.Photographed during the Bioluminescence and Vision 2015 expedition, as scientists sought to gain a better understanding of how and why organisms create their own light. (CC BY-SA; NOAA Ocean Explorer via Wikipedia Commons)

Abyssal zone

The deepest part of the ocean is the **abyssal zone**, which is at depths of 4000 m or greater. The abyssal zone (Figure 3.3.5) is very cold and has very high pressure, very low or no oxygen content, and high nutrient content as the dead and decomposing material that drifts down from the layers above. 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 sulfide and other minerals emitted from deep hydrothermal vents. These chemosynthetic bacteria use the hydrogen sulfide as an energy source and serve as the base of the food chain found around the vents.

Benthic Realm

Beneath the oceanic zone is the benthic realm, the deepwater region beyond the continental shelf (Figure 3.3.5). The bottom of the benthic realm is composed 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.

Attribution:

This page is a modified derivative of:

- 20.4 Aquatic and Marine Biomes by OpenStax CC BY
- Lake by Wikipedia, license CC-BY-SA 3.0
- Neritic Zone by Wikipedia, license CC-BY-SA 3.0
- Aphotic Zone Wikipedia, license CC-BY-SA 3.0
- Kelp Forests by Wikipedia, license CC-BY-SA 3.0
- Kelp Forest Ecosystems by LibraText, license CC BY-NC-SA 4.0

This page titled 3.3: Aquatic Biomes is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

CHAPTER OVERVIEW

4: Natural Selection and Evolution



Figure 4.1: The peppered moth exists in both light and dark colours in Great Britain, but during the industrial revolution, many of the trees on which the moths rested became blackened by soot, giving the dark-coloured moths an advantage in hiding from predators. This gave dark-coloured moths a better chance of surviving to produce dark-coloured offspring, and in just fifty years from the first dark moth being caught, nearly all of the moths in industrial Manchester were dark. The balance was reversed by the effect of the Clean Air Act 1956, and the dark moths became rare again, demonstrating the influence of natural selection on peppered moth evolution. A recent study, using image analysis and avian vision models, shows that pale individuals more closely match lichen backgrounds than dark morphs and for the first time quantifies the camouflage of moths to predation risk. (CC BY-SA 4.0; Martinowsky via Wikimedia)

Chapter Summary

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 through which the characteristics of species change and through which new species arise.

The theory of evolution is the unifying theory of biology, meaning it is the framework within which biologists ask questions about the living world. Its power is that it provides direction for predictions about living things that are borne out in experiment after experiment. The Ukrainian-born American geneticist Theodosius Dobzhansky famously wrote that “nothing makes sense in biology except in the light of evolution.” (Dobzhnsky, 1964).He meant that the principle that all life has evolved and diversified from a common ancestor is the foundation from which we understand all other questions in biology. This chapter will explain some of the mechanisms for evolutionary change and the kinds of questions that biologists can and have answered using evolutionary theory.

References

Theodosius Dobzhansky. “Biology, Molecular and Organismic.” *American Zoologist* 4, no. 4 (1964): 449.

Learning Objectives

After reading this chapter you should be able to:

- Describe the observations and evidence that lead Darwin and Wallace to form the theory of Natural Selection.
- Outline the process of Natural Selection emphasizing the importance of variation and heritability.
- Explain why natural selection depends on the environment.
- Diagram and describe the 3 different types of natural selection (directional, stabilizing, and disruptive).
- Provide examples of convergent and divergent evolution.

- Define species and describe how scientists identify species as different.
- Describe genetic variables that lead to speciation.
- Identify prezygotic and postzygotic reproductive barriers.
- Explain allopatric and sympatric speciation.
- Describe adaptive radiation.
- Explain sources of evidence for evolution
- Identify common misconceptions about evolution

4.1: Darwin, Wallace, and the Theory of Natural Selection
4.2: Evolution
4.3: Macroevolution and Speciation
4.4: Evidence of Evolution
4.5: Common Misconceptions about Evolution

This page titled 4: Natural Selection and Evolution is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

4.1: Darwin, Wallace, and the Theory of Natural Selection



Figure 4.1.1: HMS Beagle in the Galapagos by John Chancellor (artist) (CC BY-NC-SA 2.0; Karen E. James via Flickr)

The theory of evolution by natural selection describes a mechanism for species change over time. That species change had been suggested and debated well before Darwin. The view that species were unchanging was grounded in the writings of Plato, yet there were other ancient Greeks philosophers that expressed evolutionary ideas.

Definition: Natural Selection

The process by which living organisms adapt and change in nature. Natural selection results from differential survival and reproduction of individuals due to differences in heritable traits. It is a key mechanism of evolution and is the only process that results in the formation of adaptive traits and behaviors.

In the eighteenth century, ideas about the evolution of animals were reintroduced by the naturalist Georges-Louis Leclerc, Comte de Buffon and even by Charles Darwin's grandfather, Erasmus Darwin. During this time, it was accepted that there were extinct species. At the same time, **James Hutton**, the Scottish naturalist, proposed that geological change occurred gradually by the accumulation of small changes from processes (over long periods of time) just like those happening today. This contrasted with the predominant view that the geology of the planet was a consequence of catastrophic events occurring during a relatively brief past. Hutton's view was later popularized by the geologist **Charles Lyell** in the nineteenth century. Lyell became a friend to Darwin and his ideas were very influential on Darwin's thinking. Lyell argued that the greater age of Earth gave more time for gradual change in species, and the process provided an analogy for gradual change in species.

In the early nineteenth century, **Jean-Baptiste Lamarck** published a book that detailed a mechanism for evolutionary change that is now referred to as inheritance of acquired characteristics. 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, Lamarck's ideas were an important influence on evolutionary thought.

Charles Darwin and Alfred Wallace

The actual mechanism for evolution was independently conceived of and described by two naturalists, **Charles Darwin** and **Alfred Russell Wallace**, in the mid-nineteenth century. Importantly, each spent time exploring the natural world on expeditions to the tropics. From 1831 to 1836, Darwin traveled around the world on *H.M.S. Beagle*, visiting South America, Australia, and the southern tip of Africa (Figure 4.1.1). Wallace traveled to Brazil to collect insects in the Amazon rainforest from 1848 to 1852 and to the Malay Archipelago from 1854 to 1862. Darwin's journey, like Wallace's later journeys in the Malay Archipelago, included stops at several island chains, the last being the Galápagos Islands (west of Ecuador). On these islands, Darwin observed species of organisms on different islands that were clearly similar, yet had distinct differences. For example, the ground finches inhabiting the

Galápagos Islands comprised several species that each had a unique beak shape. He observed both that these finches closely resembled another finch species on the mainland of South America and that the group of species in the Galápagos formed a graded series of beak sizes and shapes, with very small differences between the most similar (Figure 4.1.2). Darwin imagined that the island species might be all species modified from one original mainland species. In 1860, he wrote, “Seeing this gradation and diversity of structure in one small, intimately related group of birds, one might really fancy that from an original paucity of birds in this archipelago, one species had been taken and modified for different ends." (Darwin, 1860).

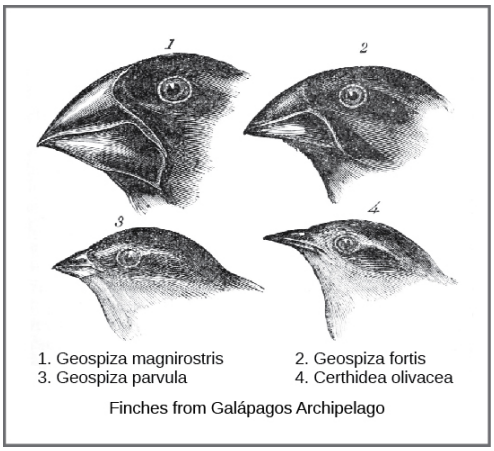


Figure 4.1.2: Darwin observed that beak shape varies among finch species. He postulated that the beak of an ancestral species had adapted over time to equip the finches to acquire different food sources. This illustration shows the beak shapes for four species of ground finch: 1. *Geospiza magnirostris* (the large ground finch), 2. *G. fortis* (the medium ground finch), 3. *G. parvula* (the small tree finch), and 4. *Certhidea olivacea* (the green-warbler finch). (CC 0; Open Stax Concepts in Biology)

? Concept Check 4.1.1

True or False: Darwin's most significant contribution to biology was proposing that species change over time (evolve).

Answer

False: By the time Darwin traveled the world it was already accepted by the scientific community that species had changed over Earth's history. What was not understood, was why this would happen in nature. Darwin's most significant contribution was proposing a mechanism, or process, for this change. His theory of natural selection is still today the most widely accepted, and supported, explanation of species change.

The Mechanism of Natural Selection

Wallace and Darwin both observed similar patterns in other organisms and independently conceived a mechanism to explain how and why such changes could take place. Darwin called this mechanism natural selection. **Natural selection**, Darwin argued, was an inevitable outcome of three principles that operated in nature:

- First, the characteristics of organisms are inherited, or passed from parent to offspring.
- Second, more offspring are produced than are able to survive; in other words, resources for survival and reproduction are limited. The capacity for reproduction in all organisms outstrips the availability of resources to support their numbers.
- Thus, there is a competition for those resources in each generation. Both Darwin and Wallace’s understanding of this principle came from reading an essay by the economist Thomas Malthus, who discussed this principle in relation to human populations. Third, offspring vary among each other in regard to their characteristics and those variations are inherited.

Out of these three principles, Darwin and Wallace 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 change in populations over generations in a process that Darwin called “descent with modification.”

Papers by Darwin and Wallace presenting the idea of natural selection were read together in 1858 before the Linnaean Society in London. The following year Darwin's book, *On the Origin of Species*, was published, which outlined in considerable detail his arguments for evolution by natural selection.



Figure 4.1.3: (a) Charles Darwin and (b) Alfred Wallace wrote scientific papers on natural selection that were presented together before the Linnean Society in 1858. (CC-0; OpenStax Concepts in Biology)

Variation and Adaptation

Natural selection can only take place if there is **variation**, or differences, among individuals in a population. Importantly, these differences must have some 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. The original source of the new gene variants that produce new heritable traits, such as fur colors, is random **mutation** (changes in DNA sequence).

A heritable trait (one that is genetically, rather than environmentally determined) that aids the survival and reproduction of an organism in its present environment is called an **adaptation**. An adaptation is a "match" of the organism to the environment. Adaptation to an environment comes about when a change in the range of genetic variation occurs over time that increases or maintains the match of the population with its environment.

Natural selection doesn't favor traits that are somehow inherently superior. Instead, it favors traits that are beneficial (that is, help an organism survive and reproduce more effectively than its peers) in a specific environment. Whether or not a trait is favorable depends on the environment at the time. Traits that are helpful in one environment might actually be harmful in another.

Modern Evidence of Natural Selection in Galapagos Finches

Demonstrations of evolution by natural selection can take years to study. One of the best lines of evidence has been in the very birds that helped to inspire the theory, the Galápagos finches. Peter and Rosemary Grant and their colleagues have studied Galápagos finch populations every year since 1976. The Grants found changes from one generation to the next in the beak shapes of the medium ground finches on the Galápagos island of Daphne Major. The medium ground finch feeds on seeds. The birds have inherited variation in the genes for bill shape. Some individuals have an allele (a variation of the gene for bill shape) that causes a wide, deep bill, and others have an allele for thinner bills. Large-billed birds feed more efficiently on large, hard seeds, whereas smaller billed birds feed more efficiently on small, soft seeds. During 1977, a drought period altered vegetation on the island. After this period, the number of seeds declined dramatically: the decline in small, soft seeds was greater than the decline in large, hard seeds. The large-billed birds were able to survive better than the small-billed birds the following year. When the Grants measured beak sizes in the much-reduced population the year after the drought, they found that the average bill size was larger. This was clear evidence for natural selection (differences in survival) of bill size caused by the availability of seeds. The Grants had studied the inheritance of bill sizes and knew that the surviving large-billed birds would tend to produce offspring with larger bills, so the selection would lead to evolution of bill size. Subsequent studies by the Grants have demonstrated selection on and evolution of bill size in this species in response to changing conditions on the island. The evolution has occurred both to larger bills, as in this case, and to smaller bills when large seeds became rare.

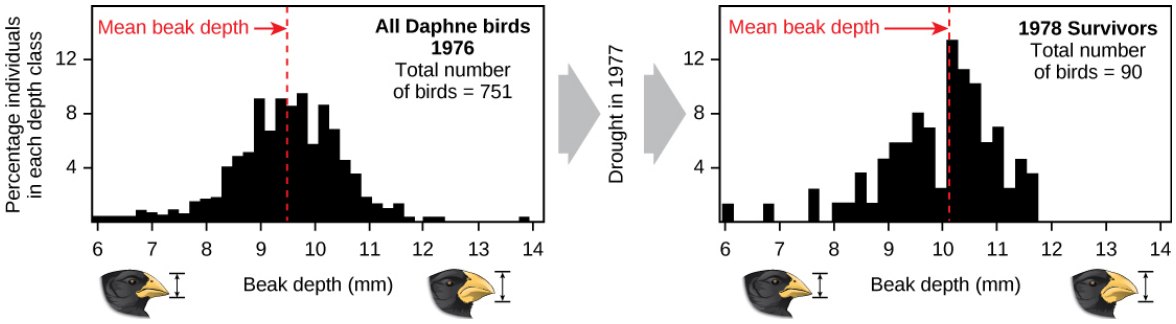


Figure 4.1.4: A drought on the Galápagos island of Daphne Major in 1977 reduced the number of small seeds available to finches, causing many of the small-beaked finches to die. This caused an increase in the average beak size of the medium ground finch between 1976 and 1978. (CC-0; OpenStax Concepts in Biology)

References

Darwin, Charles. 1860. *Journal of Researches into the Natural History and Geology of the Countries Visited during the Voyage of H.M.S. Beagle Round the World, under the Command of Capt. Fitz Roy, R.N*, 2nd. ed. (London: John Murray, 1860),

Attribution

This page is a modified derivative of:

- 11.1 Discovering How Population Change, Concepts of Biology (CC-BY; Open Stax)

This page titled 4.1: Darwin, Wallace, and the Theory of Natural Selection is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

4.2: Evolution

Evolution

Small changes caused by process such as natural selection can lead to evolution. Evolution describes the cumulative inherited change in a population of organisms through time leading to change in a lineage and/or the appearance of new forms or species. Small-scale changes (microevolution) drive huge events such as speciation (macroevolution).

Definition: Evolution

Evolution is a change in the genetic composition of a population over successive generations.

Microevolution (covered here in 4.2) is the change in allele frequencies that occurs over time within a population. This change is due to four different processes: natural selection, mutation, genetic drift, gene flow, and sexual selection. This change happens over a relatively short amount of time compared to the changes termed macroevolution.

Macroevolution (covered in section 4.3) usually means the evolution of large-scale structures and traits that go significantly beyond the intraspecific variation found in microevolution. In other words, macroevolution is the evolution of taxa above the species level.

Natural Selection

Natural selection is arguably the most important mechanism of evolution because it is the only mechanisms that leads to **adaptive** change. Natural selections acts to increase the frequency of the most adaptive traits (those that increase reproductive success), in a population for a given environment. Natural selection can also act to remove less fit traits from the population as organisms who carry such traits may not survive long enough to reproduce. Natural selection can take several forms including stabilizing, directional, and disruptive selection (Figure 4.2.2).

Definition: Adaptation

Adaptation, in biology, the process by which a species becomes fitted to its environment; it is the result of natural selection's acting upon heritable variation over several generations. Organisms are adapted to their environments in a great variety of ways: in their structure, physiology, and genetics, in their locomotion or dispersal, in their means of defense and attack, in their reproduction and development, and in other respects.

An **adaptive trait** is a genetic trait that helps an organism to maximize its reproductive success

Stabilizing Selection

If natural selection favors an average phenotype by selecting against extreme variation, the population will undergo **stabilizing selection**. For example, in a population of mice that live in the woods, natural selection will tend to favor individuals that best blend in with the forest floor and are less likely to be spotted by predators. Assuming the ground is a fairly consistent shade of brown, those mice whose fur is most-closely matched to that color will most probably survive and reproduce, passing on their genes for their brown coat. Mice that carry alleles that make them slightly lighter or slightly darker will stand out against the ground and will more probably die from predation. As a result of this stabilizing selection, the population's genetic variance will decrease.

Directional Selection

Directional selection occurs when a single phenotype is favored, causing the allele frequency to continuously shift in one direction. This may occur in response to a changing environmental condition (climate change for example) or in response to interactions with organism such as predator population that becomes faster and stronger over time to catch its prey. 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 predominately light in color, which allowed them to blend in with the light-colored trees and lichens in their environment. As soot began spewing from factories, the trees darkened and the light-colored moths became easier

for predatory birds to spot. Over time, the frequency of the melanic form of the moth increased because their darker coloration provided camouflage against the sooty tree; they had a higher survival rate in habitats affected by air pollution. Similarly, the hypothetical mouse population may evolve to take on a different coloration if their forest floor habitat changed. The result of this type of selection is a shift in the population's genetic variance toward the new, fit phenotype.

Disruptive Selection

Sometimes natural selection can select for two or more distinct phenotypes that each have their advantages. In these cases, the intermediate phenotypes are often less fit than their extreme counterparts.This type of selection often drives speciation. Known as diversifying or **disruptive selection**, this is seen in many populations of animals that have multiple male mating strategies, such as lobsters. 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 cannot overtake the alpha males and are too big to sneak copulations, are selected against.

Diversifying selection can also occur when environmental changes favor 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 favored, 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, thus, would more probably be eaten by predators. The result of this type of selection is increased genetic variance as the population becomes more diverse.

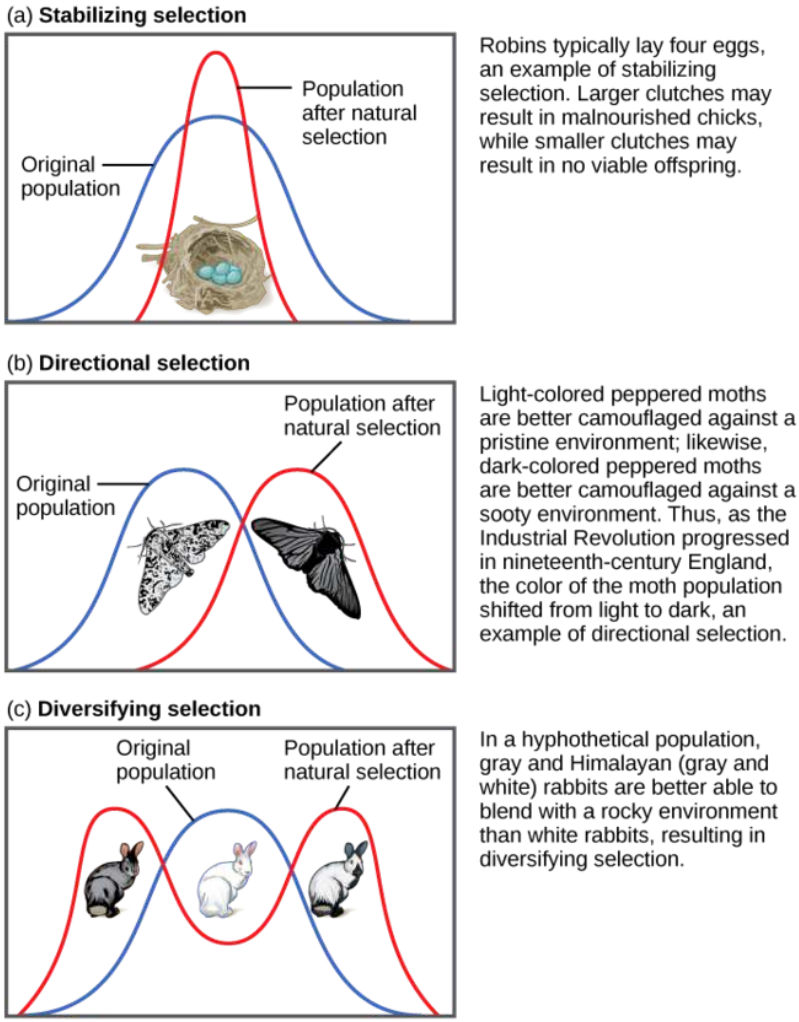


Figure 4.2.2: Types of natural selection: Different types of natural selection can impact the distribution of phenotypes within a population.In (a) stabilizing selection, an average phenotype is favored.In (b) directional selection, a change in the environment shifts the spectrum of phenotypes observed.In (c) diversifying selection, two or more extreme phenotypes are selected for, while the average phenotype is selected against.(CC BY-SA 4.0; via Boundless (now lumen learning))

Mutation

Genetic diversity in a population comes from two main sources: mutation and sexual reproduction. **Mutation**, a change in DNA, is the ultimate source of new alleles or new genetic variation in any population. An individual that has a mutated gene might have a different trait than other individuals in the population. However, this is not always the case. A mutation can have one of three outcomes on the organisms' appearance (or phenotype):

- A mutation may affect the phenotype of the organism in a way that gives it reduced fitness—lower likelihood of survival, resulting in fewer offspring.
- A mutation may produce a phenotype with a beneficial effect on fitness.
- Many mutations, called neutral mutations, will have no effect on fitness.

Mutations may also have a whole range of effect sizes on the fitness of the organism that expresses them in their phenotype, from a small effect to a great effect. Sexual reproduction and crossing over in meiosis also lead to genetic diversity: when two parents reproduce, unique combinations of alleles assemble to produce unique genotypes and, thus, phenotypes in each of the offspring.

A mutation can change one allele into another, but the net effect is a change in the frequency that the allele occurs in the population. The change in frequency resulting from mutation is small, so its effect on evolution is small unless it interacts with one of the other factors, such as selection. A mutation may produce an allele that is selected against, selected for, or selectively neutral. Harmful mutations are removed from the population by selection and will generally only be found in very low frequencies equal to the mutation rate. Beneficial mutations will spread through the population through selection, although that initial spread is slow. Whether or not a mutation is beneficial or harmful is determined by whether it helps an organism survive to sexual maturity and reproduce. It should be noted that mutation is the ultimate source of genetic variation in all populations—new alleles, and, therefore, new genetic variations arise through mutation.

Genetic Drift

Another way a population's allele frequencies can change is genetic drift (Figure 4.2.3), which is simply the effect of chance. Genetic drift is most important in small populations. Drift would be completely absent in a population with infinite individuals, but, of course, no population is this large. Genetic drift occurs because the alleles in an offspring generation are a random sample of the alleles in the parent generation. Alleles may or may not make it into the next generation due to chance events including mortality of an individual, events affecting finding a mate, and even the events affecting which gametes end up in fertilizations. If one individual in a population of ten individuals happens to die before it leaves any offspring to the next generation, all of its genes—a tenth of the population's gene pool—will be suddenly lost. In a population of 100, that 1 individual represents only 1 percent 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.

Imagine a population of ten individuals, half with allele *A* and half with allele *a* (the individuals are haploid). In a stable population, the next generation will also have ten individuals. Choose that generation randomly by flipping a coin ten times and let heads be *A* and tails be *a*. It is unlikely that the next generation will have exactly half of each allele. There might be six of one and four of the other, or some different set of frequencies. Thus, the allele frequencies have changed and evolution has occurred. A coin will no longer work to choose the next generation (because the odds are no longer one half for each allele). The frequency in each generation will drift up and down on what is known as a random walk until at one point either all *A* or all *a* are chosen and that allele is fixed from that point on. This could take a very long time for a large population. This simplification is not very biological, but it can be shown that real populations behave this way. The effect of drift on frequencies is greater the smaller a population is. Its effect is also greater on an allele with a frequency far from one half. Drift will influence every allele, even those that are being naturally selected.

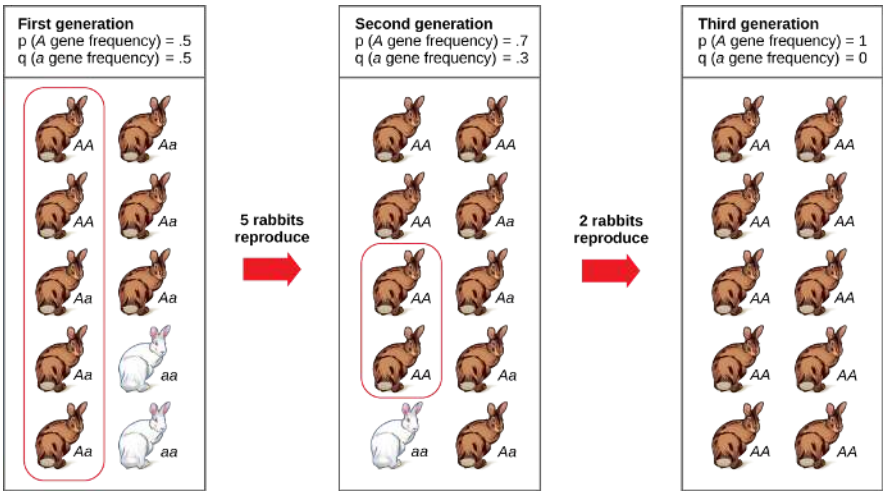


Figure 4.2.3: Genetic drift in a population can lead to the elimination of an allele from a population by chance. In each generation, a random set of individuals reproduces to produce the next generation. The frequency of alleles in the next generation is equal to the frequency of alleles among the individuals reproducing. (CC-BY; Open Stax)

Genetic drift can also be magnified by natural or human-caused events, such as a disaster that randomly kills a large portion of the population, which is known as the **bottleneck effect** that results in a large portion of the gene pool suddenly being wiped out (Figure 4.2.4). In one fell swoop, the genetic structure of the survivors becomes the genetic structure of the entire population, which may be very different from the pre-disaster population. The disaster must be one that kills for reasons unrelated to the organism's traits, such as a hurricane or lava flow. A mass killing caused by unusually cold temperatures at night, is likely to affect individuals differently depending on the alleles they possess that confer cold hardiness.

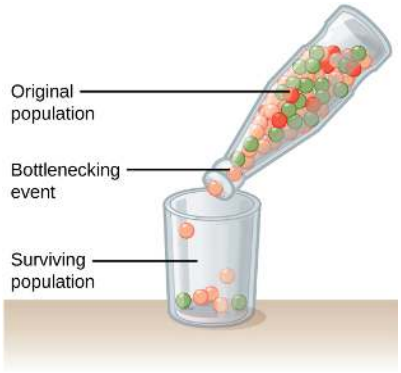


Figure 4.2.4: A chance event or catastrophe can reduce the genetic variability within a population. (CC-BY; via Open Stax)

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, or if a population gets divided by a physical barrier of some kind. In this situation, those individuals are unlikely to be representative of the entire population which results in the **founder effect**. The founder effect occurs when the genetic structure matches that of the new population's founding fathers and mothers. The founder effect is believed to have been a key factor in the genetic history of the Afrikaner population of Dutch settlers in South Africa, as evidenced by mutations that are common in Afrikaners but rare in most other populations. This is likely due to a higher-than-normal proportion of the founding colonists, which were a small sample of the original population, carried these mutations. As a result, the population expresses unusually high incidences of Huntington's disease (HD) and Fanconi anemia (FA), a genetic disorder known to cause bone marrow and congenital abnormalities, and even cancer.

Gene Flow

Another important evolutionary force is **gene flow**, or the flow of alleles in and out of a population resulting from the migration of individuals or gametes (Figure 4.2.5). While some populations are fairly stable, others experience more flux. Many plants, for example, send their seeds far and wide, by wind or in the guts of animals; these seeds may introduce alleles common in the source population to a new population in which they are rare.

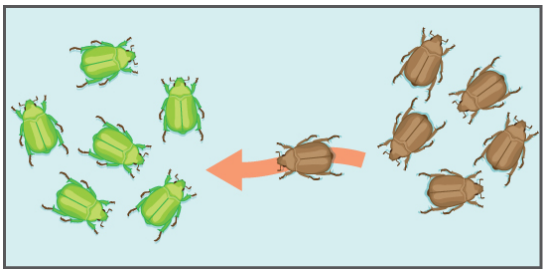


Figure 4.2.5: Gene flow can occur when an individual travels from one geographic location to another and joins a different population of the species. In the example shown here, the brown allele is introduced into the green population. (CC-BY; via Open Stax)

Sexual Selection

Darwin identified a special case of natural selection that he called **sexual selection**. Sexual selection affects an individual's ability to mate and thus produce offspring, and it leads to the evolution of dramatic traits that often appear maladaptive in terms of survival but persist because they give their owners greater reproductive success. Sexual selection occurs in two ways: through intrasexual selection, typically male-male competition for mates, and through intersexual selection, typically female mate choice. Male–male competition takes the form of conflicts between males, which are often ritualized, but may also pose significant threats to a male's survival. Sometimes the competition is for territory, with females more likely to mate with males with higher quality territories. Female choice occurs when females choose a male based on a particular trait, such as feather colors, the performance of a mating dance, or the building of an elaborate structure. In some cases male–male competition and female choice combine in the mating process. In each of these cases, the traits selected for, such as fighting ability or feather color and length, become enhanced in the males. In general, it is thought that sexual selection can proceed to a point at which natural selection against a character's further enhancement prevents its further evolution because it negatively impacts the male's ability to survive. For example, colorful feathers or an elaborate display make the male more obvious to predators. Sexual selection will be covered in more detail in the chapter on Animal Behavior.

Attribution

This page is a modified depreciative of:

- 11.2 Mechanisms of Evolution, License CC-BY via Open Stax
- 19.3B Stabilizing, Directional, and Diversifying Selection, license CC BY-SA 4.0 via Boundless (now LumenLearning)

This page titled 4.2: Evolution is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

4.3: Macroevolution and Speciation

Patterns of Evolution

The evolution of species has resulted in enormous variation in form and function. When two species evolve in different directions from a common point, it is called **divergent evolution**. Such divergent evolution can be seen in the forms of the reproductive organs of flowering plants, which share the same basic anatomies; however, they can look very different as a result of selection in different physical environments, and adaptation to different kinds of pollinators (Figure 4.3.1).



(a) (b)

Figure 4.3.1: Flowering plants evolved from a common ancestor. Notice that the (a) dense blazing star and (b) purple coneflower vary in appearance, yet both share a similar basic morphology. (credit a, b: modification of work by Cory Zanker, via open stax)

In other cases, similar phenotypes evolve independently in distantly related species. For example, flight has evolved in both bats and insects, and they both have structures we refer to as wings, which are adaptations to flight. The wings of bats and insects, however, evolved from very different original structures. When similar structures arise through evolution independently in different species it is called **convergent evolution**. The wings of bats and insects are called analogous structures; they are similar in function and appearance, but do not share an origin in a common ancestor. Instead they evolved independently in the two lineages. The wings of a hummingbird and an ostrich are homologous structures, meaning they share similarities (despite their differences resulting from evolutionary divergence). The wings of hummingbirds and ostriches did not evolve independently in the hummingbird lineage and the ostrich lineage—they descended from a common ancestor with wings.

What is a species and how do new species arise?

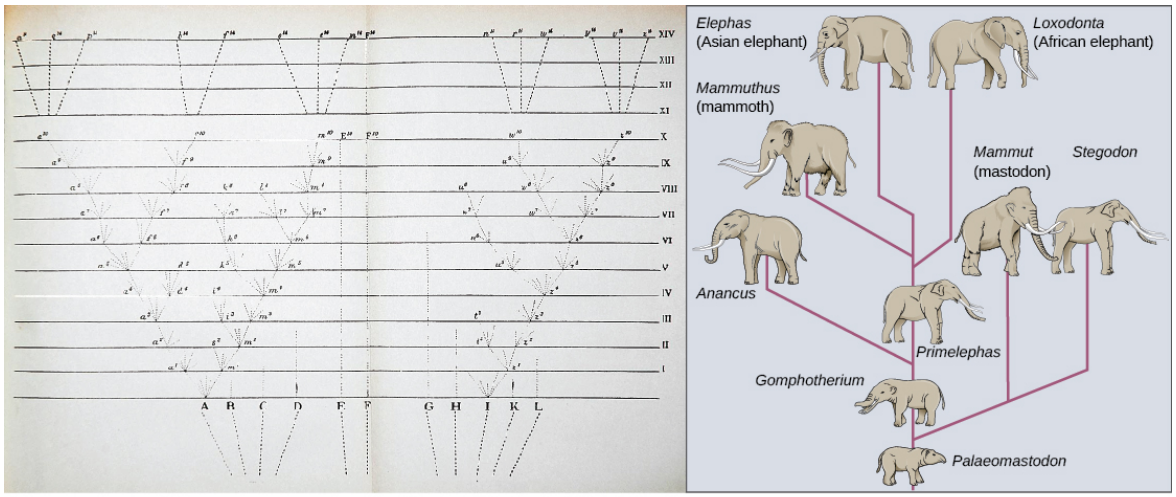
The **biological definition of species**, which works for sexually reproducing organisms, is a group of actually or potentially interbreeding individuals. According to this definition, one species is distinguished from another by the possibility of matings between individuals from each species to produce fertile offspring. There are exceptions to this rule. Many species are similar enough that hybrid offspring are possible and may often occur in nature, but for the majority of species this rule generally holds. In fact, the presence of hybrids between similar species suggests that they may have descended from a single interbreeding species and that the speciation process may not yet be completed.

Definition: Species

The biological species concept defines a species as members of populations that actually or potentially interbreed in nature and produce viable fertile offspring. Although appearance is helpful in identifying species, it does not define species.

Given the extraordinary diversity of life on the planet there must be mechanisms for **speciation**: the formation of two species from one original species. Darwin envisioned this process as a branching event and diagrammed the process in the only illustration found in *On the Origin of Species* (Figure 4.3.2a). For speciation to occur, two new populations must be formed 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. **Allopatric speciation**, meaning speciation in "other homelands," involves a geographic separation of populations from a parent species and subsequent evolution. **Sympatric speciation**, meaning speciation in the "same homeland," involves speciation occurring within a parent species while remaining in one location.

Biologists think of speciation events as the splitting of one ancestral species into two descendant species. There is no reason why there might not be more than two species formed at one time except that it is less likely and such multiple events can also be conceptualized as single splits occurring close in time.



(a) (b)

Figure 4.3.2: he 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 are drawn today to illustrate the relationships of species. (b) Modern elephants evolved from the *Palaeomastodon*, a species that lived in Egypt 35–50 million years ago. (CC-BY; via Open Stax)

Allopatric Speciation: Geographic Separation

A geographically continuous population has a gene pool that is relatively homogeneous (the same). **Gene flow**, the movement of alleles across the range of the species, is relatively free because individuals can move across their range and mate with other individuals. Thus, the frequency of an allele at one side of a distribution will be similar to the frequency of the allele at the other side. Populations can become geographically separated so that free-flow of alleles is prevented. When that separation lasts for a period of time, the two populations are able to evolve along different paths. Thus, their allele frequencies gradually become more and more different as new alleles independently arise by mutation in each population. When they become geographically isolated, it is likely that the environmental conditions, such as climate, resources, predators, and competitors, for the two populations will differ. With different sets of conditions working on an increasingly different set of alleles, natural selection will favor different adaptations in each group. Different histories of genetic drift, enhanced because the populations are smaller than the parent population, will also lead to divergence.

Given enough time, the genetic divergence between populations will likely affect characters that influence reproduction enough that, were individuals of the two populations brought together, mating would be less likely, or if a mating occurred, offspring would be non-viable or infertile. Many types of diverging characters may affect the reproductive isolation (inability to interbreed) of the two populations. These mechanisms of reproductive isolation can be divided into prezygotic mechanisms (those that operate before fertilization) and postzygotic mechanisms (those that operate after fertilization). Prezygotic mechanisms include traits that allow the individuals to find each other, such as the timing of mating, sensitivity to pheromones, or choice of mating sites. If individuals are able to encounter each other, character divergence may prevent courtship rituals from leading to a mating either because female preferences have changed or male behaviors have changed. Physiological changes may interfere with successful fertilization if mating is able to occur. Postzygotic mechanisms include genetic incompatibilities that prevent proper development of the offspring, or if the offspring live, they may be unable to produce viable gametes themselves as in the example of the mule, the infertile offspring of a female horse and a male donkey.

If the two isolated populations are brought back together and the hybrid offspring that formed from matings between individuals of the two populations have lower survivorship or reduced fertility, then selection will favor individuals that are able to discriminate between potential mates of their own population and the other population. This selection will enhance reproductive isolation.

Isolation of populations leading to allopatric speciation can occur in a variety of ways: from a river forming a new branch, erosion forming a new valley, or a group of organisms traveling to a new location without the ability to return, such as seeds floating over the ocean to an island. The nature of the geographic separation necessary to isolate populations depends entirely on the biology of the organism and its potential for dispersal. If two flying insect populations took up residence in separate nearby valleys, chances are that individuals from each population would fly back and forth, continuing gene flow. However, if two rodent populations became divided by the formation of a new lake, continued gene flow would be unlikely; therefore, speciation would be more likely.

Scientists have documented numerous cases of allopatric speciation taking place. For example, along the west coast of the United States, two separate subspecies of spotted owls exist. The northern spotted owl has genetic and phenotypic differences from its close relative, the Mexican spotted owl, which lives in the south (Figure 4.3.3). The cause of their initial separation is not clear, but it may have been caused by the glaciers of the ice age dividing an initial population into two.

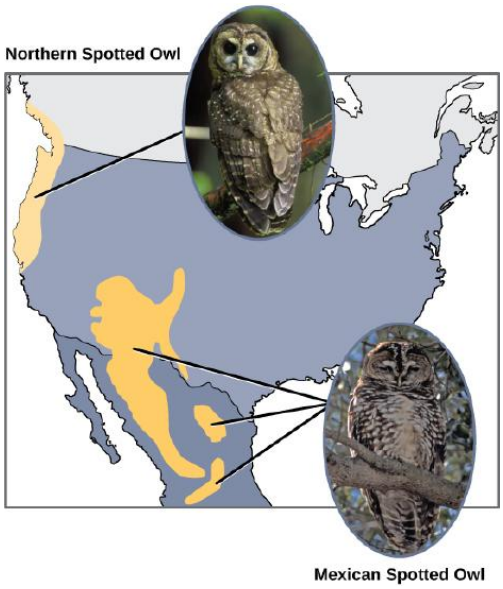


Figure 4.3.3: The northern spotted owl and the Mexican spotted owl inhabit geographically separate locations with different climates and ecosystems. The owl is an example of incipient speciation. (credit “northern spotted owl”: modification of work by John and Karen Hollingsworth, USFWS; credit “Mexican spotted owl”: modification of work by Bill Radke, USFWS)

Additionally, scientists have found that the further the distance between two groups that once were the same species, the more likely for speciation to take place. This seems logical because as the distance increases, the various environmental factors would likely have less in common than locations in close proximity. Consider the two owls; in the north, the climate is cooler than in the south; the other types of organisms in each ecosystem differ, as do their behaviors and habits; also, the hunting habits and prey choices of the owls in the south vary from the northern ones. These variances can lead to evolved differences in the owls, and over time speciation will likely occur unless gene flow between the populations is restored.

In some cases, a population of one species disperses throughout an area, and each finds a distinct niche or isolated habitat. Over time, the varied demands of their new lifestyles lead to multiple speciation events originating from a single species, which is called **adaptive radiation**. From one point of origin, many adaptations evolve causing the species to radiate into several new ones. Island archipelagos like the Hawaiian Islands provide an ideal context for adaptive radiation events because water surrounds each island, which leads to geographical isolation for many organisms. The Hawaiian honeycreeper illustrates one example of adaptive radiation. From a single species, called the founder species, numerous species have evolved, including the eight shown in (Figure 4.3.4).

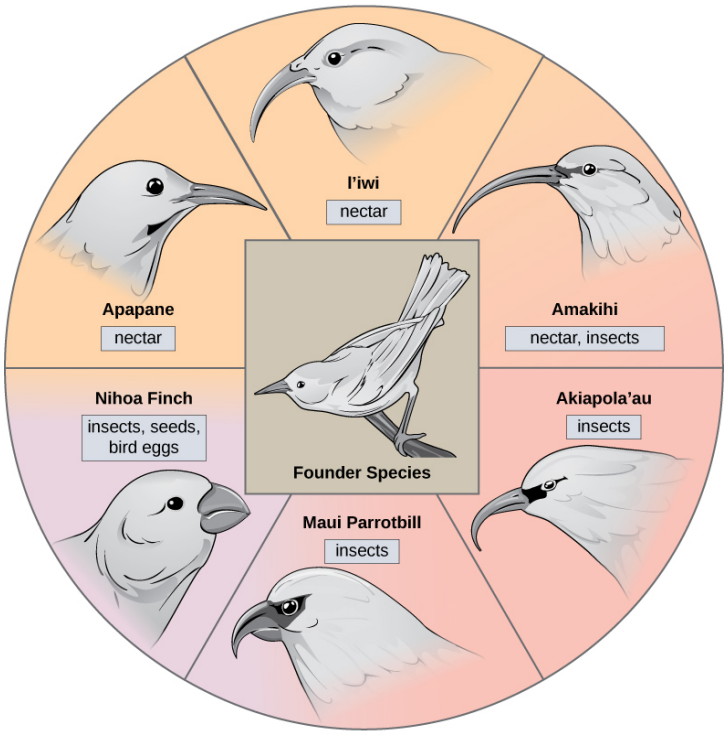


Figure 4.3.4: The honeycreeper birds illustrate adaptive radiation. From one original species of bird, multiple others evolved, each with its own distinctive characteristics.. (CC-BY; via OpenStax)

Notice the differences in the species' beaks in Figure 4.3.4) Change in the genetic variation for beaks in response to natural selection based on specific food sources in each new habitat led to evolution of a different beak suited to the specific food source. The fruit and seed-eating birds have thicker, stronger beaks which are suited to break hard nuts. The nectar-eating birds have long beaks to dip into flowers to reach their nectar. The insect-eating birds have beaks like swords, appropriate for stabbing and impaling insects. Darwin's finches are another well-studied example of adaptive radiation in an archipelago.

Sympatric Speciation: Without Geographic Separation

Can divergence occur if no physical barriers are in place to separate individuals who continue to live and reproduce in the same habitat? A number of mechanisms for **sympatric speciation** have been proposed and studied, and all of them include **reproductive isolation**.

Definition: Reproductive Isolation

Reproductive isolation are a collection of evolutionary mechanisms, behaviors and physiological processes critical for speciation. They prevent members of different populations from producing offspring, or reduce the fertility of hybrid offspring. These barriers maintain the integrity of a species by reducing gene flow between related species.

The mechanisms of reproductive isolation have been classified in two broad categories: **pre-zygotic** for those that act before fertilization (or before mating in the case of animals) and **post-zygotic** for those that act after it (Figure 4.3.5). The mechanisms are genetically controlled and can appear in species whose geographic distributions overlap (sympatric speciation) or are separate (allopatric speciation).

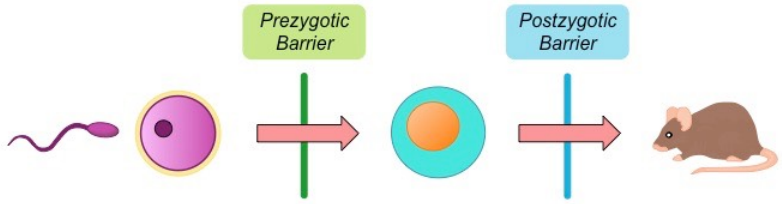


Figure 4.3.5: Prezygotic isolating mechanisms are those that occur before fertilization (before mating) and post-zygotic barriers are those that reduce the fitness of hybrids. (Public Domain; Cornell, B. via BioNinja)

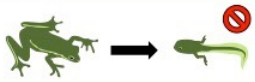
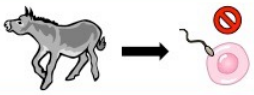
Pre-zygotic Isolating Mechanisms		Example	
Temporal	Occurs when two species mate at different times of year	Frogs live in same pond but breed during different seasons (summer vs spring)	
Ecological	Occurs when two species occupy different habitats	Lions and tigers can potentially interbreed, but usually occupy different habitats	
Behavioural	Occurs when two species have different courtship behaviours	Certain groups of birds will only respond to species-specific mating calls	
Mechanical	Occurs when physical differences prevent copulation / pollination	Certain breeds of dog are morphologically incapable of mating due to size	
Post-zygotic Isolating Mechanisms		**Examples**	
Hybrid Inviability	Hybrids are produced but fail to develop to reproductive maturity	Certain types of frogs form hybrid tadpoles that die before they can become a frog	
Hybrid Infertility	Hybrids fail to produce functional gametes (sterility)	Mules are sterile hybrids resulting from mating between a horse and a donkey	
Hybrid Breakdown	F_1 hybrids are fertile, but F_2 generation fails to develop properly	The offspring of hybrid copepods have less potential for survival or reproduction	

Figure 4.3.6: Pre-and post zygotic isolating mechanisms can work individually or in tandem to drive speciation. These mechanisms occur in both allopatric and sympatric speciation. (Cornell, B. via BioNinja)

Multiple mechanisms may drive speciation simultaneously

In general, the barriers that separate species do not consist of just one mechanism.The twin species of *Drosophila*, *D. pseudoobscura* and *D. persimilis*, are isolated from each other by habitat (*persimilis* generally lives in colder regions at higher altitudes), by the timing of the mating season (*persimilis* is generally more active in the morning and *pseuoobscura* at night) and by behavior during mating (the females of both species prefer the males of their respective species). In this way, although the distribution of these species overlaps in wide areas of the west of the United States of America, these isolation mechanisms are sufficient to keep the species separated.

Behavioral Isolation may play an important roles in sympatric speciation

Another example of sympatric speciation is that which has occurred in cichlid fish in Lake Victoria in Africa. Researchers have found hundreds of sympatric speciation events in these fish, which have not only happened in great numbers, but also over a short period of time. And now scientists are finding similar speciation events in progress among a cichlid fish population in Nicaragua (Figure 4.3.7). In this locale, two types of cichlids live in the same geographic location; however, they have come to have different morphologies that allow them to eat various food sources. Scientists believe these populations may be in an early stage of speciation. Researchers hypothesize that different morphologies specialize on different food sources which occur at different depths

of the lake. When foraging each fish is more likely to interact and mate with similar morphologies. 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.

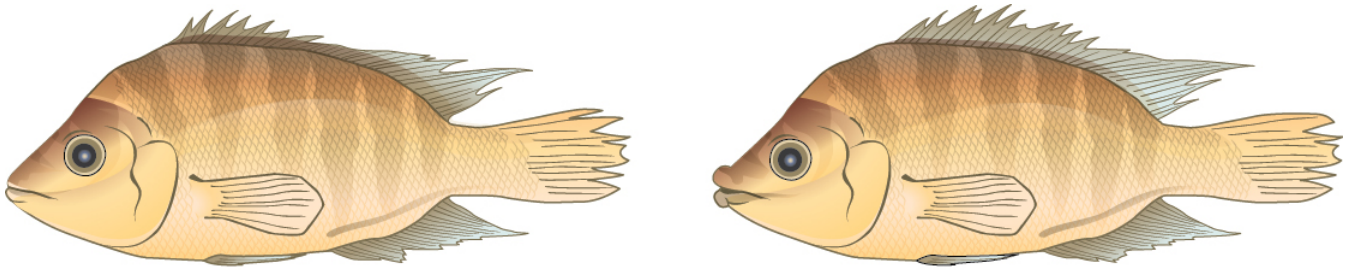


Figure 4.3.7: Cichlid fish from Lake Apoyeque, Nicaragua, show evidence of sympatric speciation. Lake Apoyeque, a crater lake, is 1800 years old, but genetic evidence indicates that the lake was populated only 100 years ago by a single population of cichlid fish. Nevertheless, two populations with distinct morphologies and diets now exist in the lake, and scientists believe these populations may be in an early stage of speciation. (CC-BY; via Open Stax)

A well-documented example of ongoing sympatric speciation occurred in the apple maggot fly, *Rhagoletis pomonella*, which arose as an isolated population sometime after the introduction of the apple into North America (Figure 4.3.8). The native population of flies fed on hawthorn species and is host-specific: it only infests hawthorn trees. Importantly, it also uses the trees as a location to meet for mating. It is hypothesized that either through mutation or a behavioral mistake, flies jumped hosts and met and mated in apple trees, subsequently laying their eggs in apple fruit. The offspring matured and kept their preference for the apple trees effectively dividing the original population into two new populations separated by host species, not by geography. The host jump took place in the nineteenth century, but there are now measurable differences between the two populations of fly. It seems likely that host specificity of parasites in general is a common cause of sympatric speciation.



Figure 4.3.8: Apple maggot fly. (CC-BY; Joseph Berger via insectimages.org.)

Attribution

This page is a modified derivative of:

- 11.1 Discovering How Populations Change, Concepts of Biology by OpenStax (licence CC-BY)
- 11.4 Speciation, Concepts of Biology by OpenStax (licence CC-BY)
- Reproductive Isolation by Wikipedia (licence CC-BY-SA 3.0

This page titled 4.3: Macroevolution and Speciation is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

4.4: 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*, identifying patterns in nature that were consistent with evolution and since Darwin our understanding has become clearer and broader.

Fossils

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 4.4.1). 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 fossils tracks 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 teeth 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.

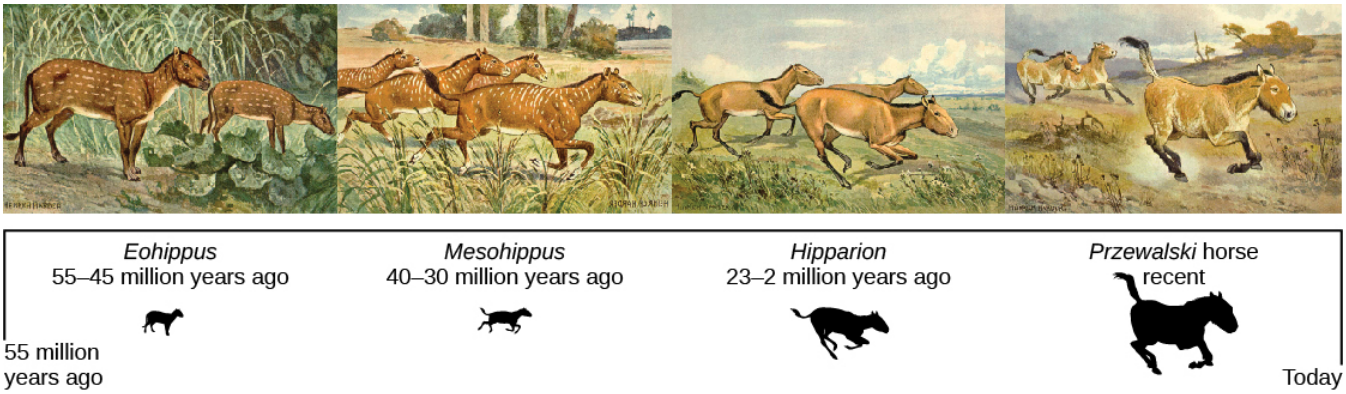


Figure 4.4.1**:** This illustration shows an artist's renderings of these species derived from fossils of the evolutionary history of the horse and its ancestors. The species depicted are only four from a very diverse lineage that contains many branches, dead ends, and adaptive radiations. One of the trends, depicted here is the evolutionary tracking of a drying climate and 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 a few living species of horse.

Anatomy and Embryology

Another type of evidence for evolution is the presence of structures in organisms that share the same basic form. For example, the bones in the appendages of a human, dog, bird, and whale all share the same overall construction (Figure 4.4.2). That similarity results from their origin in the appendages of a common ancestor. Over time, evolution led to changes in the shapes and sizes of these bones in different species, but they have maintained the same overall layout, evidence of descent from a common ancestor. Scientists call these synonymous parts homologous structures. Some structures exist in organisms that have no apparent function at all, and appear to be residual parts from a past ancestor. For example, some snakes have pelvic bones despite having no legs because they descended from reptiles that did have legs. These unused structures without function are called vestigial structures. Other examples of vestigial structures are wings on flightless birds (which may have other functions), leaves on some cacti, traces of pelvic bones in whales, and the sightless eyes of cave animals.

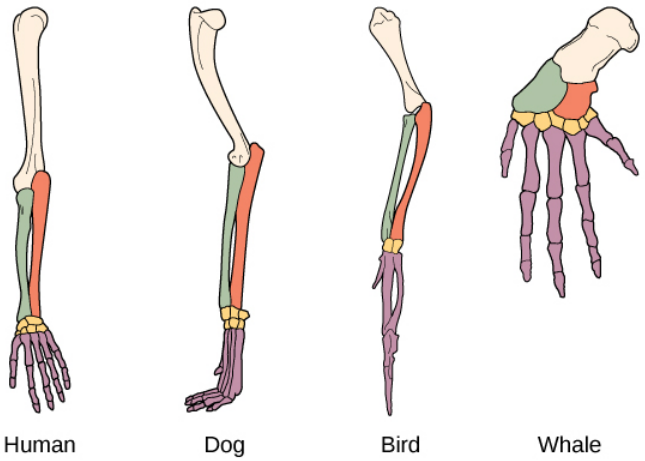


Figure 4.4.2**:** The similar construction of these appendages indicates that these organisms share a common ancestor.

Another evidence of evolution is the convergence of form in organisms that share similar environments. For example, species of unrelated animals, such as the arctic fox and ptarmigan (a bird), living in the arctic region have temporary white coverings during winter to blend with the snow and ice (Figure 4.4.3). The similarity occurs not because of common ancestry, indeed one covering is of fur and the other of feathers, but because of similar selection pressures—the benefits of not being seen by predators.



Figure 4.4.3**:** The white winter coat of (a) the arctic fox and (b) the ptarmigan's plumage are adaptations to their environments. (credit a: modification of work by Keith Morehouse)

Embryology, the study of the development of the anatomy of an organism to its adult form also provides evidence of relatedness between now widely divergent groups of organisms. Structures that are absent in some groups often appear in their embryonic forms and disappear by the time the adult or juvenile form is reached. For example, all vertebrate embryos, including humans, exhibit gill slits at some point in their early development. These disappear in the adults of terrestrial groups, but are maintained in adult forms of aquatic groups such as fish and some amphibians. Great ape embryos, including humans, have a tail structure during their development that is lost by the time of birth. The reason embryos of unrelated species are often similar is that mutational changes that affect the organism during embryonic development can cause amplified differences in the adult, even while the embryonic similarities are preserved.

Biogeography

The geographic distribution of organisms on the planet follows patterns that are best explained by evolution in conjunction with the movement of tectonic plates over geological time. Broad groups that evolved before the breakup of the supercontinent Pangaea

(about 200 million years ago) are distributed worldwide. Groups that evolved since the breakup appear uniquely in regions of the planet, for example the unique flora and fauna of northern continents that formed from the supercontinent Laurasia and of the southern continents that formed from the supercontinent Gondwana. The presence of Proteaceae in Australia, southern Africa, and South America is best explained by the plant family's presence there prior to the southern supercontinent Gondwana breaking up (Figure 4.4.4).

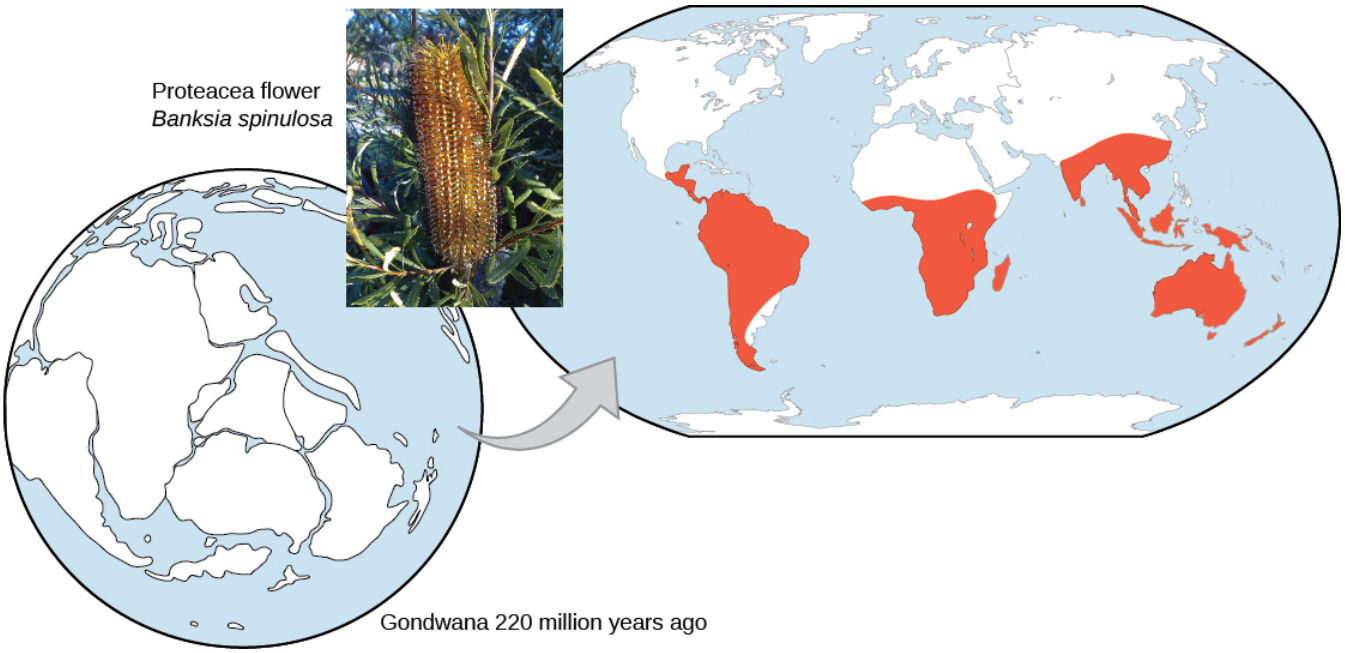


Figure 4.4.4**:** The Proteacea family of plants evolved before the supercontinent Gondwana broke up. Today, members of this plant family are found throughout the southern hemisphere (shown in red). (credit "Proteacea flower": modification of work by "dorofofoto"/Flickr)

The great diversification of the marsupials in Australia and the absence of other mammals reflects that island continent's long isolation. Australia has an abundance of endemic species—species found nowhere else—which is typical of islands whose isolation by expanses of water prevents migration of species to other regions. Over time, these species diverge evolutionarily into new species that look very different from their ancestors that may exist on the mainland. The marsupials of Australia, the finches on the Galápagos, and many species on the Hawaiian Islands are all found nowhere else but on their island, yet display distant relationships to ancestral species on mainlands.

Molecular Biology

Like anatomical structures, the structures of the molecules of life reflect descent with modification. Evidence of a common ancestor for all of life is reflected in the universality of DNA as the genetic material and of the near universality of the genetic code and the machinery of DNA replication and expression. Fundamental divisions in life between the three domains are reflected in major structural differences in otherwise conservative structures such as the components of ribosomes and the structures of membranes. In general, the relatedness of groups of organisms is reflected in the similarity of their DNA sequences—exactly the pattern that would be expected from descent and diversification from a common ancestor.

DNA sequences have also shed light on some of the mechanisms of evolution. For example, it is clear that the evolution of new functions for proteins commonly occurs after gene duplication events. These duplications are a kind of mutation in which an entire gene is added as an extra copy (or many copies) in the genome. These duplications allow the free modification of one copy by mutation, selection, and drift, while the second copy continues to produce a functional protein. This allows the original function for the protein to be kept, while evolutionary forces tweak the copy until it functions in a new way.

Section Summary

The evidence for evolution is found at all levels of organization in living things and in the extinct species we know about through fossils. Fossils provide evidence for the evolutionary change through now extinct forms that led to modern species. For example,

there is a rich fossil record that shows the evolutionary transitions from horse ancestors to modern horses that document intermediate forms and a gradual adaptation to changing ecosystems. The anatomy of species and the embryological development of that anatomy reveal common structures in divergent lineages that have been modified over time by evolution. The geographical distribution of living species reflects the origins of species in particular geographic locations and the history of continental movements. The structures of molecules, like anatomical structures, reflect the relationships of living species and match patterns of similarity expected from descent with modification.

Glossary

vestigial structure

a physical structure present in an organism but that has no apparent function and appears to be from a functional structure in a distant ancestor

Contributors and Attributions

- Samantha Fowler (Clayton State University), Rebecca Roush (Sandhills Community College), James Wise (Hampton University). Original content by OpenStax (CC BY 4.0; Access for free at https://cnx.org/contents/b3c1e1d2-83...4-e119a8aafbdd).

This page titled 4.4: Evidence of Evolution is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **11.3: Evidence of Evolution** by OpenStax is licensed CC BY 4.0.

4.5: Common Misconceptions about Evolution

Although the theory of evolution initially generated some controversy, by 20 years after the publication of *On the Origin of Species* it was almost universally accepted by biologists, particularly younger biologists. Nevertheless, the theory of evolution is a difficult concept and misconceptions about how it works abound. In addition, there are those that reject it as an explanation for the diversity of life.

CONCEPT IN ACTION

This website addresses some of the main misconceptions associated with the theory of evolution.

Evolution Is Just a Theory

Critics of the theory of evolution dismiss its importance by purposefully confounding the everyday usage of the word "theory" with the way scientists use the word. In science, a "theory" is understood to be a concept that has been extensively tested and supported over time. We have a theory of the atom, a theory of gravity, and the theory of relativity, each of which describes what scientists understand to be facts about the world. In the same way, the theory of evolution describes facts about the living world. As such, a theory in science has survived significant efforts to discredit it by scientists, who are naturally skeptical. While theories can sometimes be overturned or revised, this does not lessen their weight but simply reflects the constantly evolving state of scientific knowledge. In contrast, a "theory" in common vernacular means a guess or suggested explanation for something. This meaning is more akin to the concept of a "hypothesis" used by scientists, which is a tentative explanation for something that is proposed to either be supported or disproved. When critics of evolution say evolution is "just a theory," they are implying that there is little evidence supporting it and that it is still in the process of being rigorously tested. This is a mischaracterization. If this were the case, geneticist Theodosius Dobzhansky would not have said that "nothing in biology makes sense, except in the light of evolution."[1]

Individuals Evolve

An individual is born with the genes it has—these do not change as the individual ages. Therefore, an individual cannot evolve or adapt through natural selection. Evolution is the change in genetic composition of a population over time, specifically over generations, resulting from differential reproduction of individuals with certain alleles. Individuals do change over their lifetime, but this is called development; it involves changes programmed by the set of genes the individual acquired at birth in coordination with the individual's environment. When thinking about the evolution of a characteristic, it is probably best to think about the change of the average value of the characteristic in the population over time. For example, when natural selection leads to bill-size change in medium ground finches in the Galápagos, this does not mean that individual bills on the finches are changing. If one measures the average bill size among all individuals in the population at one time, and then measures the average bill size in the population several years later after there has been a strong selective pressure, this average value may be different as a result of evolution. Although some individuals may survive from the first time to the second, those individuals will still have the same bill size. However, there may be enough new individuals with different bill sizes to change the average bill size.

Evolution Explains the Origin of Life

It is a common misunderstanding that evolution includes an explanation of life's origins. Conversely, some of the theory's critics complain that it cannot explain the origin of life. The theory does not try to explain the origin of life. The theory of evolution explains how populations change over time and how life diversifies—the origin of species. It does not shed light on the beginnings of life including the origins of the first cells, which is how life is defined. The mechanisms of the origin of life on Earth are a particularly difficult problem because it occurred a very long time ago, over a very long time, and presumably just occurred once. Importantly, biologists believe that the presence of life on Earth precludes the possibility that the events that led to life on Earth can be repeated because the intermediate stages would immediately become food for existing living things. The early stages of life included the formation of organic molecules such as carbohydrates, amino acids, or nucleotides. If these were formed from inorganic precursors today, they would simply be broken down by living things. The early stages of life also probably included more complex aggregations of molecules into enclosed structures with an internal environment, a boundary layer of some form, and the external environment. Such structures, if they were formed now, would be quickly consumed or broken down by living organisms.

However, once a mechanism of inheritance was in place in the form of a molecule like DNA or RNA, either within a cell or within a pre-cell, these entities would be subject to the principle of natural selection. More effective reproducers would increase in frequency at the expense of inefficient reproducers. So while evolution does not explain the origin of life, it may have something to say about some of the processes operating once pre-living entities acquired certain properties.

Organisms Evolve on Purpose

Statements such as "organisms evolve in response to a change in an environment," are quite common. There are two easy misunderstandings possible with such a statement. First of all, the statement must not be understood to mean that individual organisms evolve, as was discussed above. The statement is shorthand for "a population evolves in response to a changing environment." However, a second misunderstanding may arise by interpreting the statement to mean that the evolution is somehow intentional. A changed environment results in some individuals in the population, those with particular phenotypes, benefiting and, therefore, producing proportionately more offspring than other phenotypes. This results in change in the population if the characters are genetically determined.

It is also important to understand that the variation that natural selection works on is already in a population and does not arise in response to an environmental change. For example, applying antibiotics to a population of bacteria will, over time, select for a population of bacteria that are resistant to antibiotics. The resistance, which is caused by a gene, did not arise by mutation because of the application of the antibiotic. The gene for resistance was already present in the gene pool of the bacteria, likely at a low frequency. The antibiotic, which kills the bacterial cells without the resistance gene, strongly selects for individuals that are resistant, since these would be the only ones that survived and divided. Experiments have demonstrated that mutations for antibiotic resistance do not arise as a result of antibiotic application.

In a larger sense, evolution is also not goal directed. Species do not become "better" over time; they simply track their changing environment with adaptations that maximize their reproduction in a particular environment at a particular time. Evolution has no goal of making faster, bigger, more complex, or even smarter species. This kind of language is common in popular literature. Certain organisms, ourselves included, are described as the "pinnacle" of evolution, or "perfected" by evolution. What characteristics evolve in a species are a function of the variation present and the environment, both of which are constantly changing in a non-directional way. What trait is fit in one environment at one time may well be fatal at some point in the future. This holds equally well for a species of insect as it does the human species.

Evolution Is Controversial among Scientists

The theory of evolution was controversial when it was first proposed in 1859, yet within 20 years virtually every working biologist had accepted evolution as the explanation for the diversity of life. The rate of acceptance was extraordinarily rapid, partly because Darwin had amassed an impressive body of evidence. The early controversies involved both scientific arguments against the theory and the arguments of religious leaders. It was the arguments of the biologists that were resolved after a short time, while the arguments of religious leaders have persisted to this day.

The theory of evolution replaced the predominant theory at the time that species had all been specially created within relatively recent history. Despite the prevalence of this theory, it was becoming increasingly clear to naturalists during the nineteenth century that it could no longer explain many observations of geology and the living world. The persuasiveness of the theory of evolution to these naturalists lay in its ability to explain these phenomena, and it continues to hold extraordinary explanatory power to this day. Its continued rejection by some religious leaders results from its replacement of special creation, a tenet of their religious belief. These leaders cannot accept the replacement of special creation by a mechanistic process that excludes the actions of a deity as an explanation for the diversity of life including the origins of the human species. It should be noted, however, that most of the major denominations in the United States have statements supporting the acceptance of evidence for evolution as compatible with their theologies.

The nature of the arguments against evolution by religious leaders has evolved over time. One current argument is that the theory is still controversial among biologists. This claim is simply not true. The number of working scientists who reject the theory of evolution, or question its validity and say so, is small. A Pew Research poll in 2009 found that 97 percent of the 2500 scientists polled believe species evolve.[2] The support for the theory is reflected in signed statements from many scientific societies such as the American Association for the Advancement of Science, which includes working scientists as members. Many of the scientists

that reject or question the theory of evolution are non-biologists, such as engineers, physicians, and chemists. There are no experimental results or research programs that contradict the theory. There are no papers published in peer-reviewed scientific journals that appear to refute the theory. The latter observation might be considered a consequence of suppression of dissent, but it must be remembered that scientists are skeptics and that there is a long history of published reports that challenged scientific orthodoxy in unpopular ways. Examples include the endosymbiotic theory of eukaryotic origins, the theory of group selection, the microbial cause of stomach ulcers, the asteroid-impact theory of the Cretaceous extinction, and the theory of plate tectonics. Research with evidence and ideas with scientific merit are considered by the scientific community. Research that does not meet these standards is rejected.

Other Theories Should Be Taught

A common argument from some religious leaders is that alternative theories to evolution should be taught in public schools. Critics of evolution use this strategy to create uncertainty about the validity of the theory without offering actual evidence. In fact, there are no viable alternative scientific theories to evolution. The last such theory, proposed by Lamarck in the nineteenth century, was replaced by the theory of natural selection. A single exception was a research program in the Soviet Union based on Lamarck's theory during the early twentieth century that set that country's agricultural research back decades. Special creation is not a viable alternative scientific theory because it is not a scientific theory, since it relies on an untestable explanation. Intelligent design, despite the claims of its proponents, is also not a scientific explanation. This is because intelligent design posits the existence of an unknown designer of living organisms and their systems. Whether the designer is unknown or supernatural, it is a cause that cannot be measured; therefore, it is not a scientific explanation. There are two reasons not to teach nonscientific theories. First, these explanations for the diversity of life lack scientific usefulness because they do not, and cannot, give rise to research programs that promote our understanding of the natural world. Experiments cannot test non-material explanations for natural phenomena. For this reason, teaching these explanations as science in public schools is not in the public interest. Second, in the United States, it is illegal to teach them as science because the U.S. Supreme Court and lower courts have ruled that the teaching of religious belief, such as special creation or intelligent design, violates the establishment clause of the First Amendment of the U.S. Constitution, which prohibits government sponsorship of a particular religion.

The theory of evolution and science in general is, by definition, silent on the existence or non-existence of the spiritual world. Science is only able to study and know the material world. Individual biologists have sometimes been vocal atheists, but it is equally true that there are many deeply religious biologists. Nothing in biology precludes the existence of a god, indeed biology as a science has nothing to say about it. The individual biologist is free to reconcile her or his personal and scientific knowledge as they see fit. The Voices for Evolution project (http://ncse.com/voices), developed through the National Center for Science Education, works to gather the diversity of perspectives on evolution to advocate it being taught in public schools.

Section Summary

The theory of evolution is a difficult concept and misconceptions abound. The factual nature of evolution is often challenged by wrongly associating the scientific meaning of a theory with the vernacular meaning. Evolution is sometimes mistakenly interpreted to mean that individuals evolve, when in fact only populations can evolve as their gene frequencies change over time. Evolution is often assumed to explain the origin of life, which it does not speak to. It is often spoken in goal-directed terms by which organisms change through intention, and selection operates on mutations present in a population that have not arisen in response to a particular environmental stress. Evolution is often characterized as being controversial among scientists; however, it is accepted by the vast majority of working scientists. Critics of evolution often argue that alternative theories to evolution should be taught in public schools; however, there are no viable alternative scientific theories to evolution. The alternative religious beliefs should not be taught as science because it cannot be proven, and in the United States it is unconstitutional. Science is silent on the question of the existence of a god while scientists are able to reconcile religious belief and scientific knowledge.

Footnotes

1. 1 Theodosius Dobzhansky. "Biology, Molecular and Organismic." *American Zoologist* 4, no. 4 (1964): 449.
2. 2 Pew Research Center for the People & the Press, *Public Praises Science; Scientists Fault Public, Media* (Washington, DC, 2009), 37.Contributors

Contributors and Attributions

- Samantha Fowler (Clayton State University), Rebecca Roush (Sandhills Community College), James Wise (Hampton University). Original content by OpenStax (CC BY 4.0; Access for free at https://cnx.org/contents/b3c1e1d2-83...4-e119a8aafbdd).

This page titled 4.5: Common Misconceptions about Evolution is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **11.5: Common Misconceptions about Evolution** by OpenStax is licensed CC BY 4.0.

CHAPTER OVERVIEW

5: Adaptations to the Environment



Figure 5.1: Galapagos Marine Iguana (*amblyrhynchus cristatus*). (CC-BY 2.0; Vince Smith via Flickr)

Chapter Summary

For each species, there is a set of environmental conditions within which it can best survive and reproduce. It is under these conditions that the species is best adapted. The abiotic variables most influential in determining a species adaptations are temperature, and water, and the acquisition of nutrients and energy. Temperature affects the physiology of living things and limits their distributions. There are few organisms on Earth that can survive below 0 °C (32 °F) or above 45 °C (113 °F) due to metabolic constraints. While some organisms adapt to extremes in temperatures, others are able to tolerate fluctuations in temperature, and finally, others have evolved physiological mechanisms for maintaining a stable internal temperature despite fluctuations in their surroundings. Water is required by all living things on earth and organisms must balance water acquisition with water loss to maintain a stable internal environment. Additionally, many strategies exist of acquiring energy and nutrients. The principle of allocation describes the tradefoff that exists when organisms adapt to certain sets of environmental conditions, they often loose fitness in other environmental conditions.

Learning Objectives

After reading this chapter you should be able to:

- Describe how the distribution of organisms is determined by their tolerance to environmental variables.
- Explain the concept of homeostasis.
- Describe thermoregulation of endothermic and ectothermic animals.
- Define osmoregulation and describe this process in animals and plants.
- Describe metabolic pathways that release or store energy.
- List elements required by living organisms.
- Provide examples of evolutionary trade-offs with regards to the acquisition of nutrients and energy.

5.1: Tolerance Ranges of Species
5.2: Temperature, Water, and other Factors
5.3: Homeostasis and Regulation
5.4: Energy and Nutrients
5.5: Principle of Allocation and Evolutionary Trade-offs

This page titled 5: Adaptations to the Environment is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

5.1: Tolerance Ranges of Species

Tolerance Ranges of Species

Each species within a community exploits the environment and interacts with other species in a particular manner. Ecologists use the word **niche** to describe the role of a species in its community, which can also be viewed as its "occupation" or livelihood. Some niches are relatively narrow and specialized, as is the niche of bats that feed only on flying insects of a certain size, or wasps that pollinate only one or a few species of plants. Other niches, however, are much broader, such as those of bears and humans, both of which forage over an extremely broad range and affect their ecosystem in diverse ways.

The **fundamental niche** is determined by the range of a species' tolerance of environmental conditions. Many different physical, abiotic (non- living) factors influence where species live, including temperature, humidity, soil chemistry, pH, salinity and oxygen levels. For each species, there is a set of environmental conditions within which it can best survive and reproduce. It is under these conditions that the species is best adapted.

Ecologists are interested in studying and understanding tolerance ranges of different species for different environments. If you draw a graph of how many individuals in a population live under which part of the range of any given factor, you almost always get a bell-shaped curve. For example, consider a species of fish living in the ocean (Figure 5.1.1).

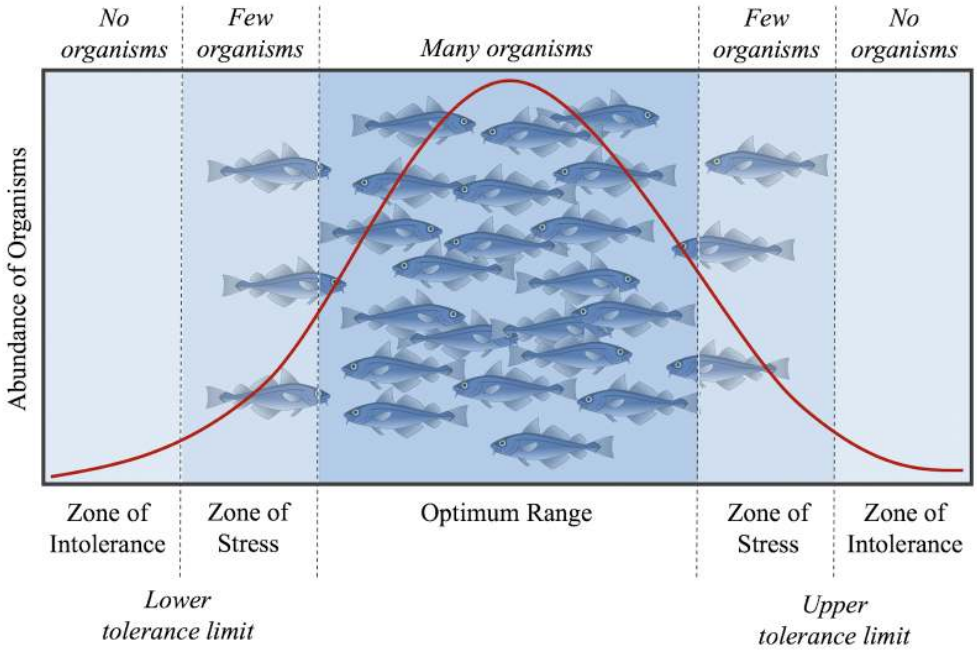


Figure 5.1.1: How tolerance ranges relate to organism abundance. (CC-BY-NC-SA 3.0; Gerhart-Barley via libretext)

This species has certain physiological tolerances in temperature, salinity, etc, that determine where the species can exist. Each of the abiotic factors has an optimum range, where the species will be abundant. Outside of this optimum range (both above and below it), are zones of stress, where the species can survive, but experiences physiological stress and will be less common than in the optimum range. Beyond the zones of stress, are zones of intolerance, which represent conditions the species cannot tolerate and in which it will not be found.

Each and every species is able to exist and reproduce successfully only within a definite range of environmental conditions. If a habitat is unsuitable, then a particular species will not be able to use it even if it is capable of dispersing to the site. Take for example the sugar maple, a species of flowering plant native to the hardwood forests of eastern Canada and eastern United States. The Sugar maple cannot tolerate average monthly high temperatures above 24–27 °C or winter temperatures below −18 °C. The western limit is determined by dryness, and this coincides with the western limits of forest vegetation in general (Figure 5.1.2).

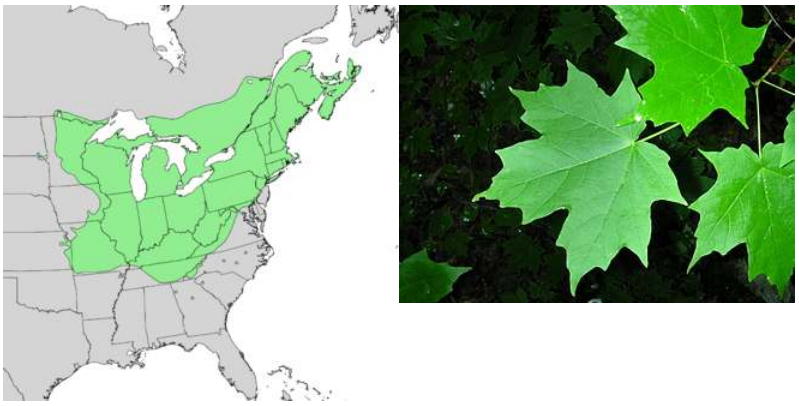


Figure 5.1.2: The distribution (left) of Sugar malple (leaves pictured right) is largely influenced by temperature and precipitation. (Left: Public Domain; Elbert L. Little, Jr. via Wikimedia - Right: CC-BY-2.0; Superior National Forest via Wikimedia)

The tolerance ranges for all relevant abiotic conditions represent the species fundamental niche (Figure 5.1.3). However, species interactions (such as predation, parasitism, mutualisms, etc) may result in a species not being found throughout its entire fundamental niche. For example, if this fish's prey species do not occur in some areas of the fundamental niche, then this fish species may not occur there even though it could physiologically tolerate these conditions. The realized niche reflects the range of environmental conditions that a species actually manages to exploit in nature. The realized niche is smaller than the fundamental niche because all species are to some degree constrained by biological interactions such as competition, predation, and disease.

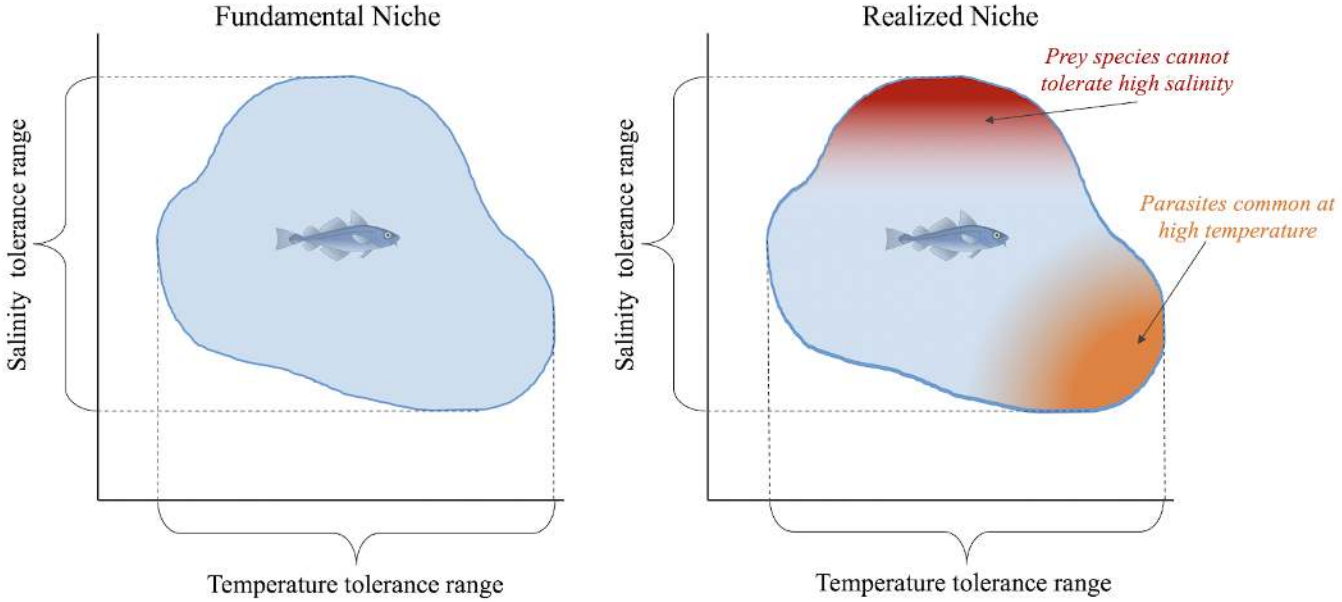


Figure 5.1.3: The relationship between the fundamental niche (based on abiotic tolerance limits) and the realized niche (based on species interactions) for a fictional fish species. (CC BY-SA 3.0; Gerhart-Barley via libretext)

The preferences and needs for certain types of conditions greatly influence the distribution of species around the planet, and it can get fairly complex when you consider that multiple abiotic and biotic factors are simultaneously influencing any given individual and species.

Attribution

This page is a modified derivative of:

- Shelford's law of tolerance by Wikipedia, license CC BY-SA 3.0
- Acer saccharum by Wikipedia, license CC BY-SA 3.0
- Ch 9 - Ecology: From Individuals to the Biosphere by Open Library, license CC-BY-NC 4.0
-

References:

Godman, Richard M.; Yawney, Harry W.; Tubbs, Carl H. (1990). "Acer saccharum". In Burns, Russell M.; Honkala, Barbara H. (eds.). Hardwoods. Silvics of North America. Washington, D.C.: United States Forest Service (USFS), United States Department of Agriculture (USDA). Vol. 2 – via Southern Research Station.

This page titled 5.1: Tolerance Ranges of Species is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

5.2: Temperature, Water, and other Factors

Temperature

Temperature affects the physiology of living things as well as the density and state of water. It exerts an important influence on living organisms because few can survive at temperatures below 0 °C (32 °F) due to metabolic constraints. It is also rare for them to survive at temperatures exceeding 45 °C (113 °F). This is a reflection of evolutionary response to typical temperatures.

Temperature can limit the distribution of living things. Enzymes are most efficient within a narrow and specific range of temperatures; enzyme degradation can occur at higher temperatures. Therefore, organisms must either maintain an internal temperature or inhabit an environment that will keep the body within a temperature range that supports metabolism. Some animals have adapted to enable their bodies to survive significant temperature fluctuations, as seen in hibernation or reptilian torpor. Similarly, some bacteria have adapted to survive in extremely-hot temperatures found in places such as geysers. Such bacteria are examples of extremophiles: organisms that thrive in extreme environments.

For instance, organisms that live in cold climates, such as the polar bear (Figure 5.2.1), have adaptations that help them withstand low temperatures and conserve body heat. Structures that aid in this type of insulation include fur, feathers, blubber, and fat. In hot climates, organisms have adaptations (such as perspiration in humans or panting in dogs) that help them to shed excess body heat.



Figure 5.2.1: Polar bears (*Ursus maritimus*) and other mammals living in ice-covered regions maintain their body temperature by generating heat and reducing heat loss through thick fur and a dense layer of fat under their skin. (credit: “longhorndave”/Flickr)

Animals faced with temperature fluctuations may respond with adaptations, such as migration, in order to survive. Migration, the movement from one place to another, is common in animals, including many that inhabit seasonally-cold climates. Migration solves problems related to temperature, locating food, and finding a mate. In migration, for instance, the arctic tern (*Sterna paradisaea*) makes a 40,000 km (24,000 mi) round trip flight each year between its feeding grounds in the southern hemisphere and its breeding grounds in the Arctic Ocean (Figure 5.2.2). Monarch butterflies (*Danaus plexippus*) live in the eastern United States in the warmer months, but migrate to Mexico and the southern United States in the wintertime. Some species of mammals also make migratory forays: reindeer (*Rangifer tarandus*) travel about 5,000 km (3,100 mi) each year to find food. Amphibians and reptiles are more limited in their distribution because they lack migratory ability. Not all animals that can migrate do so, as migration carries risk and comes at a high energy cost.



Figure 5.2.2: Arctic tern: The arctic tern is an example of a species that must migrate yearly to deal with temperature fluctuations that exist in the regions where it is found. (CC BY; OpenStax)

Some animals hibernate or estivate to survive hostile temperatures. Hibernation enables animals to survive cold conditions, while estivation allows animals to survive the hostile conditions of a hot, dry climate. Animals that hibernate or estivate enter a state known as torpor, a condition in which their metabolic rate is significantly lowered. This enables the animal to wait until its environment better supports its survival. Some amphibians, such as the wood frog (*Rana sylvatica*), have an antifreeze-like chemical in their cells, which retains the cells' integrity and prevents them from bursting.



Figure 5.2.3: Wood frog: The wood frog, like all other amphibians and reptiles, cannot migrate; as a result, the species survives extreme temperature changes through the antifreeze-like chemical found in their cells. (CC BY; OpenStax)

Water

Water is required by all living things because it is critical for cellular processes. Plants require water for photosynthesis. Most of the water molecules taken up by a plant's roots move up the stem into the leaves, out the stomata in the leaves, and then evaporate into the atmosphere. Evapotranspiration (often just called transpiration) refers to the movement of water in the plant from root to stem to leaf and out through the stomata to the atmosphere. This isn't just a dribble of water. An acre of corn will transpire about 3,000–4,000 gallons of water each day, and a large oak tree can transpire 40,000 gallons each year.

Similarly animals lose water through their skin and lungs (evaporation), and in the feces and urine. These losses must be made up by water in food and drink and from the water that is a by-product of chemical reactions. If the animal does not manage to

compensate for water loss the dissolved substances in the blood may become so concentrated they become lethal.

The rate of water loss by a plant or animal is influenced by temperature, humidity and wind. As temperatures rise, water evaporates out of the living organisms more readily. On hot summer days, the leaves of plants thus have a tendency to wilt due to lack of water in the soil and to the increased rate of transpiration. When the air around an organism is dryer there is greater evaporation losses than if the air around the organisms is saturated with water. Finally, aA breeze will clear water vapor away from the surface of an organism, leaving the humidity on the surface low and increasing the rate of evaporation and/or transpiration.

Since terrestrial organisms lose water to the environment by simple diffusion, they have evolved many adaptations to retain water. Plants have a number of interesting features on their leaves, such as leaf hairs and a waxy cuticle, that serve to decrease the rate of water loss via transpiration.

Some desert animals, like the camel, have developed a great tolerance for dehydration. Smaller animals are more able to avoid extremes of temperature or dry conditions by resting in sheltered, more humid situations during the day and being active only at night. The kangaroo rat is able to survive without access to any drinking water at all because it does not sweat and produces extremely concentrated urine. Water from its food and from chemical processes is sufficient to supply all its requirements.

Inorganic Nutrients and Soil

Inorganic nutrients, such as nitrogen and phosphorus, are important in the distribution and the abundance of living things. Plants obtain these inorganic nutrients from the soil when water moves into the plant through the roots. Therefore, soil structure (particle size of soil components), soil pH, and soil nutrient content play an important role in the distribution of plants. Animals obtain inorganic nutrients from the food they consume. Therefore, animal distributions are related to the distribution of what they eat. In some cases, animals will follow their food resource as it moves through the environment.

Attribution

This page is a modified derivative of:

-
- 1.2 Themes and Concepts of Biology by Open Stax Licence CC-BY
- 44.2 Biogeography by Open Stax Licence CC-BY
-
-

This page titled 5.2: Temperature, Water, and other Factors is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

5.3: Homeostasis and Regulation

Homeostasis refers to the relatively stable state inside the body of an animal. Animal organs and organ systems constantly adjust to internal and external changes in order to maintain this steady state. Examples of internal conditions maintained homeostatically are the level of blood glucose, body temperature, blood calcium level. These conditions remain stable because of physiologic processes that result in negative feedback relationships. If the blood glucose or calcium rises, this sends a signal to organs responsible for lowering blood glucose or calcium. The signals that restore the normal levels are examples of negative feedback. When homeostatic mechanisms fail, the results can be unfavorable for the animal. Homeostatic mechanisms keep the body in dynamic equilibrium by constantly adjusting to the changes that the body's systems encounter. Even an animal that is apparently inactive is maintaining this homeostatic equilibrium. Two examples of factors that are regulated homeostatically are temperature and water content. The processes that maintain homeostasis of these two factors are called **thermoregulation** and **osmoregulation**.

Homeostasis

The goal of homeostasis is the maintenance of equilibrium around a specific value of some aspect of the body or its cells called a set point. While there are normal fluctuations from the set point, the body's systems will usually attempt to go back to this point. A change in the internal or external environment is called a stimulus and is detected by a receptor; the response of the system is to adjust the activities of the system so the value moves back toward the set point. For instance, if the body becomes too warm, adjustments are made to cool the animal. If glucose levels in the blood rise after a meal, adjustments are made to lower them and to get the nutrient into tissues that need it or to store it for later use.

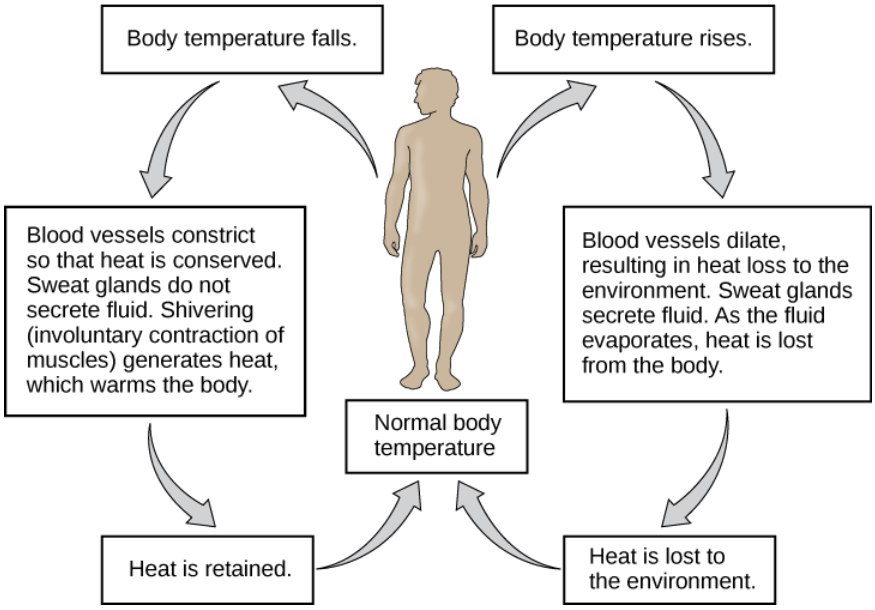


Figure 5.3.1: The body is able to regulate temperature in response to signals from the nervous system. (CC-BY; Open Stax)

When a change occurs in an animal's environment, an adjustment must be made so that the internal environment of the body and cells remains stable. The receptor that senses the change in the environment is part of a feedback mechanism. The stimulus—temperature, glucose, or calcium levels—is detected by the receptor. The receptor sends information to a control center, often the brain, which relays appropriate signals to an effector organ that is able to cause an appropriate change, either up or down, depending on the information the sensor was sending.

Set Point

Changes can be made in a group of body organ systems in order to maintain a set point in another system. This is called **acclimatization**. This occurs, for instance, when an animal migrates to a higher altitude than it is accustomed to. In order to adjust to the lower oxygen levels at the new altitude, the body increases the number of red blood cells circulating in the blood to ensure adequate oxygen delivery to the tissues. Another example of acclimatization is animals that have seasonal changes in their coats: a

heavier coat in the winter ensures adequate heat retention, and a light coat in summer assists in keeping body temperature from rising to harmful levels.

Thermoregulation

Animals can be divided into two groups: those that maintain a constant body temperature in the face of differing environmental temperatures, and those that have a body temperature that is the same as their environment and thus varies with the environmental temperature. Animals that do not have internal control of their body temperature are called **ectotherms**. The body temperature of these organisms is generally similar to the temperature of the environment, although the individual organisms may do things that keep their bodies slightly below or above the environmental temperature. This can include burrowing underground on a hot day or resting in the sunlight on a cold day. The ectotherms have been called cold-blooded, a term that may not apply to an animal in the desert with a very warm body temperature.

An animal that maintains a constant body temperature in the face of environmental changes is called an **endotherm**. These animals are able to maintain a level of activity that an ectothermic animal cannot because they generate internal heat that keeps their cellular processes operating optimally even when the environment is cold.

Animals conserve or dissipate heat in a variety of ways. Endothermic animals have some form of insulation, such as fur, fat, or feathers. Animals with thick fur or feathers create an insulating layer of air between their skin and internal organs. Polar bears and seals live and swim in a subfreezing environment and yet maintain a constant, warm, body temperature. The arctic fox, for example, uses its fluffy tail as extra insulation when it curls up to sleep in cold weather. Mammals can increase body heat production by shivering, which is an involuntary increase in muscle activity. In addition, arrector pili muscles can contract causing individual hairs to stand up when the individual is cold. This increases the insulating effect of the hair. Humans retain this reaction, which does not have the intended effect on our relatively hairless bodies; it causes “goose bumps” instead. Mammals use layers of fat as insulation also. Loss of significant amounts of body fat will compromise an individual’s ability to conserve heat.

Both ectotherms and endotherms use their circulatory systems to help maintain body temperature. Vasodilation, the opening up of arteries to the skin by relaxation of their smooth muscles, brings more blood and heat to the body surface, facilitating radiation and evaporative heat loss, cooling the body. Vasoconstriction, the narrowing of blood vessels to the skin by contraction of their smooth muscles, reduces blood flow in peripheral blood vessels, forcing blood toward the core and vital organs, conserving heat. Some animals have adaptations to their circulatory system that enable them to transfer heat from arteries to veins that are flowing next to each other, warming blood returning to the heart. This is called a countercurrent heat exchange; it prevents the cold venous blood from cooling the heart and other internal organs. The countercurrent adaptation is found in dolphins, sharks, bony fish, bees, and hummingbirds.

Some ectothermic animals use changes in their behavior to help regulate body temperature. They simply seek cooler areas during the hottest part of the day in the desert to keep from getting too warm. The same animals may climb onto rocks in the evening to capture heat on a cold desert night before entering their burrows.

Osmoregulation

Osmoregulation is the active regulation of the osmotic pressure of an organism's body fluids, to maintain the homeostasis of the organism's water content; that is, it maintains the fluid balance and the concentration of electrolytes (salts in solution which in this case is represented by body fluid) to keep the body fluids from becoming too diluted or concentrated.

Although there may be hourly and daily variations in osmotic balance, organisms are generally in an osmotic steady state over the long term. Organisms in aquatic and terrestrial environments must maintain the right concentration of solutes and amount of water in their body fluids; this involves excretion (getting rid of metabolic nitrogen wastes and other substances such as hormones that would be toxic if allowed to accumulate in the blood) through organs such as the skin and the kidneys.

Osmoregulation in Animals

Two major types of osmoregulation are osmoconformers and osmoregulators. **Osmoconformers** match their body osmolarity to their environment actively or passively. Most marine invertebrates are osmoconformers, although their ionic composition may be different from that of seawater. In a strictly osmoregulating animal, the amounts of internal salt and water are held relatively

constant in the face of environmental changes. It requires that intake and outflow of water and salts be equal over an extended period of time.

Organisms that maintain an internal osmolarity different from the medium in which they are immersed have been termed **osmoregulators**. They tightly regulate their body osmolarity, maintaining constant internal conditions. They are more common in the animal kingdom. Osmoregulators actively control salt concentrations despite the salt concentrations in the environment.

Even aquatic organisms need to maintain a balance of body fluids. Freshwater organisms, for example, are surrounded by water and constantly in danger of having water move into their cells because of osmosis. Osmosis describes the spontaneous passage or diffusion of water or other solvents through a semipermeable membrane such as a cell membrane. Many adaptations of organisms living in freshwater environments have evolved to ensure that solute concentrations in their bodies remain within appropriate levels. One such adaptation is the excretion of dilute urine. Marine organisms are surrounded by water with a higher solute concentration than the organism and, thus, are in danger of losing water to the environment because of osmosis. These organisms have morphological and physiological adaptations to retain water and release solutes into the environment. For example, marine iguanas (*Amblyrhynchus cristatus*) sneeze out water vapor that is high in salt in order to maintain solute concentrations within an acceptable range while swimming in the ocean and eating marine plants.

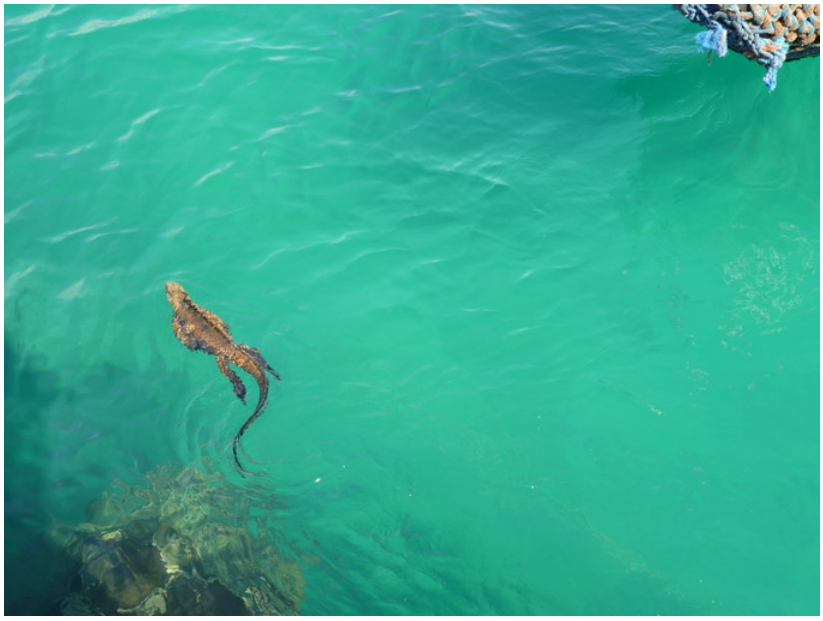


Figure 5.3.2: Marine iguanas: Marine iguanas have a special, salt-secretion adaptation that allows them to minimize bodily water loss. (CC-BY; Open Stax)

Most fish are stenohaline, which means they are restricted to either salt or fresh water and cannot survive in water with a different salt concentration than they are adapted to. However, some fish show an ability to effectively osmoregulate across a broad range of salinities; fish with this ability are known as euryhaline species, e.g., flounder. Flounder have been observed to inhabit two disparate environments—marine and fresh water—and it is inherent to adapt to both by bringing in behavioral and physiological modifications.

Some marine fish, like sharks, have adopted a different, efficient mechanism to conserve water, i.e., osmoregulation. They retain urea in their blood in relatively higher concentration. Urea damages living tissues so, to cope with this problem, some fish retain trimethylamine oxide. This provides a better solution to urea's toxicity. Sharks, having slightly higher solute concentration (i.e., above 1000 mOsm which is sea solute concentration), do not drink water like freshwater fish.

Osmoregulation in Plants

While there are no specific osmoregulatory organs in higher plants, the stomata are important in regulating water loss through evapotranspiration, and on the cellular level the vacuole is crucial in regulating the concentration of solutes in the cytoplasm. Strong winds, low humidity and high temperatures all increase evapotranspiration from leaves. Abscisic acid is an important

hormone in helping plants to conserve water—it causes stomata to close and stimulates root growth so that more water can be absorbed.

Plants share with animals the problems of obtaining water but, unlike in animals, the loss of water in plants is crucial to create a driving force to move nutrients from the soil to tissues. Certain plants have evolved methods of water conservation.

Attribution

This page is a modified derivative of:

- Osmoregulation by Wikipedia license
- 33.3 Homeostasis by Open Stax license CC-BY 4.0
- 16.1 Homeostasis and Osmoregulation by Open Stax license CC-BY 4.0
- 44.2 Biogeography by Open Stax Licence CC-BY

This page titled 5.3: Homeostasis and Regulation is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

5.4: Energy and Nutrients

All organisms require energy and nutrients. **Nutrients** are the raw materials an organism must acquire from the environment to live. Biological molecules, those that are found in or produced by living organisms, are primarily made of carbon atoms bonded with other elements and/or other carbon atoms. **Energy** is used to power life's processes and is derived from light, organic molecules or inorganic molecules. All living organisms need, at a minimum, a source of carbon for the synthesis of biological molecules, and a source of energy.

It is sometimes useful to classify organisms according to how they acquire energy and carbon. Organisms that use inorganic sources of both carbon and energy are called **autotrophs**. Because autotrophs produce their own food, they are sometimes called producers. Plants and algae are examples of producers because they use sunlight energy to produce carbohydrates in a process called photosynthesis. **Heterotrophs** are consumers that use organic molecules as a source of both carbon and energy. Animals are examples of consumers because they consume organic material by eating plants or other organisms. They then use a process called cellular respiration to extract energy from the food they eat.

Energy

Ultimately, the source of energy for many processes occurring on the earth's surface comes from solar radiation. But there are many exceptions to this rule as biology has been very clever at tapping a variety of forms of energy to construct and maintain living beings.

Scientists use the term bioenergetics to describe the concept of energy flow (Figure 5.4.1) through living systems. Cellular processes such as the building and breaking down of complex molecules occur through stepwise chemical reactions. Some of these chemical reactions are spontaneous and release energy, whereas others require energy to proceed. Just as living things must continually consume food to replenish their energy supplies, cells must continually obtain more energy to replenish that used by the many energy-requiring chemical reactions that constantly take place. Together, all of the chemical reactions that take place inside cells, including those that consume or generate energy, are referred to as the cell's metabolism.

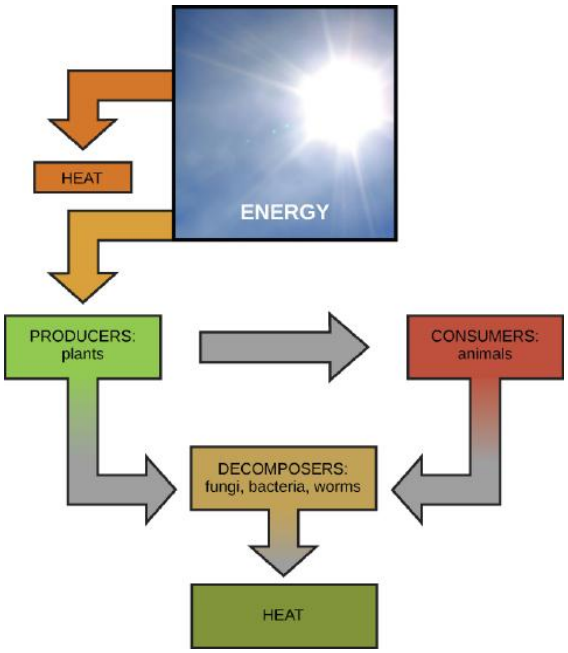


Figure 5.4.1: Ultimately, most life forms get their energy from the sun. Plants use photosynthesis to capture sunlight, and herbivores eat the plants to obtain energy. Carnivores eat the herbivores, and eventual decomposition of plant and animal material contributes to the nutrient pool. (Copyright; author via open stax)

Producers capture energy from the sun

Plants, algae, and many types of bacteria are able to capture energy from the sun through a process known as photosynthesis. During photosynthesis, plants use energy (originally from sunlight) to convert carbon dioxide gas (CO_2) into sugar molecules (like

glucose: C6H12O6). They consume carbon dioxide and produce oxygen as a waste product. This reaction is summarized as:

$6CO_2+6H_2O \rightarrow C_6H_{12}O_6+6O_2$

Sugar molecules have a great deal of energy stored within their bonds and many living things consume sugars as a major energy source. Most plants store the sugar molecules they produce in the form of starches or cellulose. Many animals consume plants to extract the energy stored in these molecules. Because they act as an energy source for animals higher in the food web plants (and other photosynthetic organisms are known as producers.

Consumers utilize the energy captured by producers

The reaction that harvests the energy of a sugar molecule in cells requiring oxygen to survive can be summarized by the reverse reaction to photosynthesis. In this reaction, oxygen is consumed and carbon dioxide is released as a waste product. This process is also known as cellular respiration. All animals, including humans, use cellular respiration to extract energy from the food they eat. The reaction is summarized as:

$C_6H_{12}O_6+6O_2 \rightarrow 6CO_2+6H_2O$

Both of these reactions involve many steps. The processes of making and breaking down sugar molecules illustrate two examples of metabolic pathways. A metabolic pathway is a series of chemical reactions that takes a starting molecule and modifies it, step-by-step, through a series of metabolic intermediates, eventually yielding a final product. This is a classic example of one of the many cellular processes that use and produce energy.

Nutrients

In order to grow, an organism has to acquire materials to make itself bigger. These materials are sometimes considered 'food' or may be described as nutrients. In this section we will consider what nutrients are required by organisms and how they are acquired. We have already considered three nutrients, carbon, hydrogen and oxygen that play a role in the energetics of organisms, but they also are important materially. Organisms are built of more than just these three and need others in order to grow. The acquisition of required materials (i.e., organismal nutrition) is something that distinguishes most of the organisms considered in this book from animals. Nutrition is highly significant, not just to the success (i.e., growth and reproduction) of organisms but also to ecology and to interactions with other organisms. The nutrition of organisms is strongly affected by their lifestyle, in particular, whether they are an autotroph or heterotroph, and also by their evolutionary history.

The elemental composition of organisms reflects their molecular composition. Typically around 98% of the mass of any organism is composed of four elements, C, H, O, and N. But other elements are present and many of these are 'essential' , i.e., the organism must have them in order to survive, grow and reproduce.

Carbon

For all autotrophic organisms carbon is acquired as carbon dioxide, either from the atmosphere or dissolved in water. For heterotrophic organisms, carbon is acquired in a variety of biomolecules: carbohydrates, proteins, lipids. The exact mix of compounds depends on the dietary preferences of the organism.

Hydrogen

For autotrophs, hydrogen is acquired in water molecules and occasionally in other compounds. For heterotrophs, hydrogen is acquired in water, carbohydrates, proteins and lipids.

Oxygen

Some abiotic factors, such as oxygen, are important in aquatic ecosystems as well as terrestrial environments. Terrestrial animals obtain oxygen from the air they breathe. Oxygen availability can be an issue for organisms living at very high elevations, however, where there are fewer molecules of oxygen in the air.

Oxygen plays two roles in organisms: a structural role, being a part of most biomolecules (carbohydrates, proteins, nucleic acids) and a dynamic role, being an essential reactant in cellular respiration that is subsequently lost as water. For autotrophs, oxygen for the structural role is acquired as carbon dioxide that is incorporated into carbohydrates and subsequently into other important biological molecules. For heterotrophs, structural oxygen is acquired in the food that they consume. For both autotrophs and

heterotrophs, oxygen for respiration is acquired as molecular oxygen (O_2) which, for terrestrial organisms, can be acquired directly from the atmosphere where it accounts for nearly 20% of the air's molecules. In aquatic systems, oxygen is obtained from the water where it usually is present as a dissolved solute.

In aquatic systems, the concentration of dissolved oxygen is related to water temperature and the speed at which the water moves. Cold water has more dissolved oxygen than warmer water. In addition, salinity, current, and tide can be important abiotic factors in aquatic ecosystems. Dissolved oxygen can also depend on biological activity. Photosynthetic organisms produce oxygen but this effect is limited to the region of the water column that receives light. Throughout the water column, oxygen is consumed by all aerobic organisms. How much the oxygen levels are lowered by this action depends on the amount of living things, their rate of oxygen consumption (this is a strong function of temperature), and the rate of oxygen delivery to the system.

Nitrogen

For heterotrophs, nitrogen is obtained from the food that they eat, primarily from proteins, but also from nucleic acids and nucleotides. Some fungi and bacteria can acquire nitrogen as nitrate (NO_3–) or ammonia (NH_3)/ammonium ion (NH_4+). For plants, nitrogen is always acquired as nitrate or ammonia dissolved in water. Although nitrate and ammonia are considered to be 'inorganic' molecules they are almost always produced from biological molecules as a consequence of biological processes:

Phosphorus

Phosphorus is a key component of phospholipids (found in all biological membranes such as those surrounding cells), and nucleic acids (such as DNA). For autotrophs, phosphorus is generally acquired as the phosphate anion ($PO\ 4\ -\ $) which is made available by the action of heterotrophs who break down organic material and release phosphate. Phosphate is a key nutrient in aquatic systems and often regulates the amount of autotroph biomass and primary production.

Sodium

Sodium is unusual because it is not an essential element for most plants but it is essential for animals. In spite of not being essential for plants, sodium is generally present in plants in amounts sufficient to supply the needs of most heterotrophs. Sodium is common in most water sources, even 'fresh water' sources and sodium is essential for some types of plants.

Resource Acquisition

Plants obtain the majority of the nutrients they need, including water, nitrogen, phosophorus, etc from the soil through their roots. The only exception is carbon, which is taken up in the form of CO_2 from the atmosphere. Resource acquisition operates somewhat differently in animals than in plants. As heterotrophs, animals must consume all nutrients they require, including glucose. Animals have a variety of acquisition strategies available to them, depending on which trophic level and ecosystem they inhabit.

Types of Feeders

Animal resource acquisition strategies can be categorized in several ways. First, we might consider categorizing animals by what types of foods they eat. For example, **herbivores** consume plant material, **carnivores** consume animal material, and **omnivores** consume both. Each of these categories can be broken down more specifically. Among carnivores, there are piscivores which eat only fish and insectivores which eat only insects, as well as many other categories. Similarly, among herbivores, there are frugivores which eat only fruit, and granivores which eat only seeds, as well as many other categories. Another important grouping is the **detritivores** which consume detritus, or decaying dead plant and animal material. Detritivores are very important in nutrient cycling, and include organisms such as fungi, bacteria, earthworms, Each of these strategies are associated with adaptations for increasing the effectiveness of that strategy. For example, herbivores often have symbiotic bacteria in their gut and particularly long intestinal tracts in order to break down the cellulose found in plant cell walls. Additionally, carnivores have a wide variety of adaptations for detecting, capturing, and consuming prey.

Animals can also be categorized by how they obtain the foods they consume. For example, suspension or filter feeders filter particles of food from the surrounding water. Deposit feeders consume material deposited in the soil or sediment and are often also detritivores. Symbionts live in close association with another organism (their host) and obtain their nutrients from that organism. Symbionts can be parasitic (such as tapeworms) or mutualistic (such as the cellulose-digesting bacteria in the gut of herbivores). Perhaps the most well-known strategy for obtaining food is **predation** in which animals use stealth or active hunting to kill and consume other animals. This category can also be broken down into more specific strategies. For example, ambush predators use

stealth and/or camouflage to hide from their prey and attack only when prey accidentally come near enough for the predator to capture or ambush. Spiders that hunt with webs are an example of ambush predators. Pursuit predators, however, actively chase fleeing prey. These two strategies have their own trade-offs; pursuit predation requires intensive energy investment in chasing down prey without guarantee of capture, while ambush predators must wait for potentially long time periods until prey come into their reach.

As can be seen in these definitions, various levels of specificity exist in both our definitions and in the strategies animals employ. Some animals are **specialists**, focusing on a particular strategy and/or food source. For example, pandas eat only bamboo and termites eat only wood (though from a variety of species). Other species are generalists and employ a wide variety of food sources and strategies. Bears, for example, are famous for their predation and also their love of berries. Goats and sharks notoriously eat things that are not even digestible food. The diets of many reptiles, such as lizards and snakes are what scientists call 'gape-limited' meaning they consume whatever fits inside their gaping mouths. Generalism and specialism have their own trade-offs. A specialist may struggle to find food that they can consume; however, they can also tailor their strategy to most effectively take advantage of a single food source. The anteater, for example, would have a difficult time consuming most types of prey, but is extremely effective at collecting ants. A **generalist**, on the other hand, can likely eat many things that it comes across in the ecosystem; however, it may not use those food sources as efficiently or effectively as a specialist.

Attribution

This page is a modified derivative of:

- Energy by LibreTexts Biology, license CC-NC-SA 3.0
- Energy and Metabolism by Open Stax, license CC-BY 4.0
- Nutrition and Nutrients by George M. Briggs, license CC-NC-SA 3.0

This page titled 5.4: Energy and Nutrients is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

5.5: Principle of Allocation and Evolutionary Trade-offs

Evolutionary Tradeoffs

When a population adapts to one set of environmental conditions its fitness (ability to survive and reproduce) decreases in other environments. For example a polar bear tolerates the extreme cold and weather of the arctic, but would die of overheating in the tropics. This tradeoff is caused, at least in part, by limited access to resources and energy.

Definition: Principle of Allocation

The Principle of Allocation states that each individual organism has a finite (limited) quantity of resources that it can use for all necessary life processes, including growth, reproduction, acquiring nutrients and resources, escaping predators or pathogens, and other processes. Resources such as nutrients or energy that an individual invests in one process cannot also be invested in other processes, meaning that not all life functions can be simultaneously maximized.

The principle of allocation leads to trade-offs, which are the relationships between the benefits of resource investment decisions in one context compared to the costs of those decisions in another context. You are already familiar with the principle of allocation through the concept of time. Each individual has 24 hours each day to invest in all the tasks that need to be accomplished. The more time a student invests in studying, for example, the less time is available for other tasks, such as sleeping. The trade-off can also be thought on in terms of costs and benefits. Investing more time in social activities may increase the number of friends you have (benefit), but will also decrease the amount of time available to study and likely result in lower grades (cost).

This concept is a cornerstone in both evolutionary biology and ecology. Species balance the principle of allocation and its associated trade-offs differently, resulting in a wide variety of strategies and traits that organisms use to accomplish life tasks. This variety of strategies and traits contributes to the diversity of species that exist on Earth.

Plants face particularly complex trade-offs when it comes to growth since investing in above-ground growth (leaves, stems, etc) reduces access to below-ground resources and vice versa. The availability of resources above ground (sunlight, CO2) and below ground (water, other nutrients) consequently influences patterns of plant resource investment in growth. An important consideration in these trade-offs is which nutrient is most limiting for plant growth in a given environment.

Optimal Foraging Theory

Animals have a variety of acquisition strategies available to them and face choices about what food sources to pursue. Each food source and each consumption strategy have a balance of nutritional benefits and energetic costs. At first glance, one might expect that evolution would favor foraging behaviors that are as energetically efficient as possible. This sort of reasoning has led to what is known as the **optimal foraging theory**, which predicts that animals will select food items that maximize their net energy intake per unit of foraging time.

Optimal foraging theory quantifies the benefits (in terms of energy content) of various prey choices and the costs (in terms of energy inputs for capturing, consuming, and digesting food) in order to predict the most energetically beneficial foraging choice.The net energy (in calories) gained by feeding on each kind of food available to a foraging animal is simply the energy content of the food minus the energy costs of pursuing and handling it.

For example, consider a population of shore crabs (*Carcinas maenas*) that primarily feed on blue mussels (*Mytilus edulis*) (Figure 5.5.1).



Figure 5.5.1: Carcinas maenas crabs (left) and their primary prey, blue mussels (*Mytilus edulis*). (Left: CC-BY-SA 3.0; Ar Rouz via Wikimedia, Right: CC-BY-SA 2.0; Benutzer Darkone via Wikimedia)

Many foragers do preferentially use food items that maximize the energy return per unit time. Shore crabs, for example, tend to feed primarily on intermediate-sized mussels, which provide the greatest energy return. In order to consume the meat of the mussel, the crab must crack open its shell. Large mussels are more difficult to crack open, but contain more meat. Smaller crabs take more time and expend more energy in breaking open mussels than larger crabs. Consequently, what size of mussel provides the optimal energy return on the crab's energy investment depends on the size of the crab.

Scientists quantified the amount of time it took for crabs of various sizes to crack open mussels of different size as well as the nutritional benefit of mussels of different size and used these data to estimate the value of different size of mussel prey for different sizes of predator crabs. Scientists then tracked prey choice by crabs when presented with a variety of prey sizes and discovered that actual prey choice closely matched the patterns of prey value estimated by optimal foraging theory. Many other animals also behave to maximize energy acquisition.

The key question, however, is whether increased energy resources acquired by optimal foraging leads to increased reproductive success. In many cases, it does. In a diverse group of animals that includes ground squirrels (Figure 5.5.2), zebra finches, and orb-weaving spiders, the number of offspring raised successfully increases when parents have access to more food energy.



Figure 5.5.2: Optimal foraging in this golden mantled ground squirrel pays off with increased reproductive success.. (Copyright; author via source)

In other cases, however, the costs of foraging seem to outweigh the benefits. An animal in danger of being eaten itself is often better off to minimize the amount of time it spends foraging. Many animals alter their foraging behavior when predators are present, reflecting this trade-off between food and risk.

Optimal foraging theory focuses entirely on energy costs of feeding and energy return from prey tissue consumed. Other environmental factors may drive organisms to make choices different from what optimal foraging theory predicts. If capturing high quality prey items exposes the organism to danger, then animals may choose less energetically valuable prey in safer areas of the habitat. Additionally, some plants contain rare nutrients that herbivores require in their diet and so grazers may seek out these plants even if they are not energetically beneficial.

Attribution

This page is a modified derivative of:

- The Principle of Allocation by Laci M. erhart-Barley, licence CC BY-NC-SA 3.0
- Resource Acquisition in Plants by Laci M. erhart-Barley, licence CC BY-NC-SA 3.0
- 4.3: Resource Acquisition in Animals by Laci M. erhart-Barley, licence CC BY-NC-SA

This page titled 5.5: Principle of Allocation and Evolutionary Trade-offs is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

CHAPTER OVERVIEW

6: Life History and Reproductive Strategies



Figure 6.1: Nesting bald eagles in the Louisa National Wildlife Refuge. (public domain; Jessica Bolservia USFWS)

Learning Objectives

- Describe how life history patterns are influenced by natural selection.
- Explain how reproductive strategies are influenced by a species survivorship curve.
- List typical characteristics of r-selected and k-selected species.
- Define sexual dimorphism and its relationship to sexual selection.
- Distinguish between male-male competition and female mate choice.
- List and explain hypotheses for the benefits females receive by being choosy.
- List different types of mating systems and provide examples of organisms that exhibit each.

6.1: Life History Theory and Natual Selection

6.2: Life Histories and Natural Selection

6.3: Life History Characteristics

6.4: Sexual Selection and Mate Choice

6.5: Mating Systems

This page titled 6: Life History and Reproductive Strategies is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

6.1: Life History Theory and Natual Selection

Natural Selection and Evolutionary Tradeoffs

All living things need energy and nutrients to grow, maintain their bodies, and reproduce. In nature, these resources are in limited supply, and there is often competition for access to them (e.g., to sunlight and minerals for plants or food sources for animals). Thus, each organism will have non-infinite resources to divide among activities like growth, body maintenance, and reproduction..

What does it mean for an organism to allocate its limited resources "well" in this context? From an evolutionary standpoint, it means that the resources are distributed among the potential activities (growth, maintenance, reproduction) in a way that maximizes **fitness**, or the number of offspring the organism leaves in the next generation. Organisms with inherited traits that cause them to distribute their resources in a more effective way will tend to leave more offspring than organisms lacking these traits, causing the traits to increase in the population over generations by natural selection.

Over very long periods of time, this process results in species with **life history strategies**, or collections of life history traits (number of offspring, timing of reproduction, amount of parental care, etc.), that are well-adapted for their role and environment. The optimal life history strategy may be different for each species, depending on its traits, environment, and other constraints.

Life History Theory

Life history theory is a general framework designed to study the diversity of life history strategies used by different organisms throughout the world, as well as the causes and results of the variation in their life cycles. It is a theory of biological evolution that seeks to explain aspects of organisms' anatomy and behavior by reference to the way that their life histories—including their reproductive development and behaviors, post-reproductive behaviors, and lifespan (length of time alive)—have been shaped by natural selection. A life history strategy is the "age- and stage-specific patterns" and timing of events that make up an organism's life, such as birth, weaning, maturation, death, etc. These events, notably juvenile development, age of sexual maturity, first reproduction, number of offspring and level of parental investment, senescence and death, depend on the physical and ecological environment of the organism.

The theory was developed in the 1950s and is used to answer questions about topics such as organism size, age of maturation, number of offspring, life span, and many others. In order to study these topics, life history strategies must be identified, and then models are constructed to study their effects. Finally, predictions about the importance and role of the strategies are made, and these predictions are used to understand how evolution affects the ordering and length of life history events in an organism's life, particularly the lifespan and period of reproduction. Life history theory draws on an evolutionary foundation, and studies the effects of natural selection on organisms, both throughout their lifetime and across generations. It also uses measures of evolutionary fitness to determine if organisms are able to maximize or optimize this fitness, by allocating resources to a range of different demands throughout the organism's life. It serves as a method to investigate further the "many layers of complexity of organisms and their worlds".

Organisms have evolved a great variety of life histories, from Pacific salmon (Figure 6.1.1), which produce thousands of eggs at one time and then die, to human beings, who produce a few offspring over the course of decades. The theory depends on principles of evolutionary biology and ecology and is widely used in other areas of science.



Figure 6.1.1: Wild Pacific salmon swim up river to spawn in Oregon. Image: Pixabay. (CC BY 2.0; author Bureau of Land Management)

Life cycle

All organisms follow a specific sequence in their development, beginning with gestation and ending with death, which is known as the life cycle. Events in between usually include birth, childhood, maturation, reproduction, and senescence, and together these comprise the life history strategy of that organism. The major events in this life cycle are usually shaped by the demographic qualities of the organism. Some are more obvious shifts than others, and may be marked by physical changes—for example, teeth erupting in young children. Some events may have little variation between individuals in a species, such as length of gestation, but other events may show a lot of variation between individuals, such as age at first reproduction. Life cycles can be divided into two major stages: growth and reproduction. These two cannot take place at the same time, so once reproduction has begun, growth usually ends. This shift is important because it can also affect other aspects of an organism's life, such as the organization of its group or its social interactions.

Each species has its own pattern and timing for these events, often known as its **ontogeny**, and the variety produced by this is what life history theory addresses. Evolution then works upon these stages to ensure that an organism adapts to its environment. For example, a human, between being born and reaching adulthood, will pass through an assortment of life stages, which include: birth, infancy, weaning, childhood and growth, adolescence, sexual maturation, and reproduction. All of these are defined in a specific biological way, which is not necessarily the same as the way that they are commonly used. In life history theory, evolution works on the life stages of particular species (e.g., length of juvenile period) but is also discussed for a single organism's functional, lifetime adaptation. In both cases, researchers assume adaptation—processes that establish fitness.

Traits

There are at least six traits that are traditionally recognized as important in life history theory. The trait that is seen as the most important for any given organism is the one where a change in that trait creates the most significant difference in that organism's level of fitness. In this sense, an organism's fitness is determined by its changing life history traits. The way in which evolutionary forces act on these life history traits serves to limit the genetic variability and heritability of the life history strategies, although there are still large varieties that exist in the world.

Commonly studied life history traits:

1. age and size at reproductive maturity
2. number and size of offspring
3. number of reproductive events
4. reproductive investments (such as parental care)
5. age- and size-specific mortality schedules
6. lifespan

Tradeoffs in Life History Traits

Parental Care and Fecundity

Fecundity is the potential reproductive capacity of an individual within a population. In other words, **fecundity** describes how many offspring could ideally be produced if an individual has as many offspring as possible, repeating the reproductive cycle as soon as possible after the birth of the offspring. In animals, fecundity is inversely related to the amount of **parental care** given to an individual offspring. Species, such as many marine invertebrates, that produce many offspring usually provide little if any care for the offspring (they would not have the energy or the ability to do so anyway). Most of their energy budget is used to produce many tiny offspring. Animals with this strategy are often self-sufficient at a very early age. This is because of the energy tradeoff these organisms have made to maximize their evolutionary fitness. Because their energy is used for producing offspring instead of parental care, it makes sense that these offspring have some ability to be able to move within their environment and find food and perhaps shelter. Even with these abilities, their small size makes them extremely vulnerable to predation, so the production of many offspring allows enough of them to survive to maintain the species.

Animal species that have few offspring during a reproductive event usually give extensive parental care, devoting much of their energy budget to these activities, sometimes at the expense of their own health. This is the case with many mammals, such as humans, kangaroos, and pandas. The offspring of these species are relatively helpless at birth and need to develop before they achieve self-sufficiency.

Plants with low fecundity produce few energy-rich seeds (such as coconuts and chestnuts) with each having a good chance to germinate into a new organism; plants with high fecundity usually have many small, energy-poor seeds (like orchids) that have a relatively poor chance of surviving. Although it may seem that coconuts and chestnuts have a better chance of surviving, the energy tradeoff of the orchid is also very effective. It is a matter of where the energy is used, for large numbers of seeds or for fewer seeds with more energy.

Early versus Late Reproduction

The timing of reproduction in a life history also affects species survival. Organisms that reproduce at an early age have a greater chance of producing offspring, but this is usually at the expense of their growth and the maintenance of their health. Conversely, organisms that start reproducing later in life often have greater fecundity or are better able to provide parental care, but they risk that they will not survive to reproductive age. Examples of this can be seen in fishes. Small fish like guppies use their energy to reproduce rapidly, but never attain the size that would give them defense against some predators. Larger fish, like the bluegill or shark, use their energy to attain a large size, but do so with the risk that they will die before they can reproduce or at least reproduce to their maximum. These different energy strategies and tradeoffs are key to understanding the evolution of each species as it maximizes its fitness and fills its niche. In terms of energy budgeting, some species "blow it all" and use up most of their energy reserves to reproduce early before they die. Other species delay having reproduction to become stronger, more experienced individuals and to make sure that they are strong enough to provide parental care if necessary.

Single versus Multiple Reproductive Events

Some life history traits, such as fecundity, timing of reproduction, and parental care, can be grouped together into general strategies that are used by multiple species. **Semelparity** occurs when a species reproduces only once during its lifetime and then dies. Such species use most of their resource budget during a single reproductive event, sacrificing their health to the point that they do not survive. Examples of semelparity are bamboo, which flowers once and then dies, and the Chinook salmon (Figure 6.1.1), which uses most of its energy reserves to migrate from the ocean to its freshwater nesting area, where it reproduces and then dies. Scientists have posited alternate explanations for the evolutionary advantage of the Chinook's post-reproduction death: a programmed suicide caused by a massive release of corticosteroid hormones, presumably so the parents can become food for the offspring, or simple exhaustion caused by the energy demands of reproduction; these are still being debated.

Iteroparity describes species that reproduce repeatedly during their lives. Some animals are able to mate only once per year, but survive multiple mating seasons. The pronghorn antelope is an example of an animal that goes into a seasonal estrus cycle ("heat"): a hormonally induced physiological condition preparing the body for successful mating (Figure 6.1.2). Females of these species mate only during the estrus phase of the cycle. A different pattern is observed in primates, including humans and chimpanzees, which may attempt reproduction at any time during their reproductive years, even though their menstrual cycles make pregnancy likely only a few days per month during ovulation (Figure 6.1.3).



Figure 6.1.2: he (b) pronghorn antelope mates during specific times of the year during its reproductive life (CC BY OpenStax).



Figure 6.1.3: himpanzees, may mate on any day, independent of ovulation (CC BY OpenStax)

Attribution:

This article is a modified derivative of:

- 9.2: Life Histories and Natural Selection by Tara Jo Holmberg, CC BY-SA 4.0 (opens in new window)
- Life History Strategies by Khan Acadamy, CC BY-NC-SA 3.0 *"Note: All Khan Academy content is available for free at www.khanacademy.org"*.
- 45.2: Life Histories and Natural Selection by OpenStax is licensed CC BY 4.0.

This page titled 6.1: Life History Theory and Natual Selection is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

6.2: Life Histories and Natural Selection

Skills to Develop

- Describe how life history patterns are influenced by natural selection
- Explain different life history patterns and how different reproductive strategies affect species' survival

A species' life history describes the series of events over its lifetime, such as how resources are allocated for growth, maintenance, and reproduction. Life history traits affect the life table of an organism. A species' life history is genetically determined and shaped by the environment and natural selection.

Life History Patterns and Energy Budgets

Energy is required by all living organisms for their growth, maintenance, and reproduction; at the same time, energy is often a major limiting factor in determining an organism's survival. Plants, for example, acquire energy from the sun via photosynthesis, but must expend this energy to grow, maintain health, and produce energy-rich seeds to produce the next generation. Animals have the additional burden of using some of their energy reserves to acquire food. Furthermore, some animals must expend energy caring for their offspring. Thus, all species have an energy budget: they must balance energy intake with their use of energy for metabolism, reproduction, parental care, and energy storage (such as bears building up body fat for winter hibernation).

Parental Care and Fecundity

Fecundity is the potential reproductive capacity of an individual within a population. In other words, fecundity describes how many offspring could ideally be produced if an individual has as many offspring as possible, repeating the reproductive cycle as soon as possible after the birth of the offspring. In animals, fecundity is inversely related to the amount of parental care given to an individual offspring. Species, such as many marine invertebrates, that produce many offspring usually provide little if any care for the offspring (they would not have the energy or the ability to do so anyway). Most of their energy budget is used to produce many tiny offspring. Animals with this strategy are often self-sufficient at a very early age. This is because of the energy tradeoff these organisms have made to maximize their evolutionary fitness. Because their energy is used for producing offspring instead of parental care, it makes sense that these offspring have some ability to be able to move within their environment and find food and perhaps shelter. Even with these abilities, their small size makes them extremely vulnerable to predation, so the production of many offspring allows enough of them to survive to maintain the species.

Animal species that have few offspring during a reproductive event usually give extensive parental care, devoting much of their energy budget to these activities, sometimes at the expense of their own health. This is the case with many mammals, such as humans, kangaroos, and pandas. The offspring of these species are relatively helpless at birth and need to develop before they achieve self-sufficiency.

Plants with low fecundity produce few energy-rich seeds (such as coconuts and chestnuts) with each having a good chance to germinate into a new organism; plants with high fecundity usually have many small, energy-poor seeds (like orchids) that have a relatively poor chance of surviving. Although it may seem that coconuts and chestnuts have a better chance of surviving, the energy tradeoff of the orchid is also very effective. It is a matter of where the energy is used, for large numbers of seeds or for fewer seeds with more energy.

Early versus Late Reproduction

The timing of reproduction in a life history also affects species survival. Organisms that reproduce at an early age have a greater chance of producing offspring, but this is usually at the expense of their growth and the maintenance of their health. Conversely, organisms that start reproducing later in life often have greater fecundity or are better able to provide parental care, but they risk that they will not survive to reproductive age. Examples of this can be seen in fishes. Small fish like guppies use their energy to reproduce rapidly, but never attain the size that would give them defense against some predators. Larger fish, like the bluegill or shark, use their energy to attain a large size, but do so with the risk that they will die before they can reproduce or at least reproduce to their maximum. These different energy strategies and tradeoffs are key to understanding the evolution of each species as it maximizes its fitness and fills its niche. In terms of energy budgeting, some species "blow it all" and use up most of their energy

reserves to reproduce early before they die. Other species delay having reproduction to become stronger, more experienced individuals and to make sure that they are strong enough to provide parental care if necessary.

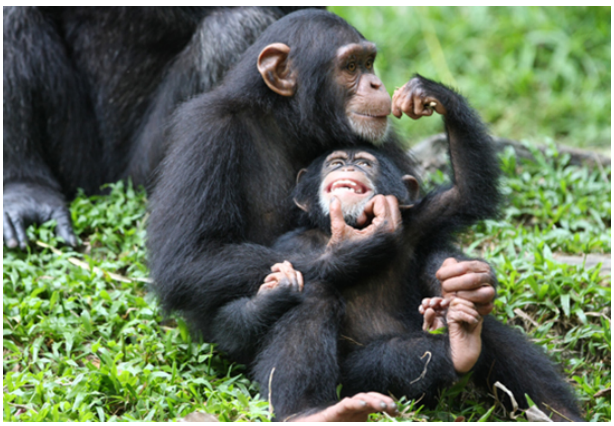
Single versus Multiple Reproductive Events

Some life history traits, such as fecundity, timing of reproduction, and parental care, can be grouped together into general strategies that are used by multiple species. Semelparity occurs when a species reproduces only once during its lifetime and then dies. Such species use most of their resource budget during a single reproductive event, sacrificing their health to the point that they do not survive. Examples of semelparity are bamboo, which flowers once and then dies, and the Chinook salmon (Figure 6.2.1a), which uses most of its energy reserves to migrate from the ocean to its freshwater nesting area, where it reproduces and then dies. Scientists have posited alternate explanations for the evolutionary advantage of the Chinook's post-reproduction death: a programmed suicide caused by a massive release of corticosteroid hormones, presumably so the parents can become food for the offspring, or simple exhaustion caused by the energy demands of reproduction; these are still being debated.

Iteroparity describes species that reproduce repeatedly during their lives. Some animals are able to mate only once per year, but survive multiple mating seasons. The pronghorn antelope is an example of an animal that goes into a seasonal estrus cycle ("heat"): a hormonally induced physiological condition preparing the body for successful mating (Figure 6.2.1b). Females of these species mate only during the estrus phase of the cycle. A different pattern is observed in primates, including humans and chimpanzees, which may attempt reproduction at any time during their reproductive years, even though their menstrual cycles make pregnancy likely only a few days per month during ovulation (Figure 6.2.1c).



a b



c

Figure 6.2.1**:** The (a) Chinook salmon mates once and dies. The (b) pronghorn antelope mates during specific times of the year during its reproductive life. Primates, such as humans and (c) chimpanzees, may mate on any day, independent of ovulation. (credit a: modification of work by Roger Tabor, USFWS; credit b: modification of work by Mark Gocke, USDA; credit c: modification of work by "Shiny Things"/Flickr)

Evolution Connection: Energy Budgets, Reproductive Costs, and Sexual Selection in *Drosophila*

Research into how animals allocate their energy resources for growth, maintenance, and reproduction has used a variety of experimental animal models. Some of this work has been done using the common fruit fly, *Drosophila melanogaster*. Studies have shown that not only does reproduction have a cost as far as how long male fruit flies live, but also fruit flies that have already mated several times have limited sperm remaining for reproduction. Fruit flies maximize their last chances at reproduction by selecting optimal mates.

In a 1981 study, male fruit flies were placed in enclosures with either virgin or inseminated females. The males that mated with virgin females had shorter life spans than those in contact with the same number of inseminated females with which they were unable to mate. This effect occurred regardless of how large (indicative of their age) the males were. Thus, males that did not mate lived longer, allowing them more opportunities to find mates in the future.

More recent studies, performed in 2006, show how males select the female with which they will mate and how this is affected by previous matings (Figure 6.2.2).[1] Males were allowed to select between smaller and larger females. Findings showed that larger females had greater fecundity, producing twice as many offspring per mating as the smaller females did. Males that had previously mated, and thus had lower supplies of sperm, were termed "resource-depleted," while males that had not mated were termed "non-resource-depleted." The study showed that although non-resource-depleted males preferentially mated with larger females, this selection of partners was more pronounced in the resource-depleted males. Thus, males with depleted sperm supplies, which were limited in the number of times that they could mate before they replenished their sperm supply, selected larger, more fecund females, thus maximizing their chances for offspring. This study was one of the first to show that the physiological state of the male affected its mating behavior in a way that clearly maximizes its use of limited reproductive resources.

	Ratio large/small females mated
Non sperm-depleted	8 ± 5
Sperm-depleted	15 ± 5

Figure 6.2.2: Male fruit flies that had previously mated (sperm-depleted) picked larger, more fecund females more often than those that had not mated (non-sperm-depleted). This change in behavior causes an increase in the efficiency of a limited reproductive resource: sperm.

These studies demonstrate two ways in which the energy budget is a factor in reproduction. First, energy expended on mating may reduce an animal's lifespan, but by this time they have already reproduced, so in the context of natural selection this early death is not of much evolutionary importance. Second, when resources such as sperm (and the energy needed to replenish it) are low, an organism's behavior can change to give them the best chance of passing their genes on to the next generation. These changes in behavior, so important to evolution, are studied in a discipline known as behavioral biology, or ethology, at the interface between population biology and psychology.

Summary

All species have evolved a pattern of living, called a life history strategy, in which they partition energy for growth, maintenance, and reproduction. These patterns evolve through natural selection; they allow species to adapt to their environment to obtain the resources they need to successfully reproduce. There is an inverse relationship between fecundity and parental care. A species may reproduce early in life to ensure surviving to a reproductive age or reproduce later in life to become larger and healthier and better able to give parental care. A species may reproduce once (semelparity) or many times (iteroparity) in its life.

Footnotes

1. 1 Adapted from Phillip G. Byrne and William R. Rice, "Evidence for adaptive male mate choice in the fruit fly *Drosophila melanogaster,*" Proc Biol Sci. 273, no. 1589 (2006): 917-922, doi: 10.1098/rspb.2005.3372.

Glossary

energy budget

allocation of energy resources for body maintenance, reproduction, and parental care

fecundity

potential reproductive capacity of an individual

iteroparity

life history strategy characterized by multiple reproductive events during the lifetime of a species

life history

inherited pattern of resource allocation under the influence of natural selection and other evolutionary forces

semelparity

life history strategy characterized by a single reproductive event followed by death

---

This page titled 6.2: Life Histories and Natural Selection is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **45.2: Life Histories and Natural Selection** by OpenStax is licensed CC BY 4.0.

6.3: Life History Characteristics

Life history characteristics, are those that affect relate to the survival, mortality, and reproduction of a species. Examples include birth rates, age at first reproduction, the numbers of offspring, and death rates. This evolve just like physical traits or behavior, leading to adaptations that affect population growth.

Reproductive Strategies

Population ecologists have hypothesized that suites of characteristics may evolve in species that lead to particular adaptations to their environments. These adaptations impact the kind of population growth their species experience. Population ecologists have described a continuum of life-history "strategies" with *K*-selected species on one end and *r*-selected species on the other (table 6.1). ***K*-selected species** are adapted to stable, predictable environments. Populations of *K*-selected species tend to exist close to their carrying capacity. These species tend to have larger, but fewer, offspring, contribute large amounts of resources to each offspring, and have long generation times. Elephants would be an example of a *K*-selected species (Figure 6.3.1). When a habitat becomes filled with a diverse collection of creatures competing with one another for the necessities of life, the advantage shifts to *K*-strategists. *K*-strategists have stable populations that are close to *K*. There is nothing to be gained from a high *r* (reproductive rate). The species will benefit most by a close adaptation to the conditions of its environment.

Table 6.1: Comparison of *K*- and *r*-selected species

Characteristics of *K*-selected species	Characteristics of *r*-selected species
Mature late	Mature early
Greater longevity	Lower longevity
Increased parental care	Decreased parental care
Strong competitors	Weak competitors (strong colonizers)
Fewer offspring	More offspring
Larger offspring	Smaller offspring



(a) K-selected species



(b) r-selected species

Figure 6.3.1: (a) Elephants are considered K-selected species as they live long, mature late, and provide long-term parental care to few offspring. Oak trees produce many offspring that do not receive parental care, but are considered K-selected species based on longevity and late maturation. (b) Dandelions and jellyfish are both considered r-selected species as they mature early, have short lifespans, and produce many offspring that receive no parental care. (CC-BY; Open Stax)

***r*-selected species** are adapted to unstable and unpredictable environments. They have large numbers of small offspring. Animals that are *r*-selected do not provide a lot of resources or parental care to offspring, and the offspring are relatively self-sufficient at birth. Examples of *r*-selected species are marine invertebrates such as jellyfish and plants such as the dandelion (Figure 6.3.1). *r*-strategists have short life spans and reproduce quickly, resulting in short generation times. For example, the housefly can produce 7 generations each year (each of about 120 young). Ragweed is well-adapted to exploiting its environment in a hurry - before competitors can become established. It grows rapidly and produces a huge number of seeds (after releasing its pollen, the bane of many hay fever sufferers). Because ragweed's approach to continued survival is through rapid reproduction (a high value of *r)* it is called an *r*-strategist. Other weeds, many insects, and many rodents are also *r*-strategists. If fact, if we consider an organism a pest, it is probably an *r*-strategist.

The two extreme strategies are at two ends of a continuum on which real species life histories will exist. In addition, life history strategies do not need to evolve as suites, but can evolve independently of each other, so each species may have some characteristics that trend toward one extreme or the other. The *r*- and *K*-selection theory, although accepted for decades and used for much groundbreaking research, has now been reconsidered, and many population biologists have abandoned or modified it. Over the years, several studies attempted to confirm the theory, but these attempts have largely failed. Many species were identified that did not follow the theory's predictions. Furthermore, the theory ignored the age-specific mortality of the populations which scientists now know is very important. New demographic-based models of life history evolution have been developed which incorporate many ecological concepts included in *r*- and *K*-selection theory as well as population age structure and mortality factors.

Life Tables

Life tables provide important information about the life history of an organism and the life expectancy of individuals at each age. They are modeled after actuarial tables used by the insurance industry for estimating human life expectancy. Life tables may include the probability of each age group dying before their next birthday, the percentage of surviving individuals dying at a particular age interval (their mortality rate, and their life expectancy at each interval. An example of a life table is shown in Table 6.2 from a study of Dall mountain sheep, a species native to northwestern North America. Notice that the population is divided into age intervals (column A).

As can be seen from the mortality rate data (column D), a high death rate occurred when the sheep were between six months and a year old, and then increased even more from 8 to 12 years old, after which there were few survivors. The data indicate that if a sheep in this population were to survive to age one, it could be expected to live another 7.7 years on average, as shown by the life-expectancy numbers

in column E. Life tables often include more information than shown in Table 6.2, such as fecundity (reproduction) rates for each age group.

Table 6.2: Life Table of Dall Mountain Sheep

Age interval (years)	Number surviving at beginning of age interval out of 1000 born	Mortality rate per 1000 alive at beginning of age interval	Life expectancy or mean lifetime remaining to those attaining age interval
0–4.5	1000	54.0	7.06
1.5–11	946	153.3	—
11–12	801	15.0	7.7
12–	789	16.5	6.8

3		
3		
3		
1		
776	15.5	5.9
2		
4		
4		
3		
764	39.3	5.0
0		
5		
5		
4		
734	62.7	4.2
6		
6		
6		
4		
688	69.8	3.4
8		
7		
7		
6		
640	107.8	2.6
9		
8		
8		
1		
571	231.2	1.9
9		
2		
9		
1		
339	426.0	1.3
8		
1		
7		
0		
1		
0		
252	619.0	0.9
6		
1		
1		
1		
96	937.5	0.6
0		
1		
2		
1		
2		
8	500.0	1.2
1		
3		
1		
3		
3	1000	0.7
1		
4		

Survivorship Curves

Another tool used by population ecologists is a **survivorship curve**, which is a graph of the number of individuals surviving at each age interval versus time. These curves allow us to compare the life histories of different populations (Figure 6.3.2). There are three types of survivorship curves. In a **type I survivorship curve**, mortality is low in the early and middle years and occurs mostly in older

individuals. Organisms exhibiting a type I survivorship typically produce few offspring and provide good care to the offspring increasing the likelihood of their survival. Humans and most mammals exhibit a type I survivorship curve. In **type II survivorship curves**, mortality is relatively constant throughout the entire life span, and mortality is equally likely to occur at any point in the life span. Many bird populations provide examples of an intermediate or type II survivorship curve. In **type III survivorship curves**, early ages experience the highest mortality with much lower mortality rates for organisms that make it to advanced years. Type III organisms typically produce large numbers of offspring, but provide very little or no care for them. Trees and marine invertebrates exhibit a type III survivorship curve because very few of these organisms survive their younger years, but those that do make it to an old age are more likely to survive for a relatively long period of time.

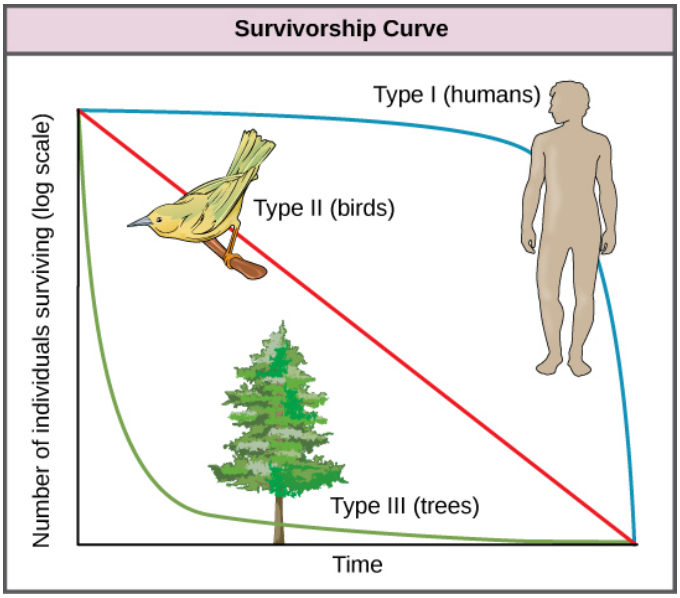


Figure 6.3.2: Survivorship curves show the distribution of individuals in a population according to age. Humans and most mammals have a Type I survivorship curve, because death primarily occurs in the older years. Birds have a Type II survivorship curve, as death at any age is equally probable. Trees have a Type III survivorship curve because very few survive the younger years, but after a certain age, individuals are much more likely to survive. (CC-BY; OpenStax)

Attribution:

This article is a modified derivative of:

- **5.4: Life History** (opens in new window) by Melissa Ha and Rachel Schleiger, CC BY-NC 4.0 (opens in new window).

This page titled 6.3: Life History Characteristics is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

6.4: Sexual Selection and Mate Choice

Sexual Dimorphism

Males and females of certain species are often quite different from one another in ways beyond the reproductive organs (Figure 6.4.1). Males are often larger, for example, and display many elaborate colors and adornments, such as the peacock's tail, while females tend to be smaller and duller in decoration. These differences are called sexual dimorphisms and arise from the variation in male reproductive success.

Definition: Sexual Dimorphism

Morphological and behavioral differences between males and females of the same species is known as sexual dimorphism.



Figure 6.4.1: Morphological differences between males and females observed in (a) peacocks and peahens, (b) Argiope appensa spiders (the female spider is the large one), and (c) wood ducks.. (Copyright; author via source)

Sexual dimorphism results from the different selective pressures on males and female to secure mates. At any given time some females are developing eggs, gestating, or carrying for young and are thus, not available to mate. This creates a bias in the sex-ratio with more males available to mate at any one time then females. As a result females almost always mate, while mating is not guaranteed for males. Furthermore, females often can maximize reproductive success with a single partner, while male fitness increases with the number of female partners he obtains (Figure 6.4.2).To maximize fitness males should invest more effort in mating effort (securing a mate) while females should be more choosy about which mate they select.

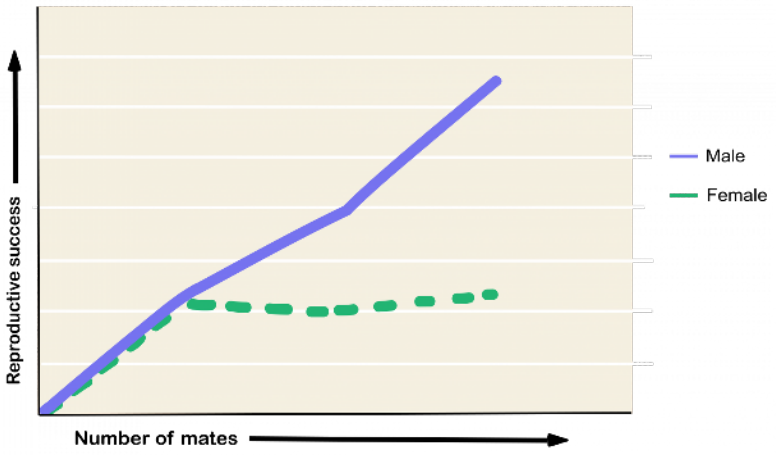


Figure 6.4.2: Males maximize their fitness by having as many mates as possible. In contrast, females maximize their fitness by having fewer, high quality mates. This difference in how males and females maximize their reproductive success can lead to conflict between the sexes.. (CC BY 4.0; Sehoya Cotner and Deena Wassenberg via The Evolution and Biology of Sex)

For most species, the bigger, stronger, or more decorated males usually obtain the vast majority of the total matings, while other males receive none. This can occur because the males are better at fighting off other males, or because females will choose to mate with the bigger or more decorated males. In either case, this variation in reproductive success generates a strong selection pressure

among males to obtain those matings, resulting in the evolution of bigger body size and elaborate ornaments in order to increase their chances of mating. Females, on the other hand, tend to get a handful of selected matings; therefore, they are more likely to select more desirable males.

Sexual Selection

The selection pressures on males and females to obtain matings is known as **sexual selection**. Sexual selection takes two major forms: intersexual selection (also known as 'mate choice' or '**female choice**') in which males compete with each other to be chosen by females; and intrasexual selection (also known as '**male–male competition**') in which members of the less limited sex (typically males) compete aggressively among themselves for access to the limiting sex. The limiting sex is the sex which has the higher parental investment (typically females), which therefore faces the most pressure to make a good mate decision.



Figure 6.4.3: This male elk has large antlers to compete with rival males for available females (intrasexual competition). In addition, the many points on his antlers represent health and longevity, and therefore he may be more desirable to females (intersexual selection). (Copyright; author via source)

It is important to note that both types result in selection of male traits. Female mate choice results in **ornaments**. Traits such as elaborate displays, fancy feather, bright colors, etc. Male-male competition results in traits that make males better at fighting for or defending females. Horns and antlers are an excellent example (Figure 6.4.3). Large body size is another common result of male-male competition. It is also important to note that sexual selection selects for traits that increase reproductive success but often at a adaptive cost. These traits also make it more difficult to survive.

What Benefits to Females Receive for being Choosy?

Direct Benefits

Direct benefits increase the fitness of the choosy sex through direct material advantages or resources. These benefits include but are not limited to increased territory quality, increased parental care, and protection from predators. There is much support for maintenance of mate choice by direct benefits and this approach offers the least controversial model to explain discriminate mating.

One example of a sexually selected trait with direct benefits is the bright plumage of the northern cardinal, a common backyard bird in the eastern United States. Male northern cardinals have conspicuous red feathers, while the females have a more cryptic coloration (Figure 6.4.4). In this example, the females are the choosy sex and will use male plumage brightness as a signal when picking a mate — research suggests that males with brighter plumage feed their young more frequently than males with duller plumage. This increased help in caring for the young lifts some of the burden from the mother so that she can raise more offspring than she could without help.



Figure 6.4.4: Northern cardinals have a short, stout bill, adapted for cracking seeds. This species is the only bright red bird with a crest. Both males and females have rosy red to orangish red beaks. Females are also crested, but their plumage is dominated by yellowish gray coloration. (CC BY 2.0; James St. John via flickr)

Indirect Benefits

Indirect benefits increase genetic fitness for the offspring, and thereby increase the parents' fitness indirectly. When it appears that the choosy sex does not receive direct benefits from his or her mate, indirect benefits may be the payoff for being selective. These indirect benefits may include high-quality genes for their offspring (known as the good genes hypothesis) or genes that make their offspring more attractive (known as the sexy sons hypothesis).

The Handicap Principle

Sexual selection can be so strong that it selects for traits that are actually detrimental to the individual's survival, even though they maximize its reproductive success. For example, while the male peacock's tail is beautiful and the male with the largest, most colorful tail will more probably win the female, it is not a practical appendage. In addition to being more visible to predators, it makes the males slower in their attempted escapes. There is some evidence that this risk, in fact, is why females like the big tails in the first place. Because large tails carry risk, only the best males survive that risk and therefore the bigger the tail, the more fit the male. This idea is known as the **handicap principle**.



Figure 6.4.1: A male bird of paradise: This male bird of paradise carries an extremely long tail as the result of sexual selection.The tail is flamboyant and detrimental to the bird's own survival, but it increases his reproductive success.This may be an example of the handicap principle. (CC BY-SA 2.0; Markaharper1 via Wikipedia)

The Good Genes Hypothesis

The good genes hypothesis states that males develop these impressive ornaments to show off their efficient metabolism or their ability to fight disease. Females then choose males with the most impressive traits because it signals their genetic superiority, which they will then pass on to their offspring. Though it might be argued that females should not be so selective because it will likely reduce their number of offspring, if better males father more fit offspring, it may be beneficial. Fewer, healthier offspring may increase the chances of survival more than many, weaker offspring.

Attribution:

- 4.4.2: Sexual Selection by boundless license CC BY-SA 4.0
- Mate Choice by Wikipedia. License CC BY-SA 3.0

References

- *Moller, A.; Jennions, M. (2001). "How important are direct benefits of sexual selection?". Naturwissenschaften.* ***88*** *(10): 401–415.*
- *Kokko, H.; Brooks, R.; Jennions, M.; Morley, J. (2003). "The evolution of mate choice and mating biases". Proceedings of the Royal Society B: Biological Sciences.* ***270*** *(1515): 653–664.*
- Linville, Susan U.; Breitwisch, Randall; Schilling, Amy J. (1998). "Plumage brightness as an indicator of parental care in northern cardinals". *Animal Behaviour*. **55** (1): 119–127.

This page titled 6.4: Sexual Selection and Mate Choice is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

6.5: Mating Systems

Animal Mating Systems

A **mating system** is a way in which a group is structured in relation to sexual behavior. The precise meaning depends upon the context. With respect to animals, the term describes which males and females mate under which circumstances. Recognized systems include monogamy, polygyny, polyandry, and promiscuity, all of which lead to different mate choice outcomes and thus these systems affect how sexual selection works in the species which practice them (Figure 6.5.1).

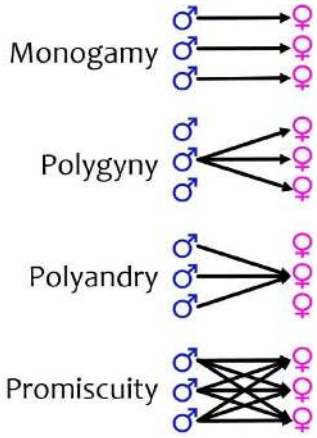


Figure 6.5.1: Animal Mating systems. (CC BY-NC-SA; via Organismalbio)

Monogamy

In **monogamous systems**, one male and one female are paired for at least one breeding season. In some animals, such as the prairie vole, these associations can last much longer, even a lifetime (Figure 6.5.2). Several explanations have been proposed for this type of mating system. The "mate-guarding hypothesis" states that males stay with the female to prevent other males from mating with her. This behavior is advantageous in such situations where mates are scarce and difficult to find. Another explanation is the "male-assistance hypothesis," where males that remain with a female to help guard and rear their young will have more and healthier offspring. Monogamy is observed in many bird populations where, in addition to the parental care from the female, the male is also a major provider of parental care for the chicks. A third explanation for the evolutionary advantages of monogamy is the "female-enforcement hypothesis." In this scenario, the female ensures that the male does not have other offspring that might compete with her own, so she actively interferes with the male's signaling to attract other mates.



Figure 6.5.2: Prarie Vole, a small midwestern rodent. Mated pairs form bonds, share a nest and raise young togetner. (CC BY-SA; US National Park Service via Wikimedia)

True monogamy, also called **sexual monogamy**, is where both partners mate only with each other; true monogamy is exceedingly rare. Much more common is **social monogamy,** where two individuals partner together to rear their offspring, but also engage in “extra-pair copulations,” or matings with other individual (in human social parlance, we would call this “infidelity”) (Figure 6.5.3). Social monogamy has both advantages and disadvantages for each partner. You can imagine the advantage for a male in this scenario: he helps rear offspring with his social partner, increasing the likely survival of those offspring, but he also mates with other females, thus increasing his total number of offspring (assuming any of these other offspring also survive).

Social monogamy can also be advantageous for the female: she has help from a social partner in raising her offspring, but she can also mate with other males who may be genetically "better." The disadvantage for the male in this scenario is that he is most likely helping to raise offspring that are not his own. The disadvantage for the female is that the male may abandon her – and her offspring – if he detects that she has mated with another male. The vast majority of songbirds demonstrate social monogamy, where up to 40% of the offspring in a mating pair's nest were not actually fathered by the male partner.



Figure 6.5.3: Male and female zebrafinch. Zebrafinches, like many songbirds, exhibit a socially monogamous mating system. (CC BY 2.0; Keith Gerstung via Wikimedia Commons)

Polygyny

When one male mating with multiple females, called **polygyny** ("many females"), the female takes responsibility for most of the parental care as the single male is not capable of providing care to that many offspring. For instance, imagine that a male has established a territory such that he can provide access to resources. Females that enter the territory are drawn to its resource richness, which may signal that he has good genes for protecting a territory. The female benefits by mating with a genetically fit male at the cost of having no male help care for the offspring. For example, in the yellow-rumped honeyguide (a bird) males defend beehives because the females feed on beewax. As the females approach to find beeswax, the male defending the nest will mate with them.

Harem mating structures are a type of polygynous system where certain males dominate mating while controlling a territory with resources. In elephant seals, the alpha male dominates the mating within the group (Figure 6.5.4). Another type of polygyny is a lek system. In leks, the species has a communal courting area where several males perform elaborate displays for females, and the females choose their mate from the performing males. Lekking behavior is observed in several bird species including the sage grouse and the prairie chicken.



Figure 6.5.4: A battle-scarred male northern elephant sealÂ among his harem of females and pups. (CC BY 2.0; Mike Baird via flickr)

polyandry

The other type of polygamy is called a **polyandry** ("many males"), where one female mates with multiple males. Polyandry very rare because it involves sex role reversal, where females invest less in offspring while males invest more.

Pipefishes, a relative of seahorses exhibit polyandry where females compete for access to males (Figure 6.5.5). In both pipefishes and seahorses, males receive the eggs from the female, fertilize them, protect them within a pouch, and give birth to the offspring (see below). However, seahorses are monogamous, while pipefish are polyandrous.

Why do these similar species differ in mating system? Ecologically, seahorses live in habitats with widely distributed resources, which means that the seahorse population is spread out and spread thin. The scattered population means that it is can be difficult to

find a mating partner. Natural selection favors keeping a partner, once found, for reproductive assurance. In contrast to seahorses, pipefish tends to live in very dense populations in resource-rich environments. Because the male's pouches, rather than the female's eggs, are the limiting resource in reproduction, females compete with each other for access to males.



Figure 6.5.5: Spiny Seahourses. (CC BY-SA 3.0; Nick Hobgood via Wikimedia Commons)

Promiscuity

Promiscuous mating systems occur when females mate with multiple males, and males mate with multiple females. Promiscuity generally occurs when a single male is unable to sexually monopolize a group of females, either because the females range more widely than the territory size of a single male, so they interact with multiple males (eg, the maximum territory size a male can defend is smaller than the females' ranges), or because males and females live together in large social groups that a single male cannot monopolize. Bonobos live in large social groups where sexual activity plays a major roles as a means of forming social bonds and conflict resolution (Figure 6.5.6).

In large social groups, often all females are sexually receptive at the same time, meaning that a single male cannot prevent other males from mating with other females while he mates with one female. Because each female mates with multiple males, paternity is never certain. The uncertainty of not knowing "who's the daddy" selects for males to avoid infanticide, as they may inadvertently kill their own offspring.



Figure 6.5.6: Social gathering of Male, female, and juvenile bonobos at the San Diego Zoo. (CC BY-SA 4.0; W. Calvin via wikimedia commons)

Attribution:

This page is a modified derivative of:

- 4.4.2E: Mating Systems and Sexual Selection by Boundless; CC-BY-SA 3.0
- Mating System by Wikipedia; CC-BY-SA 3.0
- Animal Reproductive Strategies by Organismal biology; CC-BY-NC-SA

This page titled 6.5: Mating Systems is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

CHAPTER OVERVIEW

7: Population Ecology



Figure 7.1: Image: Tons of Sarnies on the wharf in Rameswar fishing port. (public domain; Rudolph Futado)

It may seem like sardines are, well, packed like sardines in the ocean—the tiny fish travel in schools of millions. But they and other small forage fish like herring and anchovies aren't immune to the effects of commercial fishing. A new study looks at seven species over 25 years and finds that overfishing exacerbates natural boom-and-bust cycles of the fish, which are not only a food source for humans but for countless larger marine animals.

Learning Objectives

- Define population.
- Explain patters between population density and organism size.
- Explain what restricts populations to certain distributions.
- List and provide an example of the various dispersion patterns seen in nature.
- Diagram exponential population growth and logistic population growth explain the circumstances under which each type of growth is expected.
- Describe how density-independent and density-dependent factors regulate populations around their carrying capacity.
- Describe patterns in human population growth.

7.1: Characteristics of Popualtions

7.2: Population Growth and Regulation

7.3: The Human Population

Reference:

Fishing amplifies forage fish population collapses. Essington, T., Moriarty, P., Froehlich, H. Stawitz, C. 2014, The Nature Conservancy, Seattle WA

This page titled 7: Population Ecology is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

7.1: Characteristics of Popualtions

Ecologists define a **population** as a group of individuals of a single species inhabiting an area with the potential to interbreed. Populations are dynamic entities. Their size and composition fluctuate in response to numerous factors, including seasonal and yearly changes in the environment, natural disasters such as forest fires and volcanic eruptions, and competition for resources between and within species. Population studies hold the key to solving practical problems such as saving endangered species, controlling pest populations, and managing fish and game populations. All populations share a number of characteristics including size, density, distribution, dispersion, and age structure. The statistical study of populations is called demography: a set of mathematical tools designed to describe populations and investigate how they change.

Population Size and Density

Populations are characterized by their population **size** (total number of individuals) and their population **density** (number of individuals per unit area). A population may have a large number of individuals that are distributed densely, or sparsely. There are also populations with small numbers of individuals that may be dense or very sparsely distributed in a local area. Population size can affect potential for adaptation because it affects the amount of genetic variation present in the population. Density can have effects on interactions within a population such as competition for food and the ability of individuals to find a mate. Smaller organisms tend to be more densely distributed than larger organisms.

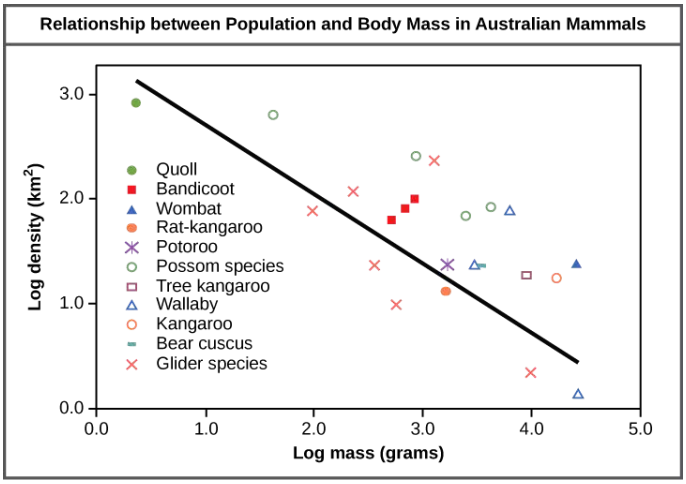


Figure 7.1.1: Populations density decreases with increasing body size for populations of mammals. (CC BY-SA 4.0; via openstax)

Sampling techniques for determining population size and density

The most accurate way to determine population size is to simply count all of the individuals within the habitat. However, this method is often not logistically or economically feasible, especially when studying large habitats. Thus, scientists usually study populations by sampling a representative portion of each habitat and using this data to make inferences about the habitat as a whole. A variety of methods can be used to sample populations to determine their size and density including quadrat sampling, transects, mark and recapture, and camera traps.

For immobile organisms such as plants, or for very small and slow-moving organisms, a **quadrat** may be used (Figure 7.1.1). A quadrat is a way of marking off square areas within a habitat, either by staking out an area with sticks and string, or by the use of a wood, plastic, or metal square placed on the ground. After setting the quadrants, researchers then count the number of individuals that lie within their boundaries. Multiple quadrat samples are performed throughout the habitat at several random locations. All of this data can then be used to estimate the population size and population density within the entire habitat.

For mobile organisms, such as mammals, birds, or fish, a technique called **mark and recapture** is often used (Figure 7.1.2). This method involves marking a sample of captured animals in some way (such as tags, bands, paint, or other body markings), and then releasing them back into the environment to allow them to mix with the rest of the population; later, a new sample is collected, including some individuals that are marked (recaptures) and some individuals that are unmarked (). Using the ratio of marked and

unmarked individuals, scientists determine how many individuals are in the sample. From this, calculations are used to estimate the total population size.

For rare organisms, such as top predators, **camera traps** can can capture wild animals on film when researcher are not present (Figure 7.1.3 and Figure 7.1.4). Camera traps are typically equipped with a motion censor that is automatically triggered by movement in its vicinity. The great advantage of camera traps is that they can record very accurate data without disturbing the photographed animal. They minimally disturb wildlife and can replace the use of more invasive survey and monitoring techniques such as live trap and release. They operate continually and silently, provide proof of species present in an area, can reveal what prints and scats belong to which species, provide evidence for management and policy decisions, and are a cost-effective monitoring tool. Camera traps are helpful in determining behavioral and activity patterns of animals, or recording animal migrations.

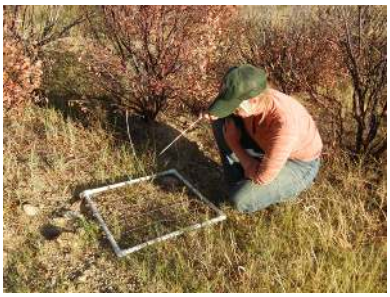


Figure 7.1.1: A scientist uses a quadrat to measure population size and density (credit: NPS Sonoran Desert Network)



(a) (b) (c)

Figure 7.1.2: Mark and recapture is used to measure the population size of mobile animals such as (a) bighorn sheep, (b) the California condor, and (c) salmon. (credit a: modification of work by Neal Herbert, NPS; credit b: modification of work by Pacific Southwest Region USFWS; credit c: modification of work by Ingrid Taylar)



Figure 7.1.3: A camera trap, for taking pictures of game on trails (CC BY-SA 3.0; by Hustvedt via Wikipedia)



Figure 7.1.4: Image of a Leopard in Garhwal Hills of Western Himalaya, India taken with a trap carea (CC BY-SA 3.0; by winterline via Wikipedia)

Population Distribution

While there are few environments on earth without life, no single species can tolerate the full range of earth's environments. Because all species find some environments too warm, too cold, too saline, and so forth, environment limits the geographic distribution of species. **Population distribution** is the geographic area where a particular population of a species occurs. This area of occupancy is determined by the local availability of appropriate habitat. Some species are **habitat generalists** and their populations spread out almost continuously across a landscape. American Robins, for example, can breed in parks, urbanized areas, farms, and the edges of forest. Other species are **habitat specialists** and only occur in specific places where a certain type of

ecosystem occurs. Aquatic species also often occur in isolated populations because their habitat is necessarily bounded by the extent of the lake, wetland, or waterway they occur in.

The Northern Spotted Owl is a subspecies of spotted owl that is a habitat specialist that only occurs in old-growth forests in the Pacific Northwest of North America (British Columbia, Washington, Oregon, California). While much of the Pacific Northwest is still forested, most forests are less than 100 years old and don't have the large, old trees that the owls nest in. The extent of each population of owls is therefore limited by the size of each patch of old growth forest.

A species' **geographic range** is the total geographic area occupied by a species. Bald Eagles can be found breeding in almost every state of the USA and most provinces of Canada. Its geographic range therefore encompasses almost all of North America north of Mexico. In contrast, Golden Eagles breed almost exclusively in western Canada, the western United States, and Mexico. The Golden Eagle's range therefore is restricted to the western part of the continent and Mexico.

A restricted range species refers to a species in which the range is so small, there is basically a single population. For example Kirtland's warblers are habitat specialists only residing in the Jack Pine Forests of northern Michigan and a few adjacent states and Canadian provinces. This results in the population distribution and geographic range is essentially the same. A species' current geographic range is often very different from its **historical range** (Figure 7.1.5). Factors such as habitat loss, hunting, and climate change can all reduce the distribution of populations and the species' overall geographic range. For example, lions previously ranged broadly over Africa, Western Asia, the Middle East and India.

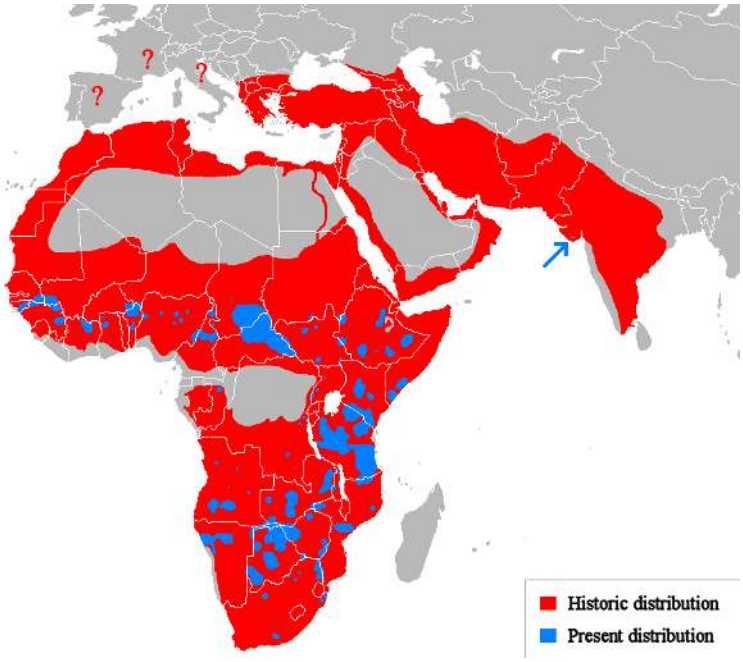


Figure 7.1.5: Historical (red) and present (blue) distribution of lions (*Panthera leo*). Source: Tommyknocker (Wikipedia), based on a map created by 'The African Lion Environmental Research Trust (ALERT).

Population Dispersion

Further information about a population can be obtained by looking at the distribution of the individuals. Species **dispersion patterns** (or distribution patterns) summarize the spatial relationship between members of a population within a habitat at a particular point in time. In other words, they show whether members of the population live close together or far apart, and what patterns are evident when they are spaced apart. On small scales, individuals within populations are distributed in patterns that may be **random**, **regular**, or **clumped**. Patterns of dispersion can be produced by the social interactions within populations, by the structure of the physical environment, or by a combination of the two.

An example of random distribution occurs with dandelion and other plants that have wind-dispersed seeds that germinate wherever they happen to fall in favorable environments (Figure 7.1.6). A clumped 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). Uniform distribution is observed in plants that secrete substances inhibiting the growth of nearby individuals (such as

the release of toxic chemicals by sage plants). It is also seen in territorial animal species, such as penguins that maintain a defined territory for nesting. The territorial defensive behaviors of each individual create a regular pattern of distribution of similar-sized territories and individuals within those territories. Thus, the distribution of the individuals within a population provides more information about how they 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.

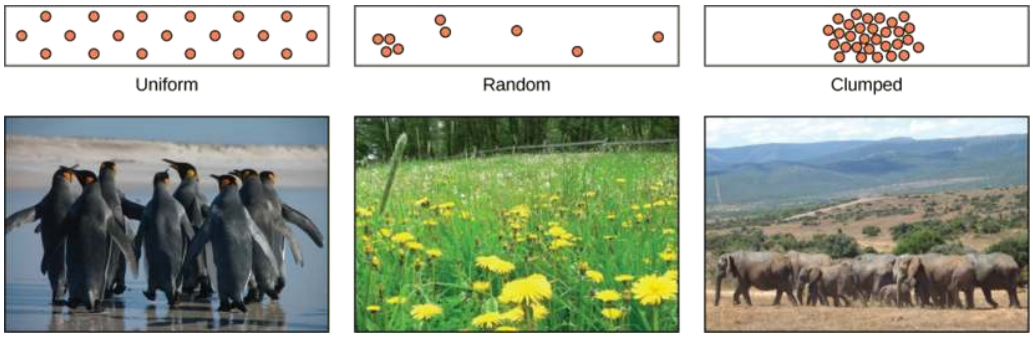


Figure 7.1.6: Species may have uniform, random, or clumped distribution. Territorial birds such as penguins tend to have uniform distribution. Plants such as dandelions with wind-dispersed seeds tend to be randomly distributed. Animals such as elephants that travel in groups exhibit clumped distribution. (credit a: modification of work by Ben Tubby; credit b: modification of work by Rosendahl; credit c: modification of work by Rebecca Wood)

Attribution

This page is a modified derivative of:

- 106 Demographics and Population Growth, via Introductory Biology: Evolutionary and Ecological Perspectives by Various Authors; license CC-BY
- 45.1 Population Demography via Open Stax, license CC-BY
- Camera Trap by Wikipedia, license CC-BY-SA 3.0
- What is population Ecology via Open Stax, CC-BY-NC-SA

This page titled 7.1: Characteristics of Popualtions is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

7.2: Population Growth and Regulation

Population ecologists make use of a variety of methods to model population dynamics. An accurate model should be able to describe the changes occurring in a population and predict future changes.

Population Growth

The two simplest models of population growth use deterministic equations (equations that do not account for random events) to describe the rate of change in the size of a population over time. The first of these models, exponential growth, describes theoretical populations that increase in numbers without any limits to their growth. The second model, logistic growth, introduces limits to reproductive growth that become more intense as the population size increases. Neither model adequately describes natural populations, but they provide points of comparison.

Exponential Growth

Charles Darwin, in developing his theory of natural selection, was influenced by the English clergyman Thomas Malthus. Malthus published his book in 1798 stating that populations with abundant natural resources grow very rapidly; however, they limit further growth by depleting their resources. The early pattern of accelerating population size is called exponential growth.

The best example of exponential growth in organisms is seen in bacteria. Bacteria are prokaryotes that reproduce largely by binary fission. This division takes about an hour for many bacterial species. If 1000 bacteria are placed in a large flask with an abundant supply of nutrients (so the nutrients will not become quickly depleted), the number of bacteria will have doubled from 1000 to 2000 after just an hour. In another hour, each of the 2000 bacteria will divide, producing 4000 bacteria. After the third hour, there should be 8000 bacteria in the flask. The important concept of exponential growth is that the growth rate—the number of organisms added in each reproductive generation—is itself increasing; that is, the population size is increasing at a greater and greater rate. After 24 of these cycles, the population would have increased from 1000 to more than 16 billion bacteria. When the population size, *N*, is plotted over time, a J-shaped growth curve is produced (Figure 7.2.1**a**).

The bacteria-in-a-flask example is not truly representative of the real world where resources are usually limited. However, when a species is introduced into a new habitat that it finds suitable, it may show exponential growth for a while. In the case of the bacteria in the flask, some bacteria will die during the experiment and thus not reproduce; therefore, the growth rate is lowered from a maximal rate in which there is no mortality. The growth rate of a population is largely determined by subtracting the death rate, *D*, (number organisms that die during an interval) from the birth rate, *B*, (number organisms that are born during an interval). The growth rate can be expressed in a simple equation that combines the birth and death rates into a single factor: *r*. This is shown in the following formula:

$$\text{Population growth} = rN$$

The value of *r* can be positive, meaning the population is increasing in size (the rate of change is positive); or negative, meaning the population is decreasing in size; or zero, in which case the population size is unchanging, a condition known as zero population growth.

Logistic Growth

Extended exponential growth is possible only when infinite natural resources are available; this is not the case in the real world. Charles Darwin recognized this fact in his description of the “struggle for existence,” which states that individuals will compete (with members of their own or other species) for limited resources. The successful ones are more likely to survive and pass on the traits that made them successful to the next generation at a greater rate (natural selection). To model the reality of limited resources, population ecologists developed the logistic growth model.

Carrying Capacity and the Logistic Model

In the real world, with its limited resources, exponential growth cannot continue indefinitely. Exponential growth may occur in environments where there are few individuals and plentiful resources, but when the number of individuals gets large enough, resources will be depleted and the growth rate will slow down. Eventually, the growth rate will plateau or level off (Figure 7.2.1**b**). This population size, which is determined by the maximum population size that a particular environment can sustain, is called the

carrying capacity, or *K*. In real populations, a growing population often overshoots its carrying capacity, and the death rate increases beyond the birth rate causing the population size to decline back to the carrying capacity or below it. Most populations usually fluctuate around the carrying capacity in an undulating fashion rather than existing right at it.

The formula used to calculate logistic growth adds the carrying capacity as a moderating force in the growth rate. The expression "*K* – *N*" is equal to the number of individuals that may be added to a population at a given time, and "*K* – *N*" divided by "*K*" is the fraction of the carrying capacity available for further growth. Thus, the exponential growth model is restricted by this factor to generate the logistic growth equation:

$$\text{Population growth} = rN\left[\frac{K-N}{K}\right]$$

Notice that when *N* is almost zero the quantity in brackets is almost equal to 1 (or *K*/*K*) and growth is close to exponential. When the population size is equal to the carrying capacity, or *N* = *K*, the quantity in brackets is equal to zero and growth is equal to zero. A graph of this equation (logistic growth) yields the S-shaped curve (Figure 7.2.1**b**). It is a more realistic model of population growth than exponential growth. There are three different sections to an S-shaped curve. Initially, growth is exponential because there are few individuals and ample resources available. Then, as resources begin to become limited, the growth rate decreases. Finally, the growth rate levels off at the carrying capacity of the environment, with little change in population number over time.

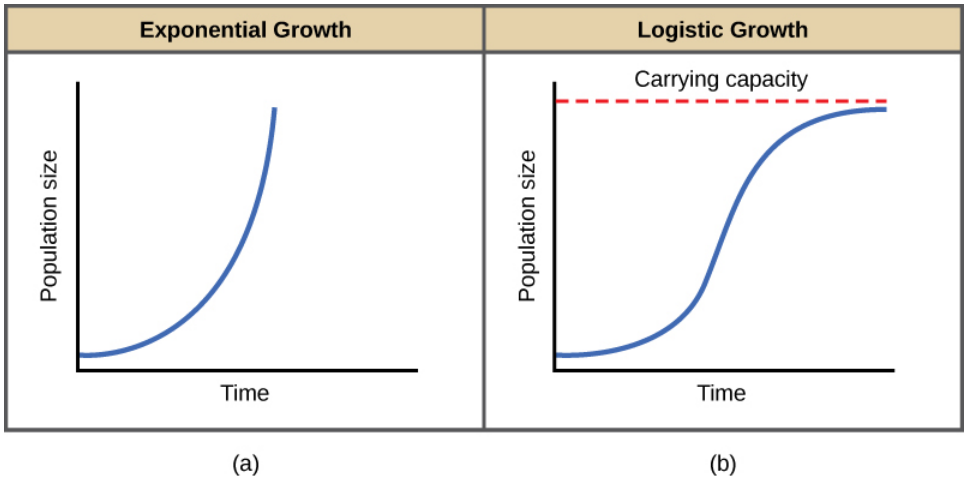


Figure 7.2.1**:** When resources are unlimited, populations exhibit (a) exponential growth, shown in a J-shaped curve. When resources are limited, populations exhibit (b) logistic growth. In logistic growth, population expansion decreases as resources become scarce, and it levels off when the carrying capacity of the environment is reached. The logistic growth curve is S-shaped.

Role of Intraspecific Competition

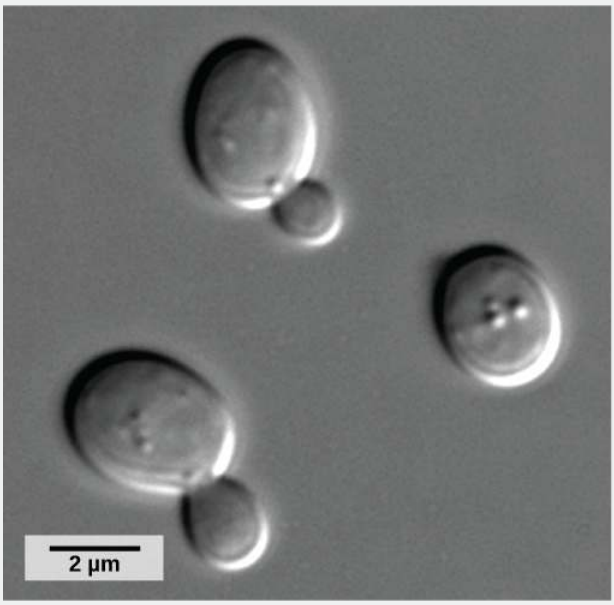
The logistic model assumes that every individual within a population will have equal access to resources and, thus, an equal chance for survival. For plants, the amount of water, sunlight, nutrients, and space to grow are the important resources, whereas in animals, important resources include food, water, shelter, nesting space, and mates.

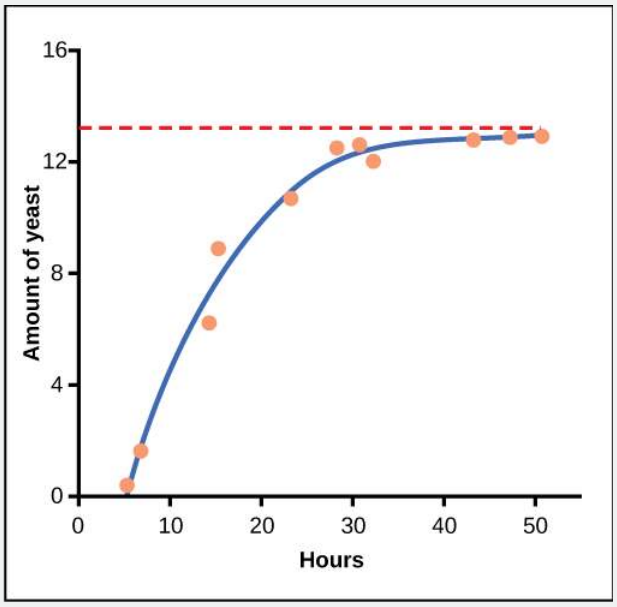
In the real world, phenotypic variation among individuals within a population means that some individuals will be better adapted to their environment than others. The resulting competition for resources among population members of the same species is termed intraspecific competition. Intraspecific competition may not affect populations that are well below their carrying capacity, as resources are plentiful and all individuals can obtain what they need. However, as population size increases, this competition intensifies. In addition, the accumulation of waste products can reduce carrying capacity in an environment.

Examples of Logistic Growth

Yeast, a microscopic fungus used to make bread and alcoholic beverages, exhibits the classical S-shaped curve when grown in a test tube (Figure 7.2.2**a**). Its growth levels off as the population depletes the nutrients that are necessary for its growth. In the real world, however, there are variations to this idealized curve. Examples in wild populations include sheep and harbor seals (Figure 7.2.2**b**). In both examples, the population size exceeds the carrying capacity for short periods of time and then falls below the carrying capacity afterwards. This fluctuation in population size continues to occur as the population oscillates around its carrying capacity. Still, even with this oscillation, the logistic model is confirmed.

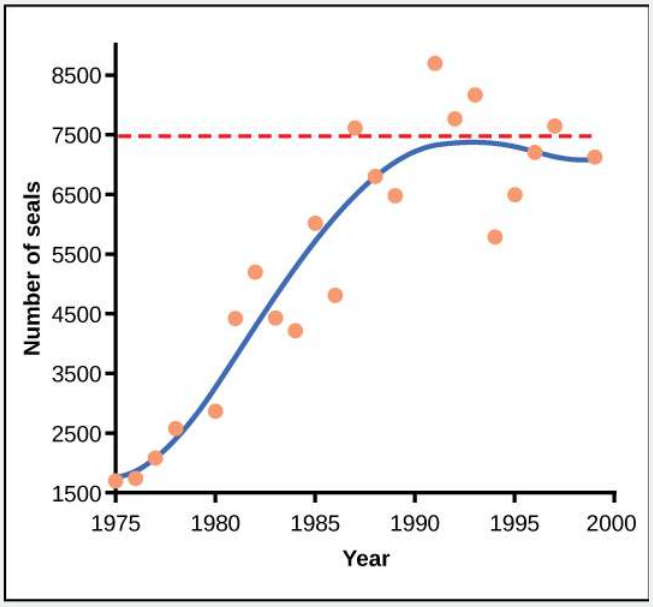
ART CONNECTION





(a)





(b)

Figure 7.2.2**:** (a) Yeast grown in ideal conditions in a test tube shows a classical S-shaped logistic growth curve, whereas (b) a natural population of seals shows real-world fluctuation. The yeast is visualized using differential interference contrast light micrography. (credit a: scale-bar data from Matt Russell)

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 decrease, as would the seal population.
B. The carrying capacity of seals would decrease, but the seal population would remain the same.
C. The number of seal deaths would increase, but the number of births would also increase, so the population size would remain the same.
D. The carrying capacity of seals would remain the same, but the population of seals would decrease.

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 that the carrying capacity of the environment does not change, which is not the case. The carrying capacity varies annually. For example, some summers are hot and dry whereas others are cold and wet; in many areas, the carrying capacity during the winter is much lower than it is during the summer. Also, natural events such as earthquakes, volcanoes, and fires can alter an environment and hence its carrying capacity. Additionally, populations do not usually exist in isolation. They share the environment with other species, competing with them for the same resources (interspecific competition). These factors are also important to understanding how a specific population will grow.

Population growth is regulated in a variety of ways. These are grouped into density-dependent factors, in which the density of the population affects growth rate and mortality, and density-independent factors, which cause mortality in a population regardless of population density. Wildlife biologists, in particular, want to understand both types because this helps them manage populations and prevent extinction or overpopulation.

Density-dependent Regulation

Most density-dependent factors are biological in nature and include predation, inter- and intraspecific competition, and parasites. Usually, the denser a population is, the greater its mortality rate. For example, during intra- and interspecific competition, the reproductive rates of the species will usually be lower, reducing their populations' rate of growth. In addition, low prey density increases the mortality of its predator because it has more difficulty locating its food source. Also, when the population is denser, diseases spread more rapidly among the members of the population, which affect the mortality rate.

Density dependent regulation was studied in a natural experiment with wild donkey populations on two sites in Australia.[1] On one site the population was reduced by a population control program; the population on the other site received no interference. The high-density plot was twice as dense as the low-density plot. From 1986 to 1987 the high-density plot saw no change in donkey density, while the low-density plot saw an increase in donkey density. The difference in the growth rates of the two populations was caused by mortality, not by a difference in birth rates. The researchers found that numbers of offspring birthed by each mother was unaffected by density. Growth rates in the two populations were different mostly because of juvenile mortality caused by the mother's malnutrition due to scarce high-quality food in the dense population. Figure 7.2.3 shows the difference in age-specific mortalities in the two populations.

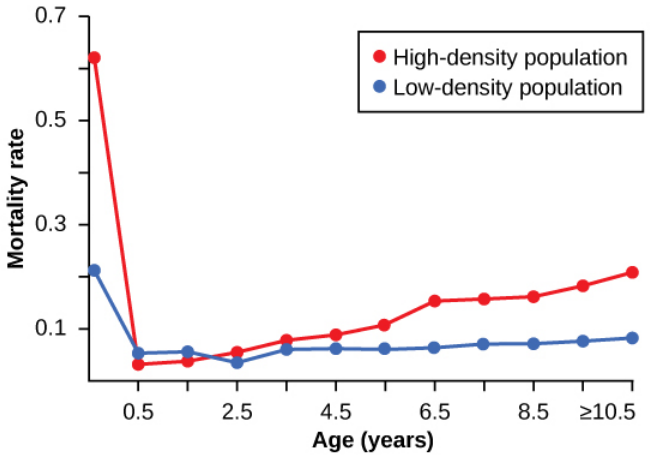


Figure 7.2.3: This graph shows the age-specific mortality rates for wild donkeys from high- and low-density populations. The juvenile mortality is much higher in the high-density population because of maternal malnutrition caused by a shortage of high-quality food.

Density-independent Regulation and Interaction with Density-dependent Factors

Many factors that are typically physical in nature cause mortality of a population regardless of its density. These factors include weather, natural disasters, and pollution. An individual deer will be killed in a forest fire regardless of how many deer happen to be in that area. Its chances of survival are the same whether the population density is high or low. The same holds true for cold winter weather.

In real-life situations, population regulation is very complicated and density-dependent and independent factors can interact. A dense population that suffers mortality from a density-independent cause will be able to recover differently than a sparse population. For example, a population of deer affected by a harsh winter will recover faster if there are more deer remaining to reproduce.

EVOLUTION IN ACTION: Why Did the Woolly Mammoth Go Extinct?

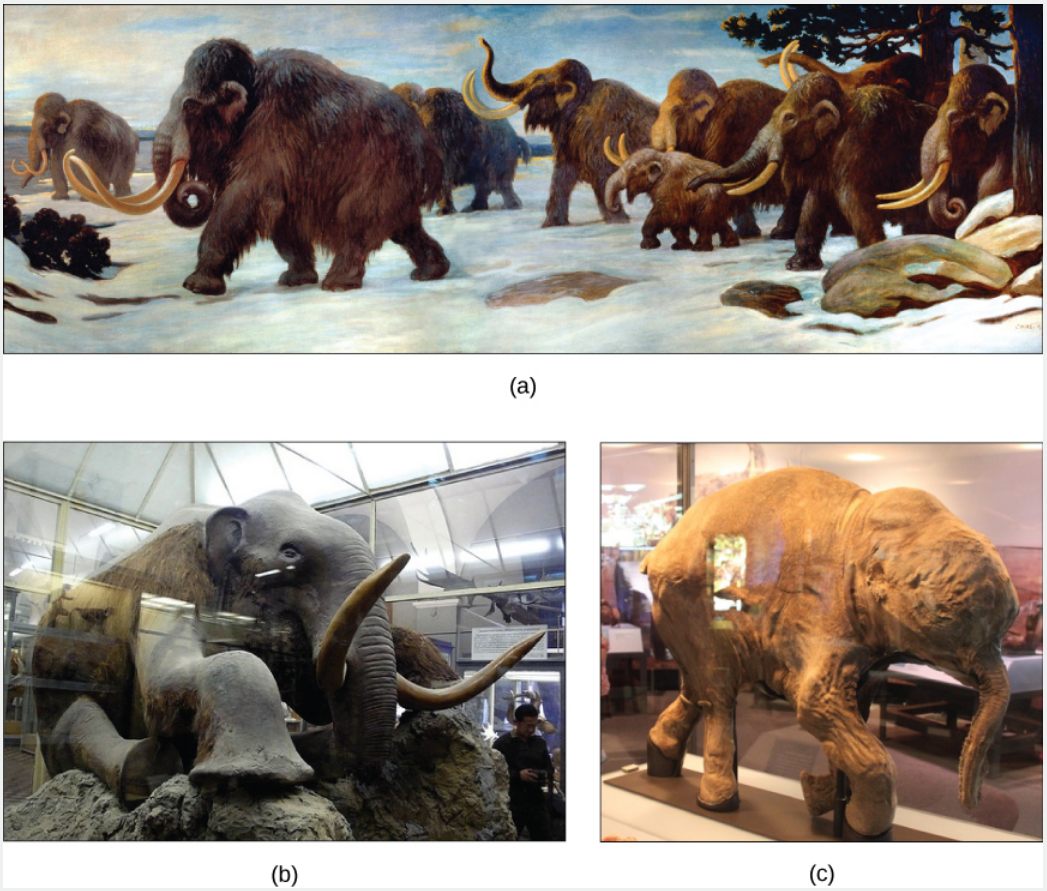


Figure 7.2.4**:** The three images include: (a) 1916 mural of a mammoth herd from the American Museum of Natural History, (b) the only stuffed mammoth in the world is in the Museum of Zoology located in St. Petersburg, Russia, and (c) a one-month-old baby mammoth, named Lyuba, discovered in Siberia in 2007. (credit a: modification of work by Charles R. Knight; credit b: modification of work by "Tanapon"/Flickr; credit c: modification of work by Matt Howry)

Woolly mammoths began to go extinct about 10,000 years ago, soon after paleontologists believe humans able to hunt them began to colonize North America and northern Eurasia (Figure 7.2.4). A mammoth population survived on Wrangel Island, in the East Siberian Sea, and was isolated from human contact until as recently as 1700 BC. We know a lot about these animals from carcasses found frozen in the ice of Siberia and other northern regions.

It is commonly thought that climate change and human hunting led to their extinction. A 2008 study estimated that climate change reduced the mammoth's range from 3,000,000 square miles 42,000 years ago to 310,000 square miles 6,000 years ago.[2] Through archaeological evidence of kill sites, it is also well documented that humans hunted these animals. A 2012 study concluded that no single factor was exclusively responsible for the extinction of these magnificent creatures.[3] In addition to climate change and reduction of habitat, scientists demonstrated another important factor in the mammoth's extinction was the migration of human hunters across the Bering Strait to North America during the last ice age 20,000 years ago.

The maintenance of stable populations was and is very complex, with many interacting factors determining the outcome. It is important to remember that humans are also part of nature. Once we contributed to a species' decline using primitive hunting technology only.

Demographic-Based Population Models

Population ecologists have hypothesized that suites of characteristics may evolve in species that lead to particular adaptations to their environments. These adaptations impact the kind of population growth their species experience. Life history characteristics such as birth rates, age at first reproduction, the numbers of offspring, and even death rates evolve just like anatomy or behavior, leading to adaptations that affect population growth. Population ecologists have described a continuum of life-history "strategies" with *K*-selected species on one end and *r*-selected species on the other. *K*-selected species are adapted to stable, predictable environments. Populations of *K*-selected species tend to exist close to their carrying capacity. These species tend to have larger, but fewer, offspring and contribute large amounts of resources to each offspring. Elephants would be an example of a *K*-selected species. *r*-selected species are adapted to unstable and unpredictable environments. They have large numbers of small offspring. Animals that are *r*-selected do not provide a lot of resources or parental care to offspring, and the offspring are relatively self-sufficient at birth. Examples of *r*-selected species are marine invertebrates such as jellyfish and plants such as the dandelion. The two extreme strategies are at two ends of a continuum on which real species life histories will exist. In addition, life history strategies do not need to evolve as suites, but can evolve independently of each other, so each species may have some characteristics that trend toward one extreme or the other.

Section Summary

Populations with unlimited resources grow exponentially—with an accelerating growth rate. When resources become limiting, populations follow a logistic growth curve in which population size will level off at the carrying capacity.

Populations are regulated by a variety of density-dependent and density-independent factors. Life-history characteristics, such as age at first reproduction or numbers of offspring, are characteristics that evolve in populations just as anatomy or behavior can evolve over time. The model of *r*- and *K*-selection suggests that characters, and possibly suites of characters, may evolve adaptations to population stability near the carrying capacity (*K*-selection) or rapid population growth and collapse (*r*-selection). Species will exhibit adaptations somewhere on a continuum between these two extremes.

Art Exercise

Figure 7.2.2: 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 decrease, as would the seal population.
B. The carrying capacity of seals would decrease, but the seal population would remain the same.
C. The number of seal deaths would increase, but the number of births would also increase, so the population size would remain the same.
D. The carrying capacity of seals would remain the same, but the population of seals would decrease.

Answer

A: The carrying capacity of seals would decrease, as would the seal population.

Footnotes

1. 1 David Choquenot, "Density-Dependent Growth, Body Condition, and Demography in Feral Donkeys: Testing the Food Hypothesis," *Ecology* 72, no. 3 (June 1991):805–813.
2. 2 David Nogués-Bravo et al., "Climate Change, Humans, and the Extinction of the Woolly Mammoth." *PLoS Biol* 6 (April 2008): e79, doi:10.1371/journal.pbio.0060079.
3. 3 G.M. MacDonald et al., "Pattern of Extinction of the Woolly Mammoth in Beringia." *Nature Communications* 3, no. 893 (June 2012), doi:10.1038/ncomms1881.

Glossary

birth rate

the number of births within a population at a specific point in time

carrying capacity

the maximum number of individuals of a population that can be supported by the limited resources of a habitat

death rate
the number of deaths within a population at a specific point in time

density-dependent regulation
the regulation of population in which birth and death rates are dependent on population size

density-independent regulation
the regulation of population in which the death rate is independent of the population size

exponential growth
an accelerating growth pattern seen in populations where resources are not limiting

intraspecific competition
the competition among members of the same species

J-shaped growth curve
the shape of an exponential growth curve

***K*-selected species**
a species suited to stable environments that produce a few, relatively large offspring and provide parental care

logistic growth
the leveling off of exponential growth due to limiting resources

***r*-selected species**
a species suited to changing environments that produce many offspring and provide little or no parental care

S-shaped growth curve
the shape of a logistic growth curve

zero population growth
the steady population size where birth rates and death rates are equal

Contributors and Attributions

- Samantha Fowler (Clayton State University), Rebecca Roush (Sandhills Community College), James Wise (Hampton University). Original content by OpenStax (CC BY 4.0; Access for free at https://cnx.org/contents/b3c1e1d2-83...4-e119a8aafbdd).

This page titled 7.2: Population Growth and Regulation is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **19.2: Population Growth and Regulation** by OpenStax is licensed CC BY 4.0.

7.3: The Human Population

Concepts of animal population dynamics can be applied to human population growth. Humans are not unique in their ability to alter their environment. For example, beaver dams alter the stream environment where they are built. Humans, however, have the ability to alter their environment to increase its carrying capacity, sometimes to the detriment of other species. Earth's human population and their use of resources are growing rapidly, to the extent that some worry about the ability of Earth's environment to sustain its human population. Long-term exponential growth carries with it the potential risks of famine, disease, and large-scale death, as well as social consequences of crowding such as increased crime.

Human technology and particularly our harnessing of the energy contained in fossil fuels have caused unprecedented changes to Earth's environment, altering ecosystems to the point where some may be in danger of collapse. Changes on a global scale including depletion of the ozone layer, desertification and topsoil loss, and global climate change are caused by human activities.

The world's human population is presently growing exponentially (Figure 7.3.1).

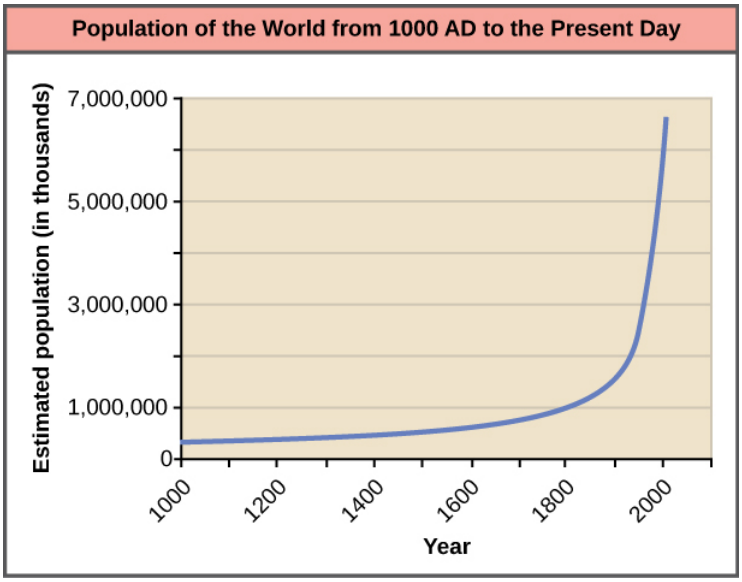


Figure 7.3.1: Human population growth since 1000 AD is exponential.

A consequence of exponential growth rate is that the time that it takes to add a particular number of humans to the population is becoming shorter. Figure 7.3.2 shows that 123 years were necessary to add 1 billion humans between 1804 and 1930, but it only took 24 years to add the two billion people between 1975 and 1999. This acceleration in growth rate will likely begin to decrease in the coming decades. Despite this, the population will continue to increase and the threat of overpopulation remains, particularly because the damage caused to ecosystems and biodiversity is lowering the human carrying capacity of the planet.

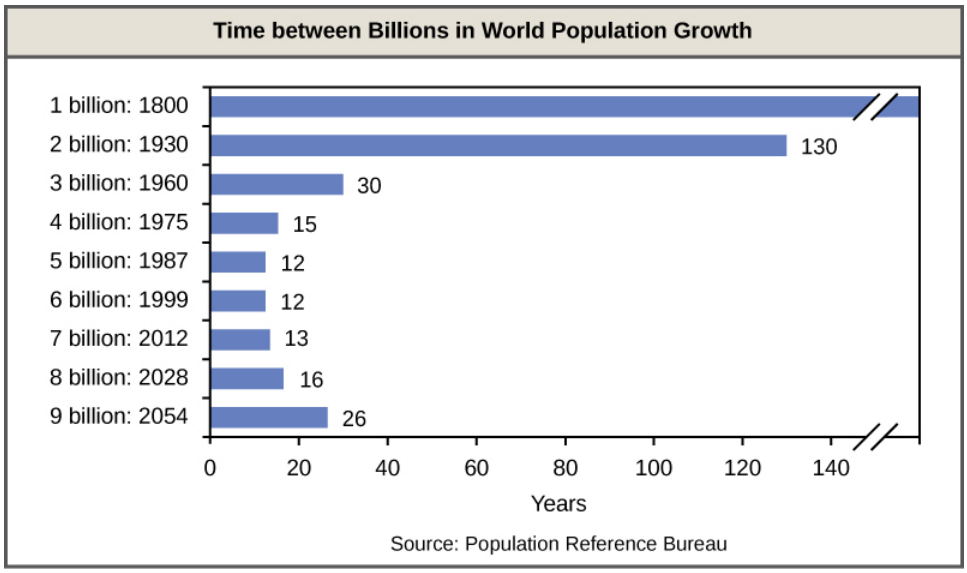


Figure 7.3.2: The time between the addition of each billion human beings to Earth decreases over time. (credit: modification of work by Ryan T. Cragun)

CONCEPT IN ACTION



Watch this video of how human populations have changed over time.

Overcoming Density-Dependent Regulation

Humans are unique in their ability to alter their environment in myriad ways. This ability is responsible for human population growth because it resets the carrying capacity and overcomes density-dependent growth regulation. Much of this ability is related to human intelligence, society, and communication. Humans construct shelters to protect themselves from the elements and have developed agriculture and domesticated animals to increase their food supplies. In addition, humans use language to communicate this technology to new generations, allowing them to improve upon previous accomplishments.

Other factors in human population growth are migration and public health. Humans originated in Africa, but we have since migrated to nearly all inhabitable land on Earth, thus, increasing the area that we have colonized. Public health, sanitation, and the use of antibiotics and vaccines have decreased the ability of infectious disease to limit human population growth in developed countries. In the past, diseases such as the bubonic plaque of the fourteenth century killed between 30 and 60 percent of Europe's population and reduced the overall world population by as many as one hundred million people. Infectious disease continues to have an impact on human population growth. For example, life expectancy in sub-Saharan Africa, which was increasing from 1950 to 1990, began to decline after 1985 largely as a result of HIV/AIDS mortality. The reduction in life expectancy caused by HIV/AIDS was estimated to be 7 years for 2005.[1]

Declining life expectancy is an indicator of higher mortality rates and leads to lower birth rates.

The fundamental cause of the acceleration of growth rate for humans in the past 200 years has been the reduced death rate due to a development of the technological advances of the industrial age, urbanization that supported those technologies, and especially the exploitation of the energy in fossil fuels. Fossil fuels are responsible for dramatically increasing the resources available for human population growth through agriculture (mechanization, pesticides, and fertilizers) and harvesting wild populations.

Age Structure, Population Growth, and Economic Development

The age structure of a population is an important factor in population dynamics. Age structure is the proportion of a population in different age classes. Models that incorporate age structure allow better prediction of population growth, plus the ability to associate this growth with the level of economic development in a region. Countries with rapid growth have a pyramidal shape in their age structure diagrams, showing a preponderance of younger individuals, many of whom are of reproductive age (Figure 7.3.3). This pattern is most often observed in underdeveloped countries where individuals do not live to old age because of less-than-optimal living conditions, and there is a high birth rate. Age structures of areas with slow growth, including developed countries such as the United States, still have a pyramidal structure, but with many fewer young and reproductive-aged individuals and a greater proportion of older individuals. Other developed countries, such as Italy, have zero population growth. The age structure of these populations is more conical, with an even greater percentage of middle-aged and older individuals. The actual growth rates in different countries are shown in Figure 7.3.3, with the highest rates tending to be in the less economically developed countries of Africa and Asia.

ART CONNECTION

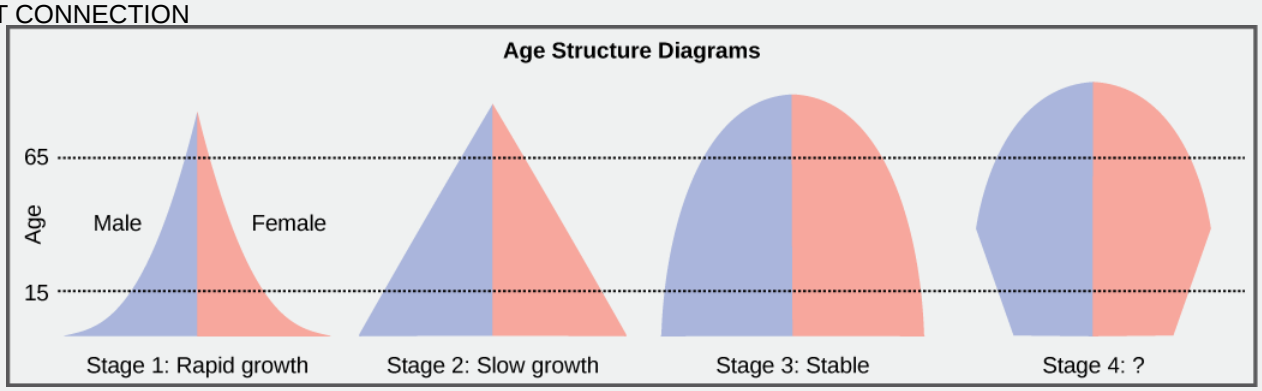


Figure 7.3.3: Typical age structure diagrams are shown. The rapid growth diagram narrows to a point, indicating that the number of individuals decreases rapidly with age. In the slow growth model, the number of individuals decreases steadily with age. Stable population diagrams are rounded on the top, showing that the number of individuals per age group decreases gradually, and then increases for the older part of the population.

Age structure diagrams for rapidly growing, slow growing, and stable populations are shown in stages 1 through 3. What type of population change do you think stage 4 represents?

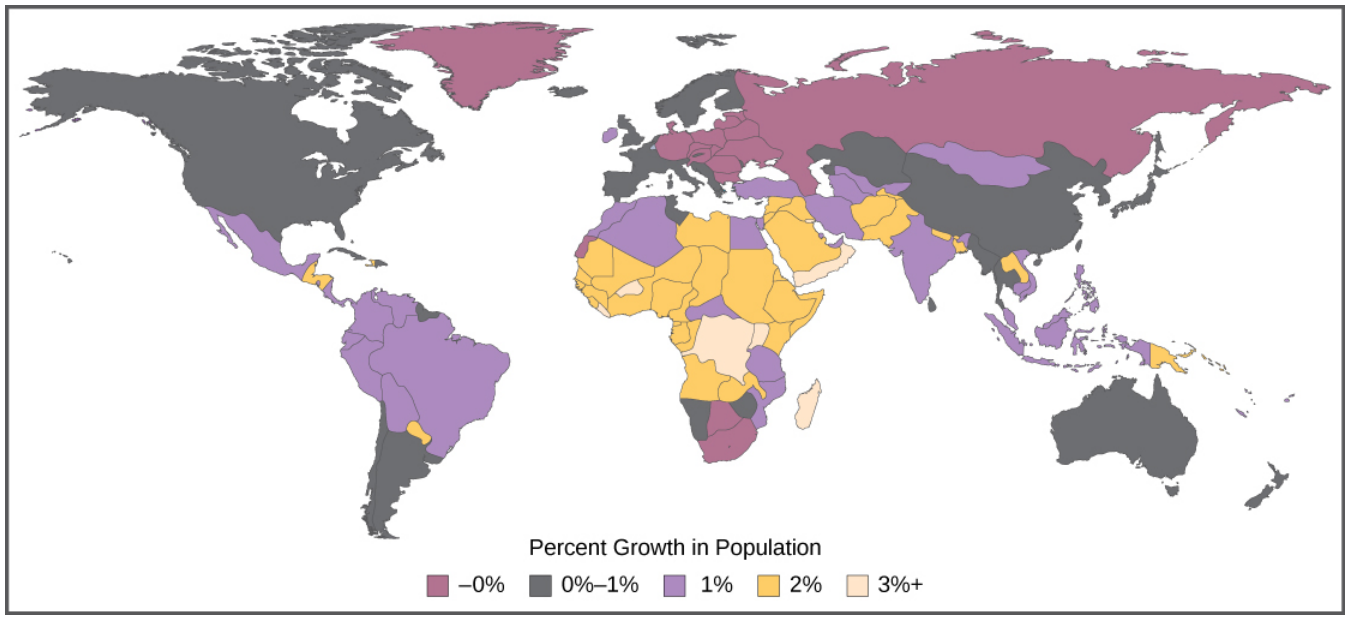


Figure 7.3.4: The percent growth rate of population in different countries is shown. Notice that the highest growth is occurring in less economically developed countries in Africa and Asia.

Long-Term Consequences of Exponential Human Population Growth

Many dire predictions have been made about the world's population leading to a major crisis called the "population explosion." In the 1968 book *The Population Bomb*, biologist Dr. Paul R. Ehrlich wrote, "The battle to feed all of humanity is over. In the 1970s hundreds of millions of people will starve to death in spite of any crash programs embarked upon now. At this late date nothing can prevent a substantial increase in the world death rate."[2] While many critics view this statement as an exaggeration, the laws of exponential population growth are still in effect, and unchecked human population growth cannot continue indefinitely.

Efforts to moderate population control led to the one-child policy in China, which imposes fines on urban couples who have more than one child. Due to the fact that some couples wish to have a male heir, many Chinese couples continue to have more than one child. The effectiveness of the policy in limiting overall population growth is controversial, as is the policy itself. Moreover, there are stories of female infanticide having occurred in some of the more rural areas of the country. Family planning education programs in other countries have had highly positive effects on limiting population growth rates and increasing standards of living. In spite of population control policies, the human population continues to grow. Because of the subsequent need to produce more and more food to feed our population, inequalities in access to food and other resources will continue to widen. The United Nations estimates the future world population size could vary from 6 billion (a decrease) to 16 billion people by the year 2100. There is no way to know whether human population growth will moderate to the point where the crisis described by Dr. Ehrlich will be averted.

Another consequence of population growth is the change and degradation of the natural environment. Many countries have attempted to reduce the human impact on climate change by limiting their emission of greenhouse gases. However, a global climate change treaty remains elusive, and many underdeveloped countries trying to improve their economic condition may be less likely to agree with such provisions without compensation if it means slowing their economic development. Furthermore, the role of human activity in causing climate change has become a hotly debated socio-political issue in some developed countries, including the United States. Thus, we enter the future with considerable uncertainty about our ability to curb human population growth and protect our environment to maintain the carrying capacity for the human species.

Art Connections

Figure 7.3.3: Age structure diagrams for rapidly growing, slow growing, and stable populations are shown in stages 1 through 3. What type of population change do you think stage 4 represents?

Answer

Stage 4 represents a population that is decreasing.

Footnotes

1. 1 Danny Dorling, Mary Shaw, and George Davey Smith, “Global Inequality of Life Expectancy due to AIDS,” *BMJ* 332, no. 7542 (March 2006): 662-664, doi: 10.1136/bmj.332.7542.662.
2. 2 Paul R. Erlich, prologue to *The Population Bomb*, (1968; repr., New York: Ballantine, 1970).

Glossary

age structure
the distribution of the proportion of population members in each age class

one-child policy
a policy in China to limit population growth by limiting urban couples to have only one child or face a penalty of a fine

Contributors and Attributions

- Samantha Fowler (Clayton State University), Rebecca Roush (Sandhills Community College), James Wise (Hampton University). Original content by OpenStax (CC BY 4.0; Access for free at https://cnx.org/contents/b3c1e1d2-83...4-e119a8aafbdd).

This page titled 7.3: The Human Population is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **19.3: The Human Population** by OpenStax is licensed CC BY 4.0.

CHAPTER OVERVIEW

8: Species Interactions in Communities



Figure 8.1: The toxic rough-skinned newt may be one of the most poisionious animals in the world. However a common garter snake doesn't have much of a problem consuming them for dinner. These snakes have evolved resistance to the poison, tetrodotoxin (TTX), by preying on rough-skinned newts, which secrete the toxin. Some newts are so poisonous that they harbor enough TTX to kill a roomful of adult humans. Why would a small animal produce such an excessive amount of poison? The answer lies in the evolutionary back-and-forth between a predator and its prey. (CC BY 2.0; BLM via Flickr)

Community ecology is an expanding and rich subfield of ecology. Ecologists investigate the factors that influence biodiversity, community structure, and the distribution and abundance of species. These factors include interactions with the abiotic world and the diverse array of interactions that occur between species. In this chapter we will explore the varied ways in which species interact with one another and the consequences of these interactions.

Learning Objectives

- Define and classify species interactions based on their outcomes: positive (+), negative (-), or neutral (0)
- Define and provide examples of exploitative interactions.
- Provide examples of defense mechanisms against predation and herbivory.
- Distinguish between intra-specific and inter-specific interactions.
- Explain the competitive exclusion principle and the possible outcomes of inter-specific competition.
- Explain evolutionary arms races between predators/prey, and herbivores/plants and the resulting adaptations of each group.
- Provide examples of mutualisms.

8.1: A summary of Interactions

8.2: Exploitative Interactions

8.3: Competition

8.4: Commensalism and Mutualism

8.5: Symbiosis

This page titled 8: Species Interactions in Communities is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

8.1: A summary of Interactions

Introduction to Communities

Populations rarely, if ever, live in isolation from populations of other species. All populations occupying the same habitat form a **community** (populations of multiple species inhabiting a specific area at the same time). The number of species occupying the same habitat and their relative abundance is known as species diversity. Areas with low diversity, such as the glaciers of Antarctica, still contain a wide variety of living things, and those living things interact with one another. In ecology, a **biological interaction** is the effect that a pair of organisms living together in a community have on each other. Interactions may involve direct contact such as a predator consuming its prey, or indirect such as two bird species competing for the same seeds to eat. Such interactions among different species play a major role in regulating population growth and abundance. Ecology is studied at the community level to understand how species interact with each other and compete for the same resources.

Definition: Community Ecology

In ecology, a community is a group or association of populations of two or more different species occupying the same geographical area at the same time. Ecologists investigate the factors that influence biodiversity, community structure, and the distribution and abundance of species. These factors include interactions with the abiotic world and the diverse array of interactions that occur between species.

A **species interaction** is the effect that a pair of organisms living together in a community have on each other. They can be either of the same species (**intraspecific interactions**), or of different species (**interspecific interactions**). Interactions between organisms can result in positive (+), negative (-), or neutral (0) outcomes; in ecology the pairwise combinations of these are defined as:

- competition (-/-)
- predation (+/-)
- mutualism (+/+)
- commensalism (+/0)
- amensalism (-/0)
- neutralism (0/0)

All of these interactions can be organized by the effects the species have on each other (Figure 8.1.1).

Species interactions may be short-term, like pollination and predation, or long-term; both often strongly influence the evolution of the species involved. Short-term interactions are short-lived in terms of the duration of a single interaction: a predator kills and eats a prey; a pollinator transfers pollen from one flower to another; but they are extremely durable in terms of their influence on the evolution of both partners. As a result, the partners coevolve.

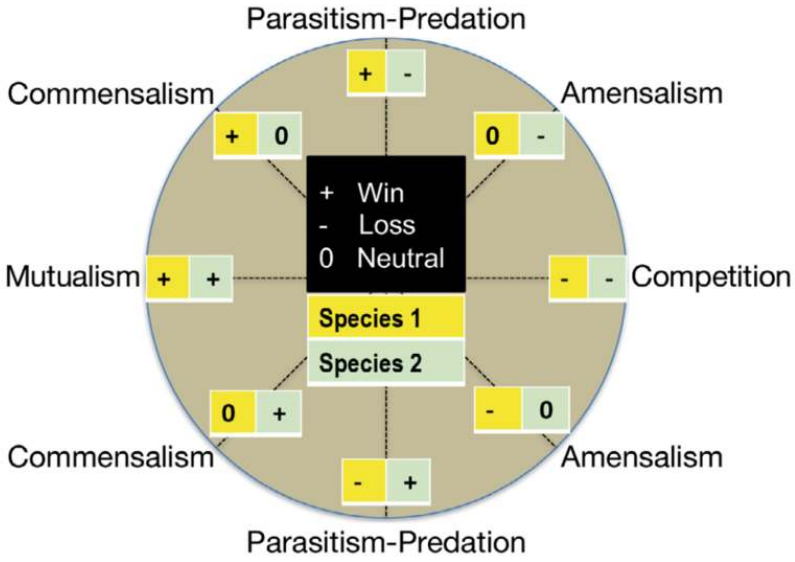


Figure 8.1.1: Summary of species interactions, showing how each species is impacted by the interaction. (CC-BY-SA-4.0; Anders K. Krabberød, Marit F. M. Bjorbækmo, Kamran Shalchian-Tabrizi, Ramiro Logares, via Wikimedia)

Competition can be defined as an interaction with negative effects on both species that require the same limited resource to survive, grow, and reproduce. Competition, is generally divided into **intraspecific competition**, competition between individuals of the same species, and **interspecific competition**, competition between individuals of different species. Competition can take the form of interference competition, involving direct interactions between individuals; or resource competition, in which individuals compete through their dependence on the same limiting resources.

We have already explored the affects of intraspecific competition in the form of logistic population growth. Competition between members of the same species for recourses in the environment affects the growth rate (r) of the population, and generally limits the population to its carrying capacity (K).

The diversity of interactions between herbivores and plants, between predators and prey, and between parasites, parasitoids, pathogens, and hosts can be grouped under the heading of **exploitative interactions**—interactions between species that enhance the fitness of one individual at the expense of another. These interactions are also known as enemy-victim interactions because one organism (the enemy) is the consumer of another (the victim), In exploitative interactions, the enemy and victim often coevolve with each other.

Mutualism, interactions between individuals that benefit both partners, is a common phenomenon in nature that has apparently made important contributions to the evolutionary history of life and continues to make key contributions to the ecological integrity of the biosphere. Mutualisms can be divided into those that are facultative, where species can live without their mutualistic partners, and obligate, where species are so dependent on the mutualistic relationship that they cannot live without their mutualistic partners.

Attribution

This Page is a modified derivative of:

- Chapter 14: Introduction to Species Interactions; CC BY-NC-SA
- 45.6: Community Ecology by OpenStax, is licensed CC BY

This page titled 8.1: A summary of Interactions is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

8.2: Exploitative Interactions

Exploitative interactions include the diversity of interactions in which the fitness of one individual is enhanced at the expense of another, such as between a predator and its prey. This interaction benefits the fitness of the predator who gets a meal (+), while the prey suffers a strong fitness cost as it does not survive the interaction (-). Not all exploitative interactions have such extreme fitness consequences, however. Take for example, the interaction between a mosquito and a human. The mosquito experiences a fitness benefit through obtaining a meal, while the fitness cost to the human (assuming no diseases were transferred such as malaria) in the form of insignificant blood loss and an annoying itchy bump is quite minimal. Thus, exploitative interactions exist over a range of fitness benefits and costs and include a diversity of interactions such as those found between herbivores and plants, between predators and prey, and between parasites, parasitoids, pathogens, and their hosts.

Predation

Populations of predator and prey can have significant effects on one other. Predators can reduce the population sizes of their prey which can in turn affect other members of the communities. Predators and prey can become locked into evolutionary arms races where both predatory and prey experience strong selective pressure to either capture prey, or escape predation.

Definition: Predation

A Predation is a biological interaction where one species, the predator, kills and eats members of another species, its prey.

Populations of predators and prey in a community are not constant over time: in most cases, they vary in cycles that appear to be related. The most often cited example of predator-prey dynamics is seen in the cycling of the lynx (predator) and the snowshoe hare (prey), using nearly 200 year-old trapping data from North American forests (Figure 8.2.1). This cycle of predator and prey lasts approximately 10 years, with the predator population lagging 1–2 years behind that of the prey population. As the hare numbers increase, there is more food available for the lynx, allowing the lynx population to increase as well. When the lynx population grows to a threshold level, however, they kill so many hares that hare population begins to decline, followed by a decline in the lynx population because of scarcity of food. When the lynx population is low, the hare population size begins to increase due, at least in part, to low predation pressure, starting the cycle anew.

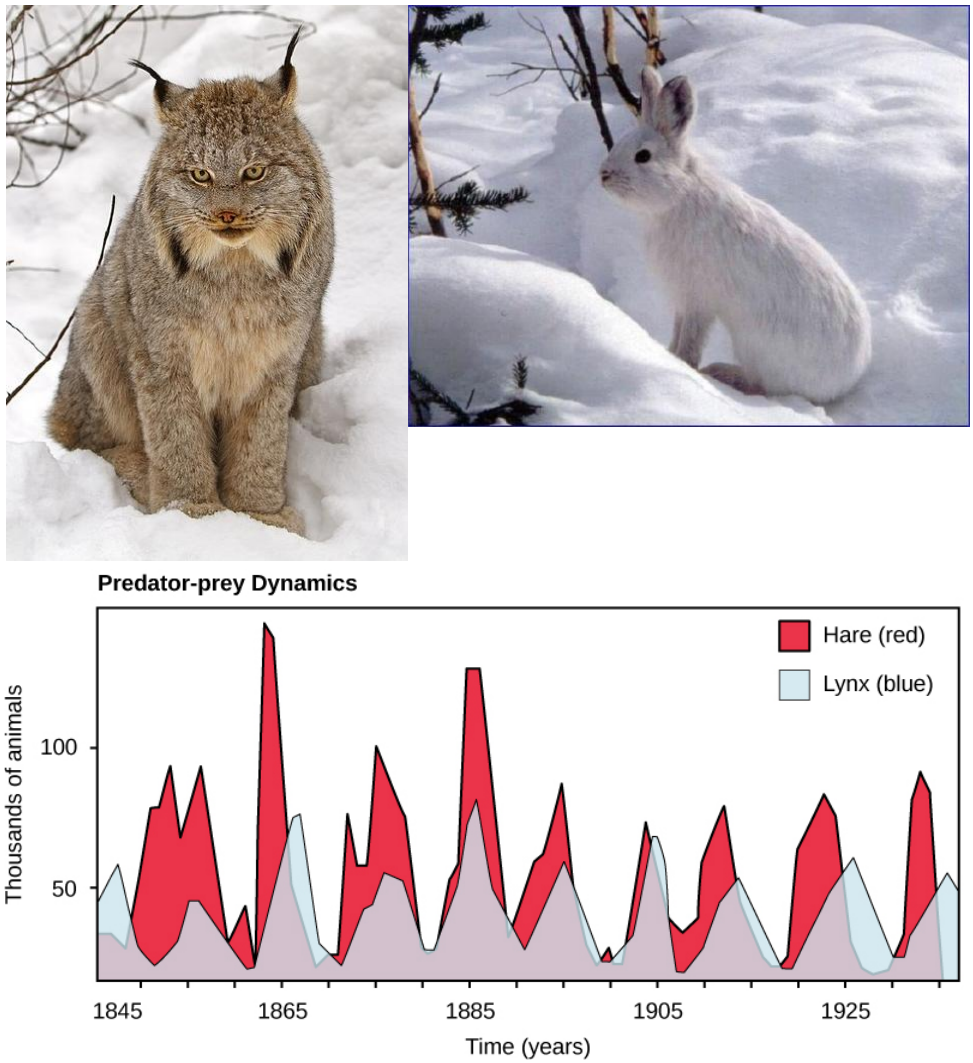


Figure 8.2.1: The cycling of lynx and snowshoe hare populations in Northern Ontario is an example of predator-prey dynamics. (CC-BY via OpenStax

Some researchers question the idea that predation models entirely control the population cycling of the two species. More recent studies have pointed to undefined density-dependent factors as being important in the cycling, in addition to predation. One possibility is that the cycling is inherent in the hare population due to density-dependent effects such as lower fecundity (maternal stress) caused by crowding when the hare population gets too dense. The hare cycling would then induce the cycling of the lynx because it is the lynxes' major food source. The more we study communities, the more complexities we find, allowing ecologists to derive more accurate and sophisticated models of population dynamics.

Parasitoids represent a special kind of predator. Parasitoids lay their eggs on or inside other animals, especially insects, and the eggs hatch into larvae that consume the host individual from the inside, eventually killing it. Most parasitoid species are wasps and flies.

Herbivory

Herbivory describes the consumption of plants by insects and other animals, and it is another interspecific relationship that affects populations. Herbivory, reduces the fitness of the plants being consumed, but is often not fatal. Still many plants have developed mechanisms to defend against herbivory such as spines, or toxic chemicals.

Definition: Herbivory

The consumption of one species (a plant) by another species (an animal) as a food source. The plant suffers a fitness cost, but often survives the interaction.

Defense Mechanisms against Predation and Herbivory

Predation and predator avoidance are strong selective agents. Any heritable character that allows an individual of a prey population to better evade its predators will be represented in greater numbers in later generations. Likewise, traits that allow a predator to more efficiently locate and capture its prey will lead to a greater number of offspring and an increase in the commonness of the trait within the population. Such ecological relationships between specific populations lead to adaptations that are driven by reciprocal evolutionary responses in those populations. Species have evolved numerous mechanisms to escape predation and herbivory (the consumption of plants for food). Defenses may be mechanical, chemical, physical, or behavioral.

Mechanical defenses, such as the presence of armor in animals or thorns in plants, discourage predation and herbivory by discouraging physical contact (Figure 8.2.2 a and b). Many animals produce or obtain **chemical defenses** from plants and store them to prevent predation. Many plant species produce secondary plant compounds that serve no function for the plant except that they are toxic to animals and discourage consumption. For example, the foxglove produces several compounds, including digitalis, that are extremely toxic when eaten (Figure 8.2.2 c).

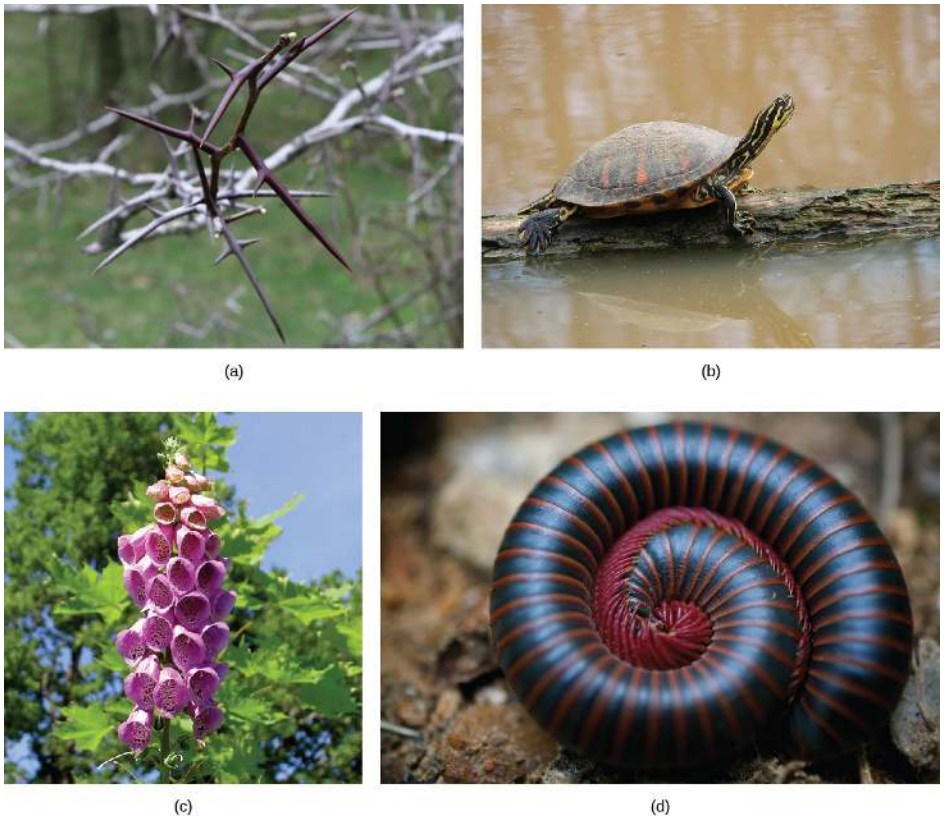


Figure 8.2.2: The (a) honey locust tree (*Gleditsia triacanthos*) uses thorns, a mechanical defense, against herbivores, while the (b) Florida red-bellied turtle (*Pseudemys nelsoni)* uses its shell as a mechanical defense against predators. (c) Foxglove (*Digitalis* sp.) uses a chemical defense: toxins produced by the plant can cause nausea, vomiting, hallucinations, convulsions, or death when consumed. (d) The North American millipede (*Narceus americanus*) uses both mechanical and chemical defenses: when threatened, the millipede curls into a defensive ball and produces a noxious substance that irritates eyes and skin. (credit a: modification of work by Huw Williams; credit b: modification of work by "JamieS93"/Flickr; credit c: modification of work by Philip Jägenstedt; credit d: modification of work by Cory Zanker). (CC-BY; via OpenStax)

Many species use physical appearance, such as body shape and coloration, to avoid being detected by predators. The tropical walking stick is an insect with the coloration and body shape of a twig which makes it very hard to see when stationary against a background of real twigs (Figure 8.2.3 a). In another example, the chameleon can, within limitations, change its color to match its

surroundings (Figure 8.2.3 b). Both of these are examples of **camouflage**, or avoiding detection by blending in with the background. There are many behavioral adaptations to avoid or confuse predators. Playing dead and traveling in large groups, like schools of fish or flocks of birds, are both behaviors that reduce the risk of being eaten.



(a) (b)

Figure 8.2.3: The tropical walking stick (a) and the chameleon (b) use body shape and/or coloration to prevent detection by predators. (credit a: modification of work by Linda Tanner; credit b: modification of work by Frank Vassen) (CC-BY; via OpenStax)

Some species use coloration as a way of warning predators that they are distasteful or poisonous. For example, the monarch butterfly caterpillar sequesters poisons from its food (plants and 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. Fire-bellied toads produce toxins that make them distasteful to their potential predators. They have bright red or orange coloration on their bellies, which they display to a potential predator to advertise their poisonous nature and discourage an attack. These are only two examples of **warning coloration**, which is a relatively common adaptation. Warning coloration only works if a predator uses eyesight to locate prey and can learn—a naïve predator must experience the negative consequences of eating one before it will avoid other similarly colored individuals (Figure 8.2.4).



(a) (b)

Figure 8.2.4: The strawberry poison dart frog (*Oophaga pumilio*) (a) uses aposematic coloration to warn predators that it is toxic, while the striped skunk (*Mephitis mephitis*) (b) uses aposematic coloration to warn predators of the unpleasant odor it produces. (credit a: modification of work by Jay Iwasaki; credit b: modification of work by Dan Dzurisin) (CC-BY; via OpenStax)

While some predators learn to avoid eating certain potential prey because of their coloration, other species have evolved mechanisms to mimic this coloration to avoid being eaten, even though they themselves may not be unpleasant to eat or contain toxic chemicals. In **Batesian mimicry**, a harmless species imitates the warning coloration of a harmful one. Assuming they share the same predators, this coloration then protects the harmless ones, even though they do not have the same level of physical or chemical defenses against predation as the organism they mimic. Many insect species mimic the coloration of wasps or bees, which are stinging, venomous insects, thereby discouraging predation (Figure 8.2.5).



(a) (b)

Figure 8.2.5: One form of mimicry is when a harmless species mimics the coloration of a harmful species, as is seen with the (a) wasp (*Polistes* sp.) and the (b) hoverfly (*Syrphus* sp.). (credit: modification of work by Tom Ings) (CC-BY; via OpenStax)

In **Müllerian mimicry**, multiple species share the same warning coloration, but all of them actually have defenses. Figure 8.2.6 shows a variety of foul-tasting butterflies with similar coloration. In Emsleyan/Mertensian mimicry, a deadly prey mimics a less dangerous one, such as the venomous coral snake mimicking the nonvenomous milk snake. This type of mimicry is extremely rare and more difficult to understand than the previous two types. For this type of mimicry to work, it is essential that eating the milk snake has unpleasant but not fatal consequences. Then, these predators learn not to eat snakes with this coloration, protecting the coral snake as well. If the snake were fatal to the predator, there would be no opportunity for the predator to learn not to eat it, and the benefit for the less toxic species would disappear.



Figure 8.2.6: Several unpleasant-tasting Heliconius butterfly species share a similar color pattern with better-tasting varieties, an example of mimicry. (credit: Joron M, Papa R, Beltrán M, Chamberlain N, Mavárez J, et al.)) (CC-BY; via OpenStax)

Parasitism

A **parasite** is an organism that feeds off another without immediately killing the organism it is feeding on. In this relationship, the parasite benefits, but the organism being fed upon, the **host**, is harmed. 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.

The reproductive cycles of parasites are often very complex, sometimes requiring more than one host species. A tapeworm causes disease in humans when contaminated, undercooked meat such as pork, fish, or beef is consumed (Figure 8.2.7). The tapeworm can live inside the intestine of the host for several years, benefiting from the host's food, and it may grow to be over 50 feet long by adding segments. The parasite moves from one host species to a second host species in order to complete its life cycle. *Plasmodium falciparum* is another parasite: the protists that cause malaria, a significant disease in many parts of the world. Living inside human

liver and red blood cells, the organism reproduces asexually in the human host and then sexually in the gut of blood-feeding mosquitoes to complete its life cycle. Thus malaria is spread from human to mosquito and back to human, one of many arthropod-borne infectious diseases of humans.

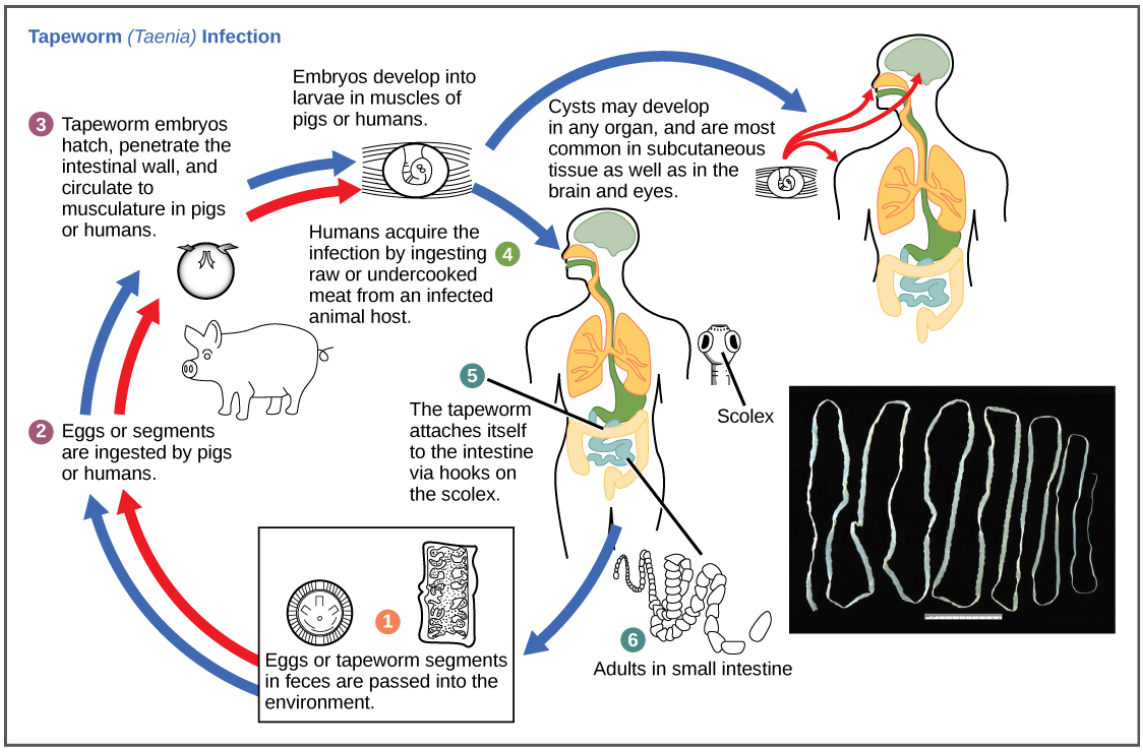


Figure 8.2.7: This diagram shows the life cycle of the tapeworm, a human worm parasite. (credit: modification of work by CDC). (CC-BY; via OpenStax)

Parasites infect many types of organisms, including other animals and plants. For example, the fleas and roundworms are common dog parasites. Plants can be infected by fungi, bacteria, and viruses; there are also parasitic plants that parasitic other plants. Even bacteria can parasitized by viruses called bacteriophages.

Attribution

This page is a modified derivative of:

- 45.6 Community Ecology; CC-BY via OpenStax
- 19.4 Community Ecology; CC-BY via OpenStax

This page titled 8.2: Exploitative Interactions is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

8.3: Competition

Competition

There is a finite amount of most resources on earth which drives species into competitive interactions. **Competition** occurs when organisms use the the same resources, and one or both organisms is harmed. Competing species are often occupy the same trophic level and compete for food, but species on different trophic levels could still compete for space, water, etc. **Intraspecific competition** occurs within a species. For example, most penguins defend territories from other individuals of the same species because they compete for suitable habitat and other resources (figure 8.3.1). **Interspecific competition** occurs between different species. For example, the **invasive** vine, kudzu, competes with trees in the southeastern United States for light (figure 8.3.2). Kudzu is considered invasive in this region because it occurs outside of its historical range (Asia and Australia) and causes ecological harm.

Definition: Competition

Competition occurs when members of the same species (intraspecific) or members of different species (interspecific) complete for access to a limited resource such as food, water, or habitat.



Figure 8.3.1: Adélie penguins at Cape Adare in Ross Sea, Antarctica. These penguins defend small territories in which they nest. Image by Brocken Inaglory (CC-BY-SA).



Figure 8.3.2: Kudzu is a vine that covers trees, shrubs, and other structures. It can fully block its competitors' access to light, eventually killing them. Image by Katie Ashdown (CC-BY).

Interspecific Competition and Extinction

When populations of different species in a community depend on the same resources, there may not be enough resources to go around. If one species has a disadvantage, such as more predators, it may get fewer of the necessary resources. As a result, members of that species are less likely to survive, and the species will have a higher death rate than the other species. Fewer offspring will be produced and the species may eventually die out in the area.

In nature, interspecific competition has often led to the extinction of species. Many other extinctions have occurred when humans introduced new species into areas where they had no predators. For example, rabbits were introduced into Australia in the mid-1800s for sport hunting. Rabbits had no predators in Australia and quickly spread throughout the continent. Many species of Australian mammals could not successfully compete with rabbits and went extinct.

Interspecific Competition and Specialization

Another possible outcome of interspecific competition is the evolution of traits that create distinct differences among the competing species. Through natural selection, competing species can become more specialized. This allows them to live together without competing for the same resources. An example is the anolis lizard (Figure 8.3.4). Many species of anolis live and prey on insects in tropical rainforests. Competition among the different species led to the evolution of specializations. Some anolis evolved specializations to prey on insects in leaf litter on the forest floor. Others evolved specializations to prey on insects on the branches of trees. This allowed the different species of anolis to co-exist without competing.

The Competitive Exclusion Principle

Ecologists have come to understand that all species have an **ecological niche**: the unique set of resources used by a species, which includes its interactions with other species. The **competitive exclusion principle** states that two species cannot occupy the exact same niche for long. In other words, different species cannot coexist in a community if they are competing for all the same resources. Competition reduces the fitness of one or both competitors because it wastes energy. However, competition is usually asymmetric with one species dominating the competition and the weaker competitor suffers a stronger fitness cost. In an experimental test of competitive exclusion two species of the freshwater microbe *Paramecium* were cultured separately and together. When cultured separately, both species reproduced, and the number of cells (individuals) increased. However, when the two species were grown together, one species (*P. aurelia*) grew, and the the other species (*P. caudatum*) was eliminated. Because both species occupied the same ecological niche, they could not coexist. *Paramecium aurelia* was the superior competitor in this case (figure 8.3.3). Competitive exclusion may be avoided if a population evolves to make use of a different resource, a different area of the habitat, or feeds during a different time of day. This is called **resource partitioning**. The two species are then said to occupy different microniches. These species coexist by minimizing direct competition.

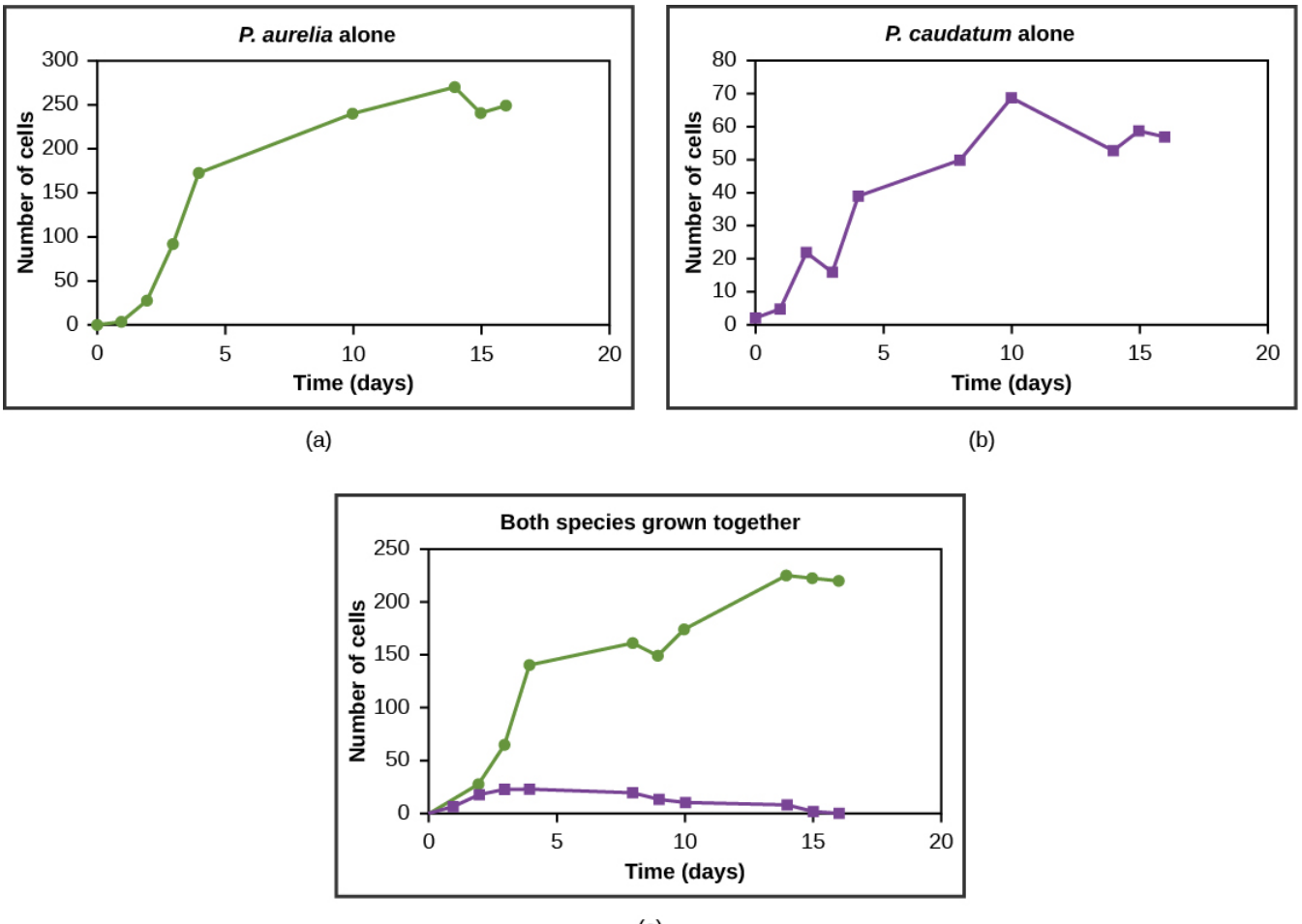


Figure 8.3.3: Graphs a, b, and c all plot number of cells versus time in days. When *Paramecium aurelia* and *P. caudatum* were grown individually in the laboratory (a and b), the two species both reproduced and reached a relatively high cell density. When the two species were placed together in the same test tube (habitat, c), *P. aurelia* (top, green) reached nearly the same cell density as it exhibited when grown alone, but *P. caudatum* (bottom, purple) hardly grew at all, and eventually its population drops to zero. *Paramecium aurelia* outcompeted *P. caudatum* for food, leading to the latter's eventual extinction.

Resource Partitioning

Competitive exclusion may be avoided if one or both of the competing species evolves to use a different resource, occupy a different area of the habitat, or feed during a different time of day. The result of this kind of evolution is that two similar species use largely non-overlapping resources and thus have different niches. This is called **resource partitioning**, and it helps the species coexist because there is less direct competition between them.

The anole lizards found on the island of Puerto Rico are a good example of resource partitioning. In this group, natural selection has led to the evolution of different species that make use of different resources. The figure below shows resource partitioning among 11 species of anole lizards. Each species lives in its own preferred habitat, which is defined by type and height of vegetation (trees, shrubs, cactus, etc.), sunlight, and moisture, among other factors. Alternatively, species can coexist on the same resources if each species is limited by different resources, or differently able to capture resources. Different types of phytoplankton can coexist when different species are differently limited by nitrogen, phosphorus, silicon, and light. In the Galapagos Islands, finches with small beaks are more able to consume small seeds, and finches with large beaks are more able to consume large seeds. If a species' density declines, then the food it most depends on will become more abundant (since there are so few individuals to consume it). As a result, the remaining individuals will experience less competition for food. Although "resource" generally refers to food, species can partition other non-consumable objects, such as parts of the habitat. For example, warblers are thought to coexist because they nest in different parts of trees . Species can also partition habitat in a way that gives them access to different types of

resources. As previously stated, anole lizards appear to coexist because each uses different parts of the forests as perch locations. This likely gives them access to different species of insects.

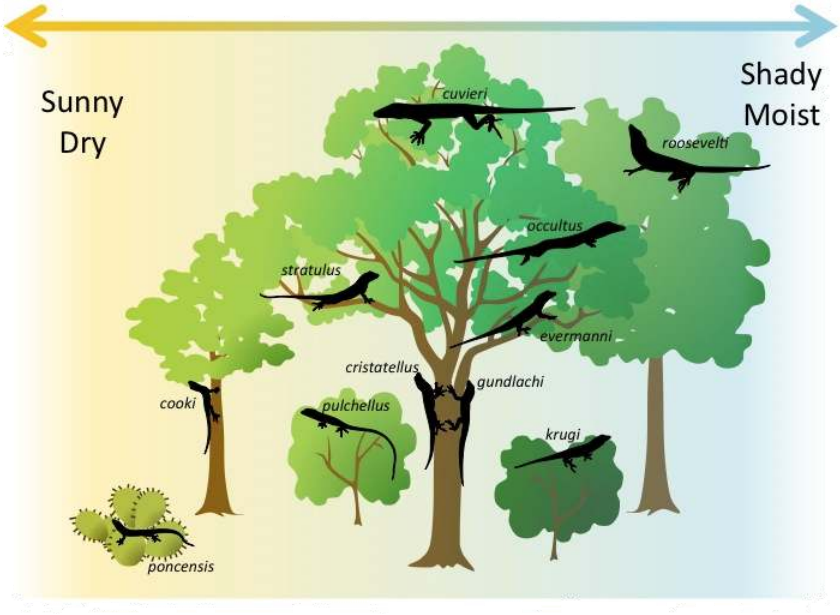


Figure 8.3.4: Resource partitioning among anole lizards. (CC-BY via Libretexts)

Character Displacement

Character displacement occurs when similar species that live in the same geographical region and occupy similar niches differentiate in order to minimize niche overlap and avoid competitive exclusion. Several species of Galapagos finches display character displacement. Each closely related species differs in beak size and beak depth, allowing them to coexist in the same region since each species eats a different type of seed: the seed best fit for its unique beak. The finches with the deeper, stronger beaks consume large, tough seeds, while the finches with smaller beaks consume the smaller, softer seeds.

Character displacement is the phenomenon where differences among similar species whose distributions overlap geographically are accentuated in regions where the species co-occur, but are minimized or lost where the species' distributions do not overlap. This pattern results from evolutionary change driven by biological competition among species for a limited resource (e.g. food). The rationale for character displacement stems from the competitive exclusion principle, which contends that to coexist in a stable environment two competing species must differ in their respective ecological niche; without differentiation, one species will eliminate or exclude the other through competition.

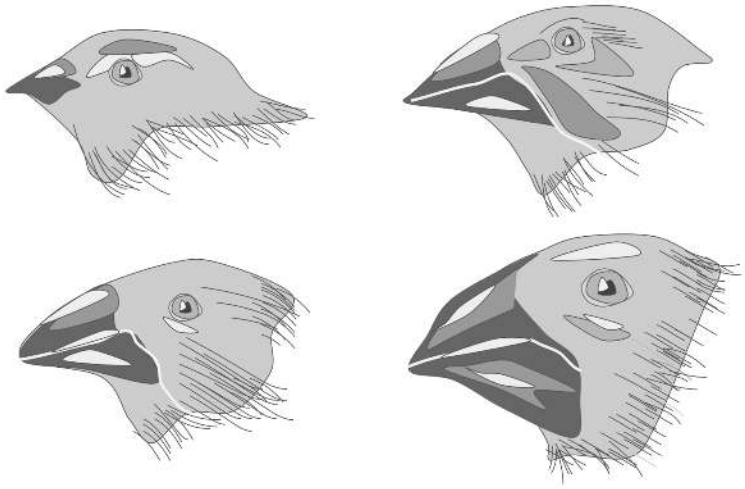


Figure 8.3.5: Several species of Galapagos finches, shown above, display character displacement. Each closely-related species differs in beak size and beak depth, allowing them to coexist in the same region since each species eats a different type of seed: the seed best fit for its unique beak. The finches with the deeper, stronger beaks consume large, tough seeds, while the finches with smaller beaks consume the smaller, softer seeds. (CC VT-SA 4.0; Awakening Conscience via Wikipedia)

For example, Darwin's finches can be found alone or together on the Galapagos Islands. Both species' populations actually have more individuals with intermediate-sized beaks when they live on islands without the other species present. However, when both species are present on the same island, competition is intense between individuals that have intermediate-sized beaks of both species because they all require intermediate sized seeds. Consequently, individuals with small and large beaks have greater survival and reproduction on these islands than individuals with intermediate-sized beaks. Different finch species can coexist if they have traits—for instance, beak size—that allow them to specialize on particular resources. When *Geospiza fortis* and *Geospiza fuliginosa* are present on the same island, *G. fuliginosa* tends to evolve a small beak and *G. fortis* a large beak. The observation that competing species' traits are more different when they live in the same area than when competing species live in different areas is called **character displacement**. For the two finch species, beak size was displaced: beaks became smaller in one species and larger in the other species.

Attribution

This page is a modified derivative of:

- 6.1.2: Competition by Melissa Ha and Rachel Schleiger (license CC BY-SA 4.0)
- 15.4.1 Ecological Consequences of Competition (license CC BY-NC-SA)
- 17.16 Competition (license CC BY-NC-SA)

This page titled 8.3: Competition is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **6.1.2: Competition** by Melissa Ha and Rachel Schleiger is licensed CC BY-SA 4.0.

8.4: Commensalism and Mutualism

Interactions in which one or both species benefit and neither is harmed are called facilitation. There are two types of facilitation: commensalism and mutualism.

Commensalism

Commensalism is a type of facilitation that occurs when one species benefits from an interaction, while the other neither benefits or is harmed. Many potential commensal relationships are difficult to identify because it is difficult to demonstrate that one partner is unaffected by the presence of the other. Birds nesting in trees provide an example of a commensal relationship (figure 8.4.1). 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 8.4.1: The Southern Masked-Weaver is starting to make a nest in a tree in Zambezi Valley, Zambia. This is an example of a commensal relationship, in which one species (the bird) benefits, while the other (the tree) neither benefits nor is harmed. (credit: "Hanay"/Wikimedia Commons)

Another example or a commensal relationship involves the Little Blue Heron and the White Ibis, which are both wading birds. The Little Blue Heron catches more fish in the presence of the White Ibis, but the White Ibis is unaffected. Interestingly, Little Blue Herons attempt to catch fish more often in the presence of the species, but the success rate of their attempts does not change. Nevertheless, more frequent attempts still increases the total number of fish caught. The White Ibis may make fish more visible to Little Blue Herons, causing changes in their behavior (figure 8.4.2).



Figure 8.4.2: The Little Blue Heron (left) and the White Ibis (right) have a commensal relationship. Image by Russ (CC-BY).

Mutualism

In a **mutualism**, both species benefit from their interaction. For example, pollinators, such as bees, butterflies, and hummingbirds, benefit because they eat the collect pollen and/or nectar that they collect from flowers. The plants also benefit because their pollen is dispersed to other plants, allowing them to reproduce. Both the pollinators and the plants benefit, demonstrating a mutualism (figure 8.4.3). Clownfish and anemones are another example of mutualisms. Clownfish gain protection from living among anemones. In return, clownfish clean the anemones and scare away predators. In addition, their waste provides nutrients (figure 8.4.4).



Figure 8.4.3: A male Broad-Tailed Hummingbird visits a scarlet gilia flower at the Rocky Mountain Biological Laboratory. The hummingbird gains food (nectar) while aiding the gilia flower with reproduction. Image by David W. Inouye (CC-BY).



Figure 8.4.4: These clownfish have a mutual relationship with the sea anemones in which they live. image by Samuel Chow (CC-BY).

Co-evolution

Co-evolution often occurs in species involved in mutualistic relationships. Coevolution occurs when two or more species reciprocally affect each other's evolution through the process of natural selection. For example Central American *Acacia* species have co-evolved with some species of ant that drink the nectar (Figure 8.4.5). The Acacia have hallow thorns and pores at the bases of their leaves that secrete nectar rich in lipids and proteins. These hollow thorns are the exclusive nest-site of some species of ant that drink the nectar. But the ants are not just taking advantage of the plant — they also defend their acacia plant against herbivores! This system is probably the product of coevolution: the plants would not have evolved hollow thorns or nectar pores unless their evolution had been affected by the ants, and the ants would not have evolved herbivore defense behaviors unless their evolution had been affected by the plants.



Figure 8.4.5: Ant (pseudomyrmex sp.) on an acatia thorn in Yucatan, Mexico. The ants will chew on the thorns so that they can get inside, they will then colonize the whole plant, feed on the "Beltan bodies" (Which are found in the tips of each leaflet and are rich in lipids and proteins) and in change, they will protect the plant from any other organism, including other plants. Also, the ants will even destroy the seeds which are left around the tree, in order to reduce competition. (CC BY 2.0; by Maximilian Paradiz via flickr)

Many examples are provided by flowering plants and the species that pollinate them. Plants have evolved flowers with traits that promote pollination by particular species. Pollinator species, in turn, have evolved traits that help them obtain pollen or nectar from certain species of flowers. For example, the plant with tube-shaped flowers shown in (Figure 8.4.3) co-evolved with hummingbirds. The birds evolved long, narrow beaks that allowed them to sip nectar from the tubular blooms.

Attribution

This page is a Modified derivative of:

- Facilitation by Melissa Ha from *Environmental Science* (license CC BY-NC 4.0)

This page titled 8.4: Commensalism and Mutualism is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **6.1.3: Facilitation** by Melissa Ha and Rachel Schleiger is licensed CC BY-NC 4.0.

8.5: Symbiosis

Some biological interactions are brief, such as predation. In others, species are closely associated for long periods. Such associations are called **symbiotic** ("living together"). One species always benefits in a symbiosis, but the other may be harmed (parasitism), unaffected (commensalism), or benefited (mutualism). Some experts considered all parasitisms, commmensalisms, and mutualisms to be symbiotic, but others only consider interactions in which species are living together in a close association (such as when one species lives on or in the other) as symbiotic.

Termites have a symbiotic relationship with microorganisms called protozoa that live in the insect's gut (figure 8.5.a-a). The termite benefits from the ability of the protozoa to digest cellulose, a carbohydrate important in plant structure. However, the protozoa are able to digest cellulose only because of the presence of symbiotic bacteria within their cells that produce the cellulase enzyme. The termite itself cannot do this; without the protozoa, it would not be able to obtain energy from its food (cellulose from the wood it chews and eats). The protozoa benefit by having a protective environment and a constant supply of food from the wood chewing actions of the termite. In turn, the protists benefit from the enzymes provided by their bacterial endosymbionts, while the bacteria benefit from a doubly protective environment and a constant source of nutrients from two hosts.

Lichen are a symbiotic relationship between a fungus and algae (or a photosynthetic bacteria; Figure 8.5.a-b). In lichen, the algal cells are fully surrounded by the fungus. The sugars produced by the algae through photosynthesis provide nourishment for both organisms. The physical structure of the fungus protects the algae from the elements and makes certain nutrients in the atmosphere more available to the algae. The algae of lichens can sometimes live independently given the right environment, but many of the fungal partners are unable to live on their own. Note that while both lichen and the example involving termites mutually benefit the species involved, symbioses are not always mutualisms.



Figure 8.5.a: (a) Termites form a symbiotic relationship with protozoa living in their guts. Their association which allows both organisms to obtain energy from the cellulose the termite consumes. (b) Lichen is a fungus that has symbiotic photosynthetic algae living in close association. (credit a: modification of work by Scott Bauer, USDA; credit b: modification of work by Cory Zanker)

The remora and the shark is a commensal symbiosis. The top fin of the remora is modified into a sucker with which it forms an attachment to the shark. When the shark feeds, the remora picks up scraps. Additionally, the remora gains transportation and protection. The shark makes no attempt to prey on the remora and is unaffected by it (figure 8.5.b).



Figure 8.5.b: A remora attached to the top of a shark in an aquarium. This is an example of a symbiosis because the remora lives in close association with the shark. Image by Brian Snelson (CC-BY)

There are many additional examples of symbiosis. Coral are small animals that harbor photosynthetic microorganisms called dinoflagellates. (The corals group together and deposit hardened calcium carbonate skeletons.) **Mycorrhizae** are fungi that surround or live within plant root cells and help plants absorb nutrients from the soil in exchange for sugars. In fact truffles are often found in oak forests because the fungus that produce this spore-forming body establishes mycorrhizae on oak roots. **Root nodules** are structures on the roots of legume plants that house nitrogen-fixing bacteria (see The Nitrogen Cycle). **Epiphytes** are plants adapted to live on top of other plants and are common in the tropical rainforest (see Biomes). Humans have a diversity of microorganisms, called the **normal flora**, that live in and on our bodies. While we often think of bacteria as causing infection (a parasitism), the species of our normal floral exemplify commensalism and mutualism. For example, our gut microbiota aids with digestion and helps us synthesize certain vitamins.

Attributions

Modified by Melissa Ha from the following sources:

- Symbiosis from *Biology* by John W. Kimball (licensed under CC-BY)
- Community Ecology from *Environmental Biology* by Matthew R. Fisher's (licensed under CC-BY)

This page titled 8.5: Symbiosis is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **6.1.4: Symbiosis** by Melissa Ha and Rachel Schleiger is licensed CC BY-NC 4.0.

CHAPTER OVERVIEW

9: Community Structure and Dynamics



Figure 9.1: Until the late 1800s, Bison (*Bison bison*) numbered tens of millions in the Great Plains of the United States. By 1890, roughly 1000 Bison were left because the United States government campaign to eradicate the native people, their culture, and habitats they relied on. Slowly, a movement started to try and save Bison from extinction. It took until the early 2000's for Bison numbers to reach a half a million. During this time, scientists were able to observe the Bison reintroduction back into the Great Plains. Bison were found to be the most critical species to restoring and maintaining the function and diversity in the Great Plains community. Both plants and animal populations in the community were strengthened from the return of the Bison. Understanding community dynamics is essential to conserving and restoring these systems and the species that define them. This is particularly critical for communities with one particular species that acts as a keystone to the health of the system. Image by NPS photos/Kim Acker (Public Domain)

Chapter Summary

Populations that interact within a given area form a community. Ecologists study the organization and function of communities from the scale at many spatial and temporal scales. Communities are complex systems that can be characterized by **community structure** (the number and size of populations and their interactions) and **community dynamics** (how the members and their interactions change over time). Scientists study ecology at the community level to understand how interactions between species and abiotic factors affect the way communities are structured, function, and change over time. Understanding community structure and dynamics allows us to minimize human impacts on ecosystems and manage ecological communities we benefit from.

Learning Objectives

After reading this chapter you should be able to:

- Define a community. Describe how Ecologist measure community structure through species richness and species diversity.
- List hypotheses for why biodiversity tends to be highest near the equator.
- Describe the role of foundational species, keystone species, and invasive species in community structure and stability.
- Explain the flow of energy through the trophic levels of a community.
- Describe the process of biomagnification.
- Explain how disturbances can increase biodiversity of a community,
- Compare primary and secondary ecological succession and be able to identify and describe examples of each.

9.1: Community Structure
9.2: The Role of Species within Communities

9.3: Food Chains and Food Webs
9.4: Disturbance
9.5: Succession

This page titled 9: Community Structure and Dynamics is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

9.1: Community Structure

Community Structure

Community structure is the ecologist's term for indicating what organisms are present in a given environment, in what numbers, and how they relate to each other. Another way to look at a community is as a collection of niches or slots that organisms can fit into in order to “make a living.” The term community is rather arbitrary. Its boundaries can be as wide or as narrow as one chooses to make them. For example, a rocky-shore community could refer to a thousand miles of coastline or to a kelp community in a band tens to hundreds of feet wide on that coast, or the kelp epiphyte community could refer to those organisms growing on single kelp plants (Figure 9.1.1). Reasonably sharp community boundaries are required for such a designation, but even that criterion is sometimes rather fuzzy. Traditionally, a biological community is named for a dominant element or elements. An *Acropora palmata* reef community is conspicuously dominated by that single coral species as a major element of biomass or structure, controlling many other organisms by its presence. A *Batis–Distichlis* salt marsh community is a salt marsh in which the saltwort *Batis* and the salt grass *Distichlis* more or less equally provide the primary vegetation and therefore cover in the marsh.



Figure 9.1.1: A kelp forest community provides habitat and food for a wide range of invertebrates, fish (a) and ephiphytes (algae growing on kelp stipe). (Image a via wikimedia; licence CC 2.0, Image b via wikimedia; licence CC-SA 3.0)

How do we measure community structure?

Two important measures ecologists use to describe the composition of a community are species richness and relative abundance (or species evenness)**. Species richness** is the term used to describe the number of species living in a habitat or other unit. **Relative species abundance** is the number individuals in a species relative to the total number of individuals in all species within a system. Larger numbers of species and more even abundances of species lead to higher species diversity. For example, both communities in figure 9.1.2 have three different trees species and thus a species richness of three. However, there is a dominant species (represented by six individuals) in community #1. In community #2, there are three of individuals of each species. Therefore, community #2 has a greater species evenness and greater species diversity overall.



Figure\(\
PageIndex
{2}\): Two hypothetical tree communities have the same species richness, but community #2 (bottom) has a greater species evenness. Both communities have nine trees and three tree species. In community #1, one species is dominant, represented by six individuals. There are two individuals of a conifer species, and only one individual of the final species. In community #2, there are three individuals from each species. Images compiled by Melissa Ha from
Alone tree George Hodan
,
Old Tree Silhouette
, and
Tree
(all public domain).

Definition: Biodiversity

One measure of biodiversity used by ecologists is the number of different species in a particular area and their relative abundance.

Ecologists have struggled to understand the determinants of biodiversity. One well known pattern is that species richness varies with latitude. Communities with the highest species richness tend to be found in areas near the equator, which have lots of solar energy (supporting high primary productivity), warm temperatures, large amounts of rainfall, and little seasonal change. Communities with the lowest species richness lie near the poles, which get less solar energy and are colder, drier, and less amenable to life. This pattern is illustrated below for mammalian species richness (Figure 9.1.3).

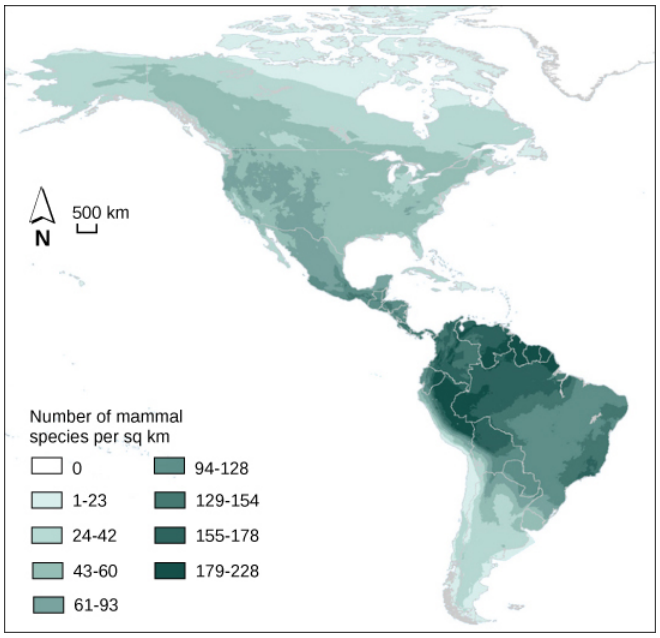


Figure 9.1.3: The greatest species richness for mammals in North America is associated in the equatorial latitudes. (credit: modification of work by NASA, CIESIN, Columbia University). (CC-BY; via OpenStax)

Other factors influence species richness as well. Island biogeography attempts to explain the great species richness found in isolated islands, and has found relationships between species richness, island size, and distance from the mainland. In general, ecologists think that more diverse ecological communities are more stable (that is, more able to recover after a disturbance) than less diverse communities. However, the diversity-stability relationship isn't a universal rule, and there are some cases where other factors (besides species diversity) are more important in determining community and ecosystem stability.

What factors shape community structure?

The structure of a community is the result of many interacting factors, both abiotic (non-living) and biotic (living organism-related). Here are some important factors that influence community structure:

- The climate patterns of the community's location.
- The geography of the community's location.
- The heterogeneity (patchiness) of the environment.
- The frequency of disturbances, or disruptive events.
- Interactions between organisms.

A community's structure can also be shaped by the chance events that happened during its history. For instance, suppose that a single seed blows into the dirt of a particular area. If it happens to take root, the species may establish itself and, after some period of time, become dominant (excluding similar species). If the seed fails to sprout, another similar species may instead be the lucky one to establish itself and become dominant.

Attribution

This page is a modified derivative of:

- 19.4 Community Ecology Via Open Stax; license CC-BY 4.0
- 9.2 Species Diversity by Melissa Ha and Rachel Schleiger via Environmental Science; license CC BY-NC 4.0

This page titled 9.1: Community Structure is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

9.2: THE ROLE OF SPECIES WITHIN COMMUNITIES

There are three main types of species that play strong roles in structuring a community. These include the foundation species, keystone species, and invasive species. Each of these has a specific role in how communities are formed and function.

FOUNDATION SPECIES

Foundation species are considered the "base" or "bedrock" of a community, having the greatest influence on its overall structure. They are usually the primary producers: organisms that bring most of the energy into the community. Kelp, a brown algae, is a foundation species that forms the basis of the kelp forests off the coast of California.

DEFINITION: FOUNDATION SPECIES

Foundation species are species that have a strong role in structuring a community such as the corals on a coral reef or the redwoods of a redwood forest.

Foundation species may physically modify the environment to produce and maintain habitats that benefit the other organisms that use them. An example is the photosynthetic corals of the coral reef. Corals themselves are not photosynthetic, but harbor symbionts within their body tissues (dinoflagellates called zooxanthellae) that perform photosynthesis; this is another example of a mutualism. The exoskeletons of living and dead coral make up most of the reef structure, which protects many other species from waves and ocean currents.

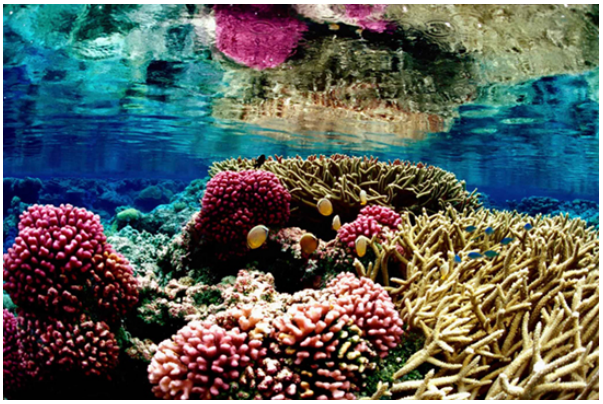


Figure **9.2.1**: Foundation species: Coral is the foundation species of coral reef ecosystems. The photosynthetic algae within the corals provides energy for them so that they can build the reefs.

KEYSTONE SPECIES

A **keystone species** is one whose presence is key to maintaining biodiversity within an ecosystem and to upholding an ecological community's structure.The term "keystone" is an architectural reference to a wedge-shaped stone at the top of an archway. It is the last stone builders place in the arch to lock the other stones into position and enables the arch to bear a building's weight. If the keystone is removed, the arch—and possibly the entire building—could collapse. Similarly, a keystone species helps to keep an ecosystem together and functioning by shaping it in various ways, from being apex predators to ecosystem engineers.

Predator species such as wolves, orcas and sea otters help maintain the population sizes of prey species, and sometimes even other predators, in an ecosystem. If a keystone predator is removed, other species may explode in number, potentially outcompeting and displacing other species. Overharvesting of sea otters is a classic example. Sea otters were hunted for their soft fur, which caused local extinctions throughout much of their range. Sea otters feed on sea urchins, which feed on kelp. As the otters declined, sea urchins rapidly increased and vastly overgrazed the ocean's kelp forests, destroying important habitat for a host of other species. The intertidal sea star, *Pisaster ochraceus*, of the northwestern United States is also predatory keystone species (Figure **9.2.1**). Studies have shown that when this organism is removed from communities, populations of their natural prey (mussels) increase, completely altering the species composition and reducing biodiversity.



Figure **9.2.1**: Keystone species maintain biodiveristy: The *Pisaster ochraceus* sea star is a keystone species. When this animal is removed from certain areas, its prey species greatly alters the dynamics of the ecosystem, reducing biodiversity.

Some keystone species physically modify or maintain an ecosystem. A prime example of ecosystem engineers are beavers, which dam rivers to make pools and wetlands that become habitats for a wide diversity of species. These wetlands also help moderate environmental changes such as flooding or drought. If beavers are removed, rivers become faster flowing, which often reduces their diversity.

Some keystone species are important providers of shelter and habitats for other species. Corals, for example, provide many nooks and crannies for coral reef species to hide. This habitat complexity allows coral reefs to become hotspots of ocean biodiversity. Sagebrush is another example. This shrub not only provides food for species such as the sage grouse, it also allows many species to shelter underneath its canopy to hide from predators. Sagebrush also adds nutrients to the soil and helps to retain moisture in the arid regions where it is found.

INVASIVE SPECIES

Invasive species are foreign species whose introduction can cause harm to the economy and the environment. These species have many ways of entering foreign environments, including through ship's ballast water: when planes take off, organisms can sometimes become stuck in the cargo area. When the plane arrives in its destination, the organisms are now in a foreign environment. Travelers sometimes illegally smuggle items, such as fruits, plants, or even animals as pets, from one state or country to another..

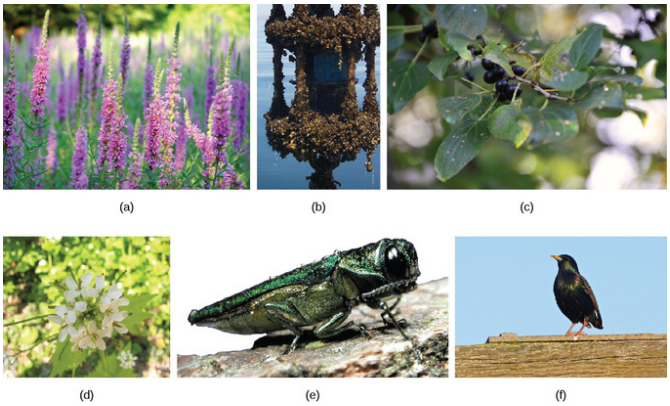


Figure **9.2.1**: Invasive species threaten ecosystems: In the United States, invasive species such as (a) purple loosestrife (*Lythrum salicaria*) and the (b) zebra mussel (*Dreissena polymorpha*) threaten certain ecosystems. Some forests are threatened by the spread of (c) common buckthorn (*Rhamnus cathartica*), (d) garlic mustard (*Alliaria petiolata*), and (e) the emerald ash borer (*Agrilus planipennis*). The (f) European starling (*Sturnus vulgaris*) may compete with native bird species for nest holes.

Invasive species are often better competitors than native species, resulting in population explosions. These new species usually overtake the native populations, driving them to localized extinctions.

One of the many recent proliferations of an invasive species concerns the growth of Asian carp populations. Asian carp were introduced to the United States in the 1970s by fisheries and sewage treatment facilities that used the fish's excellent filter feeding capabilities to clean their ponds of excess plankton. Some of the fish escaped, however, and by the 1980s, they had colonized many waterways of the Mississippi River basin, including the Illinois and Missouri Rivers.

Voracious eaters and rapid reproducers, Asian carp may outcompete native species for food, potentially leading to native species extinctions. For example, black carp are voracious eaters of native mussels and snails, limiting this food source for native fish species. Silver carp eat plankton that native mussels and snails feed upon, reducing this food source by a different alteration of the food web. In some areas of the Mississippi River, Asian carp species have become predominant, effectively outcompeting native fish for habitat. In some parts of the Illinois River, Asian carp constitute 95 percent of the community's biomass. Although edible, the fish is bony and not a desirable food in the United States. Moreover, their presence threatens the native fish and fisheries of the Great Lakes, which are important to local economies and recreational anglers. Asian carp have even injured humans. The fish, frightened by the sound of approaching motorboats, thrust themselves into the air, often landing in the boat or directly hitting the boaters.

One infested waterway of particular importance is the Chicago Sanitary and Ship Channel, the major supply waterway linking the Great Lakes to the Mississippi River. To prevent the Asian carp from leaving the canal, a series of electric barriers have been successfully used to discourage their migration; however, the threat is significant enough that several states and Canada have sued to have the Chicago channel permanently cut off from Lake Michigan. Local and national politicians have weighed in on how to solve the problem, but no one knows whether the Asian carp will ultimately be considered a nuisance, like other invasive species, such as the water hyacinth and zebra mussel, or whether it will be the destroyer of the largest freshwater fishery of the world.

ATTRIBUTION

This page is a modified derivative of:

- 9.2: The Role of Species within Communities is shared under a CC BY-SA 4.0 license and was authored, remixed, and/or curated by Boundless.

This page titled 9.2: The Role of Species within Communities is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

9.3: Food Chains and Food Webs

Trophic Interactions

Trophic interactions occur when one organism feeds on another. Trophic interreactions strongly influence the structure of communities as the populations of one species (a predator) can influence population sizes of other species (prey). The three main types of trophic interactions that influence community structure are predation (Figure 9.3.1) and herbivory. During these interactions, one species benefits by gaining food at the expense of the other, which either dies or loses nutrients, tissues, or organs (such as leaves). Trophic interactions involve the flow of energy, and the trophic interactions in a community can be represented by **food chains** and **food webs**.

Definition: Trophic Level

A species' trophic level is their position in the food chain or web. At the bottom of the food web are autotrophs, also known as producers. The next level is herbivores (primary consumers), these species feed on producers for their energy source. Herbivores are consumed by omnivores or carnivores. These species are secondary and tertiary consumers. Additional levels to the trophic scale come when smaller omnivores or carnivores are eaten by larger ones. At the top of the food web is the apex predator, this animal species is not consumed by any other in the community.



Figure 9.3.1: A hawk (*Buteo jamaicensis*) eats a vole (*Microtus californicus*), exemplifying predation, a common trophic interaction. Image by Jrockley(opens in new window) (public domain).

Food Chains

A food chain is a linear sequence of organisms through which nutrients and energy pass as one organism eats another; the levels in the food chain are producers, primary consumers, higher-level consumers, and finally decomposers. These levels are used to describe ecosystem structure and dynamics. There is a single path through a food chain. Each organism in a food chain occupies a specific **trophic level** (energy level), its position in the food chain or food web.

In many ecosystems, the base, or foundation, of the food chain consists of photosynthetic organisms (plants or phytoplankton), which are called **producers**. The organisms that consume the producers are herbivores: the **primary consumers**. **Secondary consumers** are usually carnivores that eat the primary consumers. **Tertiary consumers** are carnivores that eat other carnivores. Higher-level consumers feed on the next lower trophic levels, and so on, up to the organisms at the top of the food chain: the apex

consumers. In the Lake Ontario food chain, shown in Figure 9.3.2, the Chinook salmon is the apex consumer at the top of this food chain.

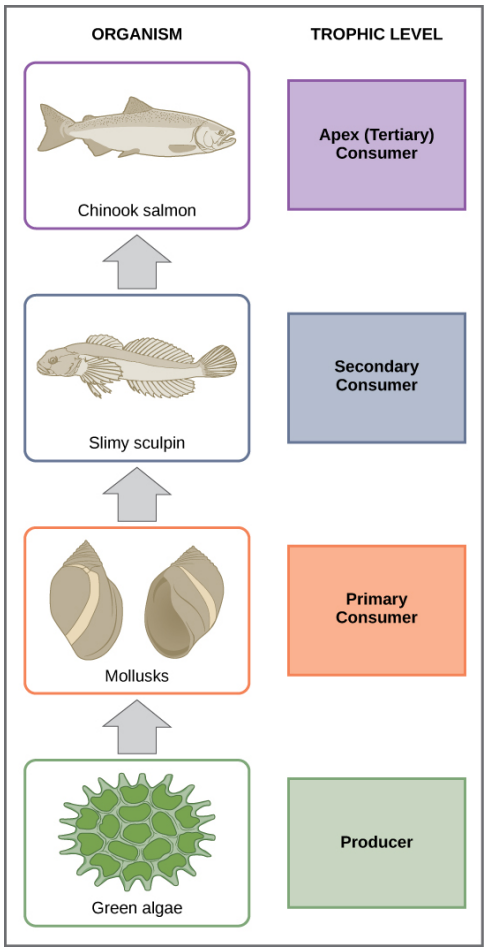


Figure 9.3.2: These are the trophic levels of a food chain in Lake Ontario at the United States–Canada border. Energy and nutrients flow from photosynthetic green algae at the base to the top of the food chain: the Chinook salmon. (credit: modification of work by National Oceanic and Atmospheric Administration/NOAA)

Trophic Level Transfer Efficiency

One major factor that limits the number of steps in a food chain is energy. Energy is lost at each trophic level and between trophic levels as heat and in the transfer to decomposers (Figure 9.3.3). Only a fraction of the energy captured by one trophic level is assimilated into biomass, which makes it available to the next trophic level. Assimilation is the biomass of the present trophic level after accounting for the energy lost due to incomplete ingestion of food, energy used to conduct work by that trophic level, and energy lost as waste. Incomplete ingestion refers to the fact that some consumers eat only a part of their food. For example, when a lion kills an antelope, it will eat everything except the hide and bones. The lion is missing the energy-rich bone marrow inside the bone, so the lion does not make use of all the calories its prey could provide.

The **trophic level transfer efficiency** is the percentage of biomass or energy at one trophic level that is transferred to the next. On average trophic level transfer efficiency is only about 10%. Thus, after a limited number of trophic energy transfers, the amount of energy remaining in the food chain may not be great enough to support viable populations at yet a higher trophic level. As a result most communities are limited to 4 or 5 trophic levels.

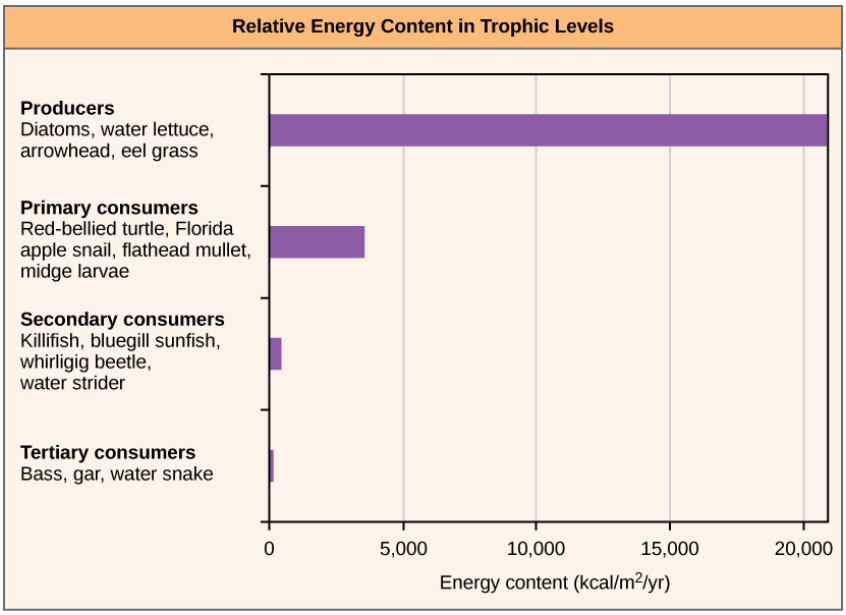


Figure 9.3.3: The relative energy in trophic levels in a Silver Springs, Florida, ecosystem is shown. Each trophic level has less energy available, and usually, but not always, supports a smaller mass of organisms at the next level.

Food Webs

There is a one problem when using food chains to describe most ecosystems. Even when all organisms are grouped into appropriate trophic levels, some of these organisms can feed on more than one trophic level; likewise, some of these organisms can also be fed on from multiple trophic levels. In addition, species feed on and are eaten by more than one species. In other words, the linear model of ecosystems, the food chain, is a hypothetical, overly simplistic representation of ecosystem structure. A holistic model—which includes all the interactions between different species and their complex interconnected relationships with each other and with the environment—is a more accurate and descriptive model for ecosystems. A **food web** is a concept that accounts for the multiple trophic (feeding) interactions between each species and the many species it may feed on, or that feed on it. In a food web, the several trophic connections between each species and the other species that interact with it may cross multiple trophic levels. The matter and energy movements of virtually all ecosystems are more accurately described by food webs (Figure 9.3.4).

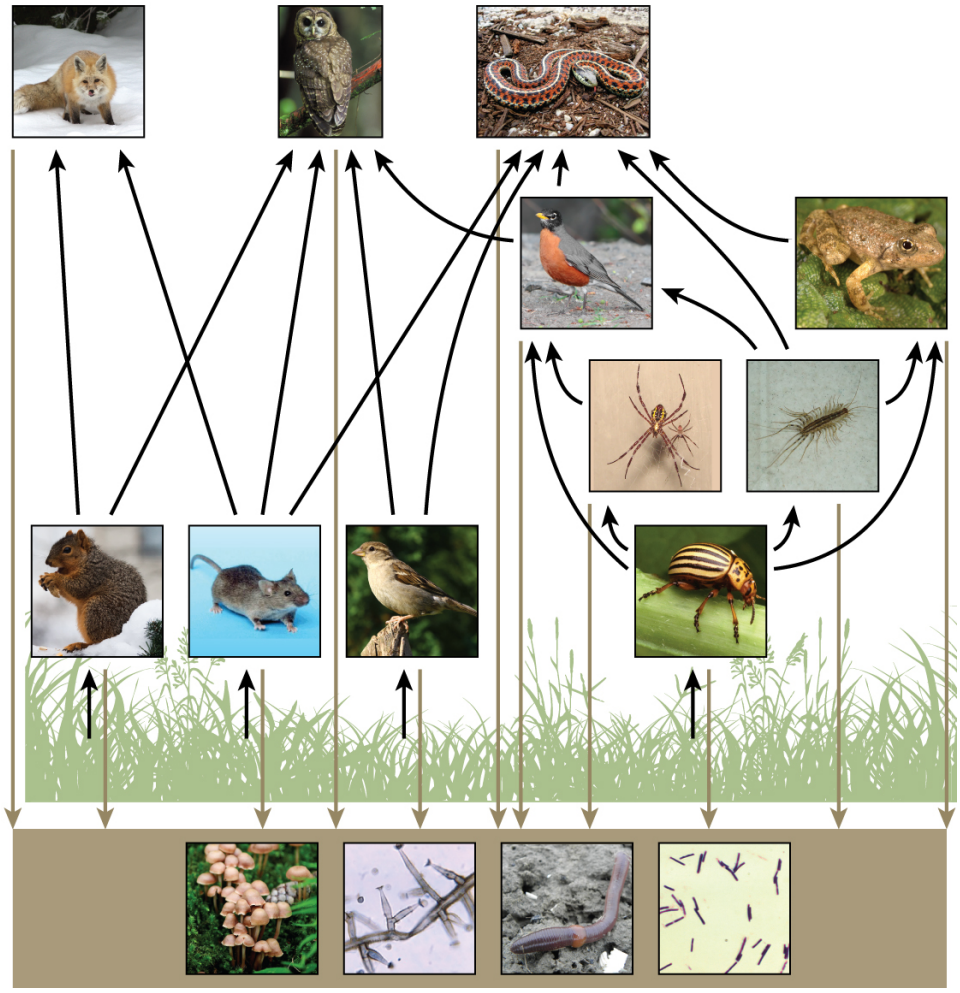


Figure 9.3.4: This food web shows the interactions between organisms across trophic levels. Arrows point from an organism that is consumed to the organism that consumes it. All the producers and consumers eventually become nourishment for the decomposers (fungi, mold, earthworms, and bacteria in the soil). (credit "fox": modification of work by Kevin Bacher, NPS; credit "owl": modification of work by John and Karen Hollingsworth, USFWS; credit "snake": modification of work by Steve Jurvetson; credit "robin": modification of work by Alan Vernon; credit "frog": modification of work by Alessandro Catenazzi; credit "spider": modification of work by "Sanba38"/Wikimedia Commons; credit "centipede": modification of work by “Bauerph”/Wikimedia Commons; credit "squirrel": modification of work by Dawn Huczek; credit "mouse": modification of work by NIGMS, NIH; credit "sparrow": modification of work by David Friel; credit "beetle": modification of work by Scott Bauer, USDA Agricultural Research Service; credit "mushrooms": modification of work by Chris Wee; credit "mold": modification of work by Dr. Lucille Georg, CDC; credit "earthworm": modification of work by Rob Hille; credit "bacteria": modification of work by Don Stalons, CDC)

A comparison of the two types of structural ecosystem models shows strength in both. Food chains are more flexible for analytical modeling, are easier to follow, and are easier to experiment with, whereas food web models more accurately represent ecosystem structure and dynamics, and data can be directly used as input for simulation modeling.

Two general types of food webs are often shown interacting within a single ecosystem. A grazing food web has plants or other photosynthetic organisms at its base, followed by herbivores and various carnivores. A detrital food web consists of a base of organisms that feed on decaying organic matter (dead organisms), including decomposers (which break down dead and decaying organisms) and detritivores (which consume organic detritus). These organisms are usually bacteria, fungi, and invertebrate animals that recycle organic material back into the biotic part of the ecosystem as they themselves are consumed by other organisms. As ecosystems require a method to recycle material from dead organisms, grazing food webs have an associated detrital food web. For example, in a meadow ecosystem, plants may support a grazing food web of different organisms, primary and other levels of consumers, while at the same time supporting a detrital food web of bacteria and fungi feeding off dead plants and animals. Simultaneously, a detrital food web can contribute energy to a grazing food web, as when a robin eats an earthworm.

Top Down vs Bottom Up Control

Changes to one of the levels in the food chain can result in changes in other levels which scientists call a **trophic cascade**. These cascades can affect levels below that altered level or levels above the altered level. We categorize these directional cascades as top-down or bottom-up control, which simply means the changes to the food chain occurred at either the top trophic level or the bottom trophic level and then impacted the other levels up or down the food chain.

In the **top-down contro**l, the populations of the organisms lower trophic levels (bottom of the pyramid) are controlled by the organisms at the top. This approach is also called the predator-controlled food web of an ecosystem.

For instance, imagine a simplified ecosystem where there are just 3 tropic levels: plants, an herbivore, and a carnivores. The presence of the carnivore keeps the herbivore population in check. If there were no carnivores in this ecosystem, then the herbivore population would rapidly increase. As a result, all the plants would be eaten. When almost all the plants are eaten by the huge, unsustainable population of herbivores, there is no food. So, that population of herbivores would eventually starve to death and the ecosystem would collapse. Thus, the carnivores keep the herbivore population in check, so that the plants are not overeaten and the ecosystem will continue to function.

The **bottom-up control** is driven by the presence or absence of the producers in the ecosystem. Changes in their population will affect the population of all the species in the food web, and thus, the ecosystem. This approach is also called the resource-controlled (or food-limited) food web of an ecosystem.

In the same simplified example ecosystem above, let us consider the reverse scenario. What if the population of plants in the ecosystem dwindled to extremely low numbers? Then, the herbivores would have less food to feed on. Consequently, their population would shrink to reflect the lack of food. When the population of herbivores decreases, the carnivores will also automatically face a shortage of food. The carnivore population would also decline. If plants disappeared altogether, then the ecosystem would collapse.

Does an ecosystem have to choose to be either top-down or bottom-up?

No. In most ecosystems, studies have shown that these two approaches are not mutually exclusive. For example, in marine ecosystems that were initially thought to be purely bottom-up, there have been periods of top-down control due to extraction of large predators through fishing.

Consequences of Food Webs: Biological Magnification

Definition: Biomagnification

Biomagnification is the increasing concentration of persistent, toxic substances in organisms at each successive trophic level. These are substances that are fat soluble, not water soluble, and are stored in the fat reserves of each organism.

One of the most important consequences of ecosystem dynamics in terms of human impact is biomagnification. Many substances have been shown to biomagnify, including classical studies with the pesticide dichlorodiphenyltrichloroethane (DDT), which were described in the 1960s bestseller, *Silent Spring* by Rachel Carson. DDT was a commonly used pesticide before its dangers to apex consumers, such as the bald eagle, became known. In aquatic ecosystems, organisms from each trophic level consumed many organisms in the lower level, which caused DDT to increase in birds (apex consumers) that ate fish. Thus, the birds accumulated sufficient amounts of DDT to cause fragility in their eggshells. This effect increased egg breakage during nesting and was shown to have devastating effects on these bird populations. The use of DDT was banned in the United States in the 1970s.

Other substances that biomagnify are polychlorinated biphenyls (PCB), which were used as coolant liquids in the United States until their use was banned in 1979, and heavy metals, such as mercury, lead, and cadmium. These substances are best studied in aquatic ecosystems, where predatory fish species accumulate very high concentrations of toxic substances that are at quite low concentrations in the environment and in producers. As illustrated in a study performed by the NOAA in the Saginaw Bay of Lake Huron of the North American Great Lakes (Figure 9.3.7), PCB concentrations increased from the producers of the ecosystem (phytoplankton) through the different trophic levels of fish species. The apex consumer, the walleye, has more than four times the amount of PCBs compared to phytoplankton. Also, based on results from other studies, birds that eat these fish may have PCB levels at least one order of magnitude higher than those found in the lake fish.

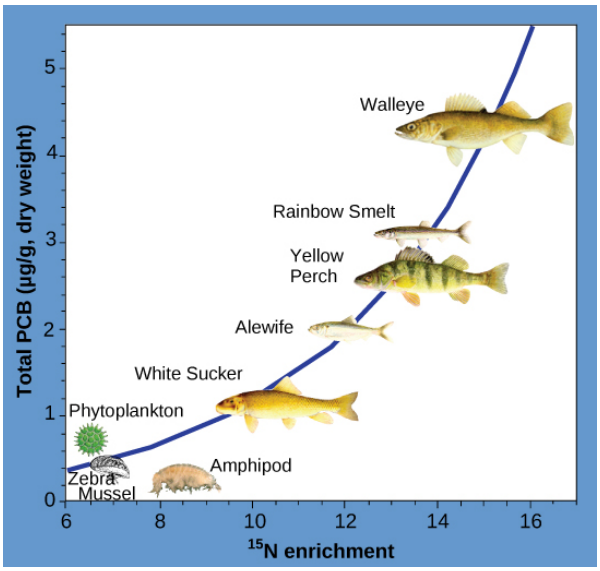


Figure 9.3.7: This chart shows the PCB concentrations found at the various trophic levels in the Saginaw Bay ecosystem of Lake Huron. Notice that the fish in the higher trophic levels accumulate more PCBs than those in lower trophic levels. (credit: Patricia Van Hoof, NOAA)

Other concerns have been raised by the biomagnification of heavy metals, such as mercury and cadmium, in certain types of seafood. The United States Environmental Protection Agency recommends that pregnant women and young children should not consume any swordfish, shark, king mackerel, or tilefish because of their high mercury content. These individuals are advised to eat fish low in mercury: salmon, shrimp, pollock, and catfish. Biomagnification is a good example of how ecosystem dynamics can affect our everyday lives, even influencing the food we eat.

Attributions

This page is a modified derivative of:

- **20.1: Energy Flow through Ecosystems** via OpenStax; license CC BY 4.0.

This page titled 9.3: Food Chains and Food Webs is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **20.1: Energy Flow through Ecosystems** by OpenStax is licensed CC BY 4.0.

9.4: Disturbance

Ecological Disturbance

Ecological disturbance, is a temporary change in environmental conditions that causes a pronounced change in a community. Disturbances often act quickly and with great effect, to alter the physical structure or arrangement of biotic and abiotic elements. Disturbance plays a significant role in shaping the structure of individual populations and the biodiversity of whole ecosystems.

Minor disturbances include localized wind events, droughts, floods, small wildland fires, and disease outbreaks in plant and animal populations. In contrast, major disturbances include large-scale wind events (such as tropical cyclones), volcanic eruptions, tsunamis, intense forest fires, epidemics, ocean temperature changes stemming from El Niño events or other climate phenomena, and the devastating effects of human impact on the environment (anthropogenic disturbances) such as clear cutting, pollution, or the introduction of invasive species. Not only invasive species can have a profound effect on an ecosystem, but also naturally occurring species can cause disturbance by their behavior.

Disturbance forces can have profound immediate effects on ecosystems and can, accordingly, greatly alter the natural community's population size or species richness. Because of these and the impacts on populations, disturbance determines the future shifts in dominance, various species successively becoming dominant as their life history characteristics, and associated life-forms, are exhibited over time. The notion of ecological disturbance has deep historical roots in ecological thinking; the first conceptual disturbance-related model in modern ecology was **ecological succession**, an idea emphasizing the progressive changes in ecosystem structure that follow a disturbance.



Figure \(\
PageIndex
{1}\): Jack Pine by
Crusier
via Wikipedia CC-BY 3.0
(top), mature unopened cones of the Jack Pine by Joseph O'Brien via Wikipedia CC-BY 3.0 (center), a boreal forest fire in Canada in 2015 by Stephan Doerr via imaggeo (bottom) CC-BY-ND 3.0

Impact

The ecological impact of a disturbance is dependent on its intensity and frequency, on the spatial distribution (or the spatial pattern) and size of the disturbed patches, and on the scale (the spatial extent) of the disturbance. Some disturbances may by cyclic. Fire disturbances, for example, occur more often in areas with a higher incidence of lightning and flammable biomass. Other disturbances, such as those caused by humans, invasive species or impact events, can occur anywhere and are not necessarily cyclic. When multiple disturbance events affect the same location in quick succession, this often results in a "compound

disturbance," an event which, due to the combination of forces, creates a new situation which is more than the sum of its parts. For example, windstorms followed by fire can create fire temperatures and durations that are not expected in even severe wildfires, and may have surprising effects on post-fire recovery. Diversity is generally low in harsh environments (with frequent or compound disturbances) because of the intolerance of all but opportunistic and highly resistant species to such conditions.

The spatial scale of natural disturbances, which is known to span about 10 orders of magnitude, is also important. For example, a drought that might devastate microbes in a temporary pond would be inconsequential to an elephant. A single tree uprooted by a hurricane is a disaster for the resident ants, but it may become a necessary resource for forest frogs as sufficient water collects around the root cavity. Likewise, while a fire may decimate wildlife populations and scorch large areas of land, the cones of the northern jack pine (*Pinus banksiana*), which are tiny in comparison, require the presence of fire to open (Figure \(\PageIndex{1}\)).

Recovery

The recovery process for species removed by a disturbance is critically dependent on its dispersal capability and the distance between the disturbed site and surviving source populations. Immediately after a disturbance there is a pulse of recruitment or regrowth under conditions of little competition for space or other resources. These conditions may favor the success of different species than the pre-disturbed community. After the initial pulse, recruitment slows since once an individual species is established it may be very difficult to displace. However, in the absence of further disturbance forces, many communities trend back toward pre-disturbance conditions. Long lived species and those that can regenerate in the presence of their own adults finally become dominant.

Some species are particularly suited for exploiting recently disturbed sites. Vegetation with the potential for rapid growth can quickly take advantage of the lack of competition. In the northeastern United States, shade-intolerant trees like pin cherry and aspen quickly fill in forest gaps created by fire or windstorm (or human disturbance). Silver maple and eastern sycamore are similarly well adapted to floodplains. They are highly tolerant of standing water and will frequently dominate floodplains where other species are periodically wiped out. Species that are well adapted for exploiting disturbance sites are referred to as pioneers. They usually grow and reproduce quickly, but may not be the strongest competitors and are usually replaced by other, more competitively dominant species over time.

The interplay between disturbance and biological processes seems to account for a major portion of the organization and spatial patterning of natural communities. Although disturbances tend to negatively affect populations of resident plants, animals, and other organisms in a given ecosystem, they provide some fugitive species with opportunities to move into and gain footholds in ecosystems whose biological communities once excluded them. This process results in an increase in the biodiversity of the ecosystem.

Intermediate Disturbance Hypothesis

Disturbance variability and species diversity are heavily linked. The success of a wide range of species from all taxonomic groups is closely tied to natural disturbance events such as fire, flooding, and windstorm. Diversity tends to be low in harsh environments because of the intolerance of all but opportunistic and highly resistant species to such conditions. The interplay between disturbance and these biological processes seems to account for a major portion of the organization and spatial patterning of natural communities.

The intermediate disturbance hypothesis (IDH) suggests that local species diversity is maximized when ecological disturbance is neither too rare nor too frequent. At low levels of disturbance, more competitive organisms will push subordinate species to extinction and dominate the ecosystem. At high levels of disturbance, due to frequent forest fires or human impacts like deforestation, all species are at risk of going extinct. According to IDH theory, at intermediate levels of disturbance, diversity is thus maximized because species that thrive at both early and late successional stages can coexist (Figure 9.4.2). IDH is a nonequilibrium model used to describe the relationship between disturbance and species diversity.

IDH is based on the following premises:

1. ecological disturbances have major effects on species richness within the area of disturbance,

2. interspecific competition results from one species driving a competitor to extinction and becoming dominant in the ecosystem, and
3. moderate ecological scale disturbances prevent interspecific competition.

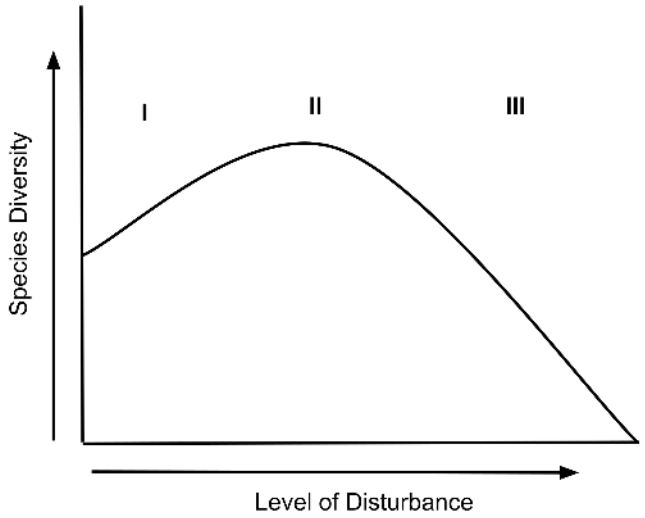


Figure 9.4.2: At low levels of ecological disturbance species richness decreases as competitive exclusion increases, II. at intermediate levels of disturbance, diversity is maximized because species that thrive at both early and late successional stages can coexist, III. at high levels of disturbance species richness is decreased due to an increase in species movement.. (CC-BY-SA 4.0; via Wikimedia)

Disturbances act to disrupt stable ecosystems and clear species' habitat. As a result, disturbances lead to species movement into the newly cleared area. Once an area is cleared there is a progressive increase in species richness and competition between species takes place. Once the conditions that create a disturbance are gone, and competition between species in the formerly disturbed area increases, species richness decreases as competitive exclusion increases. Another explanation is that proposed by Joseph H. Connell who suggested that relatively low disturbance leads to decreased diversity while high disturbance causes an increase in species movement. These proposed relationships lead to the hypothesis that intermediate disturbance levels would be the optimal amount of disorder within an ecosystem.

Another way of thinking about the IDH requires that we consider the types of organisms that could specialize in areas with different levels of disturbance. K-selected species generally demonstrate more competitive traits. Their primary investment of resources is directed towards growth, causing them to dominate stable ecosystems over a long period of time. In contrast, r-selected species colonize open areas quickly and can dominate landscapes that have been recently cleared by disturbance. These characteristics attribute to the species that thrive in habitats with higher and lower amounts of disturbance. Based on the contradictory characteristics of both of these examples, areas of occasional disturbance allow both r and K species to flourish in the same area. If K-selected and r-selected species can live in the same region, species richness can reach its maximum.

References

1. Dial, R.; Roughgarden, J. (1988). "Theory of marine communities: the intermediate disturbance hypothesis". *Ecology*. **79** (4): 1412–1424.
2. Wilkinson, David M. (1999). "The Disturbing History of Intermediate Disturbance". *Oikos*. **84** (1): 145–7.
3. Kricher, John C. (2011). *Tropical Ecology*. New Jersey, Princeton: Princeton University Press.
4. Catford, Jane A.; Daehler, Curtis C.; Murphy, Helen T.; Sheppard, Andy W.; Hardesty, Britta D.; Westcott, David A.; Rejmánek, Marcel; Bellingham, Peter J.; et al. (2012). "The intermediate disturbance hypothesis and plant invasions: Implications for species richness and management". *Perspectives in Plant Ecology, Evolution and Systematics*. **14** (3): 231–41.
5. Vandermeer, John; Boucher, Douglas; Perfecto, Ivette; de la Cerda, Inigo Granzow (1996). "A Theory of Disturbance and Species Diversity: Evidence from Nicaragua After Hurricane Joan". *Biotropica*. **28** (4): 600–13.
6. Connell, J. H. (1978). "Diversity in Tropical Rain Forests and Coral Reefs". *Science*. **199** (4335): 1302–10.

7. Hall, A. R.; Miller, A. D.; Leggett, H. C.; Roxburgh, S. H.; Buckling, A.; Shea, K. (2012). "Diversity-disturbance relationships: Frequency and intensity interact". *Biology Letters*. **8** (5): 768–71.

Attribution

This page is a modified derivative of:

- Disturbance (ecology) via Wikipedia (CC-SA 4.0)
- 18.2: What are the Effects of Disturbance? from Ecology for All! by Joshua Halpernunder a CC BY-NC-SA license

This page titled 9.4: Disturbance is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

9.5: Succession

Ecological Succession

Communities with a stable structure are said to be at equilibrium. Following a disturbance, the community may or may not return to the equilibrium state. Thus, disturbance can initiate successional change. **Ecological succession** is the process by which natural communities replace (or "succeed") one another over time. Successional changes are often orderly and predictable. Succession may be initiated either by formation of new, unoccupied habitat, such as from a lava flow or a severe landslide, or by some form of disturbance of a community, such as from a fire, logging, or hurricane.

For example, when an old farm field in the midwestern U.S. is abandoned and left alone for many years, it gradually becomes a meadow, then a few bushes grow, and eventually, trees completely fill in the field, producing a forest. Each plant community creates conditions that subsequently allow different plant communities to thrive. For example, early colonizers like grasses might add nutrients to the soil, whereas later ones like shrubs and trees might create cover and shade. Succession stops temporarily when a "climax" community forms; such communities remain in relative equilibrium until a disturbance restarts the succession process.

Understanding how succession happens in a variety of ecosystems—and what kinds of disturbances and time spans lead to the formation of different plant and animal communities—is important for scientists who want to understand ecosystem dynamics and effectively protect or restore natural communities. For example, many natural communities in North America have adapted to periodic disturbances from wildfires: This can help maintain prairie or savanna communities that depend on open habitat and nutrient cycling that might occur as a result of fire.

Primary Succession and Pioneer Species

Primary succession occurs when new substrate is formed or rock is exposed: for example, following the eruption of volcanoes, such as those on the Big Island of Hawaii. As lava flows into the ocean, new land is continually being formed. On the Big Island, approximately 32 acres of land are added each year. First, weathering and other natural forces break down the substrate enough for the establishment of pioneer species such as hearty plants and lichens with few soil requirements (Figure 9.5.1). These species help to further break down the mineral-rich lava into the soil where other, less hardy species will grow and eventually replace the pioneer species. In addition, as these early species grow and die, they add to an ever-growing layer of decomposing organic material and contribute to soil formation. Over time the area will reach an equilibrium state, with a set of organisms quite different from the pioneer species.

Definition: Primary Succession

The predictable change in a community following a disturbance that completely removes and/or destroys the soil such as glacial retreat, volcanic eruption, or newly uplifted land. Primary succession describes how organisms populate an area for the first time.

Because primary succession begins without intact soil and the presence of organisms it generally occurs over much longer time scales than secondary succession.



Figure 9.5.1: During primary succession in lava on Maui, Hawaii, succulent plants are the pioneer species. (CC BY 4.0; Forest and Kim Starr via OpenStax)

The early stages of primary succession are dominated by species with small propagules (seed and spores), which can be dispersed long distances. The early colonizers—often algae, fungi, and lichens—stabilize the substrate and create soils by breaking down rocks into smaller particles. Nitrogen supplies are limited in new soils, and nitrogen-fixing species tend to play an important role early in primary succession. Thus early, successional species may alter the substrate in such a way that facilitates colonization by other species. Over time organic matter gradually accumulates, favoring the growth of herbaceous plants like grass, ferns and herbs. These plants further improve the habitat by creating more organic matter when they die, and providing habitats for insects and other small animals. This leads to the occurrence of larger vascular plants like shrubs, or trees. More animals are then attracted to the area and a climax community is reached.

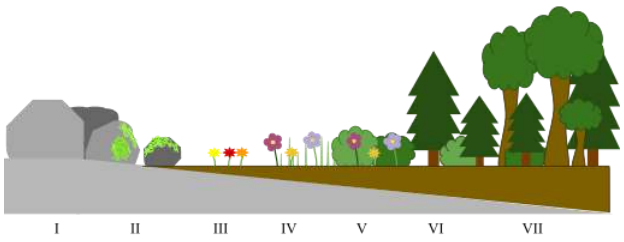


Figure 9.5.2: Primary succession occurring over time. The soil depths increase with respect to the increase in decomposition of organic matter, and there is a gradual increase of species diversity in the ecosystem. The labels I-VII represent the different stages of primary succession. I-bare rocks, II-pioneers (mosses, lichen, algae, fungi), III-annual herbaceous plants, IV-perennial herbaceous plants and grasses, V-shrubs, VI-shade intolerant trees, VII-shade tolerant trees.. (CC BY-SA 4.0; Rcole17 via Wikimedia)

Secondary succession

A classic example of **secondary succession** occurs in oak and hickory forests cleared by wildfire (Figure 9.5.3). Wildfires will burn most vegetation and kill those animals unable to flee the area. Their nutrients, however, are returned to the ground in the form of ash. Thus, even when areas are devoid of life due to severe fires, the area will soon be ready for new life to take hold.

Definition: Secondary Succession

The predictable change in a community following a disturbances that does not completely destroy the soil such as a forest fire, hurricane, flood, or farming. The disturbance significantly alters the area, but it is not rendered completely lifeless. Because the soil retains nutrients and seeds colonization by pioneer species occurs quickly.

Before the fire, the vegetation was dominated by tall trees with access to the major plant energy resource: sunlight. Their height gave them access to sunlight while also shading the ground and other low-lying species. After the fire, though, these trees are no longer dominant. Thus, the first plants to grow back are usually annual plants followed within a few years by quickly growing and spreading grasses and other pioneer species. Due to, at least in part, changes in the environment brought on by the growth of the

grasses and other species, over many years, shrubs will emerge along with small pine, oak, and hickory trees. These organisms are called intermediate species. Eventually, over 150 years, the forest will reach its equilibrium point where species composition is no longer changing and resembles the community before the fire. This equilibrium state is referred to as the **climax community**, which will remain stable until the next disturbance.

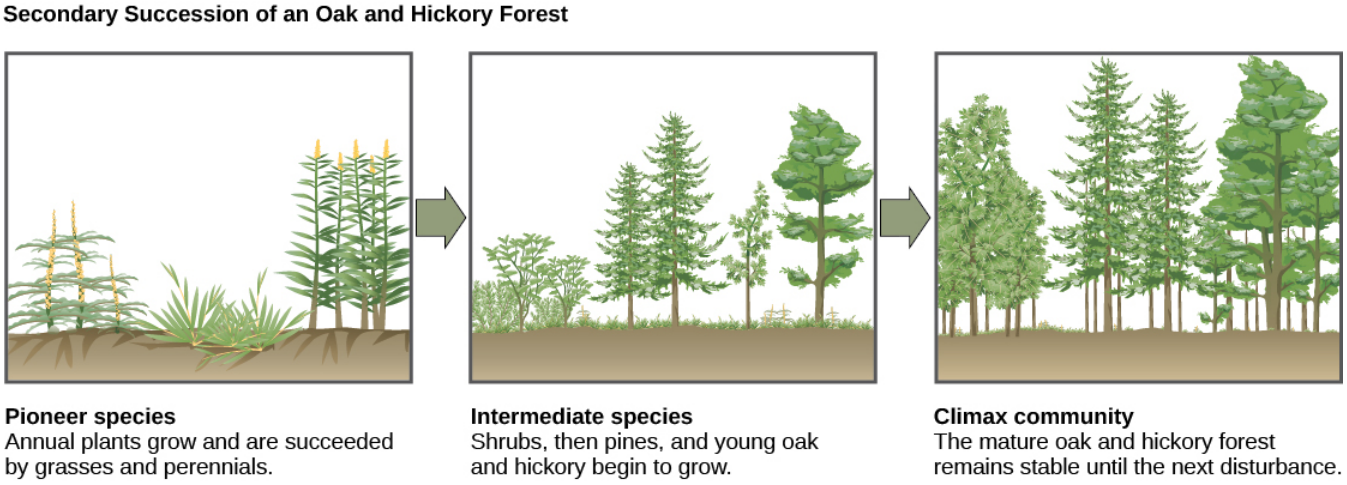


Figure 9.5.3: Secondary succession is shown in an oak and hickory forest after a forest fire. (CC BY-SA 4.0; via OpenStax)

Climatic factors may be very important, but on a much longer time-scales than any other. Changes in temperature and rainfall patterns will promote changes in communities. As the climate warmed at the end of each ice age, great successional changes took place. The tundra vegetation and bare glacial till deposits underwent succession to mixed deciduous forest. The greenhouse effect resulting in increased temperatures is likely to bring profound community changes in the next century. Geological and climatic catastrophes such as volcanic eruptions, earthquakes, avalanches, meteors, floods, fires, and high winds also bring successional changes.

In general, communities in early succession will be dominated by fast-growing, well-dispersed species (opportunist, fugitive, or r-selected life histories). As succession proceeds, these species will tend to be replaced by more competitive (K-selected) species. Trends in ecosystem and community properties in succession have been suggested, but few appear to be general. For example, species diversity almost necessarily increases during early succession as new species arrive, but may decline in later succession as competition eliminates opportunistic species and leads to dominance by locally superior competitors.

Dynamics in secondary succession are strongly influenced by pre-disturbance conditions, including soil development, seed banks, remaining organic matter, and residual living organisms. Because of residual fertility and pre-existing organisms, community change in early stages of secondary succession can be relatively rapid. Secondary succession is much more commonly observed and studied than primary succession. Particularly common types of secondary succession include responses to natural disturbances such as fire, flood, and severe winds, and to human-caused disturbances such as logging and agriculture.

Unlike in primary succession, the species that dominate secondary succession, are usually present from the start of the process. In some systems, the successional pathways are fairly consistent, and thus, are easy to predict. In others, there are many possible pathways, potentially leading to **alternate stable states**.

Definition: Alternative Stable States

In ecology, the theory of **alternative stable states** predicts that ecosystems can exist under multiple "states" (sets of unique biotic and abiotic conditions). These alternative states are non-transitory and therefore considered stable over ecologically-relevant timescales. However, ecosystems may transition from one stable state to another, (sometimes termed a phase shift or regime shift), when disturbed. Due to ecological feedbacks, ecosystems display resistance to state shifts and therefore tend to remain in one state unless disturbances are large enough.

Climax Communities?

Ecological succession is a foundational concept in ecology, which as a field examines the structure and dynamics of biological communities. Today, the concept of ecological succession continues to be studied from new angles as humans modify the global environment more than ever before. As new nuances have been added to the original theory, insights have emerged that are valuable to humans interested in managing natural resources.

For example, recent studies show that even in “climax” communities, changes in what resources are available may shift the balance of the species composition over time, even without a formal disturbance. While other natural ecosystems experience disturbance at a rate that makes a "climax" community unattainable. Thus, modern ecologists have largely abandoned the idea of stable end-stage climax community in favor of non-equilibrium ideas of ecosystem dynamics. Other work has examined the impact of biodiversity loss, invasive species, climate change and other anthropogenic factors in altering the way ecosystems respond to change.

As native species go extinct or become rare, new species enter ecosystems, and climate baselines shift, the communities that once dominated an ecosystem may be less likely to eventually return after a disturbance. However, studying succession can also provide valuable insights for ecologists and wildlife managers interested in restoring those natural systems: through careful management such as controlled burning or invasive species control, people can help ecological communities stay strong.

Attribution:

This page is a modified derivative of:

- Ecological Succession by Tara Jo Holmberg via General Ecology; license CC BY-SA 4.0
- Primary succession via Wikipedia; license CC BY-SA 4.0

This page titled 9.5: Succession is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

CHAPTER OVERVIEW

10: Ecosystems



Figure 10.1: A coral reef is an underwater ecosystem characterized by reef-building corals. Coral reefs are one of the most productive, biodiverse, and economically valuable ecosystem on Earth. They are home to 25% of all marine species including many species of commercially important fish and shellfish. Healthy coral reefs support commercial and subsistence fisheries as well as jobs and businesses through tourism and recreation. Local economies receive billions of dollars from visitors to reefs through diving tours, recreational fishing trips, hotels, restaurants, and other businesses based near reef ecosystems. Coral reef structures also buffer shorelines against 97 percent of the energy from waves, storms, and floods, helping to prevent loss of life, property damage, and erosion. Despite their great economic and recreational value, coral reefs are severely threatened by pollution, disease, and habitat destruction. (CC BY-SA 3.0; Toby Hudson via Wikipedia)

Chapter Summary

chapter summary here

10.1: Introduction to Ecosystem Ecology

10.2: Energy Flow through Ecosystems

10.3: Biogeochemical Cycles

10.4: Ecosystem Services

10.5: Resistance, Resilience, and Stability

This page titled 10: Ecosystems is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

10.1: Introduction to Ecosystem Ecology

Introduction to Ecosystem Ecology

Like other systems, an **ecosystem** is a set of interacting components that form a complex whole. The interacting components of an ecosystem are all of its living things and its nonliving environment. The nonliving environment includes such abiotic factors as temperature, water, sunlight, and minerals in the soil. A community is the biotic part of an ecosystem. It consists of all the populations of all the species that live and interact in the ecosystem.

The abiotic and biotic parts of an ecosystem are linked together by **flows of energy** and **cycles of nutrients** through the system. The amount of energy, and the efficiency with which energy is transferred determines the number of trophic levels and biomass of organisms that exist at each level. Elements such as oxygen, carbon, nitrogen, and phosphorus cycle among the biotic and abiotic components of ecosystems. The movement of such elements between living and nonliving pools (such as the movement of carbon from the atmosphere into the body of a plan via photosynthesis) is affected by chemical, physical, and biological process.

Definition: Ecosystem

An **ecosystem** consists of all the organisms and the physical environment with which they interact. These biotic and abiotic components are linked together through nutrient cycles and energy flows.

Ecosystems are considered to be complex ecological systems that can include thousand of different species living under a great variety of conditions.

There is no widely agreed upon way to delineate a specific ecosystem. Theoretically, ecosystems can vary tremendously in size. Ecosystems can be small, such as the tide pools found near the rocky shores of many oceans, or large, such as the Amazon Rainforest in Brazil (Figure 10.1.1). Consider a forest as an example. It might cover hundreds or even thousands of acres, forming a large ecosystem in which an individual tree is of little consequence. However, an individual tree can also be considered an ecosystem, with millions of organisms living in and on it, ranging from microbes to small mammals. Even a single leaf can be considered an ecosystem. Several generations of an aphid population can exist over the lifespan of the leaf. Each of the aphids, in turn, supports a diverse community of bacteria.



(a) (b)

Figure 10.1.1: A (a) tidal pool ecosystem in Matinicus Island in Maine is a small ecosystem, while the (b) Amazon Rainforest in Brazil is a large ecosystem. (credit a: modification of work by "takomabibelot"/Flickr; credit b: modification of work by Ivan Mlinaric)

Classifying Ecosystems by Environment

There are three broad categories of ecosystems based on their general environment: freshwater, ocean water, and terrestrial. Within these broad categories are individual ecosystem types based on the organisms present and the type of environmental habitat.

Life in an ecosystem often involves competition for limited resources, which occurs both within a single species and between different species. Organisms compete for food, water, sunlight, space, and mineral nutrients. These resources provide the energy for metabolic processes and the matter to make up organisms' physical structures. Other critical factors influencing community dynamics are the components of its physical environment: a habitat's climate (seasons, sunlight, and rainfall), elevation, and geology. These can all be important environmental variables that determine which organisms can exist within a particular area.

Marine ecosystems are the most common, comprising 75 percent of the Earth's surface and consisting of three basic types: shallow ocean, deep ocean water, and deep ocean surfaces (the low depth areas of the deep oceans). The shallow ocean ecosystems include extremely biodiverse coral reef ecosystems, and the deep ocean surface is known for its large numbers of plankton and krill (small crustaceans) that support it. These two environments are especially important to aerobic respirators worldwide as the phytoplankton perform 40 percent of all photosynthesis on Earth. Although not as diverse as the other two, deep ocean ecosystems contain a wide variety of marine organisms. Such ecosystems exist even at the bottom of the ocean where light is unable to penetrate through the water.

Freshwater ecosystems are the rarest, occurring on only 1.8 percent of the Earth's surface. Lakes, rivers, streams, and springs comprise these systems; they are quite diverse, and they support a variety of fish, amphibians, reptiles, insects, phytoplankton, fungi, and bacteria.

Terrestrial ecosystems, also known for their diversity, are grouped into large categories called biomes, such as tropical rain forests, savannas, deserts, coniferous forests, deciduous forests, and tundra. Grouping these ecosystems into just a few biome categories obscures the great diversity of the individual ecosystems within them. For example, there is great variation in desert vegetation: the saguaro cacti and other plant life in the Sonoran Desert, in the United States, are relatively abundant compared to the desolate rocky desert of Boa Vista, an island off the coast of Western Africa (Figure 10.1.2).



(a) (b)

Figure 10.1.2: Desert ecosystems, like all ecosystems, can vary greatly. The desert in (a) Saguaro National Park, Arizona, has abundant plant life, while the rocky desert of (b) Boa Vista island, Cape Verde, Africa, is devoid of plant life. (credit a: modification of work by Jay Galvin; credit b: modification of work by Ingo Wölbern)

Ecosystems are complex with many interacting parts. They are routinely exposed to various disturbances, or changes in the environment that effect their compositions: yearly variations in rainfall and temperature and the slower processes of plant growth, which may take several years. Many of these disturbances are a result of natural processes. For example, when lightning causes a forest fire and destroys part of a forest ecosystem, the ground is eventually populated by grasses, then by bushes and shrubs, and later by mature trees, restoring the forest to its former state. The impact of environmental disturbances caused by human activities is as important as the changes wrought by natural processes. Human agricultural practices, air pollution, acid rain, global deforestation, overfishing, eutrophication, oil spills, and illegal dumping on land and into the ocean are all issues of concern to conservationists.

Equilibrium is the steady state of an ecosystem where all organisms are in balance with their environment and with each other. In ecology, two parameters are used to measure changes in ecosystems: **resistance** and **resilience**. The ability of an ecosystem to remain at equilibrium in spite of disturbances is called resistance. The speed at which an ecosystem recovers equilibrium after being disturbed, called its resilience. Ecosystem resistance and resilience are especially important when considering human impact. The nature of an ecosystem may change to such a degree that it can lose its resilience entirely. This process can lead to the complete destruction or irreversible altering of the ecosystem.

Attribution

This page is a modified derivative of:

- 46.1: Ecology of Ecosystems via OpenStax; license CC BY 4.0.

This page titled 10.1: Introduction to Ecosystem Ecology is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **46.1: Ecology of Ecosystems** by OpenStax is licensed CC BY 4.0.

10.2: Energy Flow through Ecosystems

Energy

One area of ecosystem ecology focuses on the transfer of energy among living organisms in an ecosystem, including how efficiently organisms acquire it, use it, and how much remains for use by other organisms of the food web. The amount of energy, and the efficiency with which energy is transferred determines the number of trophic levels and biomass of organisms that exist at each level. **Energy** is defined as the ability to do work – which, for biology purposes, can be thought of as the ability to cause some kind of change. All living organisms, whether a single cell microbe or a large multicellular blue whale, require energy to sustain life. Energy is used for growth, movement, reproduction, and to maintain a stable internal environment (homeostasis).

How Organisms Acquire Energy

Energy is acquired by living things in three ways: **photosynthesis**, **chemosynthesis**, and the **consumption** and digestion of other living or previously living organisms by consumers.

Photosynthetic and chemosynthetic organisms are both grouped into a category known as **autotrophs**: organisms capable of synthesizing their own food (more specifically, capable of using inorganic carbon as a carbon source). Because autotrophs produce complex energy rich organic molecules they are also called **producers**. Photosynthetic autotrophs (photoautotrophs) use sunlight as an energy source, whereas chemosynthetic autotrophs (chemoautotrophs) use inorganic molecules as an energy source. Autotrophs are critical for all ecosystems. Without these organisms, energy would not be available to other living organisms and life itself would not be possible.

Photoautotrophs, such as plants, algae, and photosynthetic bacteria, serve as the energy source for a majority of the world's ecosystems. These ecosystems are often described by grazing food webs. Photoautotrophs harness the solar energy of the sun by converting it to chemical energy in the form complex organic molecules (such as sugars and starch).

Chemoautotrophs are primarily bacteria that are found in rare ecosystems where sunlight is not available, such as in those associated with dark caves or hydrothermal vents at the bottom of the ocean (Figure 10.2.1). Many chemoautotrophs in hydrothermal vents use hydrogen sulfide (H_2S), which is released from the vents as a source of chemical energy. This allows chemoautotrophs to synthesize complex organic molecules for their own energy and in turn supplies energy to the rest of the ecosystem.

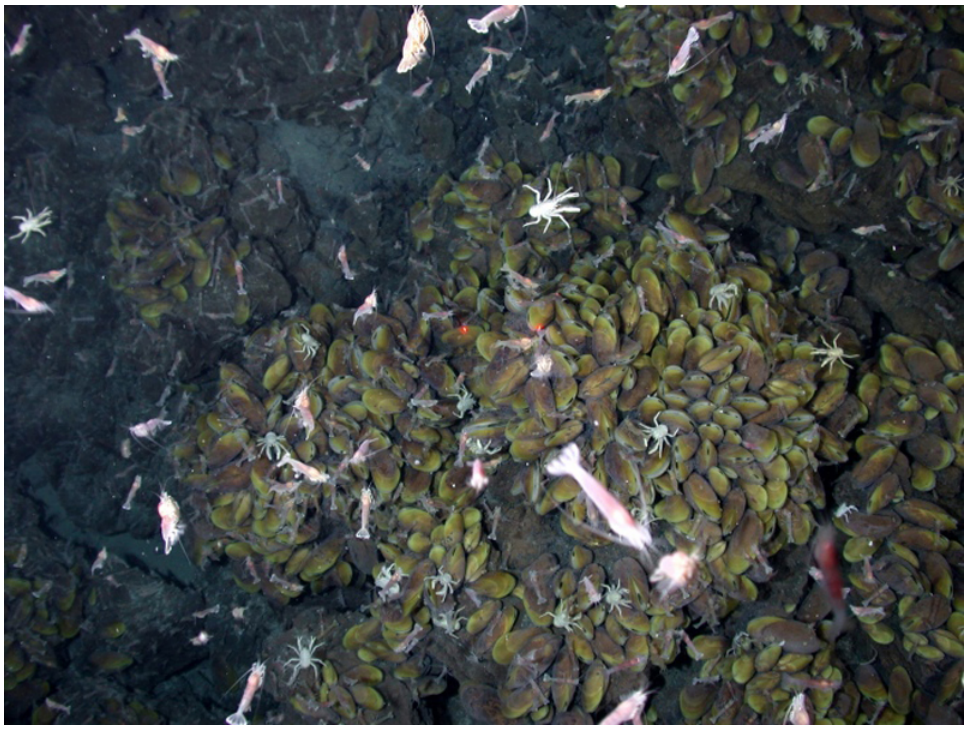


Figure 10.2.1: Swimming shrimp, a few squat lobsters, and hundreds of vent mussels are seen at a hydrothermal vent at the bottom of the ocean. As no sunlight penetrates to this depth, the ecosystem is supported by chemoautotrophic bacteria and organic material that sinks from the ocean's surface. This picture was taken in 2006 at the submerged NW Eifuku volcano off the coast of Japan by the National Oceanic and Atmospheric Administration (NOAA). The summit of this highly active volcano lies 1535 m below the surface.

Productivity within Trophic Levels

Productivity within an ecosystem can be defined as the percentage of energy entering the ecosystem incorporated into biomass in a particular trophic level. **Biomass** is the total mass, in a unit area at the time of measurement, of living or previously living organisms within a trophic level. Ecosystems have characteristic amounts of biomass at each trophic level. For example, in the English Channel ecosystem the primary producers account for a biomass of 4 g/m^2 (grams per meter squared), while the primary consumers exhibit a biomass of 21 g/m^2.

The productivity of the primary producers is especially important in any ecosystem because these organisms bring energy to other living organisms by photoautotrophy or chemoautotrophy. The rate at which photosynthetic primary producers incorporate energy from the sun is called **gross primary productivity**. An example of gross primary productivity is shown in the compartment diagram of energy flow within the Silver Springs aquatic ecosystem as shown (Figure 10.2.2). In this ecosystem, the total energy accumulated by the primary producers (gross primary productivity) was shown to be 20,810 $kcal/m^2/yr$.

Because all organisms need to use some of this energy for their own functions (like respiration and resulting metabolic heat loss) scientists often refer to the **net primary productivity** of an ecosystem. Net primary productivity is the energy that remains in the primary producers after accounting for the organisms' respiration and heat loss. The net productivity is then available to the primary consumers at the next trophic level. In our Silver Spring example, 13,187 of the 20,810 $kcal/m^2/yr$ were used for respiration or were lost as heat, leaving 7,632 $kcal/m^2/yr$ of energy for use by the primary consumers.

Ecological Efficiency: The Transfer of Energy between Trophic Levels

As illustrated in Figure 10.2.2, large amounts of energy are lost from the ecosystem from one trophic level to the next level as energy flows from the primary producers through the various trophic levels of consumers and decomposers. The main reason for this loss is the second law of thermodynamics, which states that whenever energy is converted from one form to another, there is a tendency toward disorder (entropy) in the system. In biologic systems, this means a great deal of energy is lost as metabolic heat when the organisms from one trophic level consume the next level. In the Silver Springs ecosystem example (Figure 10.2.2), we see that the primary consumers produced 1103 $kcal/m^2/yr$ from the 7618 $kcal/m^2/yr$ of energy available to them from the primary

producers. The measurement of energy transfer efficiency between two successive trophic levels is termed the **trophic level transfer efficiency** (TLTE) and is defined by the formula:

$$\text{TLTE} = \frac{\text{production at present trophic level}}{\text{production at previous trophic level}} * 100$$

In Silver Springs, the TLTE between the first two trophic levels was approximately 14.8 percent. The low efficiency of energy transfer between trophic levels is usually the major factor that limits the length of food chains observed in a food web. The fact is, after four to six energy transfers, there is not enough energy left to support another trophic level. In the Summer grassland example shown in Figure 10.2.2, only four energy transfers occurred between the primary producer, (grass plants), and the apex consumer (birds).

Ecologists have many different methods of measuring energy transfers within ecosystems. Some transfers are easier or more difficult to measure depending on the complexity of the ecosystem and how much access scientists have to observe the ecosystem. In other words, some ecosystems are more difficult to study than others, and sometimes the quantification of energy transfers has to be estimated.

Secondary Production

Another main parameter that is important in characterizing energy flow within an ecosystem is the **net production efficiency** (also called **secondary production**). Net production efficiency (NPE) allows ecologists to quantify how efficiently organisms of a particular trophic level incorporate the energy they receive into biomass; it is calculated using the following formula:

$$\text{NPE} = \frac{\text{consumer productivity}}{\text{assimilation}} * 100$$

Consumer productivity is the energy assimilated into new biomass (including new biomass generated through reproduction). It is, consequently, also the energy available to the organisms of the next trophic level. Assimilation is the biomass consumed (energy content generated per unit area) after accounting for the energy lost due to incomplete ingestion of food and energy lost as waste through excretion (feces). Incomplete ingestion refers to the fact that some consumers eat only a part of their food. For example, when a lion kills an antelope, it will eat everything except the hide and bones. The lion is missing the energy-rich bone marrow inside the bone, so the lion does not make use of all the calories its prey could provide.

Thus, NPE measures how efficiently each trophic level uses and incorporates the energy from its food into biomass to fuel the next trophic level. In general, cold-blooded animals (ectotherms), such as invertebrates, fish, amphibians, and reptiles, use less of the energy they obtain for respiration and heat than warm-blooded animals (endotherms), such as birds and mammals. The extra heat generated in endotherms, although an advantage in terms of the activity of these organisms in colder environments, is a major disadvantage in terms of NPE. Therefore, many endotherms have to eat more often than ectotherms to get the energy they need for survival. In general, NPE for ectotherms is an order of magnitude (10x) higher than for endotherms. For example, the NPE for a caterpillar eating leaves has been measured at 18 percent, whereas the NPE for a squirrel eating acorns may be as low as 1.6 percent.

The inefficiency of energy use by warm-blooded animals has broad implications for the world's food supply. It is widely accepted that the meat industry uses large amounts of crops to feed livestock, and because the NPE is low, much of the energy from animal feed is lost. For example, it costs about 1¢ to produce 1000 dietary calories (kcal) of corn or soybeans, but approximately $0.19 to produce a similar number of calories growing cattle for beef consumption. The same energy content of milk from cattle is also costly, at approximately $0.16 per 1000 kcal. Much of this difference is due to the low NPE of cattle. Thus, there has been a growing movement worldwide to promote the consumption of non-meat and non-dairy foods so that less energy is wasted feeding animals for the meat industry.

Modeling Ecosystems Energy Flow: Ecological Pyramids

The structure of ecosystems can be visualized with **ecological pyramids**, which show the relative amounts of various parameters (such as number of organisms, energy, and biomass) across trophic levels.

Pyramids of numbers can be either upright or inverted, depending on the ecosystem. As shown in Figure 10.2.2b, typical grassland during the summer has a base of many plants and the numbers of organisms decrease at each trophic level. However, during the

summer in a temperate forest, the base of the pyramid consists of few trees compared with the number of primary consumers, mostly insects. Because trees are large, they have great photosynthetic capability, and dominate other plants in this ecosystem to obtain sunlight. Even in smaller numbers, primary producers in forests are still capable of supporting other trophic levels.

Another way to visualize ecosystem structure is with pyramids of biomass. This pyramid measures the amount of energy converted into living tissue at the different trophic levels. Using the Silver Springs ecosystem example, this data exhibits an upright biomass pyramid (Figure 10.2.2a), whereas the pyramid from the English Channel example is inverted. The plants (primary producers) of the Silver Springs ecosystem make up a large percentage of the biomass found there. However, the phytoplankton in the English Channel example make up less biomass than the primary consumers, the zooplankton. As with inverted pyramids of numbers, this inverted pyramid is not due to a lack of productivity from the primary producers, but results from the high turnover rate of the phytoplankton. The phytoplankton are consumed rapidly by the primary consumers, thus, minimizing their biomass at any particular point in time. However, phytoplankton reproduce quickly, thus they are able to support the rest of the ecosystem.

Pyramid ecosystem modeling can also be used to show energy flow through the trophic levels. Pyramids of energy are always upright, and an ecosystem without sufficient primary productivity cannot be supported. All types of ecological pyramids are useful for characterizing ecosystem structure. However, in the study of energy flow through the ecosystem, pyramids of energy are the most consistent and representative models of ecosystem structure (Figure 10.2.2c).

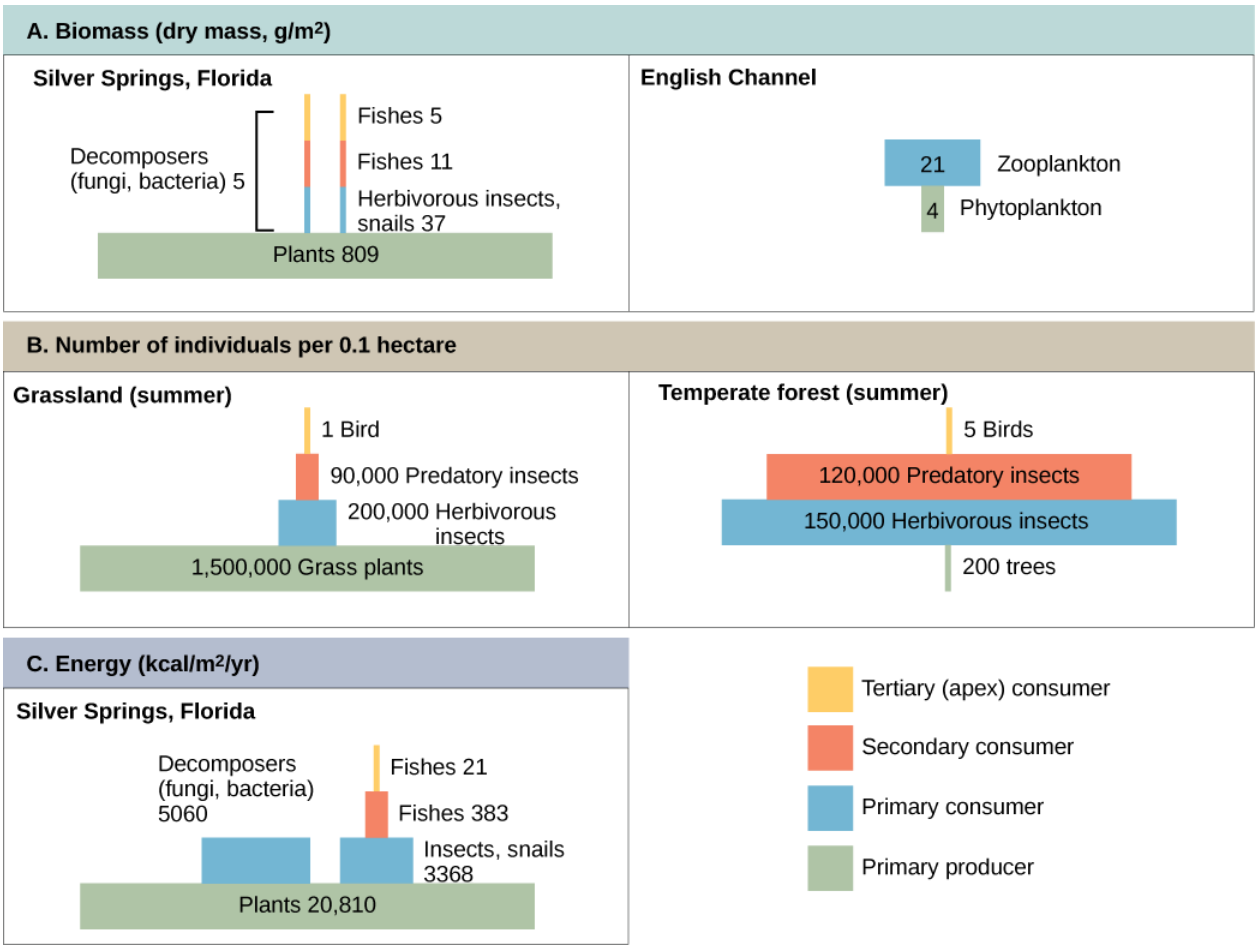


Figure 10.2.2: Ecological pyramids depict the (a) biomass, (b) number of organisms, and (c) energy in each trophic level.

? Test your understanding 10.2.1

Pyramids depicting the number of organisms or biomass may be inverted, upright, or even diamond-shaped. Energy pyramids, however, are always upright. Why?

Answer

Pyramids of organisms may be inverted or diamond-shaped because a large organism, such as a tree, can sustain many smaller organisms. Likewise, a low biomass of organisms can sustain a larger biomass at the next trophic level because the organisms reproduce rapidly and thus supply continuous nourishment. Energy pyramids, however, must always be upright because of the laws of thermodynamics. The first law of thermodynamics states that energy can neither be created nor destroyed; thus, each trophic level must acquire energy from the trophic level below. The second law of thermodynamics states that, during the transfer of energy, some energy is always lost as heat; thus, less energy is available at each higher trophic level.

Attribution

This page is a modified derivative of:

- **46.2: Energy Flow through Ecosystems** via OpenStax; licensed CC BY 4.0.

This page titled 10.2: Energy Flow through Ecosystems is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **46.2: Energy Flow through Ecosystems** by OpenStax is licensed CC BY 4.0.

10.3: Biogeochemical Cycles

Biogeochemical cycles

Energy flows directionally through ecosystems, entering as sunlight (or inorganic molecules for chemoautotrophs) and leaving as heat during the many transfers between trophic levels. However, the matter that makes up living organisms is conserved and recycled. The six most common elements associated with organic molecules—carbon, nitrogen, hydrogen, oxygen, phosphorus, and sulfur—take a variety of chemical forms and may exist for long periods in the atmosphere, on land, in water, or beneath the Earth's surface. Geologic processes, such as weathering, erosion, water drainage, and the subduction of the continental plates, all play a role in this recycling of materials. Because geology and chemistry have major roles in the study of this process, the recycling of inorganic matter between living organisms and their environment is called a **biogeochemical cycle**.

Definition: Biogeochemical Cycles

A biogeochemical cycle, or more generally a cycle of matter, is the movement and transformation of chemical elements and compounds between living organisms, the atmosphere, and the Earth's crust.

Water contains hydrogen and oxygen, which is essential to all living processes. The hydrosphere is the area of the Earth where water movement and storage occurs: as liquid water on the surface and beneath the surface or frozen (rivers, lakes, oceans, groundwater, polar ice caps, and glaciers), and as water vapor in the atmosphere. **Carbon** is found in all organic macromolecules and is an important constituent of fossil fuels. **Nitrogen** is a major component of our nucleic acids and proteins and is critical to human agriculture. **Phosphorus**, a major component of nucleic acid (along with nitrogen), is one of the main ingredients in artificial fertilizers used in agriculture and their associated environmental impacts on our surface water. **Sulfur**, critical to the 3–D folding of proteins (as in disulfide binding), is released into the atmosphere by the burning of fossil fuels, such as coal.

The cycling of these elements is interconnected. For example, the movement of water is critical for the leaching of nitrogen and phosphate into rivers, lakes, and oceans. Furthermore, the ocean itself is a major reservoir for carbon. Thus, mineral nutrients are cycled, either rapidly or slowly, through the entire biosphere, from one living organism to another, and between the biotic and abiotic world.

The Water (Hydrologic) Cycle

Water is the basis of all living processes. The human body is more than 1/2 water and human cells are more than 70 percent water. Thus, most land animals need a supply of fresh water to survive. However, when examining the stores of water on Earth, 97.5 percent of it is non-potable salt water (Figure 10.3.1). Of the remaining water, 99 percent is locked underground as water or as ice. Thus, less than 1 percent of fresh water is easily accessible from lakes and rivers. Many living things, such as plants, animals, and fungi, are dependent on the small amount of fresh surface water supply, a lack of which can have massive effects on ecosystem dynamics. Humans, of course, have developed technologies to increase water availability, such as digging wells to harvest groundwater, storing rainwater, and using desalination to obtain drinkable water from the ocean. Although this pursuit of drinkable water has been ongoing throughout human history, the supply of fresh water is still a major issue in modern times.

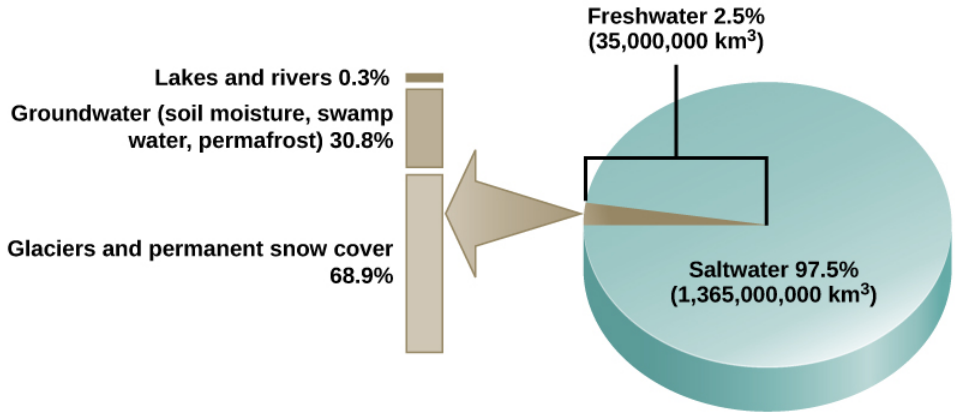


Figure 10.3.1: Only 2.5 percent of water on Earth is fresh water, and less than 1 percent of fresh water is easily accessible to living things.

Water cycling is extremely important to ecosystem dynamics. Water has a major influence on climate and, thus, on the environments of ecosystems, some located on distant parts of the Earth. Most of the water on Earth is stored for long periods in the oceans, underground, and as ice. Figure 10.3.2 illustrates the average time that an individual water molecule may spend in the Earth's major water reservoirs. **Residence time** is a measure of the average time an individual water molecule stays in a particular reservoir. A large amount of the Earth's water is locked in place in these reservoirs as ice, beneath the ground, and in the ocean, and, thus, is unavailable for short-term cycling (only surface water can evaporate).

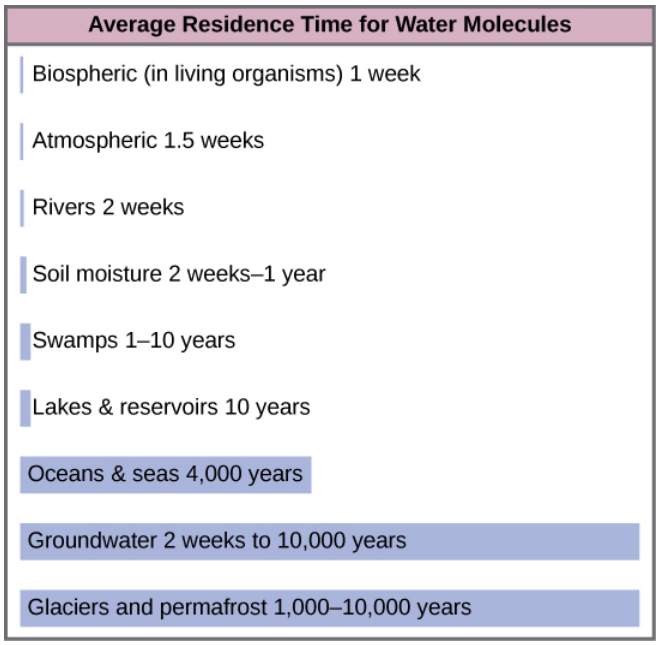


Figure 10.3.2: This graph shows the average residence time for water molecules in the Earth's water reservoirs.

There are various processes that occur during the cycling of water, shown in Figure 10.3.3. These processes include the following:

- evaporation/sublimation
- condensation/precipitation
- subsurface water flow
- surface runoff/snowmelt
- streamflow

The water cycle is driven by the sun's energy as it warms the oceans and other surface waters. This leads to the evaporation (water to water vapor) of liquid surface water and the sublimation (ice to water vapor) of frozen water, which deposits large amounts of water vapor into the atmosphere. Over time, this water vapor condenses into clouds as liquid or frozen droplets and is eventually followed by precipitation (rain or snow), which returns water to the Earth's surface. Rain eventually permeates into the ground,

where it may evaporate again if it is near the surface, flow beneath the surface, or be stored for long periods. More easily observed is surface runoff: the flow of fresh water either from rain or melting ice. Runoff can then make its way through streams and lakes to the oceans or flow directly to the oceans themselves.

In most natural terrestrial environments rain encounters vegetation before it reaches the soil surface. A significant percentage of water evaporates immediately from the surfaces of plants. What is left reaches the soil and begins to move down. Surface runoff will occur only if the soil becomes saturated with water in a heavy rainfall. Most water in the soil will be taken up by plant roots. The plant will use some of this water for its own metabolism, and some of that will find its way into animals that eat the plants, but much of it will be lost back to the atmosphere through a process known as evapotranspiration. Water enters the vascular system of the plant through the roots and evaporates, or transpires, through the stomata of the leaves. Water in the soil that is not taken up by a plant and that does not evaporate is able to percolate into the subsoil and bedrock. Here it forms groundwater.

Groundwater is a significant reservoir of fresh water. It exists in the pores between particles in sand and gravel, or in the fissures in rocks. Shallow groundwater flows slowly through these pores and fissures and eventually finds its way to a stream or lake where it becomes a part of the surface water again. Streams do not flow because they are replenished from rainwater directly; they flow because there is a constant inflow from groundwater below. Some groundwater is found very deep in the bedrock and can persist there for millennia. Most groundwater reservoirs, or aquifers, are the source of drinking or irrigation water drawn up through wells. In many cases these aquifers are being depleted faster than they are being replenished by water percolating down from above.

Rain and surface runoff are major ways in which minerals, including carbon, nitrogen, phosphorus, and sulfur, are cycled from land to water. The environmental effects of runoff will be discussed later as these cycles are described.

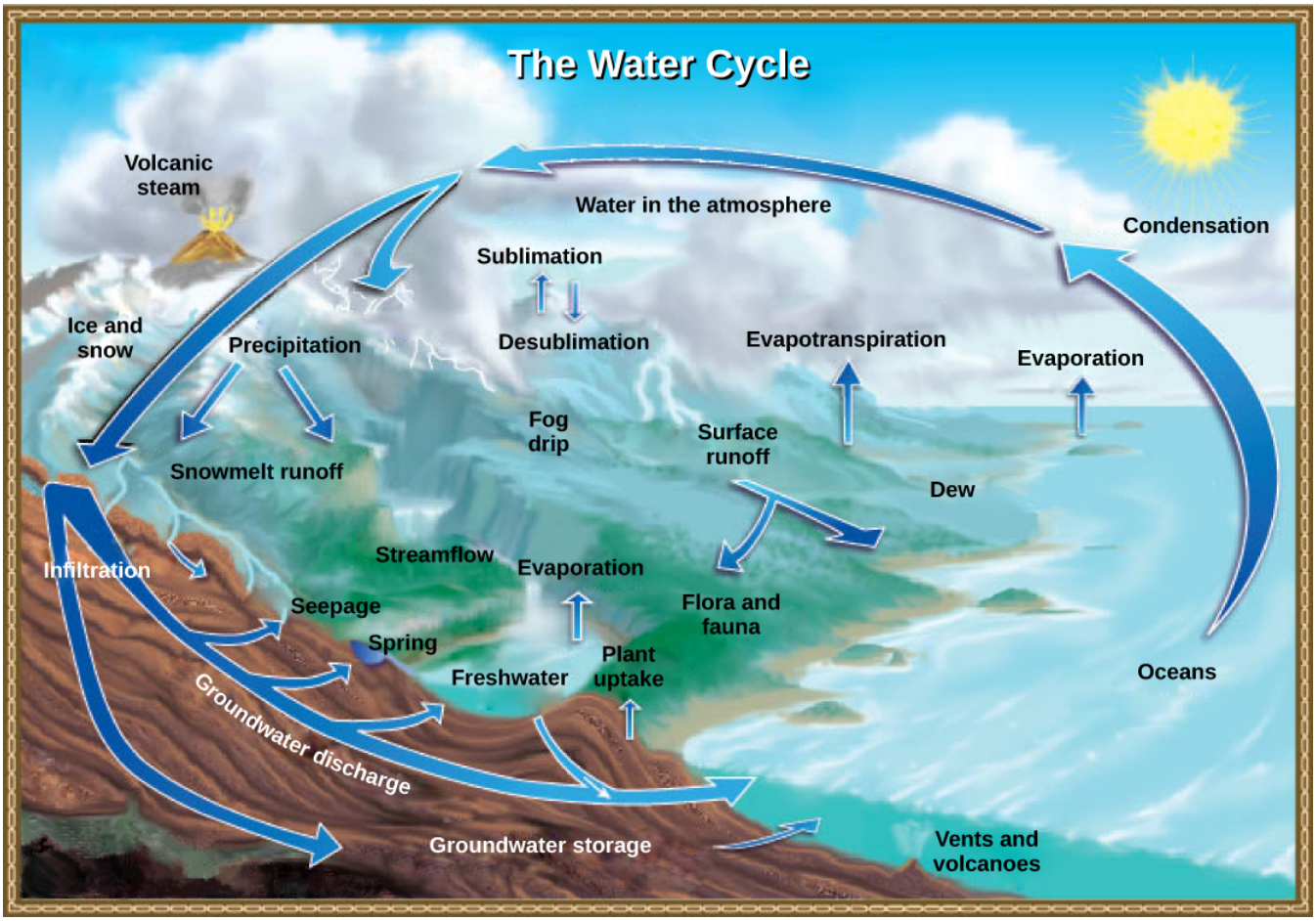


Figure 10.3.3: Water from the land and oceans enters the atmosphere by evaporation or sublimation, where it condenses into clouds and falls as rain or snow. Precipitated water may enter freshwater bodies or infiltrate the soil. The cycle is complete when surface or groundwater reenters the ocean. (credit: modification of work by John M. Evans and Howard Perlman, USGS)

The Carbon Cycle

Carbon is the second most abundant element in living organisms. Carbon is present in all organic molecules, and its role in the structure of macromolecules is of primary importance to living organisms. Carbon compounds contain especially high energy, particularly those derived from fossilized organisms, mainly plants, which humans use as fuel. Since the 1800s, the number of countries using massive amounts of fossil fuels has increased. Since the beginning of the Industrial Revolution, global demand for the Earth's limited fossil fuel supplies has risen; therefore, the amount of carbon dioxide in our atmosphere has increased. This increase in carbon dioxide has been associated with climate change and other disturbances of the Earth's ecosystems and is a major environmental concern worldwide. Thus, the "carbon footprint" is based on how much carbon dioxide is produced and how much fossil fuel countries consume.

The carbon cycle is most easily studied as two interconnected sub-cycles: one dealing with rapid carbon exchange among living organisms and the other dealing with the long-term cycling of carbon through geologic processes. The entire carbon cycle is shown in Figure 10.3.4.

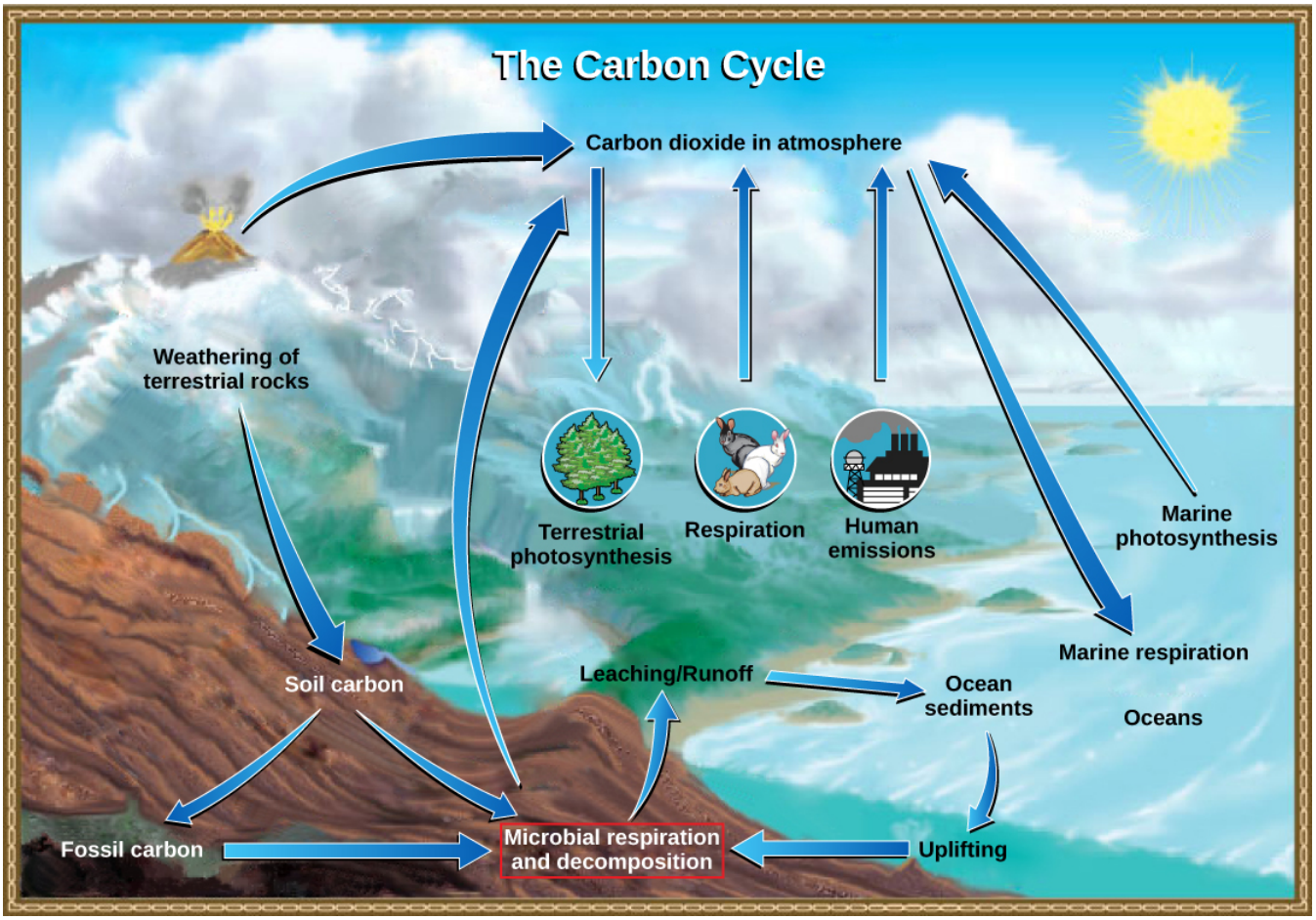


Figure 10.3.4: Carbon dioxide gas exists in the atmosphere and is dissolved in water. Photosynthesis converts carbon dioxide gas to organic carbon, and respiration cycles the organic carbon back into carbon dioxide gas. Long-term storage of organic carbon occurs when matter from living organisms is buried deep underground and becomes fossilized. Volcanic activity and, more recently, human emissions, bring this stored carbon back into the carbon cycle. (credit: modification of work by John M. Evans and Howard Perlman, USGS)

The Biological Carbon Cycle

Living organisms are connected in many ways, even between ecosystems. A good example of this connection is the exchange of carbon between autotrophs and heterotrophs within and between ecosystems by way of atmospheric carbon dioxide. Carbon dioxide is the basic building block that most autotrophs use to build sugars via photosynthesis. Most terrestrial autotrophs obtain their carbon dioxide directly from the atmosphere. A by-product of the process is oxygen. The photosynthetic organisms are responsible for depositing approximately 21 percent oxygen content of the atmosphere that we observe today.

Heterotrophs and autotrophs are partners in biological carbon exchange (especially the primary consumers, largely herbivores). Heterotrophs acquire energy from the autotrophs by consuming them, and breaking them down by cellular respiration. The most efficient type of respiration, aerobic respiration, requires oxygen obtained from the atmosphere or dissolved in water. Thus, there is a constant exchange of oxygen and carbon dioxide between the autotrophs (which need the carbon) and the heterotrophs (which need the oxygen). Gas exchange through the atmosphere and water is one way that the carbon cycle connects all living organisms on Earth.

The Biogeochemical Carbon Cycle

The movement of carbon through the land, water, and air is complex, and in many cases, it occurs much more slowly geologically than as seen between living organisms. Carbon is stored for long periods in what are known as carbon reservoirs, which include the atmosphere, bodies of liquid water (mostly oceans), ocean sediment, soil, land sediments (including fossil fuels), and the Earth's interior.

As stated, the atmosphere is a major reservoir of carbon in the form of carbon dioxide and is essential to the process of photosynthesis. The level of carbon dioxide in the atmosphere is greatly influenced by the reservoir of carbon in the oceans. The exchange of carbon between the atmosphere and water reservoirs influences how much carbon is found in each location, and each one affects the other reciprocally. Carbon dioxide (CO_2) from the atmosphere dissolves in water and combines with water molecules to form carbonic acid, and then it ionizes to carbonate and bicarbonate ions (Figure 10.3.5)

Step 1: CO_2 (atmospheric) $\rightleftharpoons$ CO_2 (dissolved)
Step 2: CO_2 (dissolved) + H_2O $\rightleftharpoons$ H_2CO_3 (carbonic acid)
Step 3: H_2CO_3 $\rightleftharpoons$ + H^+ + HCO_3^- (biocarbonate ion)
Step 4: HCO_3^- $\rightleftharpoons$ H^+ + CO_3^{2-} (carbonate ion)

Figure 10.3.5: Carbon dioxide reacts with water to form bicarbonate and carbonate ions.

The equilibrium coefficients are such that more than 90 percent of the carbon in the ocean is found as bicarbonate ions. Some of these ions combine with seawater calcium to form calcium carbonate ($CaCO_3$), a major component of marine organism shells. These organisms eventually form sediments on the ocean floor. Over geologic time, the calcium carbonate forms limestone, which comprises the largest carbon reservoir on Earth.

On land, carbon is stored in soil as a result of the decomposition of living organisms (by decomposers) or from weathering of terrestrial rock and minerals. This carbon can be leached into the water reservoirs by surface runoff. Deeper underground, on land and at sea, are fossil fuels: the anaerobically decomposed remains of plants that take millions of years to form. Fossil fuels are considered a non-renewable resource because their use far exceeds their rate of formation. A **non-renewable resource**, such as fossil fuel, is either regenerated very slowly or not at all. Another way for carbon to enter the atmosphere is from land (including land beneath the surface of the ocean) by the eruption of volcanoes and other geothermal systems. Carbon sediments from the ocean floor are taken deep within the Earth by the process of subduction: the movement of one tectonic plate beneath another. Carbon is released as carbon dioxide when a volcano erupts or from volcanic hydrothermal vents.

Carbon dioxide is also added to the atmosphere by the animal husbandry practices of humans. The large numbers of land animals raised to feed the Earth's growing population results in increased carbon dioxide levels in the atmosphere due to farming practices and the respiration and methane production. This is another example of how human activity indirectly affects biogeochemical cycles in a significant way. Although much of the debate about the future effects of increasing atmospheric carbon on climate change focuses on fossils fuels, scientists take natural processes, such as volcanoes and respiration, into account as they model and predict the future impact of this increase.

The Nitrogen Cycle

Getting nitrogen into the living world is difficult. Plants and phytoplankton are not equipped to incorporate nitrogen from the atmosphere (which exists as tightly bonded, triple covalent N_2) even though this molecule comprises approximately 78 percent of the atmosphere. Nitrogen enters the living world via free-living and symbiotic bacteria, which incorporate nitrogen into their macromolecules through nitrogen fixation (conversion of N_2). Cyanobacteria live in most aquatic ecosystems where sunlight is

present; they play a key role in nitrogen fixation. Cyanobacteria are able to use inorganic sources of nitrogen to “fix” nitrogen. *Rhizobium* bacteria live symbiotically in the root nodules of legumes (such as peas, beans, and peanuts) and provide them with the organic nitrogen they need. Free-living bacteria, such as *Azotobacter*, are also important nitrogen fixers.

Definition: Nitrogen fixation

Nitrogen fixation is an important process in the nitrogen cycle. In this process, the N_2 from air is reduced to NH_3 (or NH_4^+), which can be further converted to nitrogen-containing organic compounds, such as proteins and nucleic acids (DNA). Generally, N_2 fixation proceeds via natural processes by bacteria.

Organic nitrogen is especially important to the study of ecosystem dynamics since many ecosystem processes, such as primary production and decomposition, are limited by the available supply of nitrogen. As shown in Figure 10.3.6, the nitrogen that enters living systems by **nitrogen fixation** is successively converted from organic nitrogen back into nitrogen gas by bacteria. This process occurs in three steps in terrestrial systems: ammonification, nitrification, and denitrification. First, the ammonification process converts nitrogenous waste from living animals or from the remains of dead animals into ammonium (NH_4^+) by certain bacteria and fungi. Second, the ammonium is converted to nitrites (NO_2^-) by nitrifying bacteria, such as *Nitrosomonas*, through nitrification. Subsequently, nitrites are converted to nitrates (NO_3^-) by similar organisms. Third, the process of denitrification occurs, whereby bacteria, such as *Pseudomonas* and *Clostridium*, convert the nitrates into nitrogen gas, allowing it to re-enter the atmosphere.

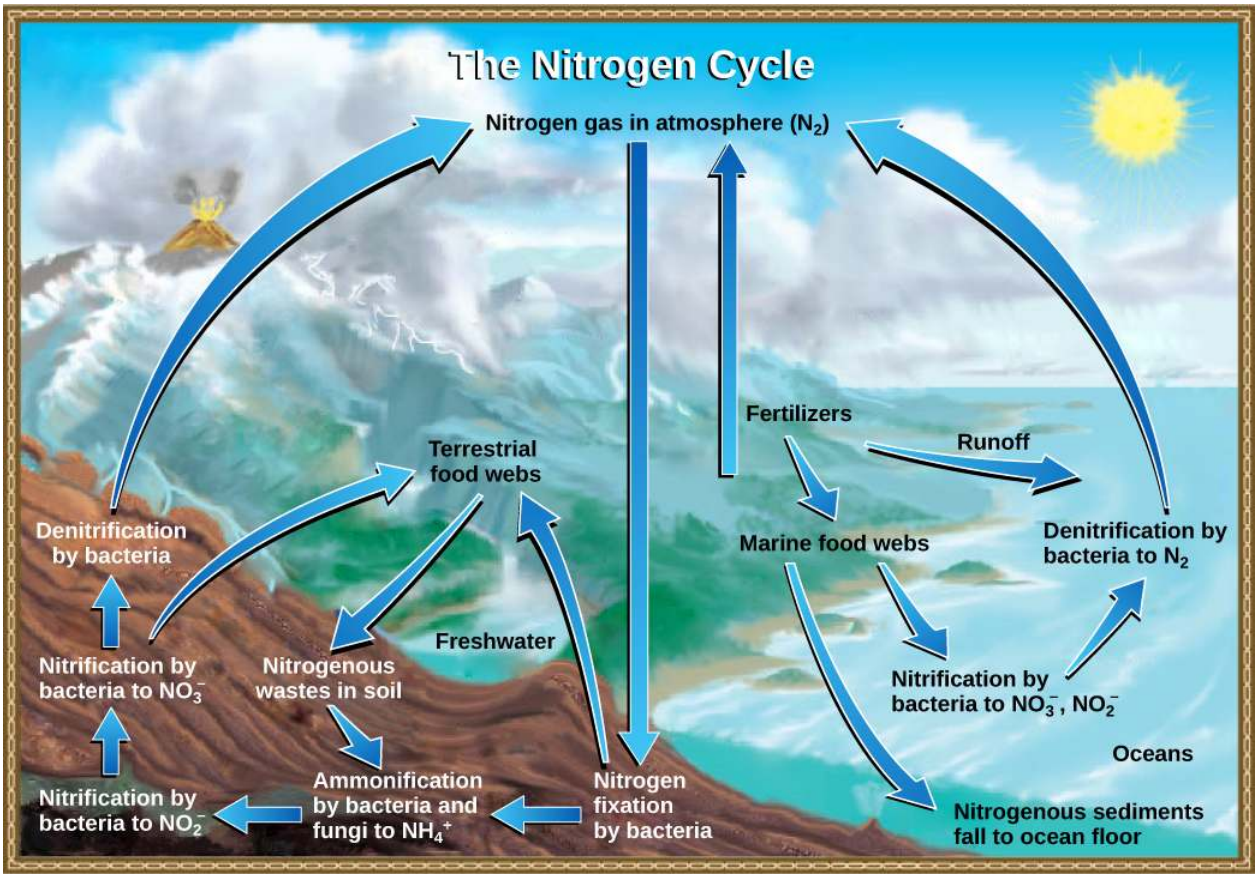


Figure 10.3.6: Nitrogen enters the living world from the atmosphere via nitrogen-fixing bacteria. This nitrogen and nitrogenous waste from animals is then processed back into gaseous nitrogen by soil bacteria, which also supply terrestrial food webs with the organic nitrogen they need. (credit: modification of work by John M. Evans and Howard Perlman, USGS)

Human activity can release nitrogen into the environment by two primary means: the combustion of fossil fuels, which releases different nitrogen oxides, and by the use of artificial fertilizers in agriculture, which are then washed into lakes, streams, and rivers by surface runoff. Atmospheric nitrogen is associated with several effects on Earth’s ecosystems including the production of acid rain (as nitric acid, HNO_3) and greenhouse gas (as nitrous oxide, N_2O) potentially causing climate change. A major effect from

fertilizer runoff is saltwater and freshwater **eutrophication**, a process whereby nutrient runoff causes the excess growth of microorganisms, depleting dissolved oxygen levels and killing ecosystem fauna.

The Phosphorus Cycle

Phosphorus is an essential nutrient for living processes; it is a major component of DNA, cell membranes, and makes up the supportive components of our bones. Phosphorus is often the limiting nutrient (necessary for growth) in aquatic ecosystems (Figure 10.3.7).

Phosphorus occurs in nature as the phosphate ion (PO_4^{3-}). In addition to phosphate runoff as a result of human activity, natural surface runoff occurs when it is leached from phosphate-containing rock by weathering, thus sending phosphates into rivers, lakes, and the ocean. This rock has its origins in the ocean. Phosphate-containing ocean sediments form primarily from the bodies of ocean organisms and from their excretions. However, in remote regions, volcanic ash, aerosols, and mineral dust may also be significant phosphate sources. This sediment then is moved to land over geologic time by the uplifting of areas of the Earth's surface.

Phosphorus is also reciprocally exchanged between phosphate dissolved in the ocean and marine ecosystems. The movement of phosphate from the ocean to the land and through the soil is extremely slow, with the average phosphate ion having an oceanic residence time between 20,000 and 100,000 years.

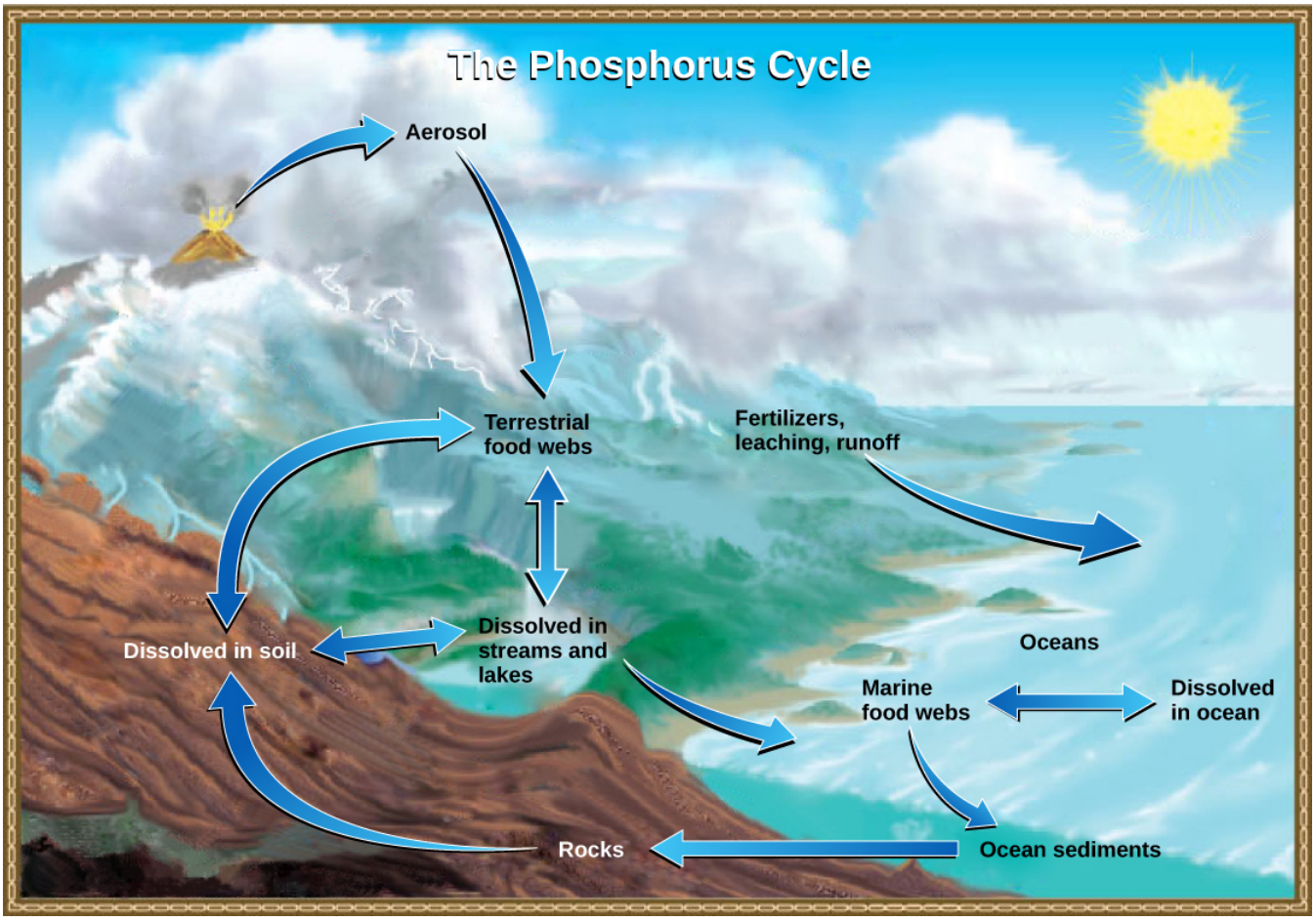


Figure 10.3.7: In nature, phosphorus exists as the phosphate ion (PO_4^{3-}). Weathering of rocks and volcanic activity releases phosphate into the soil, water, and air, where it becomes available to terrestrial food webs. Phosphate enters the oceans via surface runoff, groundwater flow, and river flow. Phosphate dissolved in ocean water cycles into marine food webs. Some phosphate from the marine food webs falls to the ocean floor, where it forms sediment. (credit: modification of work by John M. Evans and Howard Perlman, USGS)

Eutrophication

Excess phosphorus and nitrogen that enters these ecosystems from fertilizer runoff and from sewage causes excessive growth of microorganisms and depletes the dissolved oxygen, which leads to the death of many ecosystem fauna, such as shellfish and finfish. This process is responsible for dead zones in lakes and at the mouths of many major rivers (Figure 10.3.8).

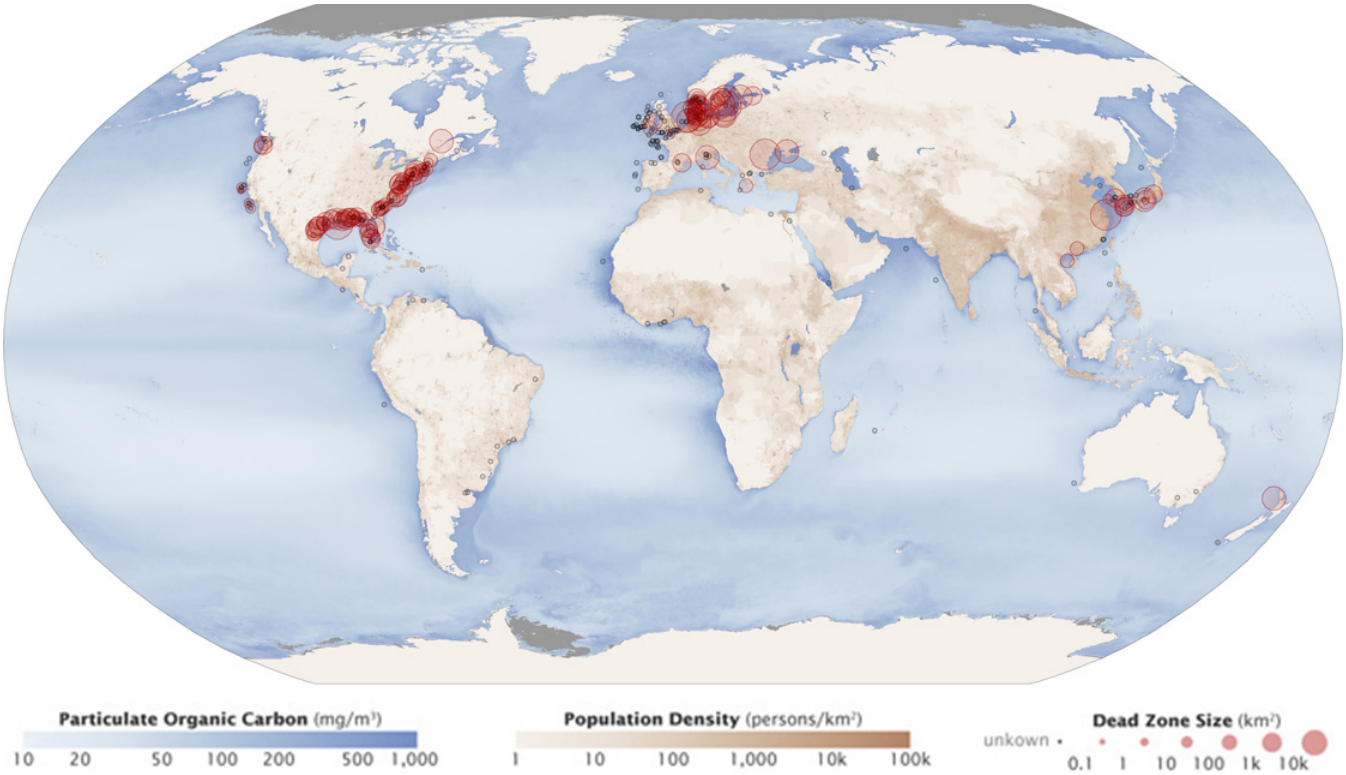


Figure 10.3.8: Dead zones occur when phosphorus and nitrogen from fertilizers cause excessive growth of microorganisms, which depletes oxygen and kills fauna. Worldwide, large dead zones are found in coastal areas of high population density. (credit: NASA Earth Observatory)

A dead zone is an area within a freshwater or marine ecosystem where large areas are depleted of their normal flora and fauna; these zones can be caused by eutrophication, oil spills, dumping of toxic chemicals, and other human activities. The number of dead zones has been increasing for several years, and more than 400 of these zones were present as of 2008. One of the worst dead zones is off the coast of the United States in the Gulf of Mexico, where fertilizer runoff from the Mississippi River basin has created a dead zone of over 8463 square miles. Phosphate and nitrate runoff from fertilizers also negatively affect several lake and bay ecosystems including the Chesapeake Bay in the eastern United States.

Everyday Connection: Chesapeake Bay



(a) (b)

Figure 10.3.9: This (a) satellite image shows the Chesapeake Bay, an ecosystem affected by phosphate and nitrate runoff. A (b) member of the Army Corps of Engineers holds a clump of oysters being used as a part of the oyster restoration effort in the bay. (credit a: modification of work by NASA/MODIS; credit b: modification of work by U.S. Army)

The Chesapeake Bay has long been valued as one of the most scenic areas on Earth; it is now in distress and is recognized as a declining ecosystem. In the 1970s, the Chesapeake Bay was one of the first ecosystems to have identified dead zones, which continue to kill many fish and bottom-dwelling species, such as clams, oysters, and worms. Several species have declined in the Chesapeake Bay due to surface water runoff containing excess nutrients from artificial fertilizer used on land. The source of the fertilizers (with high nitrogen and phosphate content) is not limited to agricultural practices. There are many nearby urban areas and more than 150 rivers and streams empty into the bay that are carrying fertilizer runoff from lawns and gardens. Thus, the decline of the Chesapeake Bay is a complex issue and requires the cooperation of industry, agriculture, and everyday homeowners.

Of particular interest to conservationists is the oyster population; it is estimated that more than 200,000 acres of oyster reefs existed in the bay in the 1700s, but that number has now declined to only 36,000 acres. Oyster harvesting was once a major industry for Chesapeake Bay, but it declined 88 percent between 1982 and 2007. This decline was due not only to fertilizer runoff and dead zones but also to overharvesting. Oysters require a certain minimum population density because they must be in close proximity to reproduce. Human activity has altered the oyster population and locations, greatly disrupting the ecosystem.

The restoration of the oyster population in the Chesapeake Bay has been ongoing for several years with mixed success. Not only do many people find oysters good to eat, but they also clean up the bay. Oysters are filter feeders, and as they eat, they clean the water around them. In the 1700s, it was estimated that it took only a few days for the oyster population to filter the entire volume of the bay. Today, with changed water conditions, it is estimated that the present population would take nearly a year to do the same job.

Restoration efforts have been ongoing for several years by non-profit organizations, such as the Chesapeake Bay Foundation. The restoration goal is to find a way to increase population density so the oysters can reproduce more efficiently. Many disease-resistant varieties (developed at the Virginia Institute of Marine Science for the College of William and Mary) are now available and have been used in the construction of experimental oyster reefs. Efforts to clean and restore the bay by Virginia and Delaware have been hampered because much of the pollution entering the bay comes from other states, which stresses the need for inter-state cooperation to gain successful restoration.

The new, hearty oyster strains have also spawned a new and economically viable industry—oyster aquaculture—which not only supplies oysters for food and profit, but also has the added benefit of cleaning the bay.

The Sulfur Cycle

Sulfur is an essential element for the macromolecules of living things. As a part of the amino acid cysteine, it is involved in the formation of disulfide bonds within proteins, which help to determine their 3-D folding patterns, and hence their functions. As shown in Figure 10.3.10, sulfur cycles between the oceans, land, and atmosphere. Atmospheric sulfur is found in the form of sulfur dioxide (SO_2) and enters the atmosphere in three ways: from the decomposition of organic molecules, from volcanic activity and geothermal vents, and from the burning of fossil fuels by humans.

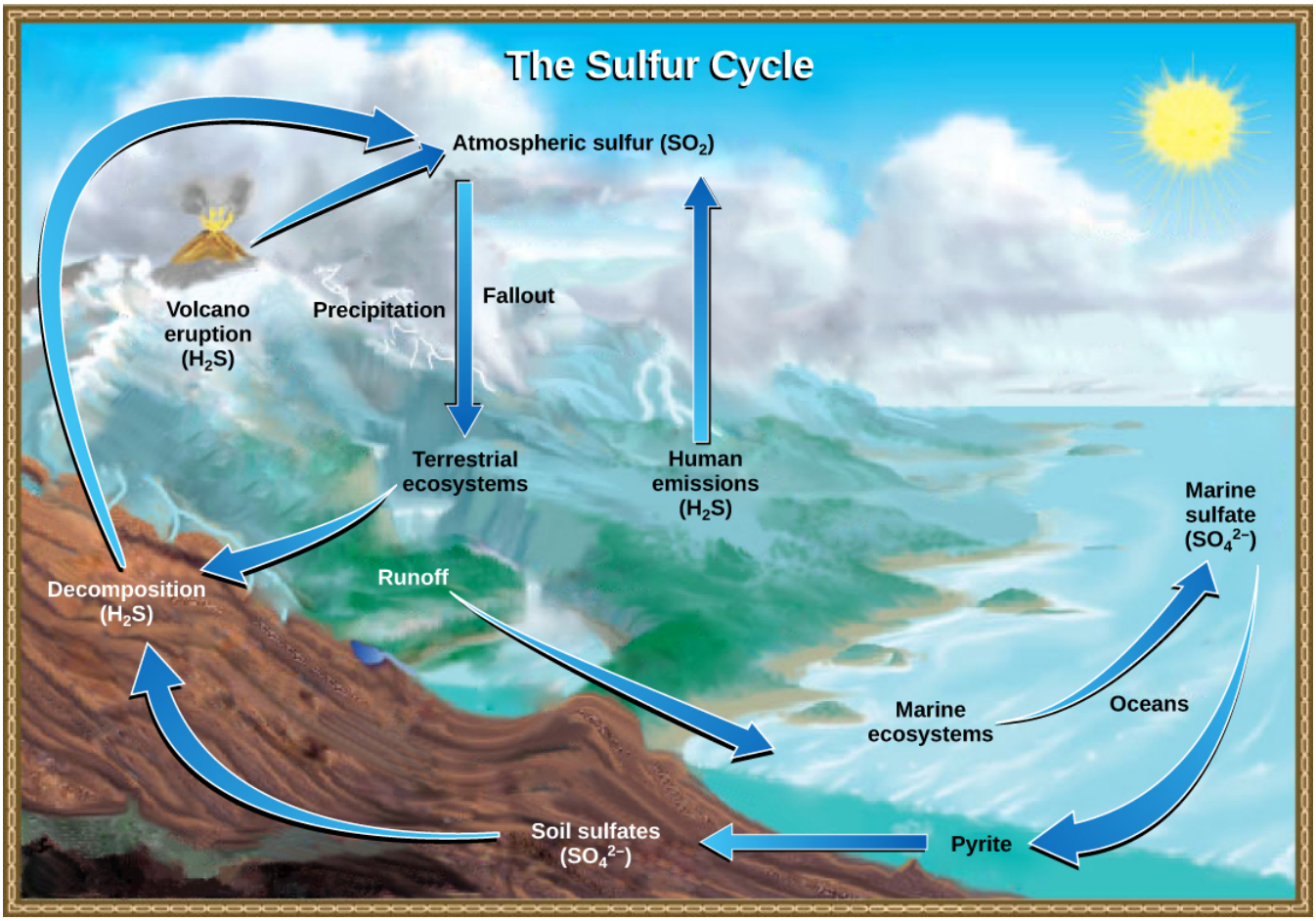


Figure 10.3.10: Sulfur dioxide from the atmosphere becomes available to terrestrial and marine ecosystems when it is dissolved in precipitation as weak sulfuric acid or when it falls directly to the Earth as fallout. Weathering of rocks also makes sulfates available to terrestrial ecosystems. Decomposition of living organisms returns sulfates to the ocean, soil and atmosphere. (credit: modification of work by John M. Evans and Howard Perlman, USGS)

On land, sulfur is deposited in four major ways: precipitation, direct fallout from the atmosphere, rock weathering, and geothermal vents (Figure 10.3.11). Atmospheric sulfur is found in the form of sulfur dioxide (SO_2), and as rain falls through the atmosphere, sulfur is dissolved in the form of weak sulfuric acid (H_2SO_4). Sulfur can also fall directly from the atmosphere in a process called fallout. Also, the weathering of sulfur-containing rocks releases sulfur into the soil. These rocks originate from ocean sediments that are moved to land by the geologic uplifting of ocean sediments. Terrestrial ecosystems can then make use of these soil sulfates (SO_4^{2-}), and upon the death and decomposition of these organisms, release the sulfur back into the atmosphere as hydrogen sulfide (H_2S) gas.



Figure 10.3.11: At this sulfur vent in Lassen Volcanic National Park in northeastern California, the yellowish sulfur deposits are visible near the mouth of the vent.

Sulfur enters the ocean via runoff from land, from atmospheric fallout, and from underwater geothermal vents. Some ecosystems rely on chemoautotrophs using sulfur as a biological energy source. This sulfur then supports marine ecosystems in the form of sulfates.

Human activities have played a major role in altering the balance of the global sulfur cycle. The burning of large quantities of fossil fuels, especially from coal, releases larger amounts of hydrogen sulfide gas into the atmosphere. As rain falls through this gas, it creates the phenomenon known as acid rain. Acid rain is corrosive rain caused by rainwater falling to the ground through sulfur dioxide gas, turning it into weak sulfuric acid, which causes damage to aquatic ecosystems. Acid rain damages the natural environment by lowering the pH of lakes, which kills many of the resident fauna; it also affects the man-made environment through the chemical degradation of buildings. For example, many marble monuments, such as the Lincoln Memorial in Washington, DC, have suffered significant damage from acid rain over the years. These examples show the wide-ranging effects of human activities on our environment and the challenges that remain for our future.

Summary

Mineral nutrients are cycled through ecosystems and their environment. Of particular importance are water, carbon, nitrogen, phosphorus, and sulfur. All of these cycles have major impacts on ecosystem structure and function. As human activities have caused major disturbances to these cycles, their study and modeling is especially important. A variety of human activities, such as pollution, oil spills, and other events have damaged ecosystems, potentially causing global climate change. The health of Earth depends on understanding these cycles and how to protect the environment from irreversible damage.

Attribution:

This page is a modified derivative of

- **46.3: Biogeochemical Cycles** by OpenStax is licensed CC BY 4.0.

This page titled 10.3: Biogeochemical Cycles is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **46.3: Biogeochemical Cycles** by OpenStax is licensed CC BY 4.0.

10.4: Ecosystem Services

Ecosystem Services

Ecosystem services are the many and varied benefits to humans provided by the natural environment and healthy ecosystems. Functioning healthy ecosystems offer such things as natural pollination of crops, clean air, extreme weather mitigation, and human mental and physical well-being. Collectively, these benefits are becoming known as ecosystem services, and are often integral to the provision of food, the provisioning of clean drinking water, the decomposition of wastes, and the resilience and productivity of food ecosystems.



Figure 10.4.1: Honey bee on an avocado flower. Pollination is an example of an ecosystem service. (Honeybee by Andrew Mandemaker via Wikimedia; CC BY-SA 2.5)

Many ecologists also believe that the provision of ecosystem services can be stabilized with biodiversity. Increasing biodiversity also benefits the variety of ecosystem services available to society. Understanding the relationship between biodiversity and an ecosystem's stability is essential to the management of natural resources and their services.

Types of Ecosystem Services

The Millennium Ecosystem Assessment (MA), a major UN-sponsored effort to analyze the impact of human actions on ecosystems and human well-being, identified four major categories of ecosystem services: provisioning, regulating, cultural and supporting services.

Provisioning Services: When people are asked to identify a service provided by nature, most think of food. Fruits, vegetables, trees, fish, and livestock are available to us as direct products of ecosystems. A provisioning service is any type of benefit to people that can be extracted from nature. Along with food, other types of provisioning services include drinking water, timber, wood fuel, natural gas, oils, plants that can be made into clothes and other materials, and medicinal benefits.

Regulating Services: Ecosystems provide many of the basic services that make life possible for people. Plants clean air and filter water, bacteria decompose wastes, bees pollinate flowers, and tree roots hold soil in place to prevent erosion. All these processes work together to make ecosystems clean, sustainable, functional, and resilient to change. A regulating service is the benefit provided by ecosystem processes that moderate natural phenomena. Regulating services include pollination, decomposition, water purification, erosion and flood control, and carbon storage and climate regulation.

Cultural Services: As we interact and alter nature, the natural world has in turn altered us. It has guided our cultural, intellectual, and social development by being a constant force present in our lives. The importance of ecosystems to the human mind can be traced back to the beginning of mankind with ancient civilizations drawing pictures of animals, plants, and weather patterns on cave walls. A cultural service is a non-material benefit that contributes to the development and cultural advancement of people, including how ecosystems play a role in local, national, and global cultures; the building of knowledge and the spreading of ideas; creativity born from interactions with nature (music, art, architecture); and recreation.

Supporting Services: The natural world provides so many services, sometimes we overlook the most fundamental. Ecosystems themselves couldn't be sustained without the consistency of underlying natural processes, such as photosynthesis, nutrient cycling, the creation of soils, and the water cycle. These processes allow the Earth to sustain basic life forms, let alone whole ecosystems and people. Without supporting services, provisional, regulating, and cultural services wouldn't exist.

Services under the threat of humans

Ecosystem services are the set of ecosystem functions that are useful to humans. These services make the planet inhabitable by supplying and purifying the air we breathe and the water we drink. However, may of these services are being impacted by human activities.

Disruptions of biogeochemical cycles can lead to floods, droughts, climate change, pollution, acid rain, and many other environmental problems. Soils provide critical ecosystem services, especially for sustaining ecosystems and growing food crops, but soil erosion and degradation are serious problems worldwide. Increasing habitat loss, climate change, settlement of wild areas, and wildlife consumption facilitate the transition of diseases of animals to humans, and other ecosystem alterations are increasing the prevalence of other diseases.

Human activities are causing loss of wildlife and biodiversity. Higher biodiversity usually increases ecosystem efficiency and productivity, stabilizes overall ecosystem functioning, thus, a decline in diversity makes ecosystems less resistant to disturbances. Decline in wildlife also reduces the services provided by organisms such a pollination, seed dispersal, and natural pest control. Thousands of species that are the components of ecosystems harbor unique chemicals and pharmaceuticals that can save people’s lives, but traditional knowledge of medicinal plants is disappearing and many potentially valuable species are threatened with extinction.

Attribution

This page is a modified derivative of:

- Ecosystem service via Wikipedia; CC BY-SA 4.0

This page titled 10.4: Ecosystem Services is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

10.5: Resistance, Resilience, and Stability

Stability

An ecosystem is said to possess ecological **stability** (or equilibrium) if it is capable of returning to its equilibrium state after a perturbation (a capacity known as resilience) or does not experience unexpected large changes in its characteristics across time. Although the terms community stability and ecological stability are sometimes used interchangeably, community stability refers only to the characteristics of communities. It is possible for an ecosystem or a community to be stable in some of their properties and unstable in others.

The relation between diversity and stability has been widely studied. **Diversity** can operate to enhance the stability of ecosystem functions at various ecological scales. For example, genetic diversity can enhance resistance to environmental perturbations. At the community level, the structure of food webs can affect stability. At the level of landscapes, environmental heterogeneity across locations has been shown to increase the stability of ecosystem functions

Resistance and Resilience

Resistance is the ability for an ecosystem to remain unchanged when being subjected to a disturbance or disturbances. Some ecosystems are better at resisting change than others, and therefore have high resistance.

Resilience is the ability and rate of an ecosystem to recover from a disturbance and return to its pre-disturbed state. Some ecosystems can shift greatly from their previous state and still return to pre-disturbance conditions. The measure for how far an ecosystem can be shifted from its previous state and still return to normal is called its amplitude.

Both resistance and resilience are components of determining **ecosystem stability**. Both can also occur at the community, population, and individual level. An ecosystem can have high resistance to disturbance, but low resilience, and vice versa. Low resistance can sometimes be advantageous, such as in ecosystems that rely on natural disturbances to temporarily change their conditions in order to remain stable over the long term.

This page titled 10.5: Resistance, Resilience, and Stability is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

CHAPTER OVERVIEW

11: Landscape Ecology and Island Biogeography

Learning Objectives

- Understand the origins and aims of Landscape Ecology
- Learn some of the important terms used in Landscape Ecology
- Understand the basics of the Theory of Island Biogeography
- Make connections between the Theory of Island Biogeography and its application in Ecology

11.1: What is Landscape Ecology?

11.2: Terminology

11.3: Applications of Landscape Ecology

11.4: Island Biogeography

Summary

Landscape ecology is the science of studying and improving relationships between ecological processes in the environment and particular ecosystems. This is done within a variety of landscape scales, development spatial patterns, and organizational levels of research and policy. Landscape ecology often focuses on the composition of landscapes, and how the size, shape, and adjacency of different habitat patches affect ecological processes. The development of the Theory of Island Biogeography in the 1960s was fundamental to our understanding of how the size and isolation of habitat patches affect the life histories of species found within them. This, in turn, resulted in a strong focusses on habitat fragmentation within the subfield of Landscape Ecology.

This page titled 11: Landscape Ecology and Island Biogeography is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

11.1: What is Landscape Ecology?

Landscape Ecology

Landscape ecology is the science of studying and improving relationships between ecological processes in the environment and particular ecosystems. This is done within a variety of landscape scales, development spatial patterns, and organizational levels of research and policy (Wu, 2006; Wu & Hobbs, 2007; Wu, 2008). Concisely, landscape ecology can be described as the science of landscape diversity as the synergetic result of biodiversity and geodiversity (Leser & Nagel, 2001).

As a highly interdisciplinary field in systems science, landscape ecology integrates biophysical and analytical approaches with humanistic and holistic perspectives across the natural sciences and social sciences. Landscapes are spatially heterogeneous geographic areas characterized by diverse interacting patches or ecosystems, ranging from relatively natural terrestrial and aquatic systems such as forests, grasslands, and lakes to human-dominated environments including agricultural and urban settings (Wu & Hobbs, 2007; Turner et al., 2001; Forman, 1995).

The most salient characteristics of landscape ecology are its emphasis on the relationship among pattern, process and scale, and its focus on broad-scale ecological and environmental issues. These necessitate the coupling between biophysical and socioeconomic sciences. Key research topics in landscape ecology include ecological flows in landscape mosaics, land use and land cover change, scaling, relating landscape pattern analysis with ecological processes, and landscape conservation and sustainability (Wu & Hobbs, 2002). Landscape ecology also studies the role of human impacts on landscape diversity in the development and spreading of new human pathogens that could trigger epidemics (Bloomfield et al., 2020; Bausch & Scwarz, 2014).

Heterogeneity is the measure of how parts of a landscape differ from one another. Landscape ecology looks at how this spatial structure affects organism abundance at the landscape level, as well as the behavior and functioning of the landscape as a whole. This includes studying the influence of pattern, or the internal order of a landscape, on process, or the continuous operation of functions of organisms (Turner, 1989). Landscape ecology also includes geomorphology as applied to the design and architecture of landscapes (Allaby, 1998). Geomorphology is the study of how geological formations are responsible for the structure of a landscape.

History

Terminology

The German term Landschaftsökologie–thus landscape ecology–was coined by German geographer Carl Troll in 1939 (1939). He developed this terminology and many early concepts of landscape ecology as part of his early work, which consisted of applying aerial photograph interpretation to studies of interactions between environment and vegetation.

Evolution of theory

One central landscape ecology theory originated from MacArthur & Wilson's The Theory of Island Biogeography (see 21.4: Island Biogeography). This work considered the biodiversity on islands as the result of competing forces of colonization from a mainland stock and stochastic extinction. The concepts of island biogeography were generalized from physical islands to abstract patches of habitat by Levins' metapopulation model (which can be applied e.g. to forest islands in the agricultural landscape) (Banaszak, 2000). A **metapopulation** is a group of smaller populations of an organism in distinct habitat patches or islands which have individuals moving between patches. This generalization spurred the growth of landscape ecology by providing conservation biologists a new tool to assess how habitat fragmentation affects population viability. Recent growth of landscape ecology owes much to the development of geographic information systems (GIS) and the availability of large-extent habitat data (e.g. remotely sensed datasets) Figure 11.1.1 (Steiniger & Hay, 2009).

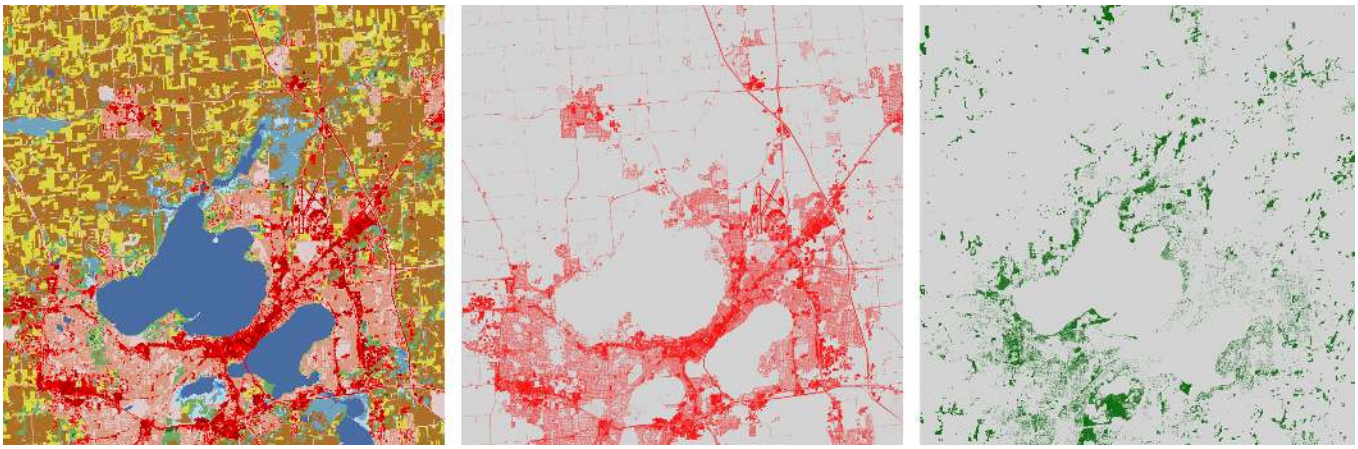


Figure 11.1.1**:** Land cover surrounding Madison, WI. Left: fields are colored yellow and brown, water is colored blue, and urban surfaces are colored red. Center: impervious surfaces. Right: canopy cover.

Development as a discipline

Landscape ecology developed in Europe from historical planning on human-dominated landscapes. Concepts from general ecology theory were integrated in North America. While general ecology theory and its sub-disciplines focused on the study of more homogenous, discrete community units organized in a hierarchical structure (typically as ecosystems, populations, species, and communities), landscape ecology built upon heterogeneity in space and time. It frequently included anthropogenic (human-caused) landscape changes in theory and application of concepts (Sanderson & Harris, 2000).

By 1980, landscape ecology was a discrete, established discipline. It was marked by the organization of the International Association for Landscape Ecology (IALE) in 1982. Landmark book publications defined the scope and goals of the discipline, including Naveh and Lieberman and Forman and Godron (1984; 1986). Forman wrote that although study of "the ecology of spatial configuration at the human scale" was barely a decade old, there was strong potential for theory development and application of the conceptual framework (1995).Today, the theory and application of landscape ecology continue to develop through a need for innovative applications in a changing landscape and environment. Landscape ecology relies on advanced technologies such as remote sensing, GIS, and models. There has been associated development of powerful quantitative methods to examine the interactions of patterns and processes (Turner et al., 2001). An example would be determining the amount of carbon present in the soil based on landform over a landscape, derived from GIS maps, vegetation types, and rainfall data for a region. Remote sensing work has been used to extend landscape ecology to the field of predictive vegetation mapping, for instance by Janet Franklin.

Sources

Allaby, M. (1998). *Oxford dictionary of ecology*. Oxford University Press.

Banaszak, J. (Ed.). (2000). *Ecology of forest islands* (p. 313). Bydgoszcz University Press.

Bausch, D. G., & Schwarz, L. (2014). Outbreak of Ebola virus disease in Guinea: Where ecology meets economy. *PLOS Neglected Tropical Diseases*, *8*(7), e3056. https://doi.org/10.1371/journal.pntd.0003056

Bloomfield, L. S., McIntosh, T. L., & Lambin, E. F. (2020). Habitat fragmentation, livelihood behaviors, and contact between people and nonhuman primates in Africa. *Landscape Ecology*, *35*(4), 985–1000. https://doi.org/10.1007/s10980-020-00995-w

Forman, R. T., & Godron, M. (1986). *Landscape ecology*. John Wiley and Sons, Inc.

Forman, R. T. (1995). *Land mosaics: The ecology of landscapes and regions*. Cambridge University Press.

Leser, H., & Nagel, P. (2001). Landscape diversity—A holistic approach. In *Biodiversity* (pp. 129–143). Springer. https://doi.org/10.1007/978-3-662-06071-1_9

Naveh, Z., & Lieberman, A. (1984). *Landscape ecology: Theory and application*. Springer-Verlag.

Ryszkowski, L. (Ed.). (2002). *Landscape ecology in agroecosystems management*. CRC Press.

Sanderson, J., & Harris, L. D. (Eds.). (2000). *Landscape ecology: A top-down approach*. Lewis Publishers.

Steiniger, S., & Hay, G. J. (2009). Free and open source geographic information tools for landscape ecology. *Ecological Informatics*, *4*(4), 183–195. https://doi.org/10.1016/j.ecoinf.2009.07.004

Troll, C. (1939). Luftbildplan und ökologische Bodenforschung [Aerial photography and ecological studies of the earth]. *Zeitschrift der Gesellschaft für Erdkunde*, 241–298.

Turner, M. G. (1989). Landscape ecology: The effect of pattern on process. *Annual Review of Ecology and Systematics*, *20*, 171–197. https://doi.org/10.1146/annurev.es.20.110189.001131

Turner, M. G., Gardner, R. H., & O'Neill, R. V. (2001). *Landscape ecology in theory and practice*. Springer-Verlag.

Wu, J., & Hobbs, R. J. (2002). Key issues and research priorities in landscape ecology. *Landscape Ecology*, *17*(4), 355–365. https://doi.org/10.1023/A:1020561630963

Wu, J. (2006). Landscape ecology, cross-disciplinarity, and sustainability science. *Landscape Ecology*, *21*(1), 1–4. https://doi.org/10.1007/s10980-006-7195-2

Wu, J., & Hobbs, R. (Eds.). (2007). *Key topics in landscape ecology*. Cambridge University Press.

Wu, J. (2008). Landscape ecology. In S. E. Jorgensen (Ed.), *Encyclopedia of ecology.* Elsevier.

Contributors and Attributions

Modified by Andy Wilson (Gettysburg College) and Kyle Whittinghill (University of Vermont) from the following sources:

- Wikipedia, the free encyclopedia https://en.Wikipedia.org/wiki/Landscape_ecology

This page titled 11.1: What is Landscape Ecology? is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

11.2: Terminology

Landscape

Certainly, 'landscape' is a central concept in landscape ecology. It is, however, defined in quite different ways. For example: Carl Troll conceives of landscape not as a mental construct but as an objectively given 'organic entity', a *harmonic individuum of space* (Kirchhoff et al., 2013; Troll, 2007). Ernst Neef defines landscapes as sections within the uninterrupted earth-wide interconnection of geofactors which are defined as such on the basis of their uniformity in terms of a specific land use, and are thus defined in an anthropocentric and relativistic way (Neef, 1967; Haase, 1990). According to Richard Forman and Michel Godron, a landscape is a heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout, whereby they list woods, meadows, marshes and villages as examples of a landscape's ecosystems, and state that a landscape is an area at least a few kilometers wide (1981). John A. Wiens defines 'landscape'—regardless of scale—as "the template on which spatial patterns influence ecological processes" (Wiens, 1999; Wiens, 2005). Some define 'landscape' as an area containing two or more ecosystems in close proximity (Sanderson & Harris, 2000).

Scale and heterogeneity (incorporating composition, structure, and function)

A main concept in landscape ecology is *scale*. Scale represents the real world as translated onto a map, relating distance on a map image and the corresponding distance on earth (Malczewski, 1999). Scale is also the spatial or temporal measure of an object or a process, or amount of spatial resolution (Turner & Gardner, 1991; Forman, 1995). Components of scale include composition, structure, and function, which are all important ecological concepts. Applied to landscape ecology, *composition* refers to the number of patch types (see below) represented on a landscape and their relative abundance. For example, the amount of forest or wetland, the length of forest edge, or the density of roads can be aspects of landscape composition. *Structure* is determined by the composition, the configuration, and the proportion of different patches across the landscape, while *function* refers to how each element in the landscape interacts based on its life cycle events (Turner & Gardner, 1991). *Pattern* is the term for the contents and internal order of a heterogeneous area of land (Forman & Godron, 1986).

A landscape with structure and pattern implies that it has spatial *heterogeneity*, or the uneven distribution of objects across the landscape (Forman, 1995). Heterogeneity is a key element of landscape ecology that separates this discipline from other branches of ecology.

Patch and mosaic

Patch, a term fundamental to landscape ecology, is defined as a relatively homogeneous area that differs from its surroundings (Forman, 1995). Patches are the basic unit of the landscape that change and fluctuate, a process called *patch dynamics*. Patches have a definite shape and spatial configuration, and can be described compositionally by internal variables such as number of trees, number of tree species, height of trees, or other similar measurements (Forman, 1995).

Matrix is the "background ecological system" of a landscape with a high degree of connectivity. *Connectivity* is the measure of how connected or spatially continuous a corridor, network, or matrix is (Forman, 1995). For example, a forested landscape (matrix) with fewer gaps in forest cover (open patches) will have higher connectivity. *Corridors* have important functions as strips of a particular type of landscape differing from adjacent land on both sides (Forman, 1995). A *network* is an interconnected system of corridors while *mosaic* describes the pattern of patches, corridors, and matrix that form a landscape in its entirety (Forman, 1995).

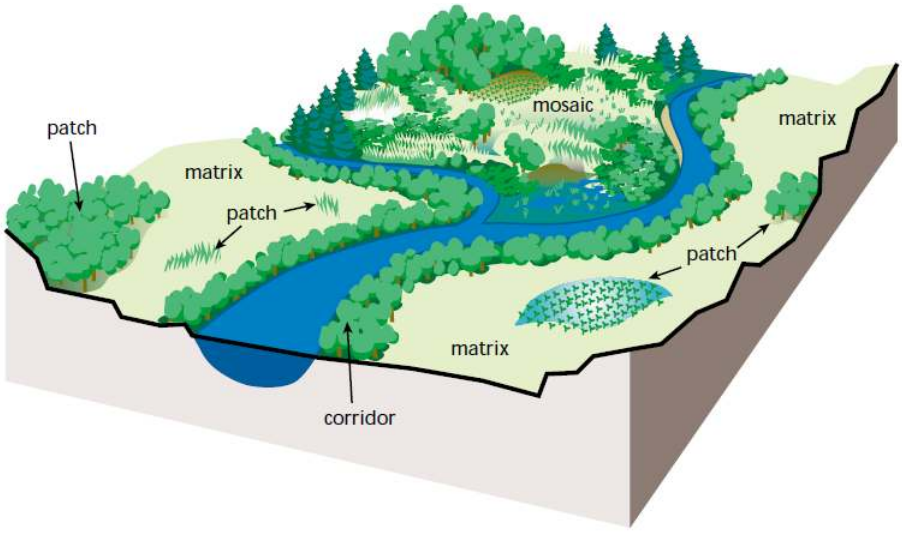


Figure 11.2.1**:** Basic terms to define landscape ecology (FISGRW 1998) from Understanding Landscape Structure Using Landscape Metrics (Ercan Gökyer) (DOI: 10.5772/55758).

Boundary and edge

Landscape patches have a boundary between them which can be defined or fuzzy (Sanderson & Harris, 2000). The zone composed of the edges of adjacent ecosystems is the *boundary* (Forman, 1995). *Edge* means the portion of an ecosystem near its perimeter, where influences of the adjacent patches can cause an environmental difference between the interior of the patch and its edge. This edge effect includes a distinctive species composition or abundance (Forman, 1995). For example, when a landscape is a mosaic of perceptibly different types, such as a forest adjacent to a grassland, the edge is the location where the two types adjoin. In a continuous landscape, such as a forest giving way to open woodland, the exact edge location is fuzzy and is sometimes determined by a local gradient exceeding a threshold, such as the point where the tree cover falls below thirty-five percent (Turner & Gardner, 1991).

Ecotones, ecoclines, and ecotopes

A type of boundary is the *ecotone*, or the transitional zone between two communities (Allaby, 1998). Ecotones can arise naturally, such as a lakeshore, or can be human-created, such as a cleared agricultural field from a forest (Allaby, 1998). The ecotonal community retains characteristics of each bordering community and often contains species not found in the adjacent communities. Classic examples of ecotones include fencerows, forest to marshlands transitions, forest to grassland transitions, or land-water interfaces such as riparian zones in forests. Characteristics of ecotones include vegetational sharpness, physiognomic change, occurrence of a spatial community mosaic, many exotic species, ecotonal species, spatial mass effect, and species richness higher or lower than either side of the ecotone (Walker et al., 2003).

An *ecocline* is another type of landscape boundary, but it is a gradual and continuous change in environmental conditions of an ecosystem or community. Ecoclines help explain the distribution and diversity of organisms within a landscape because certain organisms survive better under certain conditions, which change along the ecocline. They contain heterogeneous communities which are considered more environmentally stable than those of ecotones (Attrill & Rundle, 2002). An *ecotope* is a spatial term representing the smallest ecologically distinct unit in mapping and classification of landscapes (Forman, 1995). Relatively homogeneous, they are spatially explicit landscape units used to stratify landscapes into ecologically distinct features. They are useful for the measurement and mapping of landscape structure, function, and change over time, and to examine the effects of disturbance and fragmentation.



Figure 11.2.2**:** An ecotone between grassland and woodland. "Ecotone" by Nicholas A. Tonelli is licensed under CC BY 2.0.

Disturbance and fragmentation

Disturbance is an event that significantly alters the pattern of variation in the structure or function of a system. *Fragmentation* is the breaking up of a habitat, ecosystem, or land-use type into smaller parcels (Forman, 1995). Disturbance is generally considered a natural process. Fragmentation causes land transformation, an important process in landscapes as development occurs.

An important consequence of repeated, random clearing (whether by natural disturbance or human activity) is that contiguous cover can break down into isolated patches. This happens when the area cleared exceeds a critical level, which means that landscapes exhibit two phases: connected and disconnected (Green et al., 2006).



Figure 11.2.3**:** Rapid deforestation in Cambodia resulted in habitat loss and fragmentation (credit: Global Forest Watch. World Resources Institute. Accessed on 1/5/2022. www.globalforestwatch.org).

Sources

Allaby, M. (1998). *Oxford dictionary of ecology*. Oxford University Press.

Attrill, M. J., & Rundle, S. D. (2002). Ecotone or ecocline: Ecological boundaries in estuaries. *Estuarine, Coastal and Shelf Science*, *55*(6), 929–936. https://doi.org/10.1006/ecss.2002.1036

Forman, R. T. (1995). *Land mosaics: The ecology of landscapes and regions*. Cambridge University Press.

Forman, R. T., & Godron, M. (1981). Patches and structural components for a landscape ecology. *BioScience*, *31*(10), 733–740. https://doi.org/10.2307/1308780

Forman, R. T., & Godron, M. (1986). *Landscape ecology*. John Wiley and Sons.

Green, D. G., Klomp, N. I., Rimmington, G. R., & Sadedin, S. (2006). *Complexity in landscape ecology*. Springer.

Haase, G. (1990). Approaches to, and methods of landscape diagnosis as a basis of landscape planning and landscape management. *Ekológia*, *9*(1), 31–44.

Kirchhoff, T., Trepl, L., & Vicenzotti, V. (2013). What is landscape ecology? An analysis and evaluation of six different conceptions. *Landscape Research*, *38*(1), 33–51. https://doi.org/10.1080/01426397.2011.640751

Malczewski, J. (1999). *GIS and multicriteria decision analysis*. John Wiley and Sons.

Neef, E. (1967). *Die theoretischen Grundlagen der Landschaftslehre* [The theoretical basics of landscape science]. Haack.

Sanderson, J., & Harris, L. D. (Eds.). (2000). *Landscape ecology: A top-down approach*. Lewis Publishers.

Troll, C. (2007). The geographic landscape and its investigation. In J. A. Wiens, M. R. Moss, M. G. Turner, & D. J. Mladenoff (Eds.), *Foundation papers in landscape ecology* (pp. 71–101). Columbia University Press. (Original work published 1950) https://doi.org/10.1007/978-3-662-38240-0_20

Turner, M. G., & Gardner, R. H. (Eds.). (1991). *Quantitative methods in landscape ecology*. Springer-Verlag.

Walker, S., Wilson, J. B., Steel, J. B., Rapson, G. L., Smith, B., King, W. M., & Cottam, Y. H. (2003). Properties of ecotones: Evidence from five ecotones objectively determined from a coastal vegetation gradient. *Journal of Vegetation Science*, *14*(4), 579–

590. https://doi.org/10.1111/j.1654-1103.2003.tb02185.x

Wiens, J. A. (1999). The science and practice of landscape ecology. In J. M. Klopatek & R. H. Gardner (Eds.), *Landscape ecological analyses: Issues and applications* (pp. 371–383). Springer.

Wiens, J. A. (2005). Toward a unified landscape ecology. In J. A. Wiens & M. R. Moss (Eds.), *Issues and perspectives in landscape ecology* (pp. 365–373). Cambridge University Press.

Contributors and Attributions

Modified by Andy Wilson (Gettysburg College) and Kyle Whittinghill (University of Vermont) from the following sources:

- Wikipedia, the free encyclopedia https://en.Wikipedia.org/wiki/Landscape_ecology

This page titled 11.2: Terminology is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

11.3: Applications of Landscape Ecology

Research directions

Developments in landscape ecology illustrate the important relationships between spatial patterns and ecological processes. These developments incorporate quantitative methods that link spatial patterns and ecological processes at broad spatial and temporal scales. This linkage of time, space, and environmental change can assist managers in applying plans to solve environmental problems (Turner et al., 2001). The increased attention in recent years on spatial dynamics has highlighted the need for new quantitative methods that can analyze patterns, determine the importance of spatially explicit processes, and develop reliable models (Turner & Gardner, 1991). Multivariate analysis techniques are frequently used to examine landscape level vegetation patterns. **Vegetation classification** is the process of classifying and mapping the vegetation over an area of the earth's surface and is often performed by state based agencies as part of landuse, resource and environmental management.

Many different methods of vegetation classification have been used but vegetation classification mapping is usually now done using geographic information systems (GIS) software. Studies use statistical techniques for classifying vegetation based on a combination of remote sensing variables. For an example of a vegetation classification system see the United States Geological Survey Land Cover website. Gradient analysis is another way to determine the vegetation structure across a landscape or to help delineate critical wetland habitat for conservation or mitigation purposes (Choesin & Boerner, 2002; Lyon & Sagers, 1998).

Climate change is another major component in structuring current research in landscape ecology (Ochoa-Hueso et al., 2019). Ecotones, as a basic unit in landscape studies, may have significance for management under climate change scenarios, since change effects are likely to be seen at ecotones first because of the unstable nature of a fringe habitat (Walker et al., 2003). Research in northern regions has examined landscape ecological processes, such as the accumulation of snow, melting, freeze-thaw action, percolation, soil moisture variation, and temperature regimes through long-term measurements in Norway (Löffler & Finch, 2005). The study analyzes gradients across space and time between ecosystems of the central high mountains to determine relationships between distribution patterns of animals in their environment. Looking at where animals live, and how vegetation shifts over time, may provide insight into changes in snow and ice over long periods of time across the landscape as a whole.

Other landscape-scale studies maintain that human impact is likely the main determinant of landscape pattern over much of the globe (Ellis et al., 2021; Wilson & King, 1995). Landscapes may become substitutes for biodiversity measures because plant and animal composition differs between samples taken from sites within different landscape categories. Taxa, or different species, can “leak” from one habitat into another, which has implications for landscape ecology. As human land use practices expand and continue to increase the proportion of edges in landscapes, the effects of this leakage across edges on assemblage integrity may become more significant in conservation. This is because taxa may be conserved across landscape levels, if not at local levels (Dangerfield et al., 2003).

Land change modeling

Land change modeling is an application of landscape ecology designed to predict future changes in land use. Land change models are used in urban planning, geography, GIS, and other disciplines to gain a clear understanding of the course of a landscape (National Research Council, 2014). In recent years, much of the Earth's land cover has changed rapidly, whether from deforestation or the expansion of urban areas (University of Maryland).

Relationship to other disciplines

Landscape ecology has been incorporated into a variety of ecological subdisciplines. For example, it is closely linked to land change science, the interdisciplinary of land use and land cover change and their effects on surrounding ecology. Another recent development has been the more explicit consideration of spatial concepts and principles applied to the study of lakes, streams, and wetlands in the field of landscape limnology. Seascape ecology is a marine and coastal application of landscape ecology (Pittman, 2017).[48] In addition, landscape ecology has important links to application-oriented disciplines such as agriculture and forestry. In agriculture, landscape ecology has introduced new options for the management of environmental threats brought about by the intensification of agricultural practices. Agriculture has always been a strong human impact on ecosystems (Ryszkowski, 2002).

In forestry, from structuring stands for fuelwood and timber to ordering stands across landscapes to enhance aesthetics, consumer needs have affected conservation and use of forested landscapes. Landscape forestry provides methods, concepts, and analytic procedures for landscape forestry (Boyce, 1995). Landscape ecology has been cited as a contributor to the development of fisheries biology as a distinct biological science discipline, and is frequently incorporated in study design for wetland delineation in hydrology (Magnuson, 1991; Attrill & Rundle, 2002). It has helped shape integrated landscape management (Sayer, 2009). Lastly, landscape ecology has been very influential for progressing sustainability science and sustainable development planning. For example, a recent study assessed sustainable urbanization across Europe using evaluation indices, country-landscapes, and landscape ecology tools and methods (Shaker, 2015).

Landscape ecology has also been combined with population genetics to form the field of landscape genetics, which addresses how landscape features influence the population structure and gene flow of plant and animal populations across space and time and on how the quality of intervening landscape, known as "matrix," influences spatial variation (Manel et al., 2003; Storfer et al., 2007). After the term was coined in 2003, the field of landscape genetics had expanded to over 655 studies by 2010, and continues to grow today (Storfer et al., 2010). As genetic data has become more readily accessible, it is increasingly being used by ecologists to answer novel evolutionary and ecological questions, many with regard to how landscapes effect evolutionary processes, especially in human-modified landscapes, which are experiencing biodiversity loss (Balkenhol et al., 2015; Manel & Holderegger, 2013).

References

Attrill, M. J., & Rundle, S. D. (2002). Ecotone or ecocline: Ecological boundaries in estuaries. *Estuarine, Coastal and Shelf Science*, *55*(6), 929–936. https://doi.org/10.1006/ecss.2002.1036

Balkenhol, N., Cushman, S., Storfer, A., & Waits, L. (2015). *Landscape genetics: Concepts, methods, applications*. John Wiley & Sons.

Boyce, S. G. (1995). *Landscape forestry*. John Wiley & Sons.

Choesin, D., & Boerner, R. (2002). Vegetation boundary detection: A comparison of two approaches applied to field data. *Plant Ecology*, *158*, 85–96. https://doi.org/10.1023/A:1014720508155

Dangerfield, J. M., Pik, A. J., Britton, D., Holmes, A., Gillings, M., Oliver, I. A., Briscoe, D., & Beattie, A. J. (2003). Patterns of invertebrate biodiversity across a natural edge. *Austral Ecology*, *28*(3), 227–236. https://doi.org/10.1046/j.1442-9993.2003.01240.x

Ellis, E. C., Gauthier, N., Klein Goldewijk, K., Bliege Bird, R., Boivin, N., Díaz, S., Fuller, D. Q., Gill, J. L., Kaplan, J. O., Kingston, N., Locke, H., McMichael, C. N. H., Ranco, D., Rick, T. C., & Shaw, M. R. (2021). People have shaped most of terrestrial nature for at least 12,000 years. *Proceedings of the National Academy of Sciences*, *118*(17), e2023483118. https://doi.org/10.1073/pnas.2023483118

Löffler, J., & Finch, O. D. (2005). Spatio-temporal gradients between high mountain ecosystems of central Norway. *Arctic, Antarctic, and Alpine Research*, *37*(4), 499–513. https://doi.org/10.1657/1523-0430(20...gbhme]2.0.co;2

Lyon, J., & Sagers, C. L. (1998). Structure of herbaceous plant assemblages in a forested riparian landscape. *Plant Ecology*, *138*(1), 1–6. https://doi.org/10.1023/A:1009705912710

Magnuson, J. J. (1991). Fish and fisheries ecology. *Ecological Applications*, *1*(1), 13–26. https://doi.org/10.2307/1941844

Manel, S., Holderegger, R. (2013). Ten years of landscape genetics. *Trends in Ecology & Evolution*, *28*(10), 614–621. https://doi.org/10.1016/j.tree.2013.05.012

Manel, S., Schwartz, M. K., Luikart, G., & Taberlet, P. (2003). Landscape genetics: Combining landscape ecology and population genetics. *Trends in Ecology & Evolution*, *18*(4), 189–197. https://doi.org/10.1016/S0169-5347(03)00008-9

National Research Council. (2014). *Advancing land change modeling: Opportunities and research requirements*. National Academies Press. https://doi.org/10.17226/18385

Ochoa-Hueso, R., Delgado-Baquerizo, M., King, P. T., Benham, M., Arca, V., & Power, S. A. (2019). Ecosystem type and resource quality are more important than global change drivers in regulating early stages of litter decomposition. *Soil Biology and Biochemistry*, *129*, 144–152. https://doi.org/10.1016/j.soilbio.2018.11.009

Pittman, S. J. (Ed.). (2017). *Seascape ecology*. Wiley & Sons.

Ryszkowski, L. (Ed.). (2002). *Landscape ecology in agroecosystems management*. CRC Press.

Sayer, J. (2009). Reconciling conservation and development: Are landscapes the answer? *Biotropica*, *41*(6), 649–652. https://doi.org/10.1111/j.1744-7429.2009.00575.x

Shaker, R. R. (2015). The well-being of nations: An empirical assessment of sustainable urbanization for Europe. *International Journal of Sustainable Development & World Ecology*, *22*(5), 375–387. https://doi.org/10.1080/13504509.2015.1055524

Storfer, A., Murphy, M. A., Evans, J. S., Goldberg, C. S., Robinson, S., Spear, S. F., et al. (2007). Putting the "landscape" in landscape genetics. *Heredity*, *98*(3), 128–142. https://doi.org/10.1038/sj.hdy.6800917

Storfer, A., Murphy, M. A., Spear, S. F., Holderegger, R., & Waits, L. P. (2010). Landscape genetics: Where are we now? *Molecular Ecology*, *19*(17), 3496–3514. https://doi.org/10.1111/j.1365-294X.2010.04691.x

Turner, M. G., & Gardner, R. H. (Eds.). (1991). *Quantitative methods in landscape ecology*. Springer-Verlag.

Turner, M. G., Gardner, R. H., & O'Neill, R. V. (2001). *Landscape ecology in theory and practice*. Springer-Verlag.

University of Maryland. (n.d.). GLCF: Global Land Cover Change. Global Land Cover Facility. https://glcf.umd.edu (Archived June 9, 2019)

Wilson, J. B., & King, W. M. (1995). Human-mediated vegetation switches as processes in landscape ecology. *Landscape Ecology*, *10*(4), 191–196. https://doi.org/10.1007/BF00129253

Walker, S., Wilson, J. B., Steel, J. B., Rapson, G. L., Smith, B., King, W. M., & Cottam, Y. H. (2003). Properties of ecotones: Evidence from five ecotones objectively determined from a coastal vegetation gradient. *Journal of Vegetation Science*, *14*(4), 579–590. https://doi.org/10.1111/j.1654-1103.2003.tb02185.x

Contributors and Attributions

Modified by Andy Wilson (Gettysburg College) and Kyle Whittinghill (University of Vermont) from the following sources:

- Wikipedia, the free encyclopedia: https://en.Wikipedia.org/wiki/Landscape_ecology
- Wikipedia, the free encyclopedia: https://en.wikipedia.org/wiki/Vegeta...classification

This page titled 11.3: Applications of Landscape Ecology is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

11.4: Island Biogeography

Biogeography is the study of the distribution of species and ecosystems in geographic space and through geological time. Organisms and biological communities often vary in a regular fashion along geographic gradients of latitude, elevation, isolation, and habitat area. The latter pattern, often called the **species-area relationship**, has long been a fascination for biogeographers. Figure 11.4.1 demonstrates this species-area relationship for amphibians and reptiles in the West Indies. A study from around 1957 was included in Robert H. MacArthur and Edward O. Wilson's famous book "The Theory of Island Biogeography", and showed that among seven islands studied, the largest, Cuba, had the most species, and the smallest, Redonda, had the fewest. This general pattern has been found in many different islands groups, and across various different taxa.

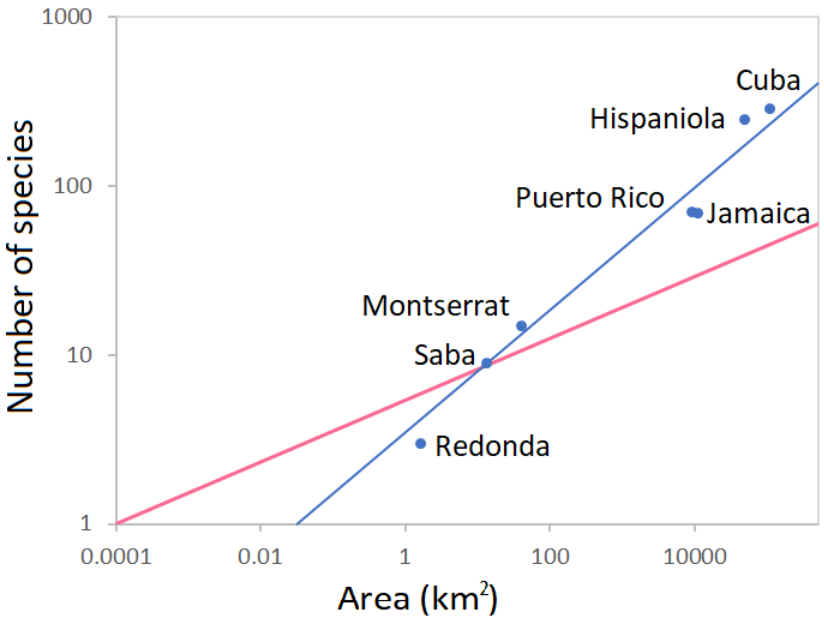


Figure 11.4.1**:** Species-area relationship for amphibians and reptilians on seven different islands in the West Indies. An original study (Darlington c. 1957), published in "The Theory of Island biogeography", showed a strong positive correlation between island size and number of species (blue line). A more recent study by Gao and Perry (2016) included data for many additional small islands (smaller than Redonda) and found that while the pattern holds, the relationship is flatter than in the original study--indicated by the pink line. Figure drawn by Andy Wilson, based on Figure 4 in Gao and Perry (2016).

While studying these species-area relationships for their seminal book, MacArthur and Wilson were drawn to another of the four geographic gradients--that of isolation. They observed that some large Islands had fewer species than would be expected for their size, while conversely, some small islands had more species than expected.

While studying patterns of species richness on islands, two ecologists, Robert H. MacArthur and Edward O. Wilson, noted some exceptions to the **species-area relationship**. For example, some large islands had fewer species than expected due to their size, while some small islands had more species than expected. These patterns were explained by MacArthur and Wilson's **Equilibrium Theory of Island Biogeography**, which takes into account the fact that islands are colonized by species from elsewhere, and natural extinctions will occur on those islands, over long periods of time.

Imagine there are two islands (**a** and **b**) located off the coast of the mainland. Although the two islands are about the same size, island **a** is located much farther away than island **b**. If you are a bird that lives on the mainland, which island are you most likely to find? The answer is generally island **b**. This means immigration (or colonization) is influenced by the distance of an island from the mainland (a source of colonists). Therefore, islands that are closer to the island are more likely to receive immigrants than islands that are further away.

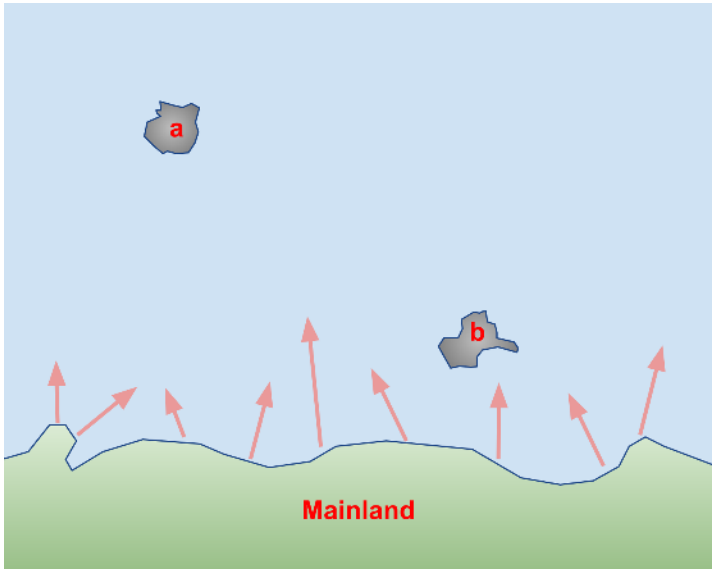


Figure 11.4.2: Two offshore islands--the Theory of Island Biogeography suggests that fewer species will colonize the more distant island **a**, in comparison to island **b** (credit: Andy Wilson, redrawn from Hdelucalowell15 (CC BY-SA 4.0)).

Once a species manages to reach and colonize an island, the rate of extinction is largely influenced by size of the island. This is because smaller islands tend to hold smaller populations (which are more likely to experience extinction due to stochastic effects like genetic drift). Larger habitat size reduces the probability of extinction of the colonized species due to chance events. Smaller islands are also likely to hold fewer populations in general because they have fewer resources and less diversity of resources. Larger islands have larger and more habitat areas, which typically leads to more differences in habitat or *habitat heterogeneity*. Higher heterogeneity means that there are more opportunities for a variety of species to find their suitable niches. Habitat heterogeneity also helps increase the number of species to successfully colonize after immigration.

Now let's consider the situation if we had two different islands sizes in our offshore archipelago, with **c** and **d**, much bigger than **a** and **b** Figure 11.4.3. We would expect extinction rates to be much lower on islands **c** and **d** than on the two smaller islands.

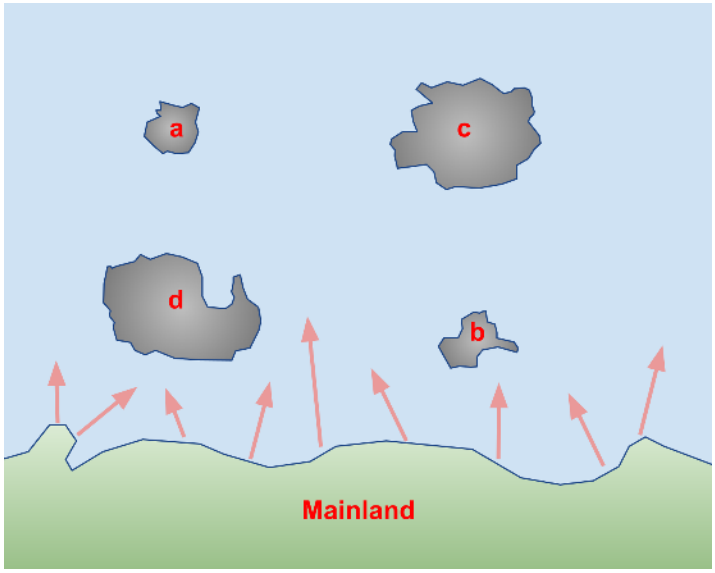


Figure 11.4.3**:** Four offshore islands--the Theory of Island Biogeography suggests that fewer species will go extinct on the larger islands **c** and **d**, in comparison to islands **a** and **b** (credit: Andy Wilson, redrawn from Wikipedia (CC BY-SA 4.0)).

We could plot both immigration and extinction relationships on a single image, as in Figure 11.4.4. Note the y-axis is the number of species (either colonizing or going extinct). Now we see that of the four islands in Figure 11.4.3, island **a** (small and far) would

likely have the fewest species, island **d** (large and close), would have the most, and islands **b** and **c** would fall between the two extremes.

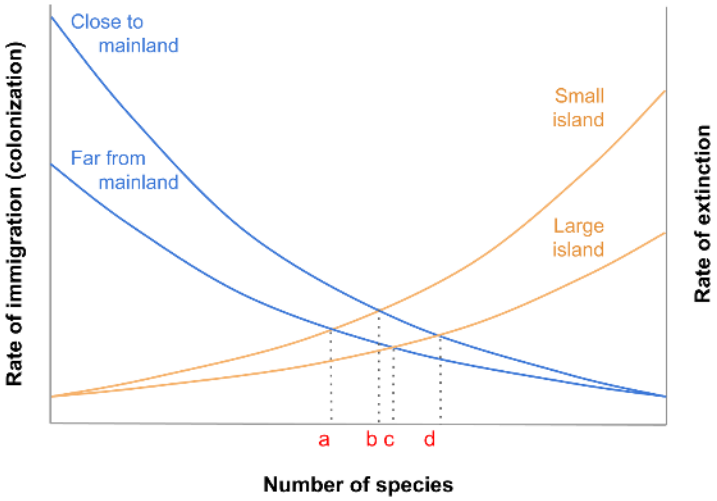


Figure 11.4.4**:** Equilibrium Theory of Island Biogeogaphy (credit: Andy Wilson, redrawn from Wikipedia (CC BY-SA 4.0)).

This basic graph makes a lot of assumptions but also offers a lot of insight. In this graph, immigration rates (blue lines) depend on proximity to mainland. Immigration rates also decline with species richness. That's becasuse its' easiest to immigrate to an island when it is empty because all the resources on the island are available. As the islands get more and more full, colonizing the island becomes more difficult.

Extinction rates (orange lines), as noted above, depend on island size. We also see that extinction rates tend to increase with the number of species. This should make sense: If there are no species on an island, extinction is impossible, but as more and more species arrive (and compete!) extinction becomes more likely.

Figure 11.4.4 shows the basic Equilibrium Theory of Island Biogeography. It suggests that islands will reach an equilibrium, or stable, number of species when immigration and extinction rates are equal! Note this model could be modified in multiple ways. Size of an island, for example, likely also impacts immigration rate (larger islands are easier to hit!), and islands that are close together may also share individuals (the Rescue effect!), but even this simple conceptualization has proven useful for understanding global species richness patterns.

One interesting point to note is that an equilibrium number of species is reached when immigration and extinction rates are equal, not when those processes stop! This means islands may consistently be changing species composition but should maintain fairly consistent levels of species richness. As odd as this sounds, early tests of the Equilibrium Theory of Island Biogeography supported these assumptions. When mangrove islands off the coast of Florida were fully cleared of their invertebrate (insect and arachnid) communities and allowed to recolonize, islands eventually stabilized with communities of about the same richness as they had before disturbance.

Conservation in Preserves as an application of Island Biogeography

The island biogeography model has crucial applications for wildlife management because wildlife reserves or patches of habitat can be considered “islands” of habitat in “an ocean” of an inhabitable area. For this reason, the Theory Island Biogeography has become central to our understanding of how habitat fragmentation leads to biodiversity loss. For a more detailed description of how habitat fragmentation leads to biodiversity loss, see the section on "Threats to Biodiversity" in the chapter on Conservation Biology from this book or see the section on "The Scramble for Space" in Conservation Biology in Sub-Saharan Africa (Wilson and Primack 2019).

Establishment of wildlife and ecosystem preserves is one of the key tools in conservation efforts (Figure 11.4.5). A **preserve** is an area of land set aside with varying degrees of protection for the organisms that exist within the boundaries of the preserve. There has been extensive research into optimal preserve designs for maintaining biodiversity. Conservation preserves can be seen as "islands" of habitat within "an ocean" of non-habitat. In general, large preserves are better because they support more species, including species with large home ranges; they have more core area of optimal habitat for individual species; they have more niches to support more species; and they attract more species because they can be found and reached more easily. One large preserve is better than the same area of several smaller preserves because there is more core habitat unaffected by less hospitable ecosystems outside the preserve boundary. For this same reason, preserves in the shape of a square or circle will be better than a preserve with many thin "arms." If preserves must be smaller, then providing **wildlife corridors** (narrow strips of protected land) between two preserves is important so that species and their genes can move between them. All of these factors are taken into consideration when planning the nature of a preserve before the land is set aside.



Figure 11.4.5**:** Mequon Nature Preserve in Wisconsin. Image by Jennifer Tomaloff (CC-BY-NC-SA).

Contributors and Attributions

Modified by Andy Wilson (Gettysburgh College), Kyle Whittinghill (University of Vermont) and Natasha Gownaris (Gettysburg College) from the following sources:

- https://sites.google.com/view/env10031004/lab/module-library/simulation-and-data-based-learning-activities/island-biogeography-simulation-simulation
- Preserving Biodiversity by OpenStax is licensed under CC BY 4.0 by Connie Rye (East Mississippi Community College), Robert Wise (University of Wisconsin, Oshkosh), Vladimir Jurukovski (Suffolk County Community College), Jean DeSaix (University of North Carolina at Chapel Hill), Jung Choi (Georgia Institute of Technology), Yael Avissar (Rhode Island College) among other contributing authors. Original content by OpenStax (CC BY 4.0; Download for free at http://cnx.org/contents/185cbf87-c72...f21b5eabd@9.87).
- Threatened and Endangered Species by California Department of Fish and Wildlife (public domain)
- Marine Mammal Protection by NOAA Fisheries (public domain)
- Ecotourism from *Life Sciences Grade 10* by Siyavula (licensed under CC-BY)
- Issues and Opinions, Biological and Land from *AP Environmental Science* by University of California College Prep, University of California (licensed under CC-BY). Download for free at CNX.

This page titled 11.4: Island Biogeography is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

CHAPTER OVERVIEW

12: Biodiversity and The Extinction Crisis



Figure 12.1: Shark fins in Hong Kong. by Cloneofsnake, CC-BY-SA 2.0

Sharks are declining rapidly on a global scale because humans have replaced them as the ocean's top predators. One way that humans hunt sharks is by using a practice called **shark finning**. This is the process of slicing off a shark's fin and discarding the rest of the still-living body, often by dumping it back into the ocean. Shark fins are tempting targets for fishermen because they have high monetary and cultural value. They are used in a popular dish called shark fin soup, which is a symbol of status in Chinese culture. Approximately 100 million sharks are killed globally each year, and one of the major incentives for this is the shark fin trade. With their slow growth and low reproductive rates, sharks are highly susceptible to extinction, and it is difficult for many shark species to replenish their populations as quickly as they are being diminished.

Biodiversity loss refers to the reduction of biodiversity due to displacement or extinction of species. The loss of a particular individual species may seem unimportant to some, especially if it is not a charismatic species like the Bengal tiger or the bottlenose dolphin. However, biologists estimate that species extinctions are currently many times higher the normal, or background, rate seen previously in Earth's history. This translates to the loss of tens of thousands of species within our lifetimes. This is likely to have dramatic effects on human welfare through the collapse of ecosystems. Loss of biodiversity may have reverberating consequences on ecosystems because of the complex interrelations among species. For example, the extinction of one species may cause the extinction of another. To measure biodiversity loss, scientists assess which species are at risk of extinction as well as survey ecosystem decline.

Learning Objectives

- Define biodiversity
- Describe types and patterns of biodiversity.
- List reasons why biodiversity is important.
- Explain how biodiversity has changed over Earth's history.
- Compare the current rate of global extinctions to the average rate observed in the geological record.
- Discuss how species are classified into categories based on their extinction risk.

12.1: Value of Biodiversity
12.2: Patterns of Biodiversity
12.3: Extinction
12.4: Measures of Biodiversity Loss

This page titled 12: Biodiversity and The Extinction Crisis is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

12.1: Value of Biodiversity

Biodiversity is a broad term for the variety of life on Earth. Traditionally, ecologists have measured biodiversity by taking into account both the number of species and the number of individuals of each species. However, biologists now measure biodiversity at a number of organizational levels, including ecosystem, species, and genetic diversity. This focuses efforts to preserve the biologically and technologically important elements of biodiversity.

Biodiversity is important to the survival and welfare of human populations because it has impacts on our health and our ability to feed ourselves through agriculture and harvesting populations of wild animals. Loss of biodiversity may have reverberating consequences on ecosystems because of the complex interrelations among species. For example, the extinction of one species may cause the extinction of another.

Ecosystem Diversity

Measuring biodiversity on a large scale involves measuring **ecosystem diversity**, the number of different ecosystems on Earth or in a geographical area as well as their relative abundances. The loss of an ecosystem means the loss of the interactions between species and the loss of biological productivity that an ecosystem is able to create. An example of a largely extinct ecosystem in North America is the prairie ecosystem (figure 12.1.1). Prairies once spanned central North America from the boreal forest in northern Canada down into Mexico. They are now all but gone, replaced by crop fields, pasture lands, and suburban sprawl. Many of the species survive, but the hugely productive ecosystem that was responsible for creating our most productive agricultural soils is now gone. As a consequence, their soils are now being depleted unless they are maintained artificially at great expense.



Figure 12.1.1: The variety of ecosystems on Earth—from the coral reef (top) to prairie (bottom)—enables a great diversity of species to exist. Top image by Wise Hok Wai Lum (CC-BY-SA). Bottom image modified from Jim Minnerath, USFWS.

The soil productivity described above is an example of an **ecosystem service**. These are the products and processes associated with biological systems and are directly or indirectly of immense value to the well-being of people. Some ecosystem services are

processes such as the regulation of climate, flooding, and disease. Nutrient cycling, pollination, and regulation of crop pests are ecosystem services important to food production (see the Food Production and Ecosystem Services box below). The water cycle provides fresh water, and photosynthesis adds oxygen to our air. Other ecosystem services are human provisions including food, fuel, and fiber (such as cotton for clothing or timber). Medicines are another important provision. Furthermore, healthy ecosystems allow for recreational activities, such as hiking, kayaking, and camping, and educational opportunities, such as field trips. Nature is also the basis for a significant part of aesthetic and spiritual values held by many cultures.

In 1997, Robert Costanza and his colleagues estimated to annual value of ecosystem services to be $33 trillion dollars ($53 trillion in 2019 dollars), and many consider this to be an underestimation. For comparison the gross domestic product of the United States in 2020 was $21 trillion. Valuing ecosystem services can be difficult, particular for those services that are processes rather than provisions. One strategy is to calculate replacement cost. For example, how much would it cost to control a pest population if it was not regulated by natural processes? Figure 12.1.2 illustrates the value of a few ecosystem services.

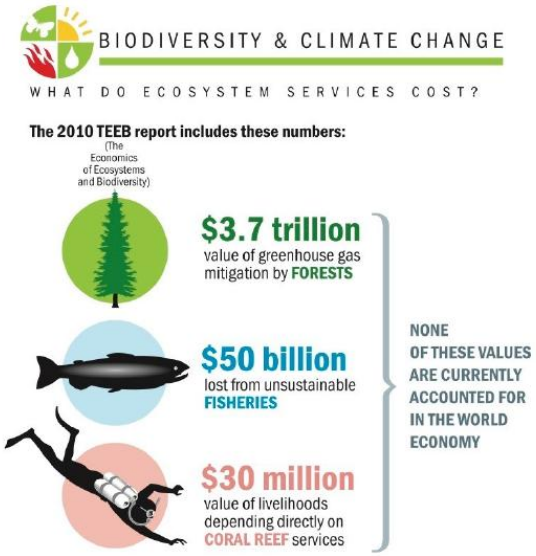


Figure 12.1.2: The value of three ecosystem services. The question, "What do ecosystem services cost?" is partially answered by the 2010 TEEB (The Economics of Ecosystems and Biodiversity) report. Greenhouse gas mitigation (which limits climate change) provided by forests is valued at $3.7 trillion. Unsustainable fisheries have compromised fish availability, costing $50 billion. Coral reef services, such as tourism, are valued at $30 million. Values are in 2010 dollars. None of these values are currently accounted for in the world economy. Data from The Economics of Ecosystems and Biodiversity Synthesis Report. Image by Future Challenges (CC-BY-SA).

Food Production

Agriculture

Food production relies on several interacting ecosystem services. Most soils contain a huge diversity of organisms that maintain nutrient cycles, breaking down organic matter into nutrient compounds that crops need for growth. These organisms also maintain soil texture that affects water and oxygen dynamics in the soil that are necessary for plant growth. Replacing the work of these organisms in forming **arable** (farmable) soil is not practically possible. They occur within ecosystems, such as soil ecosystems, as a result of the diverse metabolic activities of the organisms living there, but they provide benefits to human food production, drinking water availability, and breathable air.

Other key ecosystem services related to food production are plant pollination and crop pest control. It is estimated that honeybee pollination within the United States brings in $1.6 billion per year; other pollinators contribute up to $6.7 billion. Over 150 crops in the United States require pollination to produce. Many honeybee populations are managed by beekeepers who rent out their hives' services to farmers. Honeybee populations in North America have been suffering large losses caused by a syndrome known as **colony collapse disorder**, a phenomenon with complex and interacting causes.

Other pollinators include a diverse array of other bee species and various insects and birds. Loss of these species would make growing crops requiring pollination impossible, increasing dependence on other crops. A 2002 study by Claire Kremen and

colleagues found that **native** pollinators in Central California (those that historically occurred there; figure 12.1.3 and 4) provided full pollination to watermelon crops. This was only true on organic farms that were located near the natural habitat for these pollinators, highlighting the importance of sustainable farming practices and habitat conservation in preserving ecosystem services. Essentially, in a healthy ecosystem, native pollinators eliminated the need for rented honeybee hives. Note that while honeybees are valuable in an agricultural setting, they are not native to North America and can disrupt ecosystems by competing with native bees.



Figure 12.1.3: The California bumble bee (*Bombus californicus*) is one of several native insects that provided watermelon pollination in Kremen and colleagues' study. Image by Rhododendrites (CC-BY-SA).



Figure 12.1.4: Mason bees are efficient pollinators, and many are native to North America. Image by Robert Engelhardt (CC-BY-SA).

Finally, humans compete for their food with crop pests, most of which are insects. Pesticides control these competitors, but these are costly and lose their effectiveness over time as pest populations adapt. They also lead to collateral damage by killing non-pest species as well as beneficial insects like honeybees, and risking the health of agricultural workers and consumers. Moreover, these pesticides may migrate from the fields where they are applied and do damage to other ecosystems like streams, lakes, and even the ocean (see Industrial Agriculture and Environmental Toxicology). Ecologists believe that the bulk of the work in removing pests is actually done by predators and parasites of those pests, but the impact has not been well studied. A review found that in 74 percent of studies that looked for an effect of landscape complexity (forests and fallow fields near to crop fields) on natural enemies of pests, the greater the complexity, the greater the effect of pest-suppressing organisms. Another experimental study found that introducing multiple enemies of pea aphids (an important alfalfa pest) increased the yield of alfalfa significantly. This study shows that a diversity of pests is more effective at control than one single pest. Loss of diversity in pest enemies will inevitably make it more difficult and costly to grow food. The world's growing human population faces significant challenges in the increasing costs and other difficulties associated with producing food.

Wild Food Sources

In addition to growing crops and raising food animals, humans obtain food resources from wild populations, primarily wild fish populations. For about one billion people, aquatic resources provide the main source of animal protein. But since 1990, production from global fisheries has declined. Despite considerable effort, few fisheries on Earth are managed sustainability.

Fishery extinctions rarely lead to complete extinction of the harvested species, but rather to a radical restructuring of the marine ecosystem in which a dominant species is so over-harvested that it becomes a minor player, ecologically. In addition to

humans losing the food source, these alterations affect many other species in ways that are difficult or impossible to predict. The collapse of fisheries has dramatic and long-lasting effects on local human populations that work in the fishery. In addition, the loss of an inexpensive protein source to populations that cannot afford to replace it will increase the cost of living and limit societies in other ways. In general, the fish taken from fisheries have shifted to smaller species and the larger species are overfished. The ultimate outcome could clearly be the loss of aquatic systems as food sources.

Species Diversity

Species diversity is the number of different species in a particular area and their relative abundance. The area in question could be a habitat, a biome, or the entire biosphere. Areas with low species diversity, such as the glaciers of Antarctica, still contain a wide variety of living organisms, whereas the diversity of tropical rainforests is so great that it cannot be accurately assessed. **Species richness**, the number of species living in a habitat or other unit, is one component of biodiversity. **Species evenness** is a component of species diversity based on **relative abundance** (the number individuals in a species relative to the total number of individuals in all species within a system).

The Number of Species on Earth

Despite considerable effort, knowledge of the species that inhabit the planet is limited. About 1.5 million species have been described, but many more species are yet to be identified. Estimates of the total number of species on Earth range from 3 million to 100 million, with more recent estimates commonly ranging from 8 to 11 million species. A 2011 study suggests that only 13% of eukaryotic species (such as plants, animals, fungi, and algae) have been named (Table 12.1.1. Estimates of numbers of prokaryotic species (such as bacteria) are largely guesses, but biologists agree that science has only just begun to catalog their diversity. In fact, a 2017 study by Brendan Larsen and colleagues estimated that there are actually 1-6 billion species on Earth with at least 70% of them being bacteria. Given that Earth is losing species at an accelerating pace, science knows little about what is being lost.

Table 12.1.1: The estimated number of species by taxonomic group—including both described (named and studied) and predicted (yet to be named) species.

Type of Organism	Mora et al. 2011 Described	Mora et al. 2011 Predicted	Chapman 2009 Described	Chapman 2009 Predicted	Groombridge and Jenkins 2002 Described	Groombridge and Jenkins 2002 Predicted
Animals	1,124,516	9,920,000	1,424,153	6,836,330	1,225,500	10,820,000
Photosynthetic protists (such as algae)	17,892	34,900	25,044	200,500		
Fungi	44,368	616,320	98,998	1,500,000	72,000	1,500,000
Plants	224,244	314,600	310,129	390,800	270,000	320,000
Non-photosynthetic protists	16,236	72,800	28,871	1,000,000	80,000	600,000
Prokaryotes			10,307	1,000,000	10,175	
Total	1,438,769	10,960,000	1,897,502	10,897,630	1,657,675	13,240,000

There are various initiatives to catalog described species in accessible and more organized ways, and the internet is facilitating that effort. Nevertheless, at the current rate of species description, which according to the State of Observed Species reports is 17,000–20,000 new species a year, it would take close to 500 years to describe all of the species currently in existence. The task, however, is becoming increasingly impossible over time as extinction removes species from Earth faster than they can be described.

Naming and counting species may seem an unimportant pursuit given the other needs of humanity, but it is not simply an accounting. Describing species is a complex process by which biologists determine an organism's unique characteristics and whether or not that organism belongs to any other described species. It allows biologists to find and recognize the species after the

initial discovery to follow up on questions about its biology. That subsequent research will produce the discoveries that make the species valuable to humans and to our ecosystems. Without a name and description, a species cannot be studied in depth and in a coordinated way by multiple scientists.

Importance of Species Diversity

Healthy ecosystems contain a diversity of species, and each species plays a role in ecosystem function; therefore, species diversity as well as ecosystem diversity are essential to maintaining ecosystem services. For example, many medications are derived from natural chemicals made by a diverse group of organisms. For example, many plants produce compounds meant to protect the plant from insects and other animals that eat them. Some of these compounds also work as human medicines. Contemporary societies that live close to the land often have a broad knowledge of the medicinal uses of plants growing in their area. For centuries in Europe, older knowledge about the medical uses of plants was compiled in herbals—books that identified the plants and their uses. Humans are not the only animals to use plants for medicinal reasons. The other great apes, orangutans, chimpanzees, bonobos, and gorillas have all been observed self-medicating with plants.

Modern pharmaceutical science also recognizes the importance of these plant compounds. Examples of significant medicines derived from plant compounds include aspirin, codeine, digoxin, atropine, and vincristine (figure 12.1.6). Many medications were once derived from plant extracts but are now synthesized. It is estimated that, at one time, 25 percent of modern drugs contained at least one plant extract. That number has probably decreased to about 10 percent as natural plant ingredients are replaced by synthetic versions of the plant compounds. Antibiotics, which are responsible for extraordinary improvements in health and lifespans in developed countries, are compounds largely derived from fungi and bacteria.



Figure 12.1.6: Catharanthus roseus, the Madagascar periwinkle, has various medicinal properties. Among other uses, it is a source of vincristine, a drug used in the treatment of lymphomas. (credit: Forest and Kim Starr)

In recent years, animal venoms and poisons have excited intense research for their medicinal potential. By 2007, the FDA had approved five drugs based on animal toxins to treat diseases such as hypertension, chronic pain, and diabetes. Another five drugs are undergoing clinical trials and at least six drugs are being used in other countries. Other toxins under investigation come from mammals, snakes, lizards, various amphibians, fish, snails, octopuses, and scorpions.

Aside from representing billions of dollars in profits, these medications improve people's lives. Pharmaceutical companies are actively looking for new natural compounds that can function as medicines. It is estimated that one third of pharmaceutical research and development is spent on natural compounds and that about 35 percent of new drugs brought to market between 1981 and 2002 were from natural compounds.

Genetic Diversity

In contrast to ecosystem and species diversity, **genetic diversity** is the total number of genetic characteristics in the genetic makeup of a species, it ranges widely from the number of species to differences within species and can be attributed to the span of survival for a species. Genetic diversity provides the raw material for **evolutionary adaptation**, the process by which the genetic composition of populations change over time in a way that makes it more suited to the environment. With more variation, it is more likely that some individuals in a population will possess variations of alleles (versions of genes) that are suited for the environment.

Those individuals are more likely to survive to produce offspring bearing those same beneficial genes. The population will continue for more generations because of the success of these individuals.

Loss of genetic diversity makes a species less able to reproduce successfully and less adaptable to a changing environment or to a new disease. Small populations of species are especially susceptible to loss of genetic diversity. When a species loses too many individuals, it becomes genetically uniform. Some of the causes for the loss in genetic diversity include: **inbreeding** among closely related individuals and **genetic drift**, the process by which the genetic composition of a population fluctuates randomly over time.

Low genetic diversity makes the Tasmanian devil (figure 12.1.7) especially vulnerable to Devil Facial Tumor Disease (DFTD), a cancer that threatens it with extinction. Contagious cancers are typically spread by viruses, which can transmit cancer-causing genes; however, in the case of DFTD, the cancerous cells themselves are spread among individuals. Usually, the immune system can recognize cancerous cells, infected cells, and foreign cells, but DFTD cells evade the immune system. If Tasmanian devils had high genetic diversity, it is likely that some individuals would have alleles that made them resistant to DFTD. These individuals would survive and reproduce more frequently than others, and the resistant alleles would become more common in the population (evolutionary adaptation would occur). Because Tasmanian devils have low genetic diversity, there is less opportunity for such evolutionary adaptation.



Figure 12.1.7: The Tasmanian devil in a defensive stance, at Tasmanian Devil Conservation Park, Tasman Peninsula. Image by Wayne McLean (CC-BY-SA).

Genetic diversity is important to agriculture. Since the beginning of human agriculture more than 10,000 years ago, human groups have been breeding and selecting crop varieties. This crop diversity matched the cultural diversity of highly subdivided populations of humans. For example, potatoes were domesticated beginning around 7,000 years ago in the central Andes of Peru and Bolivia. The people in this region traditionally lived in relatively isolated settlements separated by mountains. The potatoes grown in that region belong to seven species and the number of varieties likely is in the thousands. Each variety has been bred to thrive at particular elevations and soil and climate conditions. The diversity is driven by the diverse demands of the dramatic elevation changes, the limited movement of people, and the demands created by crop rotation for different varieties that will do well in different fields.

The potato demonstrates a well-known example of the risks of low crop diversity: during the tragic Irish potato famine (1845–1852 AD), the single potato variety grown in Ireland became susceptible to a potato blight—wiping out the crop (figure 12.1.8). The loss of the crop led to famine, death, and mass emigration. Resistance to disease is a chief benefit to maintaining crop biodiversity and lack of diversity in contemporary crop species carries similar risks. Seed companies, which are the source of most crop varieties in developed countries, must continually breed new varieties to keep up with evolving pest organisms. These same seed companies, however, have participated in the decline of the number of varieties available as they focus on selling fewer varieties in more areas of the world replacing traditional local varieties.



Figure 12.1.8: The effects of potato blight, which is cause by the water mold *Phytophthora infestans.* Image by USDA (public domain).

Potatoes are only one example of agricultural diversity. Every plant, animal, and fungus that has been cultivated by humans has been bred from original wild ancestor species into diverse varieties arising from the demands for food value, adaptation to growing conditions, and resistance to pests. The ability to create new crop varieties relies on the diversity of varieties available and the availability of wild forms related to the crop plant. These wild forms are often the source of new gene variants that can be bred with existing varieties to create varieties with new attributes. Loss of wild species related to a crop will mean the loss of potential in crop improvement. Maintaining the genetic diversity of wild species related to domesticated species ensures our continued supply of food.

Since the 1920s, government agriculture departments have maintained seed banks of crop varieties as a way to maintain crop diversity. This system has flaws because over time seed varieties are lost through accidents and there is no way to replace them. In 2008, the Svalbard Global seed Vault, located on Spitsbergen island, Norway, (figure 12.1.9) began storing seeds from around the world as a backup system to the regional seed banks. If a regional seed bank stores varieties in Svalbard, losses can be replaced from Svalbard should something happen to the regional seeds. The Svalbard seed vault is deep into the rock of the arctic island. Conditions within the vault are maintained at ideal temperature and humidity for seed survival, but the deep underground location of the vault in the arctic means that failure of the vault's systems will not compromise the climatic conditions inside the vault.



Figure 12.1.9: The Svalbard Global Seed Vault is a storage facility for seeds of Earth's diverse crops. (credit: Mari Tefre, Svalbard Global Seed Vault)

References

Costanza, R., d'Arge, R., de Groot, R. *et al.* The value of the world's ecosystem services and natural capital. *Nature* **387,** 253–260 (1997). DOI

Kremen, C., Williams, N. M., and Thorp, R. W. Crop pollination from native bees at risk from agricultural intensification. *PNAS* **99,** 6812-16816 (2002). DOI

Brendan B. Larsen, Elizabeth C. Miller, Matthew K. Rhodes, and John J. Wiens, "Inordinate Fondness Multiplied and Redistributed: the Number of Species on Earth and the New Pie of Life," The Quarterly Review of Biology 92, no. 3 (September 2017): 229-265.

Attributions

This page is a modified derivative of

- Genetic diversity by wikipedia (license CC BY-SA 4.0)
- 9.1 Ecosystem Diversity from Environmental Science by Melissa Ha and Rachel Schleiger (license CC BY-NC 4.0)
- 9.2 Species Diversity from Environmental Science by Melissa Ha and Rachel Schleiger (license CC BY-NC 4.0)
- 9.3 Genetic Diversity from Environmental Science by Melissa Ha and Rachel Schleiger (license CC BY-NC 4.0)

This page titled 12.1: Value of Biodiversity is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **9.1: Ecosystem Diversity** by Melissa Ha and Rachel Schleiger is licensed CC BY-SA 4.0.
- **9.2: Species Diversity** by Melissa Ha and Rachel Schleiger is licensed CC BY-NC 4.0.
- **9.3: Genetic Diversity** by Melissa Ha and Rachel Schleiger is licensed CC BY-SA 4.0.

12.2: Patterns of Biodiversity

Ecologists have extensively studied one of the fundamental characteristics of communities: **biodiversity**. One measure of biodiversity used by ecologists is the number of different species in a particular area and their relative abundance. The area in question could be a habitat, a biome, or the entire biosphere. **Species richness** is the term used to describe the number of species living in a habitat or other unit. Ecologists have struggled to understand the determinants of biodiversity.

Biodiversity is not evenly distributed on the planet. For example, Lake Victoria in Africa (figure 12.2.*a*) contained almost 500 species from a family of fishes called cichlids before the introduction of the invasive Nile Perch in the 1980s and 1990s caused a mass extinction. (Note that this number does not include species of other fish families.) Lake Huron, the second largest of North America's Great Lakes, contains about 79 species of fish, all of which are found in many other lakes in North America. What accounts for the difference in diversity between Lake Victoria and Lake Huron? Lake Victoria is a tropical lake, while Lake Huron is a temperate lake. Lake Huron in its present form is only about 7,000 years old, while Lake Victoria in its present form is about 15,000 years old. These two factors, latitude and age, are two of several hypotheses biogeographers have suggested to explain biodiversity patterns on Earth.



Figure 12.2.*a*: Lake Victoria in Africa, shown in this satellite image, was the site of one of the most extraordinary evolutionary findings on the planet, as well as a casualty of devastating biodiversity loss. (credit: modification of work by Rishabh Tatiraju, using NASA World Wind software)

Biogeography is the study of the distribution of the world's species both in the past and in the present. The work of biogeographers is critical to understanding our physical environment, how the environment affects species, and how changes in environment impact the distribution of a species. There are three main subfields of biogeography: ecological biogeography, historical biogeography, and conservation biogeography. Ecological biogeography studies the current factors affecting the distribution of plants and animals. Historical biogeography, as the name implies, studies the past distribution of species. Conservation biogeography, on the other hand, is focused on the protection and restoration of species based upon the known historical and current ecological information.

The Tropics Have High Biodiversity

One of the oldest observed patterns in ecology is that biodiversity typically increases as latitude declines. In other words, the greatest species richness occurs near the equator and the lowest richness occurs near the poles (figure 12.2.*b*).

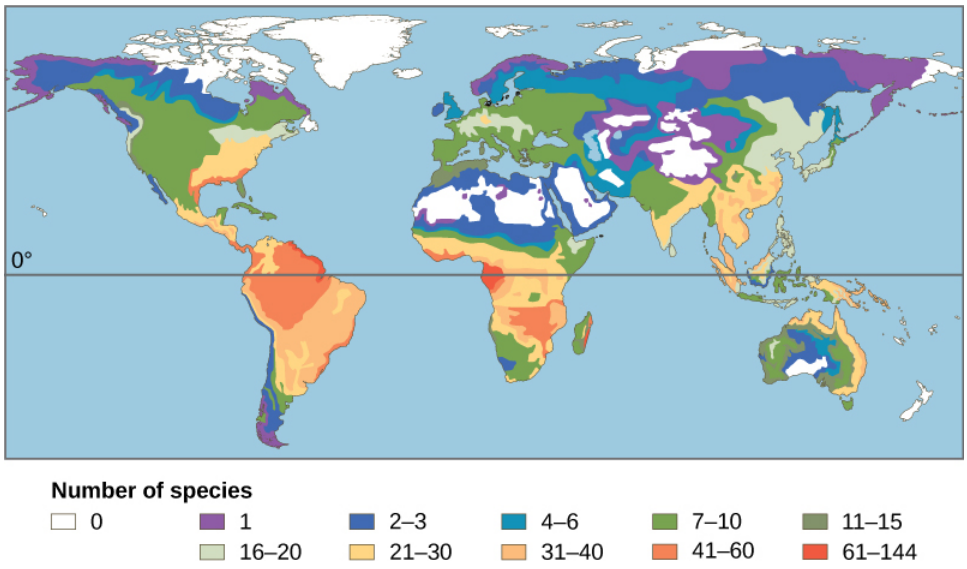


Figure 12.2.*b*: This map illustrates the number of amphibian species across the globe and shows the trend toward higher biodiversity at lower latitudes. A similar pattern is observed for most taxonomic groups. The greatest number of species, 61-144, are found in the Amazon region of South America and in parts of Africa. Between 21 and 60 species are found in other parts of South America and Africa, and in the eastern United States and Southeast Asia. Other parts of the world have between 1 and 20 amphibian species, with the fewest species occurring at northern and southern latitudes.

It is not yet clear why biodiversity increases closer to the equator, but hypotheses include the greater age of the ecosystems in the tropics versus temperate regions, which were largely devoid of life or drastically impoverished during the last ice age. The greater age provides more time for **speciation,** the evolutionary process of creating new species. Another possible explanation is the greater energy the tropics receive from the sun, but scientists have not been able to explain how greater energy input could translate into more species. The complexity of tropical ecosystems may promote speciation by increasing the habitat complexity, thus providing more **ecological niches** (see Communities chapter). Lastly, the tropics have been perceived as being more stable than temperate regions, which have a pronounced climate and day-length seasonality. The stability of tropical ecosystems might promote speciation. Regardless of the mechanisms, it is certainly true that biodiversity is greatest in the tropics. There are also high numbers of endemic species.

Biodiversity Hotspots

In 1988, British environmentalist Norman Myers developed a conservation concept to identify geographical areas rich in species and at significant risk for species loss: **biodiversity hotspots**. The original criteria for a hotspot included the presence of 1500 or more endemic plant species and 70 percent of the area disturbed by human activity. **Endemic species** are found in only one location. For example, all of cichlid species found in Lake Victoria only occurred there. The blue jay is endemic to North America, while the Barton Springs salamander is endemic to the mouth of one spring in Austin, Texas. Endemic species with highly restricted distributions, like the Barton Springs salamander, are particularly vulnerable to extinction. If a population of a widespread species declines in one region, individuals from another region may be able to recolonize the first location, but this is not possible for endemic species. Endemic species are particularly common in isolated regions, such as mountaintops or islands. Endemism is especially likely on islands that are large and far from the mainland. Identifying biodiversity hotspots aids with conservation efforts, a kind of conservation triage. By protecting hotspots, governments are able to protect a larger number of species. There are now 34 biodiversity hotspots (figure 12.2.*c*) containing large numbers of endemic species, which include half of Earth's endemic plants.

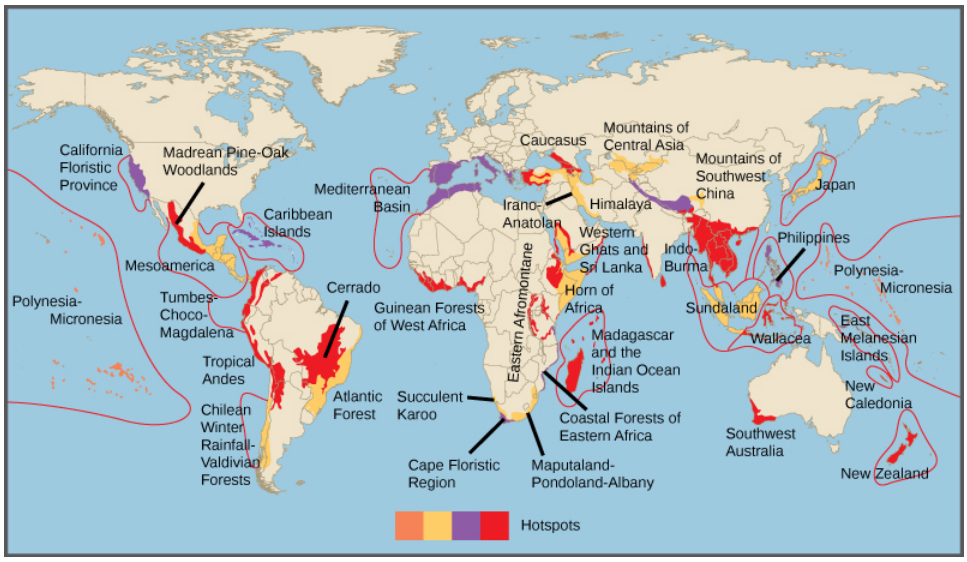


Figure 12.2.*c*: Conservation International has identified 34 biodiversity hotspots, which cover only 2.3 percent of the Earth's surface but have endemic to them 42 percent of the terrestrial vertebrate species and 50 percent of the world's plants. Hotspots are shaded in red, purple, yellow, or orange. Examples include the California Floristic Province, Tropical Andes, Mediterranean Basic, Cape Floristic Province, and Polynesia-Micronesia.

Biodiversity Hotspots in South Africa

A rich species diversity is found in South Africa. With a land surface of approximately 148,000 km^2 (about 57,000 square miles), representing approximately 1% of the Earth's total surface, South Africa contains 10% of the world's total known bird, fish and plant species, and 6% of the world's mammal and reptile species.

This natural wealth is threatened by the expansion of the human population and the increasing demand this places on the environment. The Karoo (figure 12.2.*d*) and the Cape are biodiversity hotspots in South Africa. South Africa has a wide range of climatic conditions and many variations in landscape, creating a variety of ecological niches, which can promote species diversity. These various landscapes give rise to the biomes which allow a wide variety of life to survive.



Figure 12.2.*d*: Map of South Africa, illustrating the Karoo, a dry region with hot summers and cold winters. Image by (WT-shared) NJR ZA at wts wikivoyage (CC-BY-SA).

More than 20,300 species of flowering plants occur in South Africa (figure 12.2.*e*). One of the six most important areas of plant growth in the world is in the Western Cape. Most of the 2,000 threatened species of plants are found in the **fynbos** in South-West Cape (figure 12.2.*f*).



Figure 12.2.*e*: Vegetation of the Karoo in near Willowmore, Eastern Cape, South Africa. Image by Winfried Bruenken (CC-BY-SA).



Figure 12.2.*f*: Vegetation of the fynbos in Western Cape, South Africa. Image by Joachim Huber (CC-BY-SA).

South Africa is home to 243 mammal species. Among the 17 threatened species in South Africa are the black rhino, pangolin, and giant golden mole. The blue antelope and quagga (figure 12.2.*g*) have become extinct. Of more than 800 bird species, 26 are threatened, including the penguin, Cape vulture, martial eagle (figure 12.2.*h*), and Cape parrot. In total 370 reptiles and amphibians occur in the region of which 21 are threatened. Six of these are endangered. Of the 220 freshwater fishes in South Africa, 21 are threatened. There are more than 2,000 marine fish species. While many insect species remain unidentified, 80,000 insects are known to occur.

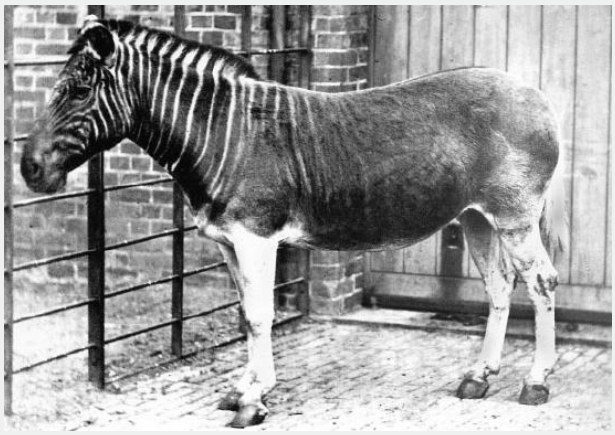


Figure 12.2.*g*: The quagga (*Equus quagga quagga*), now extinct, is technically a subspecies of the plains zebra. Image by Stanford Woods (public domain).



Figure 12.2.*h*: The Martial Eagle (*Polemaetus bellicosus*) is one of the threatened bird species found in South Africa. Image by Charles J. Sharp (CC-BY-SA).

Modified by Melissa Ha from Biodiversity and Biomes from *Life Sciences Grade 10* by Siyavula (CC-BY)

Spatial and Temporal Heterogeneity Promote Biodiversity

Environmental heterogeneity refers to the lack of uniformity in an area. Regions that are spatially heterogeneous are composed of smaller areas with contrasting vegetation, water and nutrient availability, soils and rocks, or other features. In regions that are temporally heterogeneous, conditions fluctuate over time. Heterogeneity promotes species richness by increasing the number of ecological niches, and heterogenous regions are thus priorities with respect to conserving biodiversity. Some regions are more hetergeneous than others. For example, a wetland consists of many microhabitats that differ in soil type and water availability, and water levels change over the seasons. Other regions, like the temperate grasslands in the midwestern United States, are relatively homogenous (uniform). Just as biodiversity can be assessed at a variety of scales, heterogeneity can be measured at large scales (such as within an entire biome) or small scales (such as within a single meadow).

Attributions

Modified by Melissa Ha from the following sources:

- Importance of Biodiversity from *Environmental Biology* by Matthew R. Fisher (licensed under CC-BY)
- The Biodiverisity Crisis and Prelude to Conservation Biology and Biodiversity from *General Biology* by OpenStax (licensed under CC-BY)

This page titled 12.2: Patterns of Biodiversity is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **9.4: Patterns of Biodiversity** by Melissa Ha and Rachel Schleiger is licensed CC BY-SA 4.0.

12.3: Extinction

Speciation and Extinction

The number of species on the planet, or in any geographical area, is the result of an equilibrium of two evolutionary processes that are ongoing: speciation and extinction. **Speciation** occurs when new species evolve, and **extinction** is the global loss of a species. When speciation rates begin to outstrip extinction rates, the number of species will increase; likewise, the number of species will decrease when extinction rates begin to overtake speciation rates. Throughout Earth's history, these two processes have fluctuated—sometimes leading to dramatic changes in the number of species on Earth as reflected in the fossil record (Figure 12.3.1).

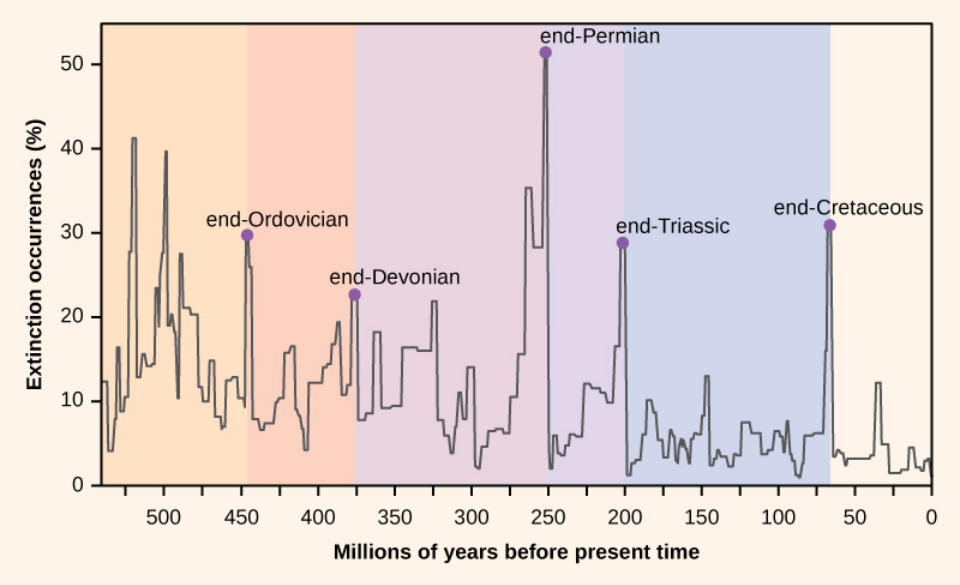


Figure 12.3.1: Percent extinction occurrences as reflected in the fossil record have fluctuated throughout Earth's history. This graph shows the extinction occurrences as a percentage over time (in millions of years before present time). At the lowest points on the cycle, extinction occurrences were between 2% and 5% percent. Sudden and dramatic losses of biodiversity, called mass extinctions, have occurred five times, marking the end of geological periods: end-Ordovician, 450 million years ago; end-Devonian, 374 million years ago; end-Permian, 252 million years ago; end-Triassic, 200 million years ago; and end-Cretaceous, 65 million years ago. During these spikes, extinction occurrences approximately ranged from 22% to 50%.

Mass Extinctions

Paleontologists have identified five events in geological history of sudden and dramatic losses in biodiversity, with more than half of all extant species disappearing from the fossil record. **Extant** species are those that are surviving (not extinct) at a point in time. These five events are called mass extinctions. There are many lesser, yet still dramatic, extinction events, but the five mass extinctions have attracted the most research. An argument can be made that the five mass extinctions are only the five most extreme events in a continuous series of large extinction events that have occurred since 542 million years ago.

The fossil record of the mass extinctions was the basis for defining periods of geological history, so they typically occur at the transition point between geological periods. The transition in fossils from one period to another reflects the dramatic loss of species and the gradual origin of new species. These transitions can be seen in the rock layers. Table 12.3.a provides the names and dates of the five mass extinctions.

In most cases, the hypothesized causes are still controversial; however, the causes of the most recent event, the end-Cretaceous extinction, are best understood (table 12.3.a). It was during this extinction event that the dinosaurs, the dominant vertebrate group for millions of years, disappeared from the planet (with the exception of a theropod clade that gave rise to birds). Indeed, every land animal that weighed more then 25 kg (55 lbs) became extinct. The cause of this extinction is now understood to be the result of a cataclysmic impact of a large meteorite, or asteroid, off the coast of what is now the Yucatán Peninsula.

Following a mass extinction, biodiversity is greatly decreased, and it stays low during a "survival interval" before beginning to climb again. While some of the species that reappear after an extinction are new, others are pre-existing. Some floras and faunas often survive in small or isolated geographic areas called refugia. And, as recovery progresses, the resulting biological communities may be very different from those that were wiped out. This is not simply because the organisms that become extinct leave behind empty ecological niches that are filled by creatures from different ancestry than the former inhabitants. Instead, it seems the niches themselves are destroyed, and new niches are created as new species appear and new ecological relationships are established.

Mass extinctions are ecological disasters and recovery of ecosystem structure and function is slow. Recovery times after mass extinctions vary, but have been up to 30 million years. Recovery of biodiversity from the Permian–Triassic extinction event, for example, took around 10 million years.

Table 12.3.*a***:** Summary of the five mass extinctions, including the name, dates, percent of biodiversity lost, and hypothesized causes.

Geological Period	Mass Extinction Name	Time (millions of years ago)	Loss in Biodiversity	Hypothesized Cause(s)
Ordovician–Silurian	end-Ordovician O–S	450–440	85% of marine species	Global cooling and then warming, gamma-ray burst from supernova removed ozone layer
Late Devonian	end-Devonian	375–360	79-87% of all species	Unknown
Permian–Triassic	end-Permian	251	96% of marine species and 70% of terrestrial (land) species	Volcanic activity, decrease on dissolved oxygen in the oceans
Triassic–Jurassic	end-Triassic	205	76% of all species	Climate change, asteroid impact, volcanic eruptions
Cretaceous–Paleogene	end-Cretaceous K–Pg (K–T)	65.5	50% of animals and plants	Asteroid impact

The Pleistocene Extinction is one of the lesser extinctions, and a recent one (Figure 12.3.2). It is well known that the North American, and to some degree Eurasian **megafauna**, or large animals, disappeared toward the end of the last glaciation (cooling) period. The extinction appears to have happened in a relatively restricted time period of 10,000–12,000 years ago. In North America, the losses were quite dramatic and included the woolly mammoths (last dated about 4,000 years ago in an isolated population), mastodon, giant beavers, giant ground sloths, saber-toothed cats, and the North American camel, just to name a few. The possibility that the rapid extinction of these large animals was caused by overhunting, a type of overexploitation, was first suggested in the 1900s. Research into this hypothesis continues today. It seems likely that overhunting caused many pre-written history extinctions in many regions of the world.



Figure 12.3.2: Late Pleistocene landscape of northern Spain. From left to right: wild horse (*Equus ferus)*, woolly mammoth (*Mammuthus primigenius*) reindeer (*Rangifer tarandus*) the cave or steppe lion (*Panthera spelaea*) and the woolly rhinoceros (*Coelodonta antiquitatis*). (CC BY 2.5; by Mauricio Antónvia wikipedia)

The Sixth Mass Extinction

The sixth, or Holocene, mass extinction appears to have begun earlier than previously believed and has mostly to do with the activities of *Homo sapiens*. Since the beginning of the Holocene period, there are numerous recent extinctions of individual species that are recorded in human writings. Most of these are coincident with the expansion of the European colonies since the 1500s.

One of the earlier and popularly known examples is the dodo bird. The dodo bird lived in the forests of Mauritius, an island in the Indian Ocean. The dodo bird became extinct around 1662 (figure 12.3.*b*). It was hunted for its meat by sailors and was easy prey because the dodo, which did not evolve with humans, would approach people without fear. Introduced pigs, rats, and dogs brought to the island by European ships also killed dodo young and eggs.



Figure 12.3.*b*: The dodo bird was hunted to extinction around 1662. (credit: Ed Uthman, taken in Natural History Museum, London, England)

Steller's sea cow became extinct in 1768; it was related to the manatee and probably once lived along the northwest coast of North America. Steller's sea cow was first discovered by Europeans in 1741 and was hunted for meat and oil. The last sea cow was killed in 1768. That amounts to 27 years between the sea cow's first contact with Europeans and extinction of the species.

In 1914, the last living passenger pigeon died in a zoo in Cincinnati, Ohio. This species had once darkened the skies of North America during its migrations, but it was hunted and suffered from habitat loss through the clearing of forests for farmland. In 1918, the last living Carolina parakeet died in captivity. This species was once common in the eastern United States, but it suffered from habitat loss. The species was also hunted because it ate orchard fruit when its native foods were destroyed to make way for farmland. The Japanese sea lion, which inhabited a broad area around Japan and the coast of Korea, became extinct in the 1950s due to fishermen. The Caribbean monk seal was distributed throughout the Caribbean Sea but was driven to extinction via hunting by 1952.

As described in the next section, the current high rates of extinction will cause a large and rapid decline in the biodiversity of the planet. According to a 2019 United Nations report, 1 million species are at risk of extinction. Considering there are estimated to be 8-11 million species total (see The Number of Species on Earth), that means up to 12.5% of species could go extinct, and many of them within our lifetimes.

Estimates of Present-Time Extinction Rates

The **background extinction rate** is estimated to be about 1 extinction per million species each year (E/MSY). For example, if there are 8-11 million species in existence, then we would expect 8-11 of those species to become extinct in a year.

Estimates of extinction rates are hampered by the fact that most extinctions are probably happening without observation. The extinction of a bird or mammal is likely to be noticed by humans, especially if it has been hunted or used in some other way. But there are many organisms that are of less interest to humans (not necessarily of less value) and many that are undescribed.

One contemporary extinction-rate estimate uses the extinctions in the written record since the year 1500. For birds alone, this method yields an estimate of 26 E/MSY, almost three times the background rate. However, this value may be underestimated for three reasons. First, many existing species would not have been described until much later in the time period and so their loss would have gone unnoticed. Second, we know the number is higher than the written record suggests because now extinct species are being described from skeletal remains that were never mentioned in written history. And third, some species are probably already extinct even though conservationists are reluctant to name them as such. Taking these factors into account raises the estimated extinction rate to nearer 100 E/MSY. The predicted rate by the end of the century is 1500 E/MSY.

A second approach to estimating present-time extinction rates is to correlate species loss with habitat loss, and it is based on measuring forest-area loss and understanding **species–area relationships**. The species-area relationship is the rate at which new species are seen when the area surveyed is increased (figure 12.3.c). Likewise, if the habitat area is reduced, the number of species seen will also decline. This kind of relationship is also seen in the relationship between an island's area and the number of species present on the island: as one increases, so does the other, though not in a straight line. Estimates of extinction rates based on habitat loss and species–area relationships have suggested that with about 90 percent of habitat loss an expected 50 percent of species would become extinct. Species–area estimates have led to estimates of present-day species extinction rates of about 1000 E/MSY and higher.

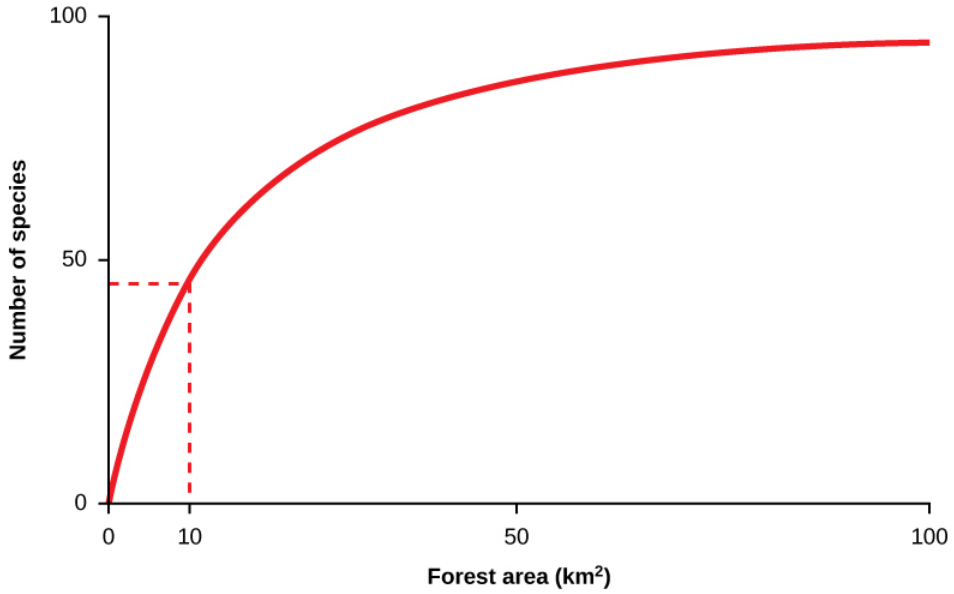


Figure 12.3.*c*: A typical species-area curve shows the cumulative number of species found as more and more area is sampled. The curve has also been interpreted to show the effect on species numbers of destroying habitat; a reduction in habitat of 90 percent from 100 km^2 to 10 km^2 reduces the number of species supported by about 50 percent.

Many extinctions will affect species that biologists have not yet discovered. Most of these "invisible" species that will become extinct currently live in tropical rainforests (figure 12.3.*d*). These rainforests are the most diverse ecosystems on the planet and are being destroyed rapidly by deforestation to provide timber and space for agriculture.



Figure 12.3.*d*: This tropical lowland rainforest in Madagascar is an example of a high biodiversity habitat. This particular location is protected within a national forest, yet only 10 percent of the original coastal lowland forest remains, and research suggests half the original biodiversity has been lost. (credit: Frank Vassen)

Extirpation

The elimination of species at a local level–known as **extirpation** – also poses threats to the integrity and sustainability of ecosystems. Widespread extirpation can obviously lead to extinction, but absence of species, even at a local scale, can affect ecosystem function. For example, by the mid-1920s wolves had been extirpated from Yellowstone National Park, although they continued to thrive elsewhere. When wolves were reintroduced to the park in the mid-1990s, they regulated elk populations, benefiting the vegetation and plant communities. What mattered for ecosystem function in Yellowstone was whether wolves were present there, not just whether the species survived somewhere.

References

UN Report: Nature's Dangerous Decline 'Unprecedented'; Species Extinction Rates 'Accelerating'. 2019. United Nations. Accessed 2020-08-01.

Attributions

Modified by Melissa Ha from the following sources:

- The Biodiversity Crisis from *General Biology* by OpenStax (licensed under CC-BY)
- Preserving Biodiversity and Importance of Biodiversity from *Environmental Biology* by Matthew R. Fisher (licensed under CC-BY)
- Biodiversity, Species Loss, and Ecosystem Function by Tom Theis and Jonathan Tomkin, Editors. Download for free at CNX. (licensed under CC-BY)

This page titled 12.3: Extinction is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **10.1: Extinction** by Melissa Ha and Rachel Schleiger is licensed CC BY-NC 4.0.

12.4: Measures of Biodiversity Loss

The Red List

The **International Union for the Conservation of Nature (IUCN)** coordinates efforts to catalog and preserve biodiversity worldwide. One way scientists gauge trends in biodiversity is by monitoring the fate of individual species. Since 1964, the IUCN has compiled information in the Red List of Threatened Species, which includes plants, animals, fungi, and selected brown algae species. Updates to the Red List are released every four years.

Species can be classified into nine Red List categories based on their extinction risk. Firstly, there are species that are already **extinct** and those that are **extinct in the wild**, meaning that the remaining individuals are only found in captivity. Species at risk of extinction are called **threatened**. Species that are at risk of becoming threatened are called **near threatened**. The Emperor Penguin (*Aptenodytes forsteri*) is an example a near threatened species, mainly due to habitat loss and climate change (figure 12.4.*a*). Those with little risk of extinction are designated **least concern**. Note that only a fraction of the 8-11 million species on Earth are identified (see The Number of Species on Earth). For many of the species that are identified, data still needs to be gathered before they can be assigned to a Red List category (**data deficient**). Less than 10% of the approximately 1.5 million identified species have been assessed for the Red List at all. Species that have not been assessed are deemed **not evaluated**.



Figure 12.4.*a*: The Emperor Penguin is an example of near threatened species. Image by Christopher Michel (CC-BY).

There are three categories of threatened species: **vulnerable, endangered,** and **critically endangered**. Of these, critically endangered species have the greatest risk while vulnerable species are at the least risk out of the threatened categories. The African elephant (*Loxodonta africana*) is listed vulnerable species due to poaching and habitat loss (figure 12.4.*b*). Interestingly, the forest subspecies (*L. africana cylotis*) is at much greater risk than the savanna subspecies (*L. africana africana*), but the Red List category is assigned at the species level in this case. The blue whale (*Balaenoptera musculus*) is endangered due to pollution, climate change, and poaching (figure 12.4.*c*). Fortunately, blue whale population size is increasing. Several species of pitcher plants, which trap insects as a source of nitrogen, are critically endangered due to overexploitation and habitat loss (figure 12.4.*d*).



Figure 12.4.*b*: The African forest elephant (*Loxodonta africana cylotis*) is at greater risk of extinction than the savanna subspecies. When both subspecies are grouped together, African elephants are considered vulnerable. Image by Peter H. Wrege (CC-BY-SA).



Figure 12.4.*c*: The blue whale (*Balaenoptera musculus*) is categorized as endangered according to the IUCN Red List. Image by Mike Baird (CC-BY).



Figure 12.4.*d*: *Nepenthes aristolochioides* is a critically endangered pitcher plant. Image by Alfindra Primaldhi (CC-BY).

Extinct and Threatened Animals

Scientists know much more about the state of **vertebrates**—especially mammals, birds, and amphibians—than they do about other forms of animal life. Of 6,594 described mammal species, 96 species have become extinct during the last 500 years (Mammal Diversity Database). According to the Red List, approximately 26% of mammal species worldwide are known to be threatened. A smaller percentage (about 14%) of the world's 10,721 identified bird species (Birds of the World) are threatened (figure 12.4.*e*).



Figure 12.4.*e*: North American passenger pigeons lived in enormous flocks and were once the most numerous birds on earth. Market hunting on a massive scale and habitat destruction combined to extinguish them as a species in the early twentieth century. Image by James St. John (CC-BY).

Among the well-studied vertebrates, amphibians are faring especially poorly. Of the more than 6,000 known species of amphibians, 35 have become extinct worldwide since 1500 (figure 12.4.*f*), and two others are extinct in the wild (Red List). Overall, 41% of the world's amphibian species are known to be threatened (Red List). Only small proportions of the world's species of reptiles and fish have been evaluated for purposes of the Red List. Among those, 34% of selected reptiles and 8% of selected bony fishes are threatened (Red List).



Figure 12.4.*f*: The extinct golden toad of Monteverde, Costa Rica, was last seen in 1989. Its extinction is attributed to fungal infection combined with especially hot, dry weather. Source: U.S. Fish and Wildlife Service via Wikimedia Commons

Invertebrates comprise the vast majority of animals, an estimated 97% of animal species. They include everything from insects and arachnids, to mollusks, crustaceans, corals, and more. Few of these groups have been assessed in a comprehensive way, but assessments within some groups call attention to disturbing, large-scale trends. For example, 33% of the world's reef-building corals are already considered threatened (Red List), and many more of them are experiencing rates of decline that move them toward threatened status (figure 12.4.*g*). The demise of reef-building corals has magnified ecological impacts, since so much other marine life depends on them.

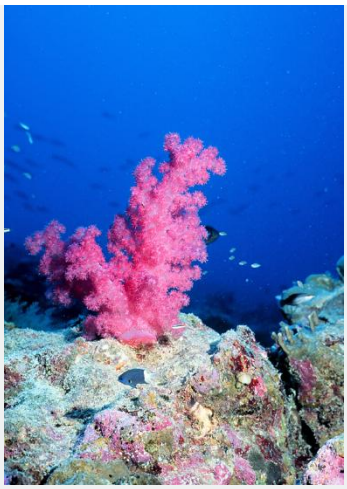


Figure 12.4.*g*: Reef-formal corals, such this pink soft coral, are at high risk of extinction. Source: Linda Wade via National Oceanic & Atmospheric Administration (NOAA)

Ecosystem Loss and Alteration

Another way of gauging biodiversity involves assessment on the scale of ecosystems. The causes of wholesale losses of ecosystems are much the same as those driving extinction or endangerment of species, with habitat destruction and fragmentation being the primary agent. Worldwide, for example, the conversion of land to agriculture and cultivation have led to significant losses in grassland ecosystems. In North America, nearly 70% of the tallgrass prairie ecosystem (which once covered 142 million acres) has been converted to agriculture, and losses from other causes, such as urban development, have brought the total to about 90%. Current estimates indicate that agricultural activity and cultivation systems now cover nearly 25% of the Earth's surface

According to the United Nations Millennium Ecosystem Assessment, by the beginning of the 21st century, 15 of the world's 24 ecosystems, from rainforests to aquifers to fisheries, were rated in serious decline. For example, tropical rainforests, which are the habitats for nearly half of the world's plant and animal species, covered about 4 billion acres in past centuries, but only 2.5 billion acres remain and nearly 1% is being lost annually. Losses have been especially severe in the tropics of Africa and Southeast Asia. Current estimates indicate that about 50% of the world's wetland habitat has been lost. (Note that wetlands are a broad collection of many different ecosytem types.) The former extent of wetland habitats worldwide (fresh, brackish and salt) is difficult to determine but certainly exceeded a billion acres.

References

Birds of the World. 2020. The Cornell Lab of Ornithology. Accessed 2020-07-29.

The IUCN Red List of Threatened Species. 2020. IUCN. Accessed 2020-07-29.

Mammal Diversity Database. 2020. American Society of Mammalogists. Accessed 2020-07-29.

Attribution

Modified by Melissa Ha from Biodiversity, Species Loss, and Ecosystem Function and The Industrialization of Nature: A Modern History (1500 to the present) from *Sustainability: A Comprehensive Foundation* by Tom Theis and Jonathan Tomkin, Editors. Download for free at CNX. (licensed under CC-BY)

This page titled 12.4: Measures of Biodiversity Loss is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **10.2: Measures of Biodiversity Loss** by Melissa Ha and Rachel Schleiger is licensed CC BY-SA 4.0.

CHAPTER OVERVIEW

13: Threats to Biodiversity



Figure 13.1: The northern spotted owl (*Strix occidentalis caurina*) is a western North American owl species that prefers large swaths of pristine old growth forests (that typically take 150-200 years to mature) for nesting. Unfortunately, most western forests have been regularly harvested for timber since around the establishment of the Forest Service in 1905. Thus, this species preferred habitat has been largely destroyed and their populations have plummeted. Habitat destruction is the number one cause for species extinction globally. For some species that are very habitat specific, like the northern spotted owl, there are not as many conservation actions to choose from that can help reverse declining population trends.. Image by USFS (licensed under CC-BY 2.0)

Chapter Summary

The core threat to biodiversity on the planet is the combination of human population growth and the resources used by that population. The human population requires resources to survive and grow, and many of those resources are being removed unsustainably from the environment. The five main threats to biodiversity are habitat loss, pollution, overexploitation, invasive

species, and climate change. Increased mobility and trade has resulted in the introduction of invasive species while the other threats are direct results of human population growth and resource use.

Learning Objectives

After reading this chapter you should be able to:

- Explain causes of habitat loss and degradation.
- Describe the effects of habitat fragmentation and the importance of corridors, and connectivity to conservation.
- Explain how plastic pollution has become a huge environmental problem and why recycling has not been an effective solution.
- Provide examples of invasive species and their ecological impacts.
- Provide examples of species that are overexploited.
- Explain why climate change is expected to accelerate biodiversity decline.

Attribution

13.1: Habitat Loss and Fragmentation
13.2: Pollution
13.3: Invasive Species
13.4: Overexploitation
13.5: Climate Change

This page titled 13: Threats to Biodiversity is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

13.1: Habitat Loss and Fragmentation

Habitats

Natural habitats are the physical, chemical and biological systems that support living things (i.e. plants, animals, fungi and microbes). More simply put, habitats are the places where these organisms live. Habitat is lost and degraded when natural or human-caused activities alter these places so that fewer species can live there. For example, when a section of forest is cut down and replaced with farmland or urban spaces, the living places of hundreds of species may be eliminated.

Although natural events such as landslides and earthquakes do alter the landscape, they generally occur in isolated areas and healthy ecosystems are able to recover from them. Human-caused habitat loss, on the other hand, is altering ecosystems on a global scale, often causing destruction that is irreversible, at least on a time scale that is of interest to society.

Habitat loss is not only a concern from the point of view of compassion for other species that share this planet. Humans are part of the great cycle of life on earth, and as such we depend on the overall function of natural systems for our own survival. Properly functioning natural systems create the air we breathe, break down our wastes, provide our food, purify our drinking water and ultimately supply all the materials we require for living. Each species plays an important role in its ecosystem. Habitat loss and degradation is the main threat to the world's endangered plants and animals, and is occurring at ever greater rates.

Despite this sobering picture, habitat loss is not always an inevitable consequence of human activities. There are ways to limit our impact on natural systems, for example by using principles of "smart growth" in urban planning. Nevertheless, major changes and efforts are required to address this critical problem.

Habitat Loss

Habitat loss occurs when the physical environment required by a species is altered so that the species can no longer live there. Human destruction of habitats accelerated in the latter half of the twentieth century. Consider the exceptional biodiversity of Sumatra: it is home to one species of orangutan, a species of critically endangered elephant, and the Sumatran tiger, but half of Sumatra's forest is now gone. The neighboring island of Borneo, home to the other species of orangutan, has lost a similar area of forest. Forest loss continues in protected areas of Borneo. The orangutan in Borneo is listed as endangered by the International Union for Conservation of Nature (IUCN), but it is simply the most visible of thousands of species that will not survive the disappearance of the forests of Borneo. The forests are removed for timber and to plant palm oil plantations (figure $13.1.a$). Palm oil is used in many products including food products, cosmetics, and biodiesel in Europe. According to Global Forest Watch, 9.7% of tree cover was lost globally from 2002 to 2019, and 9% of that occurred in Indonesia and Malaysia (where Sumatra and Borneo are located). Figure $13.1.b$ shows the average annual change in forest area around the world from 1990 to 2015.



(a) (b)



(c)



(d) (e)

Figure 13.1.*a*: (a) One species of orangutan, *Pongo pygmaeus*, is found only in the rainforests of Borneo, and the other species of orangutan (*Pongo abelii*) is found only in the rainforests of Sumatra. These animals are examples of the exceptional biodiversity of (c) the islands of Sumatra and Borneo, which are located in the south Pacific, just northwest of Australia. Sumatra is in the country of Indonesia. Half of Borneo is in Indonesia, and half is in Malaysia. Other species include the (b) Sumatran tiger (*Panthera tigris sumatrae*) and the (d) Sumatran elephant (*Elephas maximus sumatranus*), both critically endangered species. Rainforest habitat is being removed to make way for (e) oil palm plantations such as this one in Borneo's Sabah Province. (credit a: modification of work by Thorsten Bachner; credit b: modification of work by Dick Mudde; credit c: modification of work by U.S. CIA World Factbook; credit d: modification of work by "Nonprofit Organizations"/Flickr; credit e: modification of work by Dr. Lian Pin Koh)

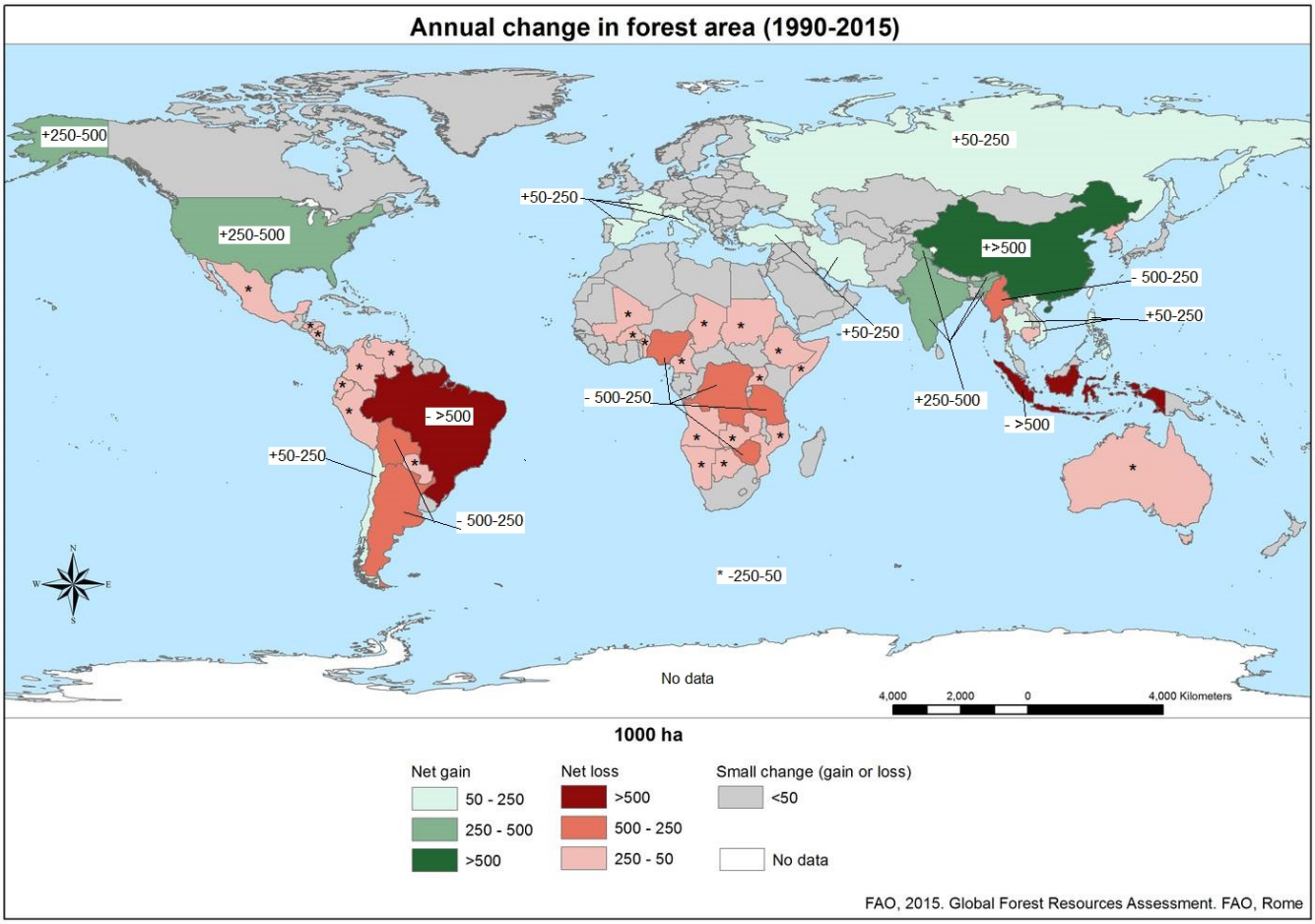


Figure 13.1.*b*: Average annual change in forest area globally from 2005 to 2015. China is dark green, indicating that have gained more than 500 "kilohectares" (kha) of forest. Medium green indicates countries that have gained 250-500 kha, including the the United States, India, Ghutan, and Bangladesh. Light green indicates countries that have gained 50-250 khA, including Chile, Spain, France, Italy, Turkey, Iran, Russia, Vietnam, and Thailand. Indonesia and Brazil lost more than 500 kha of forest (marked with dark red). Countries that lost 500-250 kha are marked with medium red, including Bolivia, Argentina, Nigeria, Democratic Republic of the Congo, Tanzania, Zimbabwe, and Myanmar. Countries that lost 250-50 kha are marked with light red and an asterisk (*). These include Mexico, Honduras, Nicaragua, Venezuela, Colombia, Ecuador, Peru, Paraguay, Mali, Burkina Faso, Benin, Cameroon, Chad, Sudan, Ethiopia, Somalia, Uganda, Angola, Namibia, Botswana, Zimbabwe, Mozambique, Cambodia, North Korea, and Australia. No data has been collected for Antarctica. All other regions have had lost or gained less than 50 kha in forest area. Image by FAO, 2015. Global Forest Resources Assessment. FAO. Rome (Open Access Policy).

Preventing Habitat Destruction with Wise Wood Choices

Most consumers do not imagine that the home improvement products they buy might be contributing to habitat loss and species extinctions. Yet the market for illegally harvested tropical timber is huge, and the wood products often find themselves in building supply stores in the United States. One estimate is that up to 10% of the imported timber in the United States, which is the world's largest consumer of wood products, is illegally logged. A 2012 United Nations and Interpol report estimated that the illegal timber trade is worth $30-100 billion each year. Most of the illegal products are imported from countries that act as intermediaries and are not the originators of the wood.

How is it possible to determine if a wood product, such as flooring, was harvested sustainably or even legally? The Forest Stewardship Council (FSC) certifies sustainably harvested forest products (figure 13.1.*c*). Looking for their certification on flooring and other hardwood products is one way to ensure that the wood has not been taken illegally from a tropical forest. There are certifications other than the FSC, but these are run by timber companies, thus creating a conflict of interest. Another approach is to buy domestic wood species. While it would be great if there was a list of legal versus illegal woods, it is not that simple. Logging and forest management laws vary from country to country; what is illegal in one country may be legal in another. Where and how a product is harvested and whether the forest from which it comes is being sustainably maintained all

factor into whether a wood product will be certified by the FSC. It is always a good idea to ask questions about where a wood product came from and how the supplier knows that it was harvested legally.



Figure 13.1.c: The sawmill in Uaxactun, Guatamala is Forest Stewardship Council (FSC) certified and provides good income from a sustainable resource for not only the saw operators but also many others who help keep the operation running. Image by Jason Houston for USAID (public domain).

Estuaries and Wetlands

Habitat loss can affect ecosystems other than forests. Estuaries and wetlands are among the most productive ecosystems in the world, and provide many services of direct benefit to people; for example, water filtration and storage, and protection from storm surges and erosion. The habitats of these ecosystems are diverse. Intertidal mud flats, submerged eelgrass beds and salt marshes in estuaries house a diversity of animals including worms, crustaceans, shellfish, seabirds, shorebirds and waterfowl, fish (including commercially important species), seals, river otters, bears, raccoons and birds of prey. Wetlands host a similar diversity of freshwater species. Along with many microbe and plant species, these animals form a complex food web. Damage to or removal of one component of the food web can affect the function of the whole system.

For instance, about 85% percent of historical tidal wetlands in California, Oregon, and Washington have been lost. These estuaries serve as critical nurseries for juvenile salmon and steelhead as they make the transition from freshwater to the ocean. They are among the most dynamic and productive habitats known, also supporting migratory birds and a variety of other fish, shellfish, and terrestrial wildlife.

Unfortunately, in many cases the value of estuaries and wetlands has been overlooked by people who have viewed them only as "waste" areas that could be diked, drained and filled in for agriculture, urban development or other more "useful" purposes. Although our perception of the utility of these sensitive areas is slowly changing, the damage continues today. The results include increased erosion, storm surge and flood damage, degraded water quality, and decline or extinction of plants and animals. Habitats in estuaries and wetlands are also damaged by pollution and invasive species. When certain types of plants and animals are killed off from these effects, other species that depend on them also die off or, when possible, move to another area.

Habitat Fragmentation

Habitat fragmentation occurs when the living space of a species is divided into discontinuous patches. For example, a mountain highway could divide a forest habitat into separate patches. Imagine you are a red squirrel, living in a large, healthy woodland. Humans then come along and put a major road right through the middle of those woods. The road becomes a serious barrier, and trying to cross it could be the last thing you do. The patch of woodland on the other side of the road might just as well be fifty miles away. You can now only breed with those in your own limited patch. Your home is effectively an island, and the population is at risk of inbreeding. On top of this, if a disease, or some other natural catastrophe strikes, you and your kind could become locally extinct. The woods are now so cut off there's little chance of squirrels making a comeback.

Habitat fragmentation is especially problematic for consumers at the top of the food chain, which require large ranges to find adequate prey. Since top predators often play a vital role in regulating populations of other organisms, the ecosystem can be seriously upset if they disappear.

Fragmentation can also lead to **Edge effects,** or changes in population or community structures that occur at the boundary of two or more habitats. For example, some species, including certain mosses and lichens, like damp, shady conditions. As a patch of forest shrinks, they may get exposed to too much sun or drying wind, and disappear. Areas with small habitat fragments exhibit especially pronounced edge effects that may extend throughout the range.

Solutions

Conservationists use a range of techniques to help increase connectivity in fragmented landscapes. These include creating corridors, buffers and stepping stones to help wildlife move around. Wildlife **corridors** mitigate the damage of habitat fragmentation by connecting patches with suitable habitat. A corridor can be anything from a hedgerow for dormice to a huge landscape-scale link. The basic idea is to create a direct connection between separate patches. For example, the bridge over a highway could allow animals to move between habitat patches (figure 13.1.*d*). Riparian areas, areas of land adjacent to bodies of water, such as streams, can serve as natural wildlife corridors when left intact.



Figure 13.1.*d*: This overpass on the Trans-Canada Highway between Banff and Lake Louise, Alberta, serves as a wildlife corridor. Image by WikiPedant at Wikimedia Commons (CC-BY-SA).

Some artificial links can help particular species. Badger tunnels and aerial runways for squirrels are used to help these animals negotiate roads. **Stepping stones** are patches of habitat which ease movement through the landscape. **Buffer zones** around a woodland can help to reduce the edge effect. They can also protect the interior of the woods from activities such as fertilizer spraying on adjacent land. When used together, corridors, buffer zones, and stepping stones can create an effective ecological network (Figure 13.1.*e*).

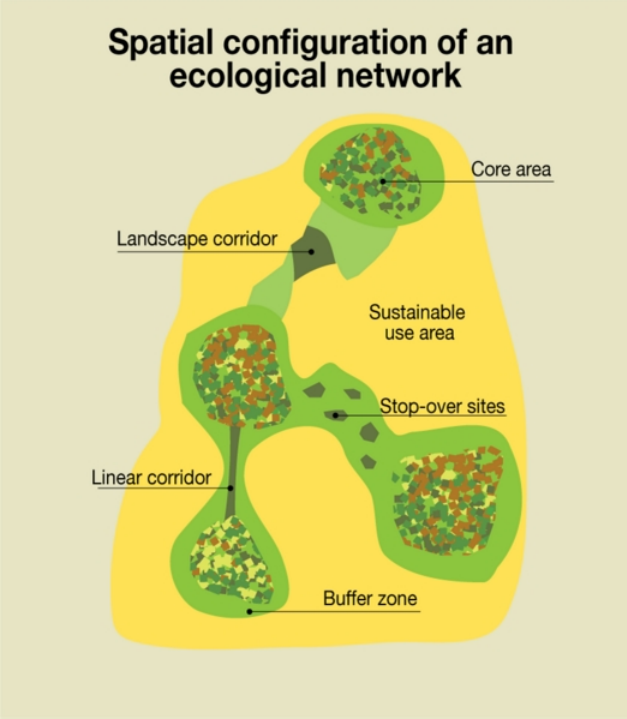


Figure 13.1.e: Copy and Paste Caption here. (CC-BY-NC-SA; by GRID-Arendal via flickr)

Reconnecting habitats isn't always straightforward, and we need to be careful not to create further problems. For example, by linking up two woodlands to help red squirrels we might accidentally help spread the invasive grey squirrel. Even so, these problems can be avoided with some careful planning. Re-establishing a more connected landscape should be seen as a conservation priority.

References

Global Forest Watch. 2020. World Resources Institute. Accessed 2020-07-29.

Illegal logging nets organized crime up to 100 billion dollars a year, INTERPOL–UNEP report reveals. 2012. Interpol. Accessed 2020-07-29.

Attributions

Modified by Melissa Ha from the following sources:

- Threats to Biodiversity from *Environmental Biology* by Matthew R. Fisher (licensed under CC-BY)
- Threats to Biodiversity from *General Biology* by OpenStax (licensed under CC-BY)

This page titled 13.1: Habitat Loss and Fragmentation is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **10.3: Habitat Loss** by Melissa Ha and Rachel Schleiger is licensed CC BY-SA 4.0.

13.2: Pollution

Pollution occurs when chemicals, particles, or other materials are released into the environment, harming the organisms there. For many thousands of years, ever since they built the first campfire, human activity has generated air, water, and soil pollution. For most of human history, however, these contaminants had relatively little environmental impact. But over the last few centuries, pollution levels skyrocketed due to population growth and the Industrial Revolution. As a result, regulations have been enacted to control emissions. Even where these are effective in curbing current pollution sources, high levels of contamination may exist from past activity. And new contamination can occur through industrial accidents or other inadvertent releases of toxic substances.

Pollution has contributed to the decline of many threatened species. For example, a 2007 study by Kingsford and colleagues found that pollution was a major pressure on 30% of threatened Red List species in Australia and surrounding regions.

Power plants, factories, and vehicles are common sources of air pollution. In some cases, the pollutants are directly toxic (for example, lead), but in other cases the pollutants indirectly cause ecological harm when they are present in unnaturally large quantities (for example, carbon dioxide emissions leading to climate change). Not only can air pollutants directly harm animals by causing respiratory issues and cancer as well as damage vegetation, but some interact with the atmosphere to form **acid deposition** (commonly called acid rain). Acid deposition disrupts aquatic ecosystems as well as soil communities and plant growth.

Heavy metals, plastics, pesticides, herbicides, fertilizers, and sediments are examples of water pollution. Heavy metals (including copper, lead, mercury, and zinc) can leach into soil and water from mines. Furthermore, **acid mine drainage** is caused by reaction of mine wastes, such as sulfides, with rainfall or groundwater to produce acids, like sulfuric acid. The Environmental Protection Agency estimates that 40% of the watersheds in the western United States are contaminated by mine run-off. Plastics harm shorebirds, turtles and aquatic invertebrates that ingest and accumulate them. Nutrients, such as nitrate and phosphates, are healthy in bodies of water to an extent, but when fertilizer pollution adds too many of these nutrients at one time, algal blooms can result. This has cascading effects that can ultimately shade and kill aquatic plants and deplete oxygen needed by fish and other animals (**eutrophication**). A particularly concerning water pollution problem is **micropollutants**. For examples, some chemical residues affect growth, cause birth defects, and have other toxic effects on humans and other organisms even at very low concentrations.

Figure 13.2.a summarizes the effects of air and water pollution on biodiversity, and the chapters about Solid Waste Management, Water Pollution, and Air Pollution explain these threats in more detail.

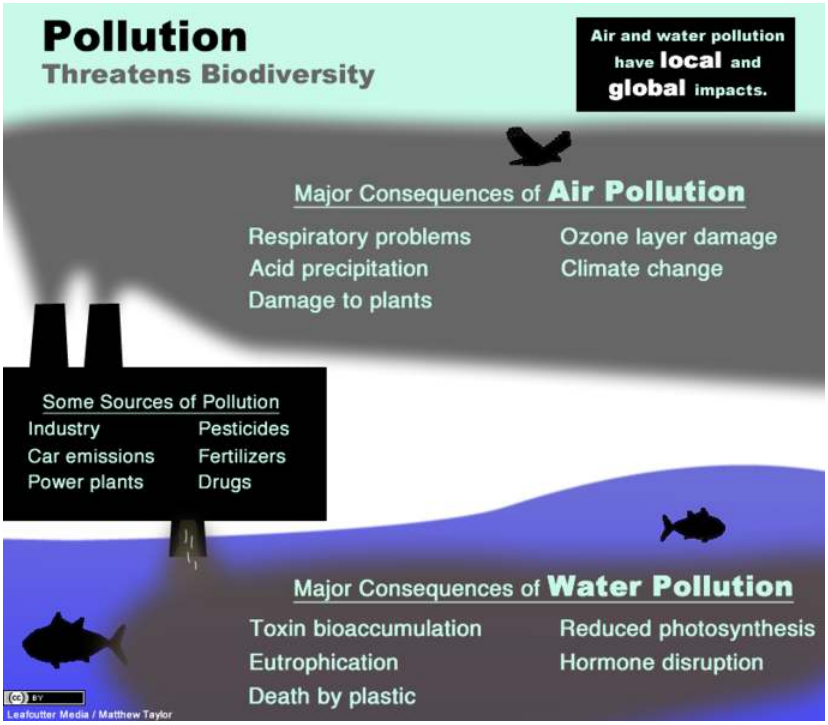


Figure 13.2.*a*: Some sources of water and air pollution and their major effects on biodiversity. Sources of pollution include industry, car emissions, power plants, pesticides, fertilizers, and drugs. Some major consequences of air pollution include respiratory problems, acid precipitation, plant damage, ozone depletion, and climate change. Water pollution can bioaccumulate and can lead to eutrophication, death by plastic, reduced photosynthesis, and hormone disruption. Image by Leafcutter Media (CC-BY-SA).

References

Kingsford RT, Watson JEM, Lundquist CJ, Venter O, Hughes L, Johnston EL, Atherton J, Gawel M, Keith DA, Mackey BG, Morley C, Possingham HP, Raynor B, Recher HF, Wilson KA. Major conservation policy issues for biodiversity in Oceania. Conservation Biology 2009;23(4):834–40.

Attributions

Modified by Melissa Ha from the following sources:

- Issues and Opinions from *AP Environmental Science* by University of California College Prep, University of California (licensed under CC-BY). Download for free at CNX.
- Biodiversity 2011- Pollution and Biodiversity 2016- Pollution from Australia State of the Environment by Commonwealth of Australia (licensed under CC-BY)

This page titled 13.2: Pollution is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **10.5: Pollution** by Melissa Ha and Rachel Schleiger is licensed CC BY-SA 4.0.

13.3: Invasive Species

Invasive species are non-native organisms that, when introduced to an area out of its native range, disrupt the community they invade. **Non-native** (exotic) refers to species occurring outside of their historic distribution. Invasive species have been intentionally or unintentionally introduced by humans into an ecosystem in which they did not evolve. Human transportation of people and goods, including the intentional transport of organisms for trade, has dramatically increased the introduction of species into new ecosystems. These new introductions are sometimes at distances that are well beyond the capacity of the species to ever travel itself and outside the range of the species' natural predators. Invasive species can cause ecological and economic damage. They threaten other species through competition for resources, predation, or disease.

In the United States, invasive species like the purple loosestrife (*Lythrum salicaria*) and the zebra mussel (*Dreissena polymorpha*) have drastically altered the ecosystems they invaded. Some well-known invasive animals include the emerald ash borer (*Agrilus planipennis*) and the European starling (*Sturnus vulgaris*; figure 13.3.*a*). Whether enjoying a forest hike, taking a summer boat trip, or simply walking down an urban street, you have likely encountered an invasive species.

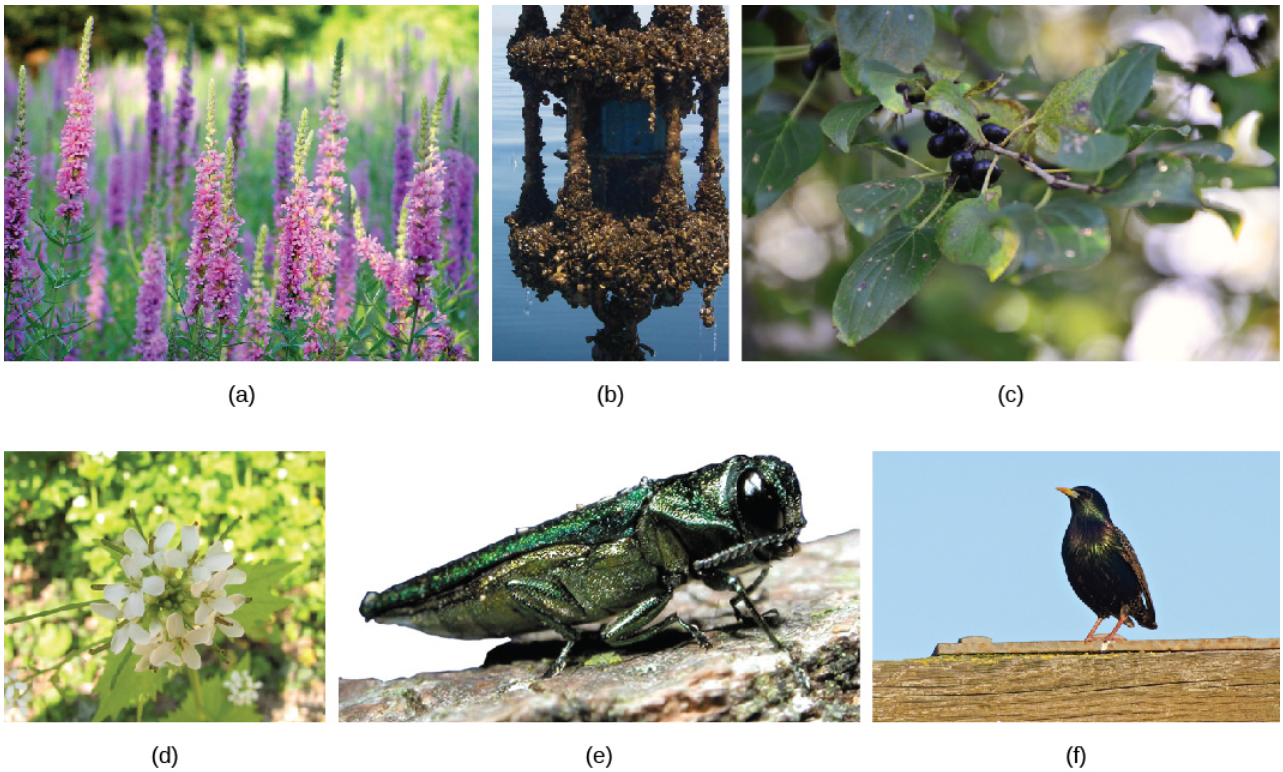


Figure 13.3.*a*: In the United States, invasive species like (a) purple loosestrife (*Lythrum salicaria*) and the (b) zebra mussel (*Dreissena polymorpha*) threaten certain aquatic ecosystems. Some forests are threatened by the spread of (c) common buckthorn (*Rhamnus cathartica*), (d) garlic mustard (*Alliaria petiolata*), and (e) the emerald ash borer (*Agrilus planipennis*). The (f) European starling (*Sturnus vulgaris*) may compete with native bird species for nest holes. (credit a: modification of work by Liz West; credit b: modification of work by M. McCormick, NOAA; credit c: modification of work by E. Dronkert; credit d: modification of work by Dan Davison; credit e: modification of work by USDA; credit f: modification of work by Don DeBold)

Asian Carp

One of the many recent proliferations of an invasive species concerns the Asian carp in the United States. Asian carp were introduced to the United States in the 1970s by fisheries (commercial catfish ponds) and by sewage treatment facilities that used the fish's excellent filter feeding abilities to clean their ponds of excess plankton. Some of the fish escaped, and by the 1980s they had colonized many waterways of the Mississippi River basin, including the Illinois and Missouri Rivers.

Voracious feeders and rapid reproducers, Asian carp may outcompete native species for food and could lead to their extinction. One species, the grass carp, feeds on phytoplankton and aquatic plants. It competes with **native** species (those that historically occurred in the area and are adapted to the local ecosystem) for these resources and alters habitats for other fish by removing aquatic plants.

In some parts of the Illinois River, Asian carp constitute 95 percent of the community's biomass. Although edible, the fish is bony and not desired in the United States.

The Great Lakes and their prized salmon and lake trout fisheries are being threatened by Asian carp. The carp are not yet present in the Great Lakes, and attempts are being made to prevent its access to the lakes through the Chicago Ship and Sanitary Canal, which is the only connection between the Mississippi River and Great Lakes basins. To prevent the Asian carp from leaving the canal, a series of electric barriers have been used to discourage their migration; however, the threat is significant enough that several states and Canada have sued to have the Chicago channel permanently cut off from Lake Michigan. Local and national politicians have weighed in on how to solve the problem. In general, governments have been ineffective in preventing or slowing the introduction of invasive species.

Effect on Endemic Species

Lakes and islands are particularly vulnerable to extinction threats from introduced species. In Lake Victoria, the intentional introduction of the Nile perch was largely responsible for the extinction of about 200 species of cichlids (see Patterns of Biodiversity). The accidental introduction of the brown tree snake via aircraft (figure 13.3.*b*) from the Solomon Islands to Guam in 1950 has led to the extinction of three species of birds and three to five species of reptiles endemic to the island. Several other species are still threatened. The brown tree snake is adept at exploiting human transportation as a means to migrate; one was even found on an aircraft arriving in Corpus Christi, Texas. Constant vigilance on the part of airport, military, and commercial aircraft personnel is required to prevent the snake from moving from Guam to other islands in the Pacific, especially Hawaii. Islands do not make up a large area of land on the globe, but they do contain a disproportionate number of endemic species because of their isolation from mainland ancestors.

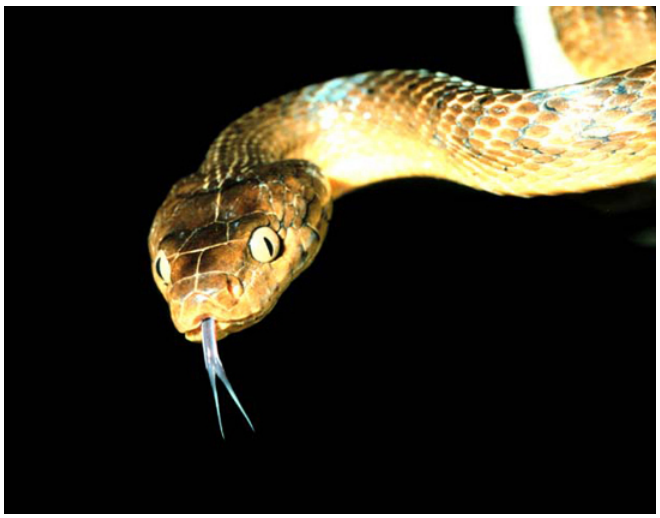


Figure 13.3.*b*: The brown tree snake, *Boiga irregularis*, is an exotic species that has caused numerous extinctions on the island of Guam since its accidental introduction in 1950. (credit: NPS)

Introduction by Ballast Water

Many introductions of aquatic species, both marine and freshwater, have occurred when ships have dumped ballast water taken on at a port of origin into waters at a destination port. Water from the port of origin is pumped into tanks on a ship empty of cargo to increase stability. The water is drawn from the ocean or estuary of the port and typically contains living organisms such as plant parts, microorganisms, eggs, larvae, or aquatic animals. The water is then pumped out before the ship takes on cargo at the destination port, which may be on a different continent. The zebra mussel was introduced to the Great Lakes from Europe prior to 1988 in ballast water. The zebra mussels in the Great Lakes have created millions of dollars in clean-up costs to maintain water intakes and other facilities. The mussels have also altered the ecology of the lakes dramatically. They threaten native mollusk populations, but have also benefited some species, such as smallmouth bass. The mussels are filter feeders and have dramatically improved water clarity, which in turn has allowed aquatic plants to grow along shorelines, providing shelter for young fish where it did not exist before. The European green crab, *Carcinus maenas*, was introduced to San Francisco Bay in the late 1990s, likely in

ship ballast water, and has spread north along the coast to Washington. The crabs have been found to dramatically reduce the abundance of native clams and crabs with resulting increases in the prey species of those native crabs.

Invasive Species as Diseases

Invading exotic species can also be disease organisms. It now appears that the global decline in amphibian species recognized in the 1990s is, in some part, caused by the fungus *Batrachochytrium dendrobatidis* (Bd), which causes the disease chytridiomycosis (figure 13.3.*c*). There is evidence that the fungus is native to Africa and may have been spread throughout the world by transport of a commonly used laboratory and pet species: the African clawed frog, *Xenopus laevis*. It may well be that biologists themselves are responsible for spreading this disease worldwide. The North American bullfrog, *Rana catesbeiana*, which has also been widely introduced as a food animal but which easily escapes captivity, survives most infections of *B. dendrobatidis* and can act as a disease **reservoir** by storing the infectious fungus.



Figure 13.3.*c*: This Limosa harlequin frog (*Atelopus limosus*), an endangered species from Panama, died from a fungal disease called chytridiomycosis. The red lesions are symptomatic of the disease. (credit: Brian Gratwicke)

Early evidence suggests that another fungal pathogen, *Geomyces destructans*, introduced from Europe is responsible for white-nose syndrome, which infects cave-hibernating bats in eastern North America and has spread from a point of origin in western New York State (figure 13.3.*d*). The disease has decimated bat populations and threatens extinction of species already listed as endangered: the Indiana bat, *Myotis sodalis*, and potentially the Virginia big-eared bat, *Corynorhinus townsendii virginianus*. How the fungus was introduced is unknown, but one logical presumption would be that recreational cavers unintentionally brought the fungus on clothes or equipment from Europe.



Figure 13.3.*d*: This little brown bat in Greeley Mine, Vermont, March 26, 2009, was found to have white-nose syndrome. (credit: modification of work by Marvin Moriarty, USFWS).

Biological Control of Invasive Species

One reason why invasive species proliferate dramatically outside of their native range is due to **release from predators**. This means that parasites, predators, or herbivores that usually regulate their populations are not present, allowing them to outcompete or overpredate native species, which are still regulated. Based on this principle, organisms that regulate the invasive species populations have been introduced to the newly colonized areas in some cases. The release of organisms (or viruses) to limit population size is called **biological control**. As described in the examples below, biological control of invasive species has had varying success, exacerbating the problem in some cases and solving it in others.

Prickly-pear Cactus (*Opuntia*)

Introduced into Australia, this cactus soon spread over millions of hectares of range land driving out forage plants. In 1924, the cactus moth, *Cactoblastis cactorum*, was introduced (from Argentina) into Australia. The caterpillars of the moth are voracious feeders on prickly-pear cactus, and within a few years, the caterpillars had reclaimed the range land without harming a single native species. However, its introduction into the Caribbean in 1957 did not produce such happy results. By 1989, the cactus moth had reached Florida, and now threatens five species of native cacti there.

Purple Loosestrife

The leaf beetle (*Galerucella calmariensis*) has been introduced to suppress purple loosestrife, a noxious weed (figure 13.3.*e*). A combination of four biological controls, including the leaf beetle were released in Minnesota since 1992. While it has not eradicated populations of this invasive species, biological control largely removed leaves from 20% of the purple loosestrive populations where it was released, which could reduce competition for native species. The biological controls established populations in most locations where they were released and even spread to new patches of purple loosestrife.



Figure 13.3.*e*: Young larvae of the leaf-beetle feed in and on the developing buds of plants, often destroying them. This may stunt plant growth and delay or prevent flowering. Adults (shown) and older larvae feed on leaves and cause severe defoliation. Leaf-beetles can be used to as a biocontrol for invasive plants such as purple loosestrife.

Klamath Weed

In 1946 two species of *Chrysolina* beetles were introduced into California to control the Klamath weed (St. Johnswort) that was ruining millions of acres of range land in California and the Pacific Northwest. Before their release, the beetles were carefully tested to make certain that they would not turn to valuable plants once they had eaten all the Klamath weed they could find. The beetles succeeded beautifully, restoring about 99% of the endangered range land and earning them a commemorative plaque at the Agricultural Center Building in Eureka, California.

European Rabbit

In 1859, the European rabbit was introduced into Australia for sport. With no important predator there, it multiplied explosively (figure 13.3.*f*). The raising of sheep (another imported species) suffered badly as the rabbits competed with them for forage.

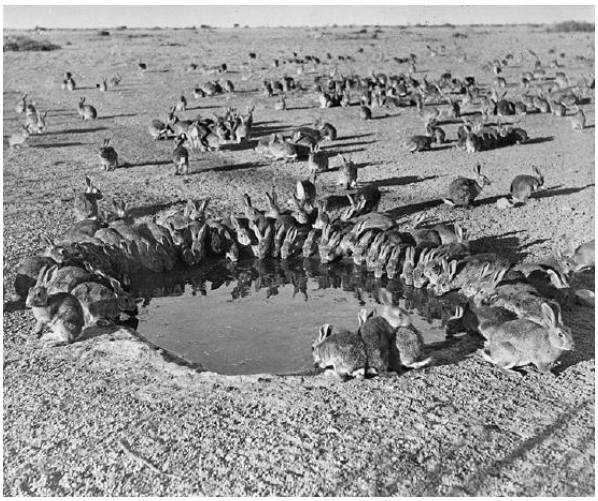


Figure 13.3.*f*: These rabbits in Australia removed all forage plants, which ordinarily supply them with water as well as food. They thus had to drink from a pool. Image by National Archives of Australia (public domain).

In 1950, the **myxoma virus** was brought from Brazil and released. The epidemic that followed killed off millions of rabbits (more than 99% of the population). Green grass returned, and sheep raising once again became profitable. Rabbit populations gradually increased, however, because the rabbits evolved to be more resistant to the virus, and the myxoma virus evolved to cause less damage. (Parasites, like viruses, benefit from multiplying inside the host and spreading to other individuals. If they kill their hosts too soon, they typically limit opportunities to multiply and spread.) More recently, the rabbit hemorrhagic disease virus has been used as biological control.

Strategies for Effective Biological Control

To summarize the lessons learned from biological control successes and failures, only candidates that have a very narrow target preference (eat only a sharply-limited range of hosts) should be chosen. Each candidate should be carefully tested to be sure that once it has cleaned up the intended target, it does not turn to desirable species. Biological controls must not be used against native species. Finally, introduction of non-native species into the environment should be avoided because they could themselves be invasive.

Attributions

Modified by Melissa Ha from the following sources:

- Threats to Biodiversity, Community Ecology, and Sustainable Agriculture from *Environmental Biology* by Matthew R. Fisher (licensed under CC-BY)
- Threats to Biodiversity from *General Biology* by OpenStax (licensed under CC-BY)
- Biological Control and Symbiosis from *Biology* by John W. Kimball (licensed under CC-BY)

This page titled 13.3: Invasive Species is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **10.6: Invasive Species** by Melissa Ha and Rachel Schleiger is licensed CC BY-NC 4.0.

13.4: Overexploitation

Overharvesting, also called **overexploitation**, refers to harvesting a renewable resource to the point of diminishing returns. Ecologists use the term to describe populations that are harvested at a rate that is unsustainable, given their natural rates of mortality and capacities for reproduction. The term applies to natural resources such as wild medicinal plants, grazing pastures, game animals, fish stocks, forests, and water aquifers. Sustained overharvesting can lead to the destruction of the resource, and is one of the five main activities – along with pollution, introduced species, habitat fragmentation, and habitat destruction – that threaten global biodiversity today.

All living organisms require resources to survive. Overharvesting these resources for extended periods of time can deplete natural resources to the point where they are unable to recover within a short time frame. Humans have always harvested food and other resources they have needed to survive; however, human populations, historically, were small and methods of collection limited to small quantities. Exponential increase in human population, expanding markets, and increasing demand, combined with improved access and techniques for capture, are causing the exploitation of many species beyond sustainable levels.

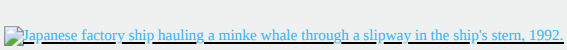
Sustained overharvesting is one of the primary threats to biodiversity. Overharvesting can lead to resource destruction, including extinction at the population level and even extinction of whole species. Depleting the numbers or amount of certain resources can also change their quality; for example, the overharvesting of footstool palm (a wild palm tree found in Southeast Asia, the leaves of which are used for thatching and food wrapping) has resulted in its leaf size becoming smaller.

Overharvesting not only threatens the resource being harvested, but can directly impact humans as well – for example by decreasing the biodiversity necessary for medicinal resources. A significant proportion of drugs and medicines are natural products which are derived, directly or indirectly, from biological sources. However, unregulated and inappropriate harvesting could potentially lead to overexploitation, ecosystem degradation, and loss of biodiversity; further, it can negatively impact the rights of the communities and states from which the resources are taken.

Tragedy of the Commons and Whaling

Overharvesting is a serious threat to many species, especially aquatic ones. Common resources – or resources that are shared, such as fisheries – are subject to an economic pressure known as “the tragedy of the commons,” in which essentially no harvester has a motivation to exercise restraint in harvesting from a certain area, because that area is not owned by that harvester. The natural outcome of harvesting common resources is their overexploitation.

Whaling offers an example of overharvesting that is interesting not only in itself but also for demonstrating how poorly biodiversity has been protected even when it is of economic value. The first whalers likely took their prey close to shore. Right whales were the “right” whales to take because they are large and slow-moving, feed near the surface and often inshore, float to the surface when harpooned, and were of considerable commercial value for their oil and baleen (*see* whalebone). The southern right whale (*Eubalaena australis*), for example, is often seen in shallow, sheltered bays in South Africa and elsewhere. Such behaviour would make any large supply of raw materials a most tempting target. Whalers had nearly exterminated the North Atlantic species of the northern right whale (*Eubalaena glacialis*) and the bowhead whale (Greenland right whale; *Balaena mysticetus*) by 1800. They succeeded in exterminating the Atlantic population of the gray whale (*Eschrichtius robustus*). Whalers then moved on to species that were more difficult to kill, such as the humpback whale (*Megaptera novaeangliae*) and the sperm whale (*Physeter macrocephalus*).

- 
- 

Humpback whale (*Megaptera novaeangliae*) breaching. *Al Giddings/Images Unlimited*

Japanese factory ship hauling a minke whale through a slipway in the ship's stern, 1992.*Culley/Greenpeace*

The Napoleonic Wars gave whales a respite, but with the peace of 1815 came a surge of whalers into the Pacific Ocean, inspired by the stories of James Cook and other explorers. The first whalers arrived in the Hawaiian Islands in 1820, and by

1846 the fleet had grown to nearly 600 ships, the majority from New England. The catch on each whaling voyage averaged 100 whales, though a voyage could last as long as four years.

In the late 1800s, steamships replaced sailing ships, and gun-launched exploding harpoons. replaced hand-thrown lances. The new technology allowed whalers to kill what until then had been the “wrong” whales—fast-swimming species such as the blue whale (*Balaenoptera musculus*) and fin whale (*B. physalus*). Whalers killed nearly 30,000 blue whales in 1931 alone; World War II gave the whales a break, but the catch of blue whales rose to 10,000 in 1947. The fin whale was next, with the annual catch peaking at 25,000 in the early 1960s; then came the smaller sei whale (*B. borealis*)—which no one had bothered to kill until the late 1950s—and finally the even smaller minke whale (*B. acutorostrata*), which whalers still hunt despite an international moratorium in effect since 1986 that seeks to curb commercial whaling.

The story of whaling is, in brief, the rapid depletion and sometimes extermination of one population after another, starting with the easiest species to kill and progressing to the most difficult. That whales are economically valuable raises the obvious question of why there were no attempts to harvest whales sustainably.

Terrestrial Animals

Terrestrial animals may be overexploited as sources of food, garments, jewelry, medicine, or pets. For example, the poaching of elephants for their valuable ivory and rhinos for their horns, which are used in traditional medicine, is a major threat to these species. There are also concerns about the effect of the pet trade on some terrestrial species such as turtles, amphibians, birds, plants, and even the orangutans. Harvesting of pangolins for their scales and meat, and as curiosities, has led to a drastic decline in population size (figure 13.4.*a*).



Figure 13.4.*a*: Pangolins are threatened by overexploitation. This work by David Brossard is licensed under CC-BY.

Bush meat is the generic term used for wild animals killed for food. Hunting is practiced throughout the world, but hunting practices, particularly in equatorial Africa and parts of Asia, are believed to threaten several species with extinction. Traditionally, bush meat in Africa was hunted to feed families directly. However, recent commercialization of the practice now has bush meat available in grocery stores, which has increased harvest rates to the level of unsustainability. Additionally, human population growth has increased the need for protein foods that are not being met from agriculture. Species threatened by the bush meat trade are mostly mammals including many monkeys and the great apes living in the Congo basin.

Aquatic Animals

Aquatic species are particularly vulnerable to overexploitation, which is more specifically called **overfishing** in this case. Global production of fish and seafood has quadrupled over the past 50 years. Globally, the share of fish stocks which are overexploited – meaning we catch them faster than they can reproduce to sustain population levels – has more than doubled since the 1980s and this means that current levels of wild fish catch are unsustainable.

One innovation has helped to alleviate some of the pressure on wild fish catch: aquaculture, the practice of fish and seafood farming. The distinction between farmed fish and wild catch is similar to the difference between raising livestock rather than hunting wild animals. Except that for land-based animals, farming is many thousand years old while it was very uncommon for seafood until just over 50 years ago. Global wild fish catch has not increased since the early 1990s and instead remained relatively

constant at around 90 to 95 million tonnes per year. Fish farming on the other hand is growing very rapidly, from 1960 until 2015 it has increased 50-fold to over 100 million per year (figure 13.4.*b*).

Figure 13.4.*c* illustrates the extent of overfishing in the U.S. Despite considerable effort, few fisheries are managed sustainability. For example, the western Atlantic cod fishery was a hugely productive fishery for 400 years, but the introduction of modern fishing vessels in the 1980s and the pressure on the fishery led to it becoming unsustainable. Bluefin tuna are in danger of extinction. The once-abundant Mediterranean swordfish fishery have been depleted to commercial and biological exhaustion.

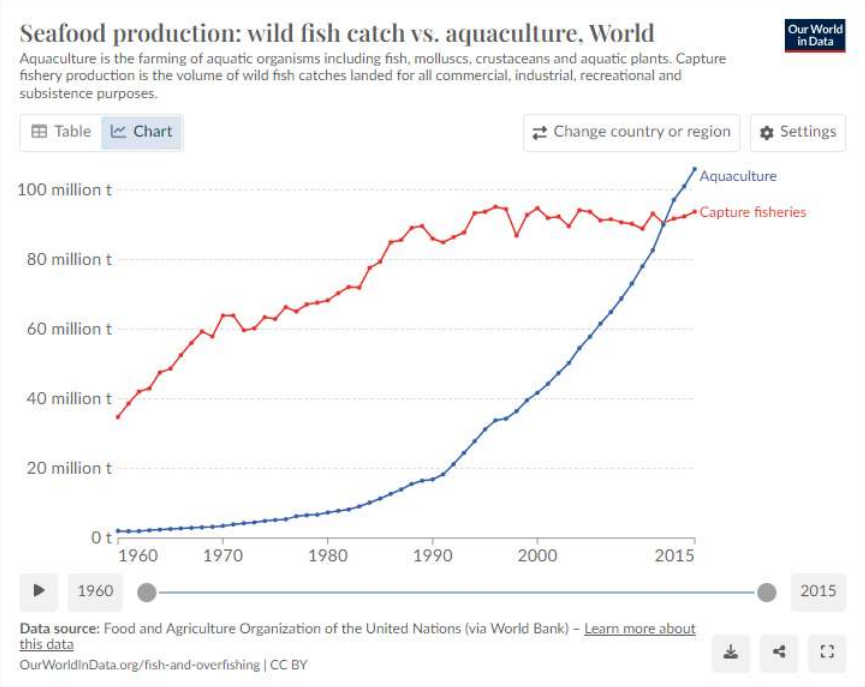


Figure 13.4.*b*: Aquaculture production has now surpassed wild catch. It has absorbed almost all of the growth in global demand in recent decades and will continue to play a critical role in protecting wild fish populations as demand for seafood continues to rise. (Our World inData: CC-BY)

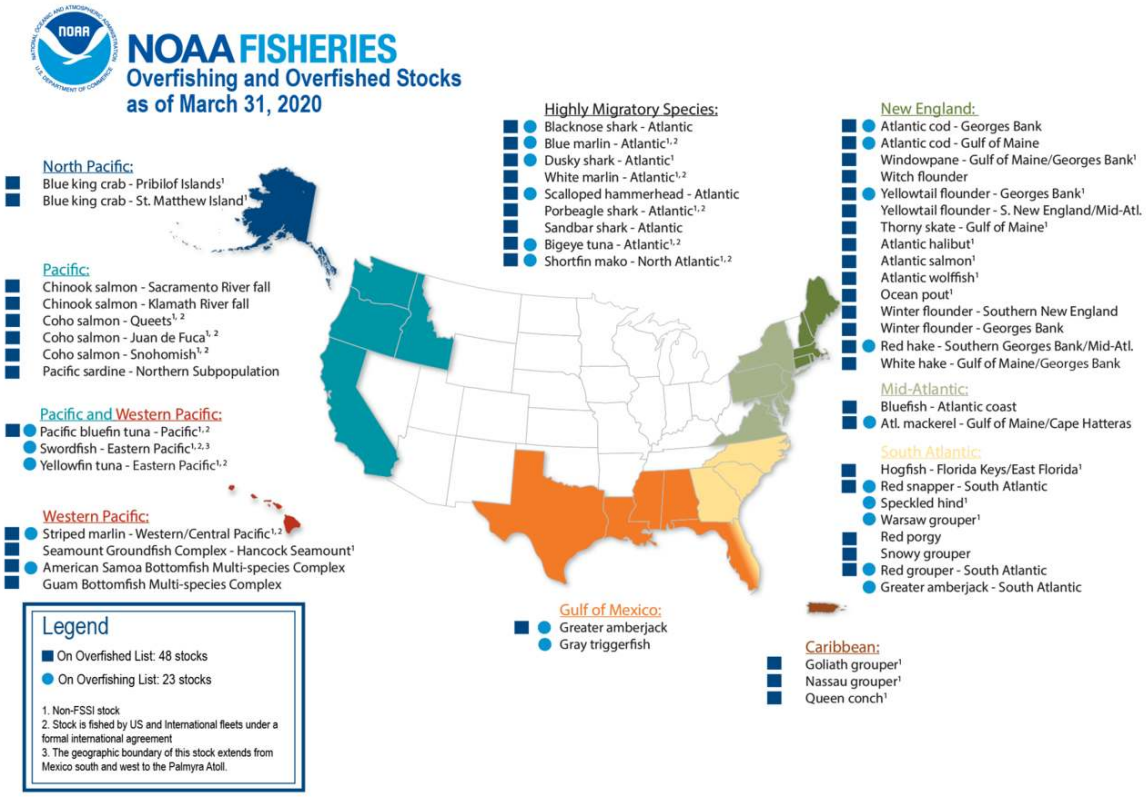


Figure 13.4.*c*: Map of overfishing and overfished stocks in the U.S. by region. Stocks on the overfishing list are being harvested too quickly, and those on the overfished list have population sizes that are too low. For example, stocks of Chinook salmon, Coho salmon, and Pacific sardines are overfished in the Pacific. Some species, including stocks of Pacific bluefin tuna and Atlantic cod, are on both the overfishing and overfished lists. Image by NOAA (public domain).

Most fisheries are managed as a common resource, available to anyone willing to fish, even when the fishing territory lies within a country's territorial waters. Common resources are subject to an economic pressure known as the **tragedy of the commons**, in which fishers have little motivation to exercise restraint in harvesting a fishery when they do not own the fishery. This results on overexploitation. In a few fisheries, the biological growth of the resource is less than the potential growth of the profits made from fishing if that time and money were invested elsewhere. In these cases—whales are an example—economic forces will drive toward fishing the population to extinction.

Overfishing can result in a radical restructuring of the marine ecosystem in which a dominant species is so overexploited that it no longer serves its ecological function. For example, overfishing a tertiary consumer could causes populations of secondary consumers to increase. Secondary consumers would then feed on primary consumes (like zooplankton), decreasing their population size. With fewer zooplankton, populations of primary producers (**phytoplankton**, or photosynthetic microorganisms) would be unregulated (see Food Chains). The collapse of fisheries has dramatic and long-lasting effects on local human populations that work in the fishery. In addition, the loss of an inexpensive protein source to populations that cannot afford to replace it will increase the cost of living and limit societies in other ways. In general, the fish taken from fisheries have shifted to smaller species, and the larger species are overfished. The ultimate outcome could clearly be the loss of aquatic systems as food sources.

A related consequence of fishing practices is "**bycatch**," animals that fishers sometimes catch and discard because they do not want them, cannot sell them, or are not allowed to keep them. Bycatch can be fish, but also includes other animals such as dolphins, whales, sea turtles, and seabirds that become hooked or entangled in fishing gear.

Coral reefs are extremely diverse marine ecosystems that face peril from several processes. Reefs are home to 1/3 of the world's marine fish species—about 4,000 species—despite making up only one percent of marine habitat. Most home marine aquaria house coral reef species that are wild-caught organisms—not cultured organisms. Although no marine species is known to have been

driven extinct by the pet trade, there are studies showing that populations of some species have declined in response to harvesting, indicating that the harvest is not sustainable at those levels.

Plants and Fungi

Some plant and fungal species are also overexploited, particularly if they are slow-growing. For example, stocks of wild ginseng, which is valued for its health benefits, are dwindling. Peyote cactus, which causes hallucinations and is used in sacred ceremonies, is also declining. Yarsagumba, dead moth larvae that were infected by fungal parasites (caterpillar fungus, *Ophiocordyceps sinensis*), is overexploited because it is highly valued in traditional medicine and used as an aphrodisiac (figure 13.4.*d*).



Figure 13.4.*d*: Yarsagumba is a combination of moth larvae and the fungus that infected and killed it. Image by Punya (CC-BY-SA).

Cascade Effects and Secondary extinctions

Once one species goes extinct, there will likely be other extinctions or even an avalanche of them. Some cases of these **secondary extinctions** are simple to understand—e.g., for every bird or mammal that goes extinct, one or several species of parasite also will likely disappear. From well-studied species, it is known that bird and mammal species tend to have parasites on or inside them that can live on no other host.

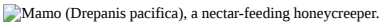
Overexploitation of species can also result in cascade effects, particularly if a habitat loses its apex predator. Species are bound together in ecological communities to form a food web (*see* food chain) of species interactions. The loss of one species can affect many other species. If a top predator is lost for example, a dramatic increase in their prey species can occur. In turn, the unchecked prey can then overexploit their own food resources until population numbers dwindle, possibly to the point of extinction. Ecological theory suggests that the patterns of secondary extinction are quite complicated and may be difficult to predict.

Generalized aquatic food web showing the network of feeding relationships that exist among species in a marine community. The disappearance of one species will affect other species up, down, and across the web, for better or worse.

> Generalized aquatic food web showing the network of feeding relationships that exist among species in a marine community. The disappearance of one species will affect other species up, down, and across the web, for better or worse.*Encyclopædia Britannica, Inc.*

The most easily recognizable secondary extinctions should be seen in species that depend closely on each other. In the Hawaiian Islands, anecdotal evidence for secondary extinctions comes from a consideration of nectar-feeding birds. Before modern human activity on the islands, there were three nectar-feeding Hawaiian honeycreepers—the mamo (*Drepanis pacifica)*, the black mamo (*Drepanis funerea*), and the iiwi (*Vestiaria coccinea*)—that had long decurved (downward-curving) beaks, the kind adapted to

inserting into appropriately long and curved flowers. The first two birds are extinct, whereas the third is extinct on two islands, is very rare on a third, and has declined on others.



Mamo (*Drepanis pacifica*), a nectar-feeding honeycreeper.*Painting by H. Jon Janosik*

Extensive habitat destruction is likely the cause of many species of Hawaiian birds, as previously discussed. In addition, native Hawaiians hunted some species for their feathers. In the case of the three honeycreepers described above, however, their extinctions may have followed the destruction of important nectar-producing plants by introduced goats and pigs. Many of the native lobelias, such as those of the genera *Trematolobelia* and *Clermontia*, have clearly evolved to be pollinated by the three honeycreepers, and the plants were once important components of the forest's understory. About a quarter of these plant species are now extinct, a rate that plainly exceeds those for the rest of the flora, perhaps because they were so vulnerable to introduced mammalian herbivores. It is not certain, however, whether the plants disappeared first and then their bird pollinators or vice versa.

Similarly, some surviving Hawaiian birds seem to be unusually specialized feeders and to be threatened as a consequence of the loss of their food sources. For example, another rare honeycreeper, the akiapolaau (*Hemignathus munroi*), is an insectivore that feeds on insects mainly on large koa (*Acacia koa*) trees (*see* acacia). Today, however, few koa forests remain, because the trees have been overharvested for their attractive wood. Yet another Hawaiian honeycreeper, a seed-eating species called the palila (*Loxioides bailleui*), is endangered because it depends almost exclusively on the seeds of one tree, the mamane (*Sophora chrysophylla*), which is grazed by introduced goats and sheep.

Stories of secondary extinctions are nearly always unsatisfactory anecdotes because of the difficulty of teasing apart the various explanations for what happened in the past. There is abundant evidence from small-scale ecological experiments that a change in one species' numbers (including its complete elimination) will cause cascading effects in the abundance of other species. The stories are plausible enough that particular attention should be paid to the future consequences of contemporary extinctions.

Attributions

This page is a modified derivative of:

- **10.4: Overexploitation** by Melissa Ha and Rachel Schleiger is licensed CC BY-SA 4.0.
- 47.3B: Overharvesting is shared under a CC BY-SA 4.0 license and was authored, remixed, and/or curated by Boundless.

This page titled 13.4: Overexploitation is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **10.4: Overexploitation** by Melissa Ha and Rachel Schleiger is licensed CC BY-SA 4.0.

13.5: Climate Change

Global **climate change** is also a consequence of human population needs for energy, and the use of fossil fuels to meet those needs. Essentially, burning **fossil fuels**, including as oil, natural gas, and coal, increases carbon dioxide concentrations in the atmosphere. Carbon dioxide traps heat energy from the sun, resulting not only in an average increase in global temperature but also in changing precipitation patterns and increased frequency and severity of extreme weather events, such as hurricanes. Scientists overwhelmingly agree the present warming trend is caused by humans. See the Climate Change chapter for a detailed description its cause and impacts. A few examples of how climate change impacts biodiversity are described in the paragraphs below.

Climate change is recognized as a major extinction threat, particularly when combined with other threats such as habitat loss. Scientists disagree about the likely magnitude of the effects, with extinction rate estimates ranging from 15 percent to 40 percent of species committed to extinction by 2050. By altering regional climates, it makes habitats less hospitable to the species living in them. The warming trend will shift colder climates toward the north and south poles, forcing species to move (if possible) with their adapted climate norms. For example, one study indicates that European bird species ranges have moved 91 kilometers (56.5 miles) northward, on average. The same study suggested that the optimal shift based on warming trends was double that distance, suggesting that the populations are not moving quickly enough. Range shifts have also been observed in plants, butterflies, other insects, freshwater fishes, reptiles, amphibians, and mammals.

The shifting ranges will impose new competitive regimes on species as they find themselves in contact with other species not present in their historic range. One such unexpected species contact is between polar bears and grizzly bears (figure $13.5.a$). Previously, these two species had separate ranges. Now, their ranges are overlapping and there are documented cases of these two species mating and producing viable offspring.



Figure 13.5.*a*: Historically, grizzly bear habitat extended from Mexico through the western United States and into the mid-latitudes of Canada. Since 2008, grizzly bears (*Ursus arctos horribilis*) have been spotted farther north than their historic range, a possible consequence of climate change. Their range now extends to the northern tip of Canada and throughout Alaska. As a result, grizzly bear habitat now overlaps polar bear (*Ursus maritimus*) habitat. The two kinds of bears, which are capable of mating and producing viable offspring, are considered separate species as historically they lived in different habitats and never met. However, in 2006 a hunter shot a wild grizzly-polar bear hybrid known as a grolar bear, the first wild hybrid ever found.

Climate gradients will also move up mountains, eventually crowding species higher in altitude and eliminating the habitat for those species adapted to the highest elevations. Some climates will completely disappear. The rate of warming appears to be accelerated in the arctic, which is recognized as a serious threat to polar bear populations that require sea ice to hunt seals during the winter months. Seals are a critical source of protein for polar bears. A trend to decreasing sea ice coverage has occurred since observations began in the mid-twentieth century. The rate of decline observed in recent years is far greater than previously predicted by climate models.

Changing climates also throw off the delicate timing adaptations that species have to seasonal food resources and breeding times. Scientists have already documented many contemporary mismatches to shifts in resource availability and timing. For example, pollinating insects typically emerge in the spring based on temperature cues. In contrast, many plant species flower based on daylength cues. With warmer temperatures occurring earlier in the year, but daylength remaining the same, pollinators ahead of peak flowering. As a result, there is less food (nectar and pollen) available for the insects and less opportunity for plants to have their pollen dispersed. For migrating birds, timing is everything – they must arrive at their summer breeding grounds when food supplies are at their peak, so that they can rebuild their body fat and reproduce successfully. In some areas, birds are showing up early, before flowers open or insects hatch, and finding very little to eat.

Ocean levels rise in response to climate change due to meltwater from glaciers and the greater volume occupied by warmer water. Shorelines will be inundated, reducing island size, which will have an effect on some species, and a number of islands will disappear entirely. Additionally, the gradual melting and subsequent refreezing of the poles, glaciers, and higher elevation mountains—a cycle that has provided freshwater to environments for centuries—will be altered. This could result in an overabundance of salt water and a shortage of freshwater.

Finally, increased carbon dioxide levels in the atmosphere react with ocean water to form carbonic acid, a phenomenon called **ocean acidification**. In combination with warmer temperatures, ocean acidification is responsible for coral bleaching, the process by which coral expel the algae that typically conduct photosynthesis within the corals. Ocean acidification can also dissolve the calcium carbonate skeletons formed by the coral. Overall, climate change plays a major role in the loss of nearly one third of coral reefs.

Attributions

Modified by Melissa Ha from the following sources:

- Threats to Biodiversity from *Environmental Biology* by Matthew R. Fisher (licensed under CC-BY)
- Threats to Biodiversity from *General Biology* by OpenStax (licensed under CC-BY)
- First Order Effects from *AP Environmental Science* by University of California College Prep, University of California (licensed under CC-BY). Download for free at CNX.

This page titled 13.5: Climate Change is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **10.7: Climate Change** by Melissa Ha and Rachel Schleiger is licensed CC BY-NC 4.0.

CHAPTER OVERVIEW

14: Protecting Biodiversity



Figure 14.1: As of 2020, there were 41,415 species on the International Union for Conservation of Nature (IUCN) Red List, 16,306 of them being endangered and threatened with extinction. This is up from 16,118 from 2019. The Island Fox (*Urocyon littoralis*) is only found on six of the California Channel Islands off the coast of southern California. In the mid-1990's four island fox subspecies experienced drastic population declines. Soon after, they were listed as critically endangered on the IUCN red list and endangered on the U.S Endangered Species Act. However, due to uncompromising recovery efforts (through supported funding from its endangered status), all four subspecies have almost completely recovered their populations. Regrettably, not all species that end up on the IUCN red list or endangered species list have trajectories that later hold such hope.. (Image by USFWS; CC-BY 2.0))

Chapter Summary

The field of **conservation** focuses on preserving biodiversity. Effective conservation depends on ecological knowledge. Today, the main efforts to preserve biodiversity involve legislative approaches to regulate human and corporate behavior, setting aside protected areas, and ecosystem restoration.

Learning Objectives

After reading this chapter you should be able to:

- Describe national and state laws designed to protect biodiversity.
- Explain the role of non-profit organization in conservation.
- Explain strategies used by conservation biologists to save or protect endangered species.
- Provide an example of ecological restoration.
- List choices that an individual could make that would help protect biodiversity.

Attribution

14.1: Policies

14.2: Non-profit Organizations

14.3: Species-level Conservation

14.4: Protected Areas

14.5: Ecosystem Restoration

14.6: Economic Influences on Conservation

14.7: Individual Choices

This page titled 14: Protecting Biodiversity is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

14.1: Policies

National and State Laws

Within many countries there are laws that protect endangered species and regulate hunting and fishing. For example, the **Endangered Species Act** (ESA) was enacted in 1973 in the United States. The ESA does not automatically protect species categorized as threatened on the Red List. Instead, the U.S. Fish and Wildlife Service (FWS), which enforces the ESA, assesses candidates for protected status as threatened or endangered (figure 14.1.*a*). Consideration of candidate species can be initiated by the FWS itself or at the request of the public. Through the Species Status Assessment Framework, the FWS compiles biological data, such as habitat and population information and current threats to the species. This biological data is used to inform decisions.



Figure 14.1.*a*: Public Affairs Specialist for the U.S. Fish and Wildlife Service, Joanna Gilkeson, takes photos of federally endangered San Diego fairy shrimp in a vernal pool in Otay Mesa, California. Vernal pools are shallow seasonal ponds, and vernal pool species are uniquely adapted to changes in water availability. Image by Maideline Sanchez/USFWS (public domain).

Once a species is listed, the FWS is required by law to develop a management plan to protect the species and bring it back to sustainable numbers. The ESA, and others like it in other countries, is a useful tool, but it suffers because it is often difficult to get a species listed or to get an effective management plan in place once a species is listed.

The 1972 **Marine Mammals Protection Act** prohibits the "take" of marine mammals—including harassment, hunting, capturing, collecting, or killing—in U.S. waters and by U.S. citizens on the high seas. The act also makes it illegal to import marine mammals and marine mammal products into the United States without a permit.

State laws can also aid in conservation. Through **California Endangered Species Act** (CESA), originally passed in 1970 and subsequently amended, the California Fish and Game Commission assesses species to be listed as threatened or endangered by the state. A listed species, or any part or product of the plant or animal, may not be imported into the state, exported out of the state, "taken" (killed), possessed, purchased, or sold without proper authorization.

Note that endangered is a subcategory of threatened on the Red List, but for ESA and CESA, threatened and endangered are separate categories, with the latter representing at the greater risk of extinction.

International Agreements

The **Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)** treaty came into force in 1975. The treaty, and the national legislation that supports it, provides a legal framework for preventing listed species from being transported across nations' borders, thus protecting them from being caught or killed when the purpose involves international trade.

Species can be listed in one of three CITES appendices. Trade is banned for Appendix I species, which are threatened with extinction. For example the trade of ivory is banned by CITES. Trade is regulated for Appendix II species, such as the meat and shells of the queen conch or big-leaf mahogany (figure 14.1.*b*). Appendix III species are protected in at least one country, and the local government needs a coordinated response through CITES. For example, several species of red and pink corals have been added to Appendix III at the request of China.



Figure 14.1.*b*: Big-leaf mahogany (*Swietenia macrophylla*) timber is used to make furniture, musical instruments, boats, and other products. It listed in CITES Appendix II, meaning that it is regulated. Specifically, a permit is required to ship big-leaf mahogany timber. Image by Forest and Kim Starr (CC-BY).

Approximately 35,800 species are protected by the CITES. The treaty is limited in its reach because it only deals with international movement of organisms or their parts. It is also limited by various countries' ability or willingness to enforce the treaty and supporting legislation.

The **Migratory Bird Treaty Act** (MBTA) is an agreement between the United States and Canada that was signed into law in 1918 in response to declines in North American bird species caused by hunting. The Act now lists over 800 protected species. It makes it illegal to disturb or kill the protected species or distribute their parts (much of the hunting of birds in the past was for their feathers). Examples of protected species include northern cardinals, the Red-tailed Hawk, and the American Black Vulture.

Attributions

Modified by Melissa Ha from the following sources:

- Preserving Biodiversity from *Environmental Biology* by Matthew R. Fisher (licensed under CC-BY)
- Threatened and Endangered Species by California Department of Fish and Wildlife (public domain)
- Marine Mammal Protection by NOAA Fisheries (public domain)

This page titled 14.1: Policies is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **11.1: Policies** by Melissa Ha and Rachel Schleiger is licensed CC BY-NC 4.0.

14.2: Non-profit Organizations

The private non-profit sector plays a large role in the conservation effort both in North America and around the world. For example, the World Wildlife Fund raised over $300 million in the 2017-2018 fiscal year to protect endangered animals, their habitats, and natural resources. Some non-profit organizations are species specific, like the Orangutan Foundation, and others are broadly focused, such as the IUCN and Trade Records Analysis of Flora and Fauna in Commerce (TRAFFIC). Illegal wildlife trade is monitored by TRAFFIC. The Nature Conservancy (figure 14.2.a) takes a novel approach. It purchases land and protects it in an attempt to set up preserves for ecosystems.



Figure 14.2.a: Jo-Ellen Darcy (left), Assistant Secretary of the Army for Civil Works, discusses the Hamilton City with Ryan Luster, project director for The Nature Conservancy, during a site tour in Hamilton City, Calif., June 3, 2014. The U.S. Army Corps of Engineers Sacramento District's Hamilton City project will let nature help do the work of reducing flood risk by restoring 1,500 acres of native habitat between the Sacramento River and a new setback levee to be built near the town. The Nature Conservancy assisted the project partners by helping acquire the land planned for restoration. Image by US Army Corps of Engineers (public domain).

Attributions

Modified by Melissa Ha from the following sources:

- Preserving Biodiversity from *General Biology* by OpenStax (licensed under CC-BY)
- Changing Human Behavior in Response to Biodiversity Loss from *General Biology* by Boundless (CC-BY-SA)

This page titled 14.2: Non-profit Organizations is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **11.2: Non-profit Organizations** by Melissa Ha and Rachel Schleiger is licensed CC BY-SA 4.0.

14.3: Species-level Conservation

Some conservation efforts center around a single species. Often this is a charismatic species that elicits public interest, such as tigers, sea otters, or the California Condor. The specific approach depends on the specific threats to the focus species. When California Condor population size plummeted, leaving only 23 individuals, they were relocated into a controlled environment and provided with optimal conditions for reproduction. This is called **captive breeding**. Individuals have since been **reintroduced** into the environment. One threat to the species was lead from bullets that were entering the food chain and ultimately poisoning the California Condor. Public education and providing lead-free bullets was thus another component of their conservation plan. By 2016, the population size increased to 446 individuals, with 276 of those living in the wild.

When disease puts species at risk, vaccination may be part of the conservation plan. For example, the black-footed ferret of the Great Plains is threatened by sylvatic plague as well as habitat loss. In response, peanut buttered-flavored oral vaccines were distributed over their habitats. Conservation efforts also focused on captive breeding and reintroduction. Once thought to be extinct, there are now several hundred black-footed ferrets in captivity and similar numbers in the wild (figure 14.3.*a*).

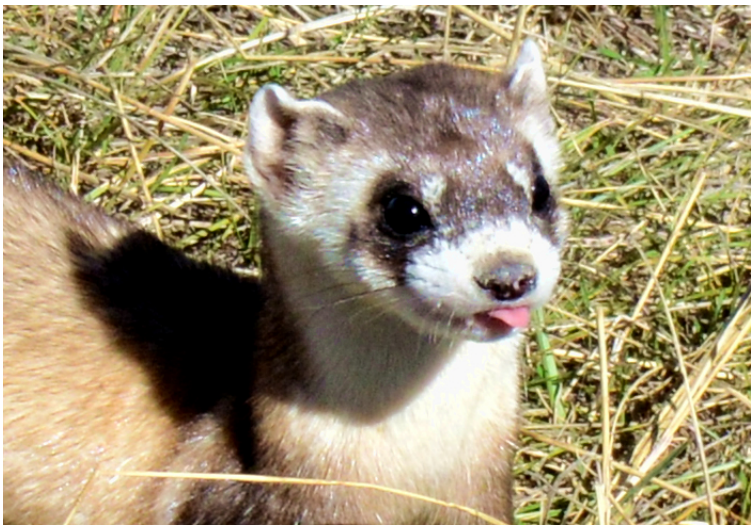


Figure 14.3.*a*: A black-footed ferret kit at the National Black-footed Ferret Conservation Center in Colorado. Image by Ryan Moehring/USFWS (CC-BY)

Protecting or restoring habitat is another component of species-level conservation. For example, the Northern Spotted Owl lives in old-growth forests. Protecting intact old-growth forests and restoring forest habitat is thus critical to their success. This is accompanied by removal of the Barred Owl, an invasive that competes with the Northern Spotted Owl. Similarly, removal of the invasive iceplant *Carpobrotus edulis* from California coasts, restores conditions for endangered dune vegetation (figure 14.3.*b*-d). In other cases, habitat restoration involves promoting populations of native species that support those at risk, such as promoting vegetation that provides food and shelter for waterfowl.



Figure 14.3.*b*: Vegetation at Martin Dunes in California. Iceplant is visible in the forefront. Photo by USFWS (public domain).



Figure 14.3.*c*: *Carpobrotus edulis* is an invasive iceplant that forms thick mats and outcompetes coastal vegetation. Image by Dr. Dwayne Meadows, NOAA/NMFS/OPR (public domain).



Figure 14.3.*d*: Removal of the iceplant restores habitat for endangered species, such as Menzies' wallflower. Image by Gordon Leppig & Andrea J. Pickart, FWS (public domain).

Seemingly unimpressive species can still serve vital ecological roles. For example, the delta smelt is an important food source for larger fish species. Additionally, it serves as an **indicator species** because the health of its populations reflect overall ecosystem health. While the delta smelt has been a focus of species-level conservation, non-charismatic species are often overlooked. In fact, a 2007 study by Colléony and colleagues found that people more often donated to conservation efforts for species that were more similar to humans rather than choosing those that were at greatest risk of extinction. Broad approaches such as establishing protected areas and ecosystem restoration benefit charismatic and non-charismatic species alike. Additionally, broad approaches protect unidentified and species that have not been assessed.

References

Colleony, Agathe, Susan Clayton, Denis Couvet, Michel Saint Jalme, and Anne-Caroline Prevot. (2017). Human preferences for species conservation: Animal charisma trumps endangered status. *Biological Conservation*. 206. 263-269. DOI

Attribution

Melissa Ha (CC-BY-NC)

This page titled 14.3: Species-level Conservation is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **11.3: Species-level Conservation** by Melissa Ha and Rachel Schleiger is licensed CC BY-NC 4.0.

14.4: Protected Areas

It is important to protect natural areas for several reasons. Some people feel a cultural or spiritual connection to the wilderness. Every year, millions of people visit recreational lands such as parks and wilderness areas to experience attractions of the great outdoors: hiking among the giant sequoias in California, traveling on a photo safari in Kenya or just picnicking at a local county park. Besides providing people with obvious health benefits and aesthetic pleasures, recreational lands also generate considerable tourist money for government and local economies. Outdoor recreation activities such as hiking and camping benefit tourist industries and manufacturers of outdoor clothes and equipment.

Establishment of preserves is one of the key tools in conservation efforts. A **preserve** is an area of land set aside with varying degrees of protection for the organisms that exist within the boundaries of the preserve (figure 14.4.a). Governments or private organizations establish nature preserves. In 2016, the IUCN estimated that 14.7 percent of Earth's land surface was covered by preserves of various kinds. This area is large, but only 20% of the key biodiversity areas identified by the IUCN were sufficiently protected.



Figure 14.4.a: Mequon Nature Preserve in Wisconsin. Image by Jennifer Tomaloff (CC-BY-NC-SA).

There has been extensive research into optimal preserve designs for maintaining biodiversity. Preserves can be seen as "islands" of habitat within "an ocean" of non-habitat. In general, large preserves are better because they support more species, including species with large home ranges; they have more core area of optimal habitat for individual species; they have more niches to support more species; and they attract more species because they can be found and reached more easily. One large preserve is better than the same area of several smaller preserves because there is more core habitat unaffected by less hospitable ecosystems outside the preserve boundary. For this same reason, preserves in the shape of a square or circle will be better than a preserve with many thin "arms." If preserves must be smaller, then providing wildlife corridors between two preserves is important so that species and their genes can move between them. All of these factors are taken into consideration when planning the nature of a preserve before the land is set aside. In addition to the physical specifications of a preserve, there are a variety of regulations related to the use of a preserve. These can include anything from timber extraction, mineral extraction, regulated hunting, human habitation, and nondestructive human recreation.

The public lands described below differ in their level of protection. For example, national parks and forests allow camping whereas wildlife refuges place more limitations on human activities.

Wilderness Areas

Wilderness areas, comprise ecosystems in which human activity has not significantly affected the plant and animal populations or their environment. Natural processes predominate. According to the "Wilderness Act of 1964," wilderness areas are defined as being those areas where the nearest road is at least five miles away and where no permanent buildings stand. Activities that could

disrupt native species, such as the use of motorized vehicles is prohibited. More than 100 million acres of land are now preserved as wilderness under this act. Sparsely populated Alaska contains the largest chunk of wilderness areas, over half of it. Although wilderness areas are scattered among most of the lower 48 states, the largest percentage is found in the western states. Few undesignated areas in the contiguous states remain that would qualify as wilderness.

National parks and forests and wildlife refuges can contain wilderness areas. California contains significant wilderness areas, with over 4 million acres of National Forest Wilderness areas, and 1.5 million acres of mostly desert wilderness in the Mojave Desert National Preserve (figure 14.4.*b*).



Figure 14.4.*b*: A variety of unique plant life grows at Mojave Desert National Preserve. Image by John Fowler (CC-BY).

Wilderness areas provide an essential habitat for a wide array of fish, wildlife, and plants, and are particularly important in protecting endangered species. For scientists, wilderness areas serve as natural laboratories, where studies can be performed that would not be possible in developed areas.

National and State Parks

The United States has set aside more land for public recreational use than any other country. The **National Park System** manages more than 380 parks, recreation areas, seashores, trails, monuments, memorials, battlefields, and other historic sites. It consists of more than 80 million acres nationwide (figure 14.4.*c*). The largest national park is Wrangell–St. Elias National Park and Preserve in Alaska with over 13 million acres. California has eight national parks: Channel Islands, Death Valley, Joshua Tree, Lassen, Redwood, Sequoia, Kings Canyon, and Yosemite. Many national parks such as Yosemite, Yellowstone and the Grand Canyon are such popular recreation destinations that the ecosystems of those parks are being severely tested by human activities.



Figure 14.4.*c*: National parks, such as Grand Teton National Park in Wyoming, help conserve biodiversity. (credit: Don DeBold)

Every state has also set aside significant amounts of land for recreational use. The **California State Park System** manages more than one million acres of parklands including: coastal wetlands, estuaries, scenic coastlines, lakes, mountains and desert areas. California's largest state park is Anza-Borrego Desert State Park, which is the largest state park in the United States with 600,000 acres. The stated mission of the California State Park System is "to provide for the health, inspiration and education of the people

of California by helping to preserve the state's extraordinary biological diversity, protecting its most valued natural and cultural resources and creating opportunities for high-quality outdoor recreation".

National Forests

The **National Forest System**, managed by the U.S. Forest Service (part of the United States Department of Agriculture), consists of more than 170 forestlands and grasslands, which are available for activities such as camping, fishing, hiking and hunting. These are managed as multiple use lands, which balance the needs for recreation, grazing, timber, watershed protection, wildlife and fish, and wilderness.

Some examples of national forests are the Sierra National Forest in California and the White Mountain National Forest in New Hampshire. The Coronado National Forest in Arizona is famous for "sky islands", or steep mountain ranges surrounded by low-lying areas. The dramatic increase in elevation is associated with changes in the flora and fauna (figure 14.4.*d*). Explore national forests using this interactive map.



Figure 14.4.*d*: The Santa Teresa Mountains of the Coronado National Forest form "sky islands". Image by Jstuby (public domain).

Wildlife Refuges

The U.S. Fish and Wildlife Service manage more than 500 national **wildlife refuges** (figure 14.4.*e*), which not only protect animal habitats and breeding areas but also provide recreational facilities. Find a Refuge is an interactive map for locating wildlife refuges.



Figure 14.4.*e*: Bobcat at Sonny Bono National Wildlife Refuge in southern California. Image by Mark Stewart/USFWS (public domain).

Supplemental Reading

America's Public Lands Explained. 2016. U.S. Department of the Interior.

Attributions

Modified by Melissa Ha from the following sources:

- Preserving Biodiversity from *Environmental Biology* by Matthew R. Fisher (licensed under CC-BY)
- Preserving Biodiversity from *General Biology* by OpenStax (licensed under CC-BY)
- Biological and Land from *AP Environmental Science* by University of California College Prep, University of California (licensed under CC-BY). Download for free at CNX.
- Multiple Use Lands. 12 May 2015. The United States Department of Justice. Accessed 28 March 2021 (public domain)

This page titled 14.4: Protected Areas is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **11.4: Protected Areas** by Melissa Ha and Rachel Schleiger is licensed CC BY-NC 4.0.

14.5: Ecosystem Restoration

Ecosystem restoration is the process of bringing an area back to its natural state, before it was impacted through destructive human activities. It holds considerable promise as a mechanism for maintaining or restoring biodiversity and reinstating ecosystem services. It requires a broad interdisciplinary approach involving many different scientific fields of study (for example, biology, ecology, hydrology and geology). Reintroducing wolves, a top predator, to Yellowstone National Park in 1995 led to dramatic changes in the ecosystem that increased biodiversity. The wolves (figure 14.5.*a*) function to suppress elk and coyote populations and provide more abundant resources to the detritivores. Reducing elk populations has allowed revegetation of **riparian areas** (those along the banks of a stream or river), which has increased the diversity of species in that ecosystem. Reduction of coyote populations by wolves has increased the prey species previously suppressed by coyotes. In this ecosystem, the wolf is a **keystone species**, meaning a species that is instrumental in maintaining diversity within an ecosystem. Removing a keystone species from an ecological community causes a collapse in diversity. The results from the Yellowstone experiment suggest that restoring a keystone species effectively can have the effect of restoring biodiversity in the community. Ecologists have argued for the identification of keystone species where possible and for focusing protection efforts on these species. It makes sense to return the keystone species to the ecosystems where they have been removed.

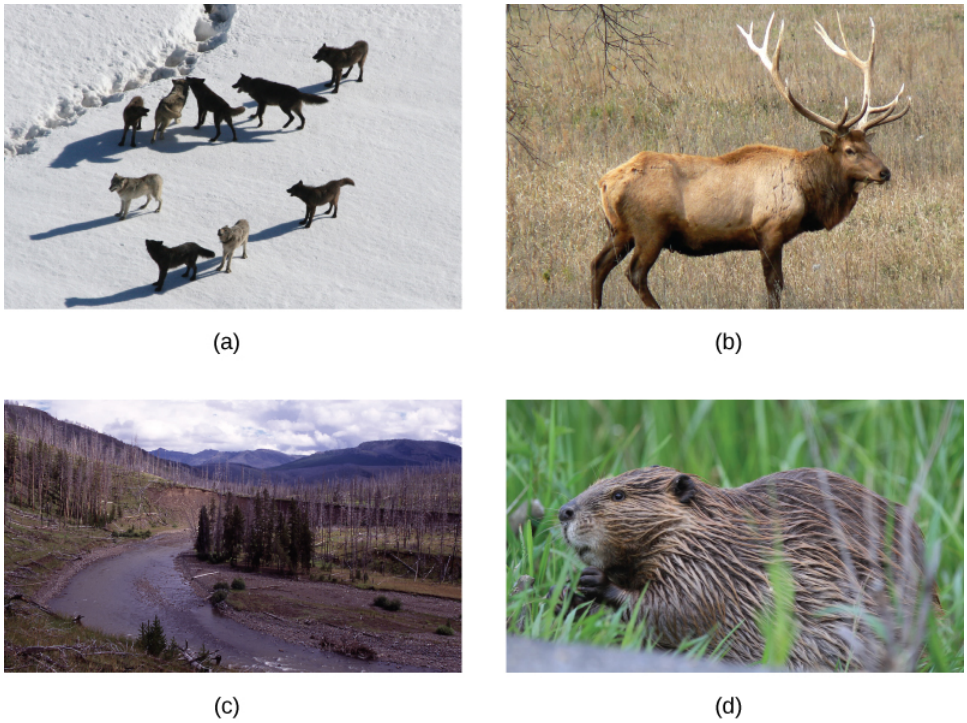


Figure 14.5.*a*: (a) The Gibbon wolf pack in Yellowstone National Park, March 1, 2007, represents a keystone species. The reintroduction of wolves into Yellowstone National Park in 1995 led to a change in the grazing behavior of (b) elk. To avoid predation, the elk no longer grazed exposed stream and riverbeds, such as (c) the Lamar Riverbed in Yellowstone. This allowed willow and cottonwood seedlings to grow. The seedlings decreased erosion and provided shading to the creek, which improved fish habitat. A new colony of (d) beaver may also have benefited from the habitat change. (credit a: modification of work by Doug Smith, NPS; credit c: modification of work by Jim Peaco, NPS; credit d: modification of work by "Shiny Things"/Flickr)

Other large-scale restoration experiments underway involve dam removal. In the United States, since the mid-1980s, many aging dams are being considered for removal rather than replacement because of shifting beliefs about the ecological value of free-flowing rivers. The measured benefits of dam removal include restoration of naturally fluctuating water levels (often the purpose of dams is to reduce variation in river flows), which leads to increased fish diversity and improved water quality (see Dams and Reservoirs for more about the impact of dams). In the Pacific Northwest of the United States, dam removal projects are expected to increase populations of salmon, which is considered a keystone species because it transports nutrients to inland ecosystems during its annual spawning migrations. In other regions, such as the Atlantic coast, dam removal has allowed the return of other spawning anadromous fish species (species that are born in fresh water, live most of their lives in salt water, and return to fresh water to spawn). Some of the largest dam removal projects have occurred recently, such as Elwha Dam on the Olympic Peninsula of

Washington State. The large-scale ecological experiments that these removal projects constitute will provide valuable data for other dam projects slated either for removal or construction.

Besides physical processes, socioeconomic factors must also be considered in a restoration project. Actions of humans have historically been important in shaping ecosystems, and are important in determining the success of restoration efforts. Because the cost to restore an individual site can involve millions of dollars, government support is a necessity.

Environmental Remediation

Danger to human health from both historic and modern pollution requires that cleanup measures be implemented. **Remediation** is aimed at neutralization, containment, and/or removal of the polluting chemicals. The goal is to prevent the spread of the pollution, or to reduce it to levels that will not appreciably risk human health. Many times, it is physically impossible or financially unfeasible to completely clear all contamination. Often, experts and the public disagree on how clean is clean enough.

Many communities are struggling to find the funds and technological expertise needed to clean up polluted areas. Some settings, such as brownfields, can be remediated fairly easily. **Brownfields** are abandoned industrial or commercial facilities or blighted urban areas that need to be cleansed of contamination before they can be redeveloped. Other areas, because of their size or the extreme toxicity of their contaminants, require very expensive, complex, and long-term remediation. Many of these have been designated as Superfund sites.

Superfund sites are areas with the most toxic contamination in the United States. The contamination may not only make the site itself too dangerous to inhabit, but often leaks toxic levels of pollutants into the surrounding soil, water, or air. An example of a Superfund site is Love Canal in Niagara Falls, New York (figure 14.5.*b*). The canal was a chemical waste dump for many years, then in the 1950's was covered with soil and sold to the city. Over time, many homes and a school were built over the former dump. In the 1970's, heavy rains raised the water table and carried contaminants back to the surface. Residents noticed foul smells, and gardens and trees turned black and died. Soon after, rates of birth defects, cancer, and other illnesses began to rise sharply. In 1977, the State of New York and the federal government began remediation work. Buildings were removed, and all residents were bought out and relocated, contaminated deposits and soils were excavated, and remaining soils and groundwater were treated and sealed off to prevent further spread of the contamination. Remediation activities have now been completed at this site.



Figure 14.5.*b*: Love Canal. Source: US Environmental Protection Agency

The type of pollution and the medium affected (air, water, or soil) determine remediation methods. Methods include incineration, absorption onto carbon, chemical methods, or bioremediation. **Bioremediation** is the use of plants, bacteria, or fungus to "digest" the contaminant to a non-toxic or less toxic form. All of these methods tend to be expensive and time-consuming.

Reclamation and Mitigation

Reclamation involves salvaging some features of a degraded habitat, but it may not restore the ecosystem fully (figure 14.5.*c*). For example, instead of abandoning a mined area once resources have been collected, it can be reclaimed by planting vegetation, reshaping the landscape, and redirecting water flow. However the reclaimed land still lacks many features of the original ecosystem, such as complex topography, vegetation that took tens or hundreds of years to grow, soil quality, and an intricate network of streams.

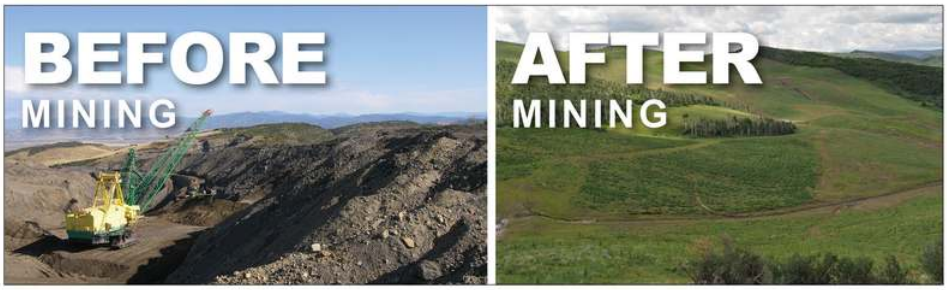


Figure 14.5.*c*: The Seneca Yoast coal once land has been cleared in preparation for mining (left) and after reclamation (right). Image by Peabody Energy, Inc. (CC-BY).

Sometimes, actions can be taken to avoid, reduce or compensate for the effects of environmental damage. Such **mitigation** efforts have been taken by the Army Corps of Engineers during construction projects. The native plants are removed from a site before construction begins and transplanted at a special holding site. After the construction project is completed, the native plants are replanted using those from the holding site. Another example of mitigation might involve the creation or enhancement of wetlands in one area, in order to compensate for permitted wetland losses in another area. Mitigation often goes hand-in-hand with restoration. Texaco, in conjunction with environmental groups and the United States Fish and Wildlife Service, restored 500 acres of agricultural lands in the lower Mississippi Delta to bottomland hardwoods. Texaco received environmental credits for the mitigating effects of the new woodlands on air quality.

Attributions

Modified by Melissa Ha from the following sources:

- Preserving Biodiversity and Case Study - The Love Canal Disaster from *Environmental Biology* by Matthew R. Fisher (licensed under CC-BY)
- Preserving Biodiversity from *General Biology* by OpenStax (licensed under CC-BY)
- Issues and Opinions from *AP Environmental Science* by University of California College Prep, University of California (licensed under CC-BY). Download for free at CNX.

This page titled 14.5: Ecosystem Restoration is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **11.5: Ecosystem Restoration** by Melissa Ha and Rachel Schleiger is licensed CC BY-NC 4.0.

14.6: Economic Influences on Conservation

Economics greatly impacts conservation success. Short-term profits can incentivize individuals, companies, or governments to harvesting resources at an unsustainable rate and at the expense of ecosystem health. In impoverished regions, compromising habitat to grow high-value crops, such as coffee or oil palms, or poaching endangered species may seem like the only source of income. One solution is **debt-for-nature swaps** through which one country forgives the debt of another if the latter agrees to protect natural areas. These conservation efforts can provide a new source of income for residents near the protected areas. For example, the United States forgave $20 million in debt from Costa Rica. In exchange, Costa Rica invested in expanding its protected areas and developing the ecotourism industry, which provides jobs to many of its residents (figure 14.6.*a*). **Ecotourism** involves visiting and enjoying natural areas while minimizing ecological damage. Ecotourism can benefit local economies and alleviate poverty especially if the earnings from it are reinvested into the communities living near tourist destinations. It generates jobs such as park operators, sellers of local crafts, and tour guides.



Figure 14.6.*a*: A tourist ziplines over the Costa Rican rainforest. Image by Khaufle at the English language Wikipedia (CC-BY-SA).

Attribution

Modified by Melissa Ha from Ecotourism from *Life Sciences Grade 10* by Siyavula (licensed under CC-BY)

This page titled 14.6: Economic Influences on Conservation is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **11.6: Economic Influences on Conservation** by Melissa Ha and Rachel Schleiger is licensed CC BY-SA 4.0.

14.7: Individual Choices

Many of the strategies for preserving biodiversity operate at the level of whole governments or large organizations; however, your choices as an individual also play a role in conservation.

Consumer Choices

The products you purchase have differing impacts on biodiversity. Educating yourself on the origin of products and food that you purchase and choosing the sustainable options can help preserve biodiveristy. For example, arabica coffee can be grown in the shade, meaning there is no need to fully clear rainforest vegetation when growing this species (figure 14.7.a). However, robusta coffee requires full sun, and cultivating it has a greater impact or rainforest biodiversity. Monterey Bay Aquarium provides a sustainable seafood guide, which identifies seafood choices that have a lower environmental impact. Choosing local products reduces the amount of fossil fuels that were burned to transport them to you, thus reducing carbon emissions that contribute to climate change.



Figure 14.7.a: Shade-grown coffee at a Columbian farm. Image by Brian Smith/American Bird Conservancy/U.S. Fish and Wildlife Service Northeast Region (CC-BY).

Some products have special certifications that indicate their impact on biodiversity. For example, certified organic products must be cultivated without the use of synthetic pesticides, herbicides, and fertilizers, which pollute the surrounding areas. Additionally, they cannot contain genetically modified organisms (GMOs), which have both positive and negative environmental implications. If you cannot afford to buy all organic produce, see the Environmental Working Group's lists of the Clean Fifteen™ (for which pesticide use is already limited) and Dirty Dozen™ (which are high priority to purchase organic or avoid due to high pesticide residues). The Roundtable on Sustainable Palm Oil (RSPO) certifies oil palm plantations that follow standards such as avoiding deforestation and using fire to clear land. Additionally, RSPO-certified business must follow guidelines to compensate their employees sufficiently. Fair Trade Certified™ goods must meet social and environmental standards that support the United Nation's Sustainable Development Goals.

Resource Conservation

Resource conservation is individual choice that can promote biodiversity. In this case, conservation refers to limiting one's use of resources, such as water, electricity, and gasoline. Landscaping with drought-tolerant plants to limit the need for irrigation or using a low-flow shower head are examples of water conservation. Because much electricity is generated from burning fossil fuels, such as coal and natural gas, conserving electricity reduces carbon emissions associated with climate change. Turning off lights and appliances when not in use and insulating one's home to reduce electricity spent on heating and cooling save money and benefit the environment. Similarly, transportation choices such as carpooling, biking, or taking public transportation can limit carbon emissions. Reusing items or not purchasing unnecessary ones also conserves the energy needed to produce and transport these

goods and reduces plastic waste, which is particularly harmful to aquatic ecosystems. See chapters about Water Resources, Renewable Energy, and Solid Waste Management for more about resource conservation.

Guide to Planting a Pollinator Garden

Whether you have a few feet on your apartment balcony or several acres, you can promote populations of native bees, butterflies, and other pollinators by building a **pollinator garden** (figure 14.7.*b*). The first step is to choose a location. While flowering plants can grow in both shady and sunny locations, consider your audience. Butterflies and other pollinators like to bask in the sun and some of their favorite wildflowers grow best in full or partial sun with some protection from the wind. The next step is to identify your soil type. Take a look at your soil - is it sandy and well-drained or more clay-like and wet? You can turn over a test patch or check out a soil mapper to learn more. Your soil type and the amount of sunlight it gets will help determine the kinds of plants you can grow.



Figure 14.7.*b*: A diversity of plant species support native pollinators in this pollinator garden. Image by Sara "Asher" Morris (CC-BY-NC).

Next, research which varieties of milkweed and wildflowers are native to your area and do well in your soil and sunlight conditions. **Native plants**, those that have historically occurred in the area, are the ideal choice, because they require less maintenance and tend to be heartier. Find a nursery that specializes in native plants near you - they'll be familiar with plants that are meant to thrive in your region. Some examples of pollinator-friendly plants native to California, include the California poppy, California lilac, milkweed, and foothill penstemon. The California Native Plant Society and UC Berkeley Urban Bee Lab have additional plant suggestions. It's essential to choose plants that have not been treated with pesticides. Choosing **perennials** will ensure your plants come back each year, reducing the need for maintenance.

Remember to think about more than just the summer growing season. Pollinators need nectar early in the spring, throughout the summer and even into the fall. Choosing plants that bloom at different times will help you create a bright and colorful garden that both you and pollinators will love for months!

Some native bee species use bare soil for nesting. While applying mulch can help control weeds, leaves some bare soil if possible. Some native pollinators also nest in tiny cavities, which may already occur naturally in or near your garden or can be provided with bee boxes.

Make sure to weed and water your garden to keep it healthy. It may take some time, but you will eventually see butterflies and other pollinators enjoying your garden.

Modified by Melissa Ha from the U.S. Fish and Wildlife Service (public domain).

Citizen Science

Finally, citizen science provides the opportunity to be directly involved in biological conservation efforts. For some opportunities like Globe at Night, which assess light pollution, or the Lost Ladybug Project, data can be collected independently

and submitted online. Others, like bird banding, are scheduled events in which experts train a group of volunteers to complete fieldwork (figure 14.7.*c*). The federal government's citizen science database lists many such opportunities.



Figure 14.7.*c*: Left: Students returning from taking phenology measurements on native trees in a native forest conservation area on Hawaii Island. Phenology refers to the timing of events in an organism's life cycle. Right: Americorp members preparing ʻōhiʻa tree cuttings for rooting and propagation – with plants to be used for disease resistance screening. Left image by UFS/USDA (public domain). Right image by USFS (public domain).

Attribution

Melissa Ha (CC-BY-NC)

This page titled 14.7: Individual Choices is shared under a CC BY 4.0 license and was authored, remixed, and/or curated by Sara Kappus (Open Educational Resource Initiative at Evergreen Valley College) .

- **11.7: Individual Choices** by Melissa Ha and Rachel Schleiger is licensed CC BY-NC 4.0.

Index

1 A

abiotic
1.1: Introduction to Ecology
abundance
11.1: What is Landscape Ecology?
11.2: Terminology
adaptation
4: Natural Selection and Evolution
adaptive radiation
12.3: Extinction
agriculture
11.3: Applications of Landscape Ecology
Alfred Wallace
4.1: Darwin, Wallace, and the Theory of Natural Selection
allopatric speciation
4.3: Macroevolution and Speciation
alternative stable state
10: Ecosystems
anthropogenic
11.1: What is Landscape Ecology?
11.3: Applications of Landscape Ecology
apex consumer
9.3: Food Chains and Food Webs
Aposematic Coloration
8.3: Competition
applied science
1.3: The Process of Science
aquatic biomes
3: Terrestrial and Aquatic Biomes
3.3: Aquatic Biomes
assimilation
10.2: Energy Flow through Ecosystems
Atmospheric Circulation
2: The Physical Environment
autotrophs
5.4: Energy and Nutrients

2 B

basic science
1.3: The Process of Science
Batesian mimicry
8.3: Competition
biodiversity
9.1: Community Structure
11.4: Island Biogeography
12.1: Value of Biodiversity
12.3: Extinction
biodiversity hotspot
12.3: Extinction
Biogeochemical cycle
10: Ecosystems
10.3: Biogeochemical Cycles
biogeography
3.1: Biogeography and Species Distributions
11.4: Island Biogeography
12: Biodiversity and The Extinction Crisis
Biomagnification
9.3: Food Chains and Food Webs
biomass
10.2: Energy Flow through Ecosystems
biomes
3.2: Terrestrial Biomes
biotic
1.1: Introduction to Ecology
boundary
11.2: Terminology

3 C

camouflage
8.2: Exploitative Interactions
8.3: Competition
carbon cycle
10: Ecosystems
10.3: Biogeochemical Cycles
Carl Troll
11.1: What is Landscape Ecology?
11.2: Terminology
Charles Darwin
4: Natural Selection and Evolution
chemical diversity
12.3: Extinction
chemoautotroph
9.3: Food Chains and Food Webs
10.2: Energy Flow through Ecosystems
climate
2: The Physical Environment
2.1: Climate
climate change
11.3: Applications of Landscape Ecology
13: Threats to Biodiversity
climax community
8.3: Competition
9.5: Succession
coevolution
8.4: Commensalism and Mutualism
colonization
11.4: Island Biogeography
commensalism
8.3: Competition
8.4: Commensalism and Mutualism
8.5: Symbiosis
communities
9.2: The Role of Species within Communities
community dynamics
9: Community Structure and Dynamics
community ecology
1.2: Levels of Ecological Research
8.1: A summary of Interactions
community structure
9: Community Structure and Dynamics
9.1: Community Structure
competitive exclusion principle
8.3: Competition
composition
11.2: Terminology
connectivity
11.2: Terminology
conservation
11.1: What is Landscape Ecology?
11.3: Applications of Landscape Ecology
14: Protecting Biodiversity
convection
2.3: Atmospheric Circulation
convection cells
2.4: Global Winds and Precipitation
coral reefs
3.3: Aquatic Biomes
Coriolis Effect
2.3: Atmospheric Circulation
corridor
11.2: Terminology
corridors
13.1: Habitat Loss and Fragmentation
cultural services
10.4: Ecosystem Services

4 D

Darwin
4.1: Darwin, Wallace, and the Theory of Natural Selection
dependent variable
1.3: The Process of Science
detrital food web
9.3: Food Chains and Food Webs
development
11.2: Terminology
differential heating
2.2: Differential Heating of Earth's Surface
distance
11.4: Island Biogeography
disturbance
9: Community Structure and Dynamics
11.2: Terminology

5 E

E. O . Wilson
11.4: Island Biogeography
E. O. Wilson
11.1: What is Landscape Ecology?
Earth
2: The Physical Environment
ecocline
11.2: Terminology
Ecological Disturbance
9.4: Disturbance
ecological network
13.1: Habitat Loss and Fragmentation
ecological process
11.3: Applications of Landscape Ecology
ecological pyramid
10.2: Energy Flow through Ecosystems
ecological restoration
14: Protecting Biodiversity
ecological stability
10.5: Resistance, Resilience, and Stability
ecology
1.1: Introduction to Ecology
ecosystem
10.1: Introduction to Ecosystem Ecology
11.2: Terminology
ecosystem diversity
12.1: Value of Biodiversity
12.3: Extinction
ecosystem dynamics
10.1: Introduction to Ecosystem Ecology
ecosystem ecology
1.2: Levels of Ecological Research

ecosystem model
10.1: Introduction to Ecosystem Ecology
ecosystem services
10: Ecosystems
10.4: Ecosystem Services
ecosystem stability
10: Ecosystems
ecotone
11.2: Terminology
11.3: Applications of Landscape Ecology
ecotope
11.2: Terminology
ecotourism
14: Protecting Biodiversity
ectotherm
5.3: Homeostasis and Regulation
edge
11.2: Terminology
elevation
11.4: Island Biogeography
Emsleyan/Mertensian mimicry
8.3: Competition
endangered species
14: Protecting Biodiversity
Endemic species
12.3: Extinction
endotherm
5.3: Homeostasis and Regulation
energy
5.4: Energy and Nutrients
energy budget
6.2: Life Histories and Natural Selection
energy flow
10: Ecosystems
environmental disturbance
8.3: Competition
equilibrium
11.4: Island Biogeography
Ernst Neef
11.2: Terminology
estuaries
3.3: Aquatic Biomes
eutrophication
10.3: Biogeochemical Cycles
evaluating scientific work
1: Introduction to Ecology
1.4: Reporting and Evaluating Scientific Work
evolution
4: Natural Selection and Evolution
4.2: Evolution
exploitative interactions
8.2: Exploitative Interactions
extinction
11.4: Island Biogeography
12: Biodiversity and The Extinction Crisis
12.3: Extinction
extinction rate
12.3: Extinction

6 F

facilitation
8.4: Commensalism and Mutualism
fecundity
6.2: Life Histories and Natural Selection
fisheries biology
11.3: Applications of Landscape Ecology
food chain
9.3: Food Chains and Food Webs
food chains
9: Community Structure and Dynamics
food web
9.3: Food Chains and Food Webs
food webs
9: Community Structure and Dynamics
forestry
11.3: Applications of Landscape Ecology
fossil
4.4: Evidence of Evolution
foundation species
8.3: Competition
9.2: The Role of Species within Communities
fragmentation
11.2: Terminology
freshwater
3.3: Aquatic Biomes
freshwater ecosystem
10.1: Introduction to Ecosystem Ecology
function
11.2: Terminology
fundamental niche
5.1: Tolerance Ranges of Species

7 G

gene flow
4.2: Evolution
11.3: Applications of Landscape Ecology
genetic diversity
12.1: Value of Biodiversity
12.3: Extinction
genetic drift
4.2: Evolution
Geographic Information Systems
11.1: What is Landscape Ecology?
geography
11.1: What is Landscape Ecology?
11.3: Applications of Landscape Ecology
geomorphology
11.1: What is Landscape Ecology?
geomorpology
11.1: What is Landscape Ecology?
GIS
11.1: What is Landscape Ecology?
11.3: Applications of Landscape Ecology
global climate
2.4: Global Winds and Precipitation
gradient analysis
11.3: Applications of Landscape Ecology
gross primary productivity
10.2: Energy Flow through Ecosystems

8 H

habitat
11.1: What is Landscape Ecology?
habitat area
11.4: Island Biogeography
habitat fragmentation
11.4: Island Biogeography
13: Threats to Biodiversity
13.1: Habitat Loss and Fragmentation
habitat heterogeneity
11.4: Island Biogeography
habitat loss
13: Threats to Biodiversity
13.1: Habitat Loss and Fragmentation
Hadley Cell
2.3: Atmospheric Circulation
heat
2.2: Differential Heating of Earth's Surface
heat budget
2.2: Differential Heating of Earth's Surface
Herbivory
8.2: Exploitative Interactions
heterogeneity
11.1: What is Landscape Ecology?
11.2: Terminology
12.3: Extinction
heterotrophs
5.4: Energy and Nutrients
homeostasis
5.3: Homeostasis and Regulation
host
8.2: Exploitative Interactions
8.3: Competition
hypothesis
1.3: The Process of Science

9 I

IALE
11.1: What is Landscape Ecology?
immigration
11.4: Island Biogeography
independent variable
1.3: The Process of Science
integrated landscape management
11.3: Applications of Landscape Ecology
intermediate disturbance hypothesis
9.4: Disturbance
International Association for Landscape Ecology
11.1: What is Landscape Ecology?
intertidal
3.3: Aquatic Biomes
introduction to Ecology
1: Introduction to Ecology
invasive species
9.2: The Role of Species within Communities
13: Threats to Biodiversity
island
11.4: Island Biogeography
island biogeography
8.3: Competition
11.1: What is Landscape Ecology?
11.4: Island Biogeography
isolation
11.4: Island Biogeography
iteroparity
6.2: Life Histories and Natural Selection

10 J

John A. Wiens
11.2: Terminology

11 K

kelp forests
- 3.3: Aquatic Biomes

keystone species
- 8.3: Competition
- 9.2: The Role of Species within Communities

12 L

lakes
- 3.3: Aquatic Biomes

land change modeling
- 11.3: Applications of Landscape Ecology

land change science
- 11.3: Applications of Landscape Ecology

land cover
- 11.1: What is Landscape Ecology?

land transformation
- 11.2: Terminology

land use
- 11.1: What is Landscape Ecology?

landscape
- 11.1: What is Landscape Ecology?
- 11.2: Terminology

landscape ecology
- 11.1: What is Landscape Ecology?
- 11.2: Terminology
- 11.3: Applications of Landscape Ecology

landscape genetics
- 11.3: Applications of Landscape Ecology

landscape limnology
- 11.3: Applications of Landscape Ecology

landscape mosaic
- 11.1: What is Landscape Ecology?

latitude
- 11.4: Island Biogeography

levels of ecology
- 1: Introduction to Ecology
- 1.2: Levels of Ecological Research

life history
- 6.2: Life Histories and Natural Selection

13 M

Müllerian Mimicry
- 8.3: Competition

macroevolution
- 4.3: Macroevolution and Speciation

mainland
- 11.4: Island Biogeography

marine
- 3.3: Aquatic Biomes

matrix
- 11.2: Terminology
- 11.3: Applications of Landscape Ecology

megafauna
- 12.3: Extinction

Mertensian mimicry
- 8.3: Competition

metapopulation
- 11.1: What is Landscape Ecology?

Michel Godron
- 11.2: Terminology

microevolution
- 4.2: Evolution

mimicry
- 8.2: Exploitative Interactions

misconceptions about evolution
- 4.5: Common Misconceptions about Evolution

model
- 11.1: What is Landscape Ecology?

mosaic
- 11.2: Terminology

multivariate statistical analysis
- 11.3: Applications of Landscape Ecology

mutation
- 4.2: Evolution

mutualism
- 8.3: Competition
- 8.4: Commensalism and Mutualism
- 8.5: Symbiosis

14 N

natural selection
- 4: Natural Selection and Evolution
- 4.1: Darwin, Wallace, and the Theory of Natural Selection

net consumer productivity
- 10.2: Energy Flow through Ecosystems

net primary productivity
- 10.2: Energy Flow through Ecosystems

net production efficiency
- 10.2: Energy Flow through Ecosystems

network
- 11.2: Terminology

niche
- 5.1: Tolerance Ranges of Species

nutrients
- 5.4: Energy and Nutrients

15 O

ocean circulation
- 2.5: Oceanic Circulation

ocean ecosystem
- 10.1: Introduction to Ecosystem Ecology

Oceanic Circulation
- 2: The Physical Environment

optimal foraging theory
- 5.5: Principle of Allocation and Evolutionary Trade-offs

organismal ecology
- 1.2: Levels of Ecological Research

osmoregulation
- 5.3: Homeostasis and Regulation

overexploitation
- 13: Threats to Biodiversity
- 13.4: Overexploitation

overfishing
- 13.4: Overexploitation

16 P

parasite
- 8.2: Exploitative Interactions
- 8.3: Competition

parasitism
- 8.5: Symbiosis

patch
- 11.2: Terminology

patch dynamics
- 11.2: Terminology

pathogen
- 11.1: What is Landscape Ecology?

pattern
- 11.1: What is Landscape Ecology?
- 11.2: Terminology

physical environment
- 2: The Physical Environment

pioneer species
- 8.3: Competition
- 9.4: Disturbance
- 9.5: Succession

Polar Cell
- 2.3: Atmospheric Circulation

pollution
- 13: Threats to Biodiversity

population ecology
- 1.2: Levels of Ecological Research

precipitation
- 2.4: Global Winds and Precipitation

predation
- 8.2: Exploitative Interactions

primary consumer
- 9.3: Food Chains and Food Webs

primary production
- 10: Ecosystems

primary succession
- 8.3: Competition
- 9.5: Succession

principle of allocation
- 5.5: Principle of Allocation and Evolutionary Trade-offs

process
- 11.1: What is Landscape Ecology?

producer
- 9.3: Food Chains and Food Webs

protected areas
- 14: Protecting Biodiversity

provisioning services
- 10.4: Ecosystem Services

pseudogenes
- 8.5: Symbiosis

17 R

R. H. MacArthur
- 11.4: Island Biogeography

realized niche
- 5.1: Tolerance Ranges of Species

regime shifts
- 10: Ecosystems

regulating services
- 10.4: Ecosystem Services

relative species abundance
- 8.3: Competition
- 9.1: Community Structure

remote sensing
- 11.1: What is Landscape Ecology?

reporting
- 1.4: Reporting and Evaluating Scientific Work

reproductive isolation
- 4.3: Macroevolution and Speciation

rescue effect
- 11.4: Island Biogeography

resilence
10: Ecosystems
resilience
10.1: Introduction to Ecosystem Ecology
10.5: Resistance, Resilience, and Stability
resilience (ecological)
10.1: Introduction to Ecosystem Ecology
resistance
10: Ecosystems
10.1: Introduction to Ecosystem Ecology
10.5: Resistance, Resilience, and Stability
resistance (ecological)
10.1: Introduction to Ecosystem Ecology
Richard Forman
11.2: Terminology
rivers
3.3: Aquatic Biomes
Robert H. MacArthur
11.1: What is Landscape Ecology?
11.4: Island Biogeography

18 S

scale
11.1: What is Landscape Ecology?
11.2: Terminology
11.3: Applications of Landscape Ecology
scientific method
1: Introduction to Ecology
1.3: The Process of Science
scientific theory
1.3: The Process of Science
seascape ecology
11.3: Applications of Landscape Ecology
secondary consumer
9.3: Food Chains and Food Webs
secondary extinctions
13.4: Overexploitation
secondary succession
8.3: Competition
9.5: Succession
semelparity
6.2: Life Histories and Natural Selection
sexual selection
4.2: Evolution
simulation model
10.1: Introduction to Ecosystem Ecology
size
11.4: Island Biogeography
solar radiation
2.2: Differential Heating of Earth's Surface
spatial
11.3: Applications of Landscape Ecology
spatial pattern
11.3: Applications of Landscape Ecology
speciation
4.3: Macroevolution and Speciation
species
11.3: Applications of Landscape Ecology
species distributions
3.1: Biogeography and Species Distributions
species diversity
12.1: Value of Biodiversity
species interactions
8.1: A summary of Interactions
Species Interactions in Communities
8: Species Interactions in Communities
species richness
8.3: Competition
9.1: Community Structure
11.4: Island Biogeography
stochastic
11.1: What is Landscape Ecology?
structure
11.2: Terminology
succession
9: Community Structure and Dynamics
supporting services
10.4: Ecosystem Services
surface winds
2.3: Atmospheric Circulation
sustainability
11.1: What is Landscape Ecology?
symbiosis
8.3: Competition
8.5: Symbiosis
sympatric specaition
4.3: Macroevolution and Speciation

19 T

temporal
11.3: Applications of Landscape Ecology
terrestiral ecosystem
10.1: Introduction to Ecosystem Ecology
terrestrial biomes
3: Terrestrial and Aquatic Biomes
3.2: Terrestrial Biomes
tertiary consumer
9.3: Food Chains and Food Webs
The Theory of Island Biogeography
11.1: What is Landscape Ecology?
theory of island biogeography
11.1: What is Landscape Ecology?
11.4: Island Biogeography
thermohaline circulation
2.5: Oceanic Circulation
thermoregulation
5.3: Homeostasis and Regulation
trade winds
2.5: Oceanic Circulation
Tragedy of the Commons
13.4: Overexploitation
trophic level
9.3: Food Chains and Food Webs
10.1: Introduction to Ecosystem Ecology
trophic level transfer efficiency
10.2: Energy Flow through Ecosystems
trophic levels
9: Community Structure and Dynamics
types of natural selection
4.2: Evolution

20 U

urban planning
11.3: Applications of Landscape Ecology

21 V

value of biodiversity
12: Biodiversity and The Extinction Crisis

22 W

warning coloration
8.2: Exploitative Interactions
wetland delineation
11.3: Applications of Landscape Ecology
wetlands
3.3: Aquatic Biomes

Glossary

Sample Word 1 | Sample Definition 1

Detailed Licensing

1 Overview

Title: Introduction to Ecology (Kappus)

Webpages: 92

All licenses found:

- CC BY 4.0: 97.8% (90 pages)
- Undeclared: 2.2% (2 pages)

2 By Page

- Introduction to Ecology (Kappus) - *CC BY 4.0*
  - Front Matter - *CC BY 4.0*
    - TitlePage - *CC BY 4.0*
    - InfoPage - *CC BY 4.0*
    - Table of Contents - *Undeclared*
    - Licensing - *CC BY 4.0*
    - About the Book - *CC BY 4.0*
    - Preface - *CC BY 4.0*
  - 1: Introduction to Ecology - *CC BY 4.0*
    - 1.1: Introduction to Ecology - *CC BY 4.0*
    - 1.2: Levels of Ecological Research - *CC BY 4.0*
    - 1.3: The Process of Science - *CC BY 4.0*
    - 1.4: Reporting and Evaluating Scientific Work - *CC BY 4.0*
  - 2: The Physical Environment - *CC BY 4.0*
    - 2.1: Climate - *CC BY 4.0*
    - 2.2: Differential Heating of Earth's Surface - *CC BY 4.0*
    - 2.3: Atmospheric Circulation - *CC BY 4.0*
    - 2.4: Global Winds and Precipitation - *CC BY 4.0*
    - 2.5: Oceanic Circulation - *CC BY 4.0*
  - 3: Terrestrial and Aquatic Biomes - *CC BY 4.0*
    - 3.1: Biogeography and Species Distributions - *CC BY 4.0*
    - 3.2: Terrestrial Biomes - *CC BY 4.0*
    - 3.3: Aquatic Biomes - *CC BY 4.0*
  - 4: Natural Selection and Evolution - *CC BY 4.0*
    - 4.1: Darwin, Wallace, and the Theory of Natural Selection - *CC BY 4.0*
    - 4.2: Evolution - *CC BY 4.0*
    - 4.3: Macroevolution and Speciation - *CC BY 4.0*
    - 4.4: Evidence of Evolution - *CC BY 4.0*
    - 4.5: Common Misconceptions about Evolution - *CC BY 4.0*
  - 5: Adaptations to the Environment - *CC BY 4.0*
    - 5.1: Tolerance Ranges of Species - *CC BY 4.0*
    - 5.2: Temperature, Water, and other Factors - *CC BY 4.0*
    - 5.3: Homeostasis and Regulation - *CC BY 4.0*
    - 5.4: Energy and Nutrients - *CC BY 4.0*
    - 5.5: Principle of Allocation and Evolutionary Trade-offs - *CC BY 4.0*
  - 6: Life History and Reproductive Strategies - *CC BY 4.0*
    - 6.1: Life History Theory and Natual Selection - *CC BY 4.0*
    - 6.2: Life Histories and Natural Selection - *CC BY 4.0*
    - 6.3: Life History Characteristics - *CC BY 4.0*
    - 6.4: Sexual Selection and Mate Choice - *CC BY 4.0*
    - 6.5: Mating Systems - *CC BY 4.0*
  - 7: Population Ecology - *CC BY 4.0*
    - 7.1: Characteristics of Popualtions - *CC BY 4.0*
    - 7.2: Population Growth and Regulation - *CC BY 4.0*
    - 7.3: The Human Population - *CC BY 4.0*
  - 8: Species Interactions in Communities - *CC BY 4.0*
    - 8.1: A summary of Interactions - *CC BY 4.0*
    - 8.2: Exploitative Interactions - *CC BY 4.0*
    - 8.3: Competition - *CC BY 4.0*
    - 8.4: Commensalism and Mutualism - *CC BY 4.0*
    - 8.5: Symbiosis - *CC BY 4.0*
  - 9: Community Structure and Dynamics - *CC BY 4.0*
    - 9.1: Community Structure - *CC BY 4.0*
    - 9.2: The Role of Species within Communities - *CC BY 4.0*
    - 9.3: Food Chains and Food Webs - *CC BY 4.0*
    - 9.4: Disturbance - *CC BY 4.0*
    - 9.5: Succession - *CC BY 4.0*
  - 10: Ecosystems - *CC BY 4.0*
    - 10.1: Introduction to Ecosystem Ecology - *CC BY 4.0*
    - 10.2: Energy Flow through Ecosystems - *CC BY 4.0*
    - 10.3: Biogeochemical Cycles - *CC BY 4.0*
    - 10.4: Ecosystem Services - *CC BY 4.0*

- 10.5: Resistance, Resilience, and Stability - *CC BY 4.0*
- 11: Landscape Ecology and Island Biogeography - *CC BY 4.0*
  - 11.1: What is Landscape Ecology? - *CC BY 4.0*
  - 11.2: Terminology - *CC BY 4.0*
  - 11.3: Applications of Landscape Ecology - *CC BY 4.0*
  - 11.4: Island Biogeography - *CC BY 4.0*
- 12: Biodiversity and The Extinction Crisis - *CC BY 4.0*
  - 12.1: Value of Biodiversity - *CC BY 4.0*
  - 12.2: Patterns of Biodiversity - *CC BY 4.0*
  - 12.3: Extinction - *CC BY 4.0*
  - 12.4: Measures of Biodiversity Loss - *CC BY 4.0*
- 13: Threats to Biodiversity - *CC BY 4.0*
  - 13.1: Habitat Loss and Fragmentation - *CC BY 4.0*
  - 13.2: Pollution - *CC BY 4.0*
  - 13.3: Invasive Species - *CC BY 4.0*
  - 13.4: Overexploitation - *CC BY 4.0*
  - 13.5: Climate Change - *CC BY 4.0*
- 14: Protecting Biodiversity - *CC BY 4.0*
  - 14.1: Policies - *CC BY 4.0*
  - 14.2: Non-profit Organizations - *CC BY 4.0*
  - 14.3: Species-level Conservation - *CC BY 4.0*
  - 14.4: Protected Areas - *CC BY 4.0*
  - 14.5: Ecosystem Restoration - *CC BY 4.0*
  - 14.6: Economic Influences on Conservation - *CC BY 4.0*
  - 14.7: Individual Choices - *CC BY 4.0*
- Back Matter - *CC BY 4.0*
  - Index - *CC BY 4.0*
  - Glossary - *CC BY 4.0*
  - Detailed Licensing - *CC BY 4.0*
  - Detailed Licensing - *Undeclared*

Detailed Licensing

Overview

Title: Introduction to Ecology (Kappus)

Webpages: 92

All licenses found:

- CC BY 4.0: 97.8% (90 pages)
- Undeclared: 2.2% (2 pages)

By Page

- Introduction to Ecology (Kappus) - *CC BY 4.0*
  - Front Matter - *CC BY 4.0*
    - TitlePage - *CC BY 4.0*
    - InfoPage - *CC BY 4.0*
    - Table of Contents - *Undeclared*
    - Licensing - *CC BY 4.0*
    - About the Book - *CC BY 4.0*
    - Preface - *CC BY 4.0*
  - 1: Introduction to Ecology - *CC BY 4.0*
    - 1.1: Introduction to Ecology - *CC BY 4.0*
    - 1.2: Levels of Ecological Research - *CC BY 4.0*
    - 1.3: The Process of Science - *CC BY 4.0*
    - 1.4: Reporting and Evaluating Scientific Work - *CC BY 4.0*
  - 2: The Physical Environment - *CC BY 4.0*
    - 2.1: Climate - *CC BY 4.0*
    - 2.2: Differential Heating of Earth's Surface - *CC BY 4.0*
    - 2.3: Atmospheric Circulation - *CC BY 4.0*
    - 2.4: Global Winds and Precipitation - *CC BY 4.0*
    - 2.5: Oceanic Circulation - *CC BY 4.0*
  - 3: Terrestrial and Aquatic Biomes - *CC BY 4.0*
    - 3.1: Biogeography and Species Distributions - *CC BY 4.0*
    - 3.2: Terrestrial Biomes - *CC BY 4.0*
    - 3.3: Aquatic Biomes - *CC BY 4.0*
  - 4: Natural Selection and Evolution - *CC BY 4.0*
    - 4.1: Darwin, Wallace, and the Theory of Natural Selection - *CC BY 4.0*
    - 4.2: Evolution - *CC BY 4.0*
    - 4.3: Macroevolution and Speciation - *CC BY 4.0*
    - 4.4: Evidence of Evolution - *CC BY 4.0*
    - 4.5: Common Misconceptions about Evolution - *CC BY 4.0*
  - 5: Adaptations to the Environment - *CC BY 4.0*
    - 5.1: Tolerance Ranges of Species - *CC BY 4.0*
    - 5.2: Temperature, Water, and other Factors - *CC BY 4.0*
    - 5.3: Homeostasis and Regulation - *CC BY 4.0*
    - 5.4: Energy and Nutrients - *CC BY 4.0*
    - 5.5: Principle of Allocation and Evolutionary Trade-offs - *CC BY 4.0*
  - 6: Life History and Reproductive Strategies - *CC BY 4.0*
    - 6.1: Life History Theory and Natual Selection - *CC BY 4.0*
    - 6.2: Life Histories and Natural Selection - *CC BY 4.0*
    - 6.3: Life History Characteristics - *CC BY 4.0*
    - 6.4: Sexual Selection and Mate Choice - *CC BY 4.0*
    - 6.5: Mating Systems - *CC BY 4.0*
  - 7: Population Ecology - *CC BY 4.0*
    - 7.1: Characteristics of Popualtions - *CC BY 4.0*
    - 7.2: Population Growth and Regulation - *CC BY 4.0*
    - 7.3: The Human Population - *CC BY 4.0*
  - 8: Species Interactions in Communities - *CC BY 4.0*
    - 8.1: A summary of Interactions - *CC BY 4.0*
    - 8.2: Exploitative Interactions - *CC BY 4.0*
    - 8.3: Competition - *CC BY 4.0*
    - 8.4: Commensalism and Mutualism - *CC BY 4.0*
    - 8.5: Symbiosis - *CC BY 4.0*
  - 9: Community Structure and Dynamics - *CC BY 4.0*
    - 9.1: Community Structure - *CC BY 4.0*
    - 9.2: The Role of Species within Communities - *CC BY 4.0*
    - 9.3: Food Chains and Food Webs - *CC BY 4.0*
    - 9.4: Disturbance - *CC BY 4.0*
    - 9.5: Succession - *CC BY 4.0*
  - 10: Ecosystems - *CC BY 4.0*
    - 10.1: Introduction to Ecosystem Ecology - *CC BY 4.0*
    - 10.2: Energy Flow through Ecosystems - *CC BY 4.0*
    - 10.3: Biogeochemical Cycles - *CC BY 4.0*
    - 10.4: Ecosystem Services - *CC BY 4.0*

- 10.5: Resistance, Resilience, and Stability - *CC BY 4.0*
- 11: Landscape Ecology and Island Biogeography - *CC BY 4.0*
  - 11.1: What is Landscape Ecology? - *CC BY 4.0*
  - 11.2: Terminology - *CC BY 4.0*
  - 11.3: Applications of Landscape Ecology - *CC BY 4.0*
  - 11.4: Island Biogeography - *CC BY 4.0*
- 12: Biodiversity and The Extinction Crisis - *CC BY 4.0*
  - 12.1: Value of Biodiversity - *CC BY 4.0*
  - 12.2: Patterns of Biodiversity - *CC BY 4.0*
  - 12.3: Extinction - *CC BY 4.0*
  - 12.4: Measures of Biodiversity Loss - *CC BY 4.0*
- 13: Threats to Biodiversity - *CC BY 4.0*
  - 13.1: Habitat Loss and Fragmentation - *CC BY 4.0*
  - 13.2: Pollution - *CC BY 4.0*
  - 13.3: Invasive Species - *CC BY 4.0*
  - 13.4: Overexploitation - *CC BY 4.0*
  - 13.5: Climate Change - *CC BY 4.0*
- 14: Protecting Biodiversity - *CC BY 4.0*
  - 14.1: Policies - *CC BY 4.0*
  - 14.2: Non-profit Organizations - *CC BY 4.0*
  - 14.3: Species-level Conservation - *CC BY 4.0*
  - 14.4: Protected Areas - *CC BY 4.0*
  - 14.5: Ecosystem Restoration - *CC BY 4.0*
  - 14.6: Economic Influences on Conservation - *CC BY 4.0*
  - 14.7: Individual Choices - *CC BY 4.0*
- Back Matter - *CC BY 4.0*
  - Index - *CC BY 4.0*
  - Glossary - *CC BY 4.0*
  - Detailed Licensing - *CC BY 4.0*
  - Detailed Licensing - *Undeclared*