4

Evolution, Biodiversity, and Population Ecology

Chapter Objectives

This chapter will help students:

Explain the process of natural selection, and cite evidence for this process

Describe the ways in which evolution influences biodiversity

Discuss reasons for species extinction and mass extinction events

List the levels of ecological organization

Outline the characteristics of populations that help predict population growth

Assess logistic growth, carrying capacity, limiting factors, and other fundamental concepts of population ecology

Lecture Outline

I. Central Case: Striking Gold in a Costa Rican Cloud Forest

A. Local residents in Costa Rica's mountainous Monteverde region told of an elusive golden toad that appeared only in the early part of the rainy season.

B. In 1964, Dr. Jay M. Savage and his colleagues encountered hundreds of golden toads during an expedition.

C. The newly discovered species went extinct 25 years later when global climate change caused drying of the forest.

II. Evolution as the Wellspring of Earth's Biodiversity

1. Biological **evolution** consists of genetic change in organisms across generations.

2. **Natural selection** is the process by which traits that enhance survival and reproduction are passed on more frequently to future generations, altering the genetic makeup of populations through time.

A. Natural selection shapes organisms and diversity.

1. In 1858, **Charles Darwin** and **Alfred Russell Wallace** each proposed the concept of natural selection as a mechanism for evolution, and as a way to explain the great variety of living things.

   a. Organisms produce more offspring than can possibly survive.

   b. Individuals of the same species vary in their characteristics.

   c. Some offspring may be more likely than others to survive and reproduce.

   d. Characteristics that give certain individuals an advantage in surviving and reproducing might be inherited by their offspring.

   e. These characteristics would tend to become more prevalent in the population in future generations.

   f. A trait that promotes success is called an **adaptive trait**, or an **adaptation**.

B. Natural selection acts on genetic variation.

1. Accidental changes in DNA are called **mutations**; they give rise to genetic variation among individuals.

2. Most mutations have little effect. There are also some which are deadly, whereas others can be beneficial.

3. Sexual reproduction also generates variation.

C. Evidence of selection is all around us.

1. Countless lab experiments have demonstrated rapid evolution of traits.

2. With domesticated animals and plants we have chosen traits we like and bred them to exaggerate the traits we prefer.

3. This process of selection conducted under human direction is termed **artificial selection**.

D. Evolution generates biological diversity.

1. **Biological diversity**, or **biodiversity**, is the sum total of all organisms in an area, taking into account the diversity of species, their genes, their populations, and their communities.

2. A **species** is a population whose members share certain characteristics and can freely breed with one another and produce fertile offspring.

3. A **population** is a group of individuals of a particular species that live in the same area.

E. **Speciation** produces new types of organisms.

1. When populations of the same species are kept separate, their individuals no longer come in contact, so their genes no longer mix.

2. If there is no contact, the mutations that occur in one population cannot spread to the other.

3. Eventually, the populations may diverge, or grow different enough, that their members can no longer mate with one another.

4. If environmental conditions happen to be different for the two populations, then natural selection may accelerate this divergence.

5. Through the speciation process, single species can generate multiple species.

F. We can learn the history of life's diversification

1. Evolutionary biologists represent life's history by using branching, treelike diagrams called **phylogenetic trees**, which show relationships among species, groups of species, populations, or genes.

2. Scientists construct these trees by analyzing patterns of similarity among present-day organisms, and by studying fossils—imprints left in stone by dead organisms.

3. The cumulative body of fossils worldwide is known as the **fossil record**.

G. Some species are more vulnerable to extinction than others.

1. Generally, extinction occurs when environmental conditions change rapidly or severely enough that a species cannot adapt genetically to the change.

2. Some species are vulnerable because they are endemic, occurring in only a single place on the planet.

H. Earth has seen several episodes of mass extinction.

1. There have been five **mass extinction events** at widely spaced intervals in Earth history that have wiped out anywhere from 50 to 95% of Earth's species each time.

I. The sixth mass extinction is upon us.

1. Many biologists have concluded that Earth is currently entering its sixth mass extinction event—and that we are the cause; human population growth, development, and resource depletion have driven many species extinct and are threatening countless more.

III. Levels of Ecological Organization

A. Ecology is studied at several levels

1. Life occurs in a hierarchy of levels, from atoms, molecules, and cells up through the **biosphere**, which is the cumulative total of living things on Earth and the areas they inhabit.

2. **Ecologists** study relationships on the higher levels of this hierarchy, namely on the organismal, population, community, and ecosystem levels.

3. At the organismal level, the science of ecology describes relationships between organisms and their physical environments.

4. **Population ecology** investigates the quantitative dynamics of how individuals within a species interact with one another.

5. **Community ecology** focuses on interactions among species, from one-to-one interactions to complex interrelationships involving entire communities.

B. Habitat, niche, and degree of specialization are important in organismal ecology.

1. The specific environment in which an organism lives is its **habitat**.

2. Each organism has patterns of habitat use.

3. A species' **niche** reflects its use of resources and its functional role in a community.

4. Species with very specific requirements are said to be **specialists**.

5. Those with broad tolerances, able to use a wide array of habitats or resources, are **generalists**.

IV. Population Ecology

A. Populations exhibit characteristics that help predict their dynamics.

1. **Population size** is the number of individual organisms present at a given time.

2. **Population density** is the number of individuals in a population per unit area.

3. **Population distribution**, or **population dispersion**, is the spatial arrangement of organisms within a particular area.

4. A population's **sex ratio** is its proportion of males to females.

5. **Age structure** describes the relative numbers of organisms of each age within a population.

B. Populations may grow, shrink, or remain stable.

1. Population growth or decline is determined by births, deaths, immigration into an area, and emigration away from an area.

2. The **growth rate** equals the birth rate plus the immigration rate minus the death rate plus the emigration rate.

C. Unregulated populations increase by **exponential growth**.

1. When a population increases by a fixed percentage each year, it is said to undergo exponential growth.

D. **Limiting factors** restrain population growth.

1. Every population is eventually contained by limiting factors, which are physical, chemical, and biological characteristics of the environment.

2. The interaction of the limiting factors determines the **carrying capacity**.

3. The **logistic growth curve** shows a population that increases sharply at first and then levels off as it is affected by limiting factors.

4. Because environments are complex and ever-changing, carrying capacities can vary.

5. A population's density can increase or decrease the impact of certain limiting factors on that population; these factors are **density-dependent**.

6. **Density-independent** factors are not affected by population density.

E. Biotic potential and reproductive strategies vary among species.

1. Organisms differ in their *biotic potential*, or ability to produce offspring.

2. Species that devote large amounts of energy and resources to caring for a few offspring are said to be **K-selected**, because their populations tend to stabilize over time at or near their carrying capacity (symbolized as K).

3. Species that are **r-selected** have high biotic potential, and devote their energy and resources to producing as many offspring as possible in a relatively short time.

F. Changes in populations influence the composition of communities.

G. Conservation practices can help reduce biodiversity loss.

V. Conclusion

1. The golden toad and other organisms of the Monteverde cloud forest help illuminate the fundamentals of evolutionary biology and population ecology.

2. The evolutionary processes of natural selection, speciation, and extinction help determine Earth's biodiversity.

3. Understanding how ecological processes function at the population level is crucial to protecting biodiversity.

Key Terms

adaptation
adaptive trait
age distribution
age structure
artificial selection
biodiversity
biological diversity
biosphere
carrying capacity
community ecology
Darwin, Charles
density-dependent
density-independent
ecologists
evolution
exponential growth
extinction
fossil
fossil record
generalists
growth rate
habitat
K-selected
limiting factors
logistic growth curve
mass extinction events
mutation
natural selection

niche
phylogenetic trees
population
population density
population dispersion
population distribution
population ecology
population size
r-selected
sex ratio
specialists
speciation
species
Wallace, Alfred Russell

Teaching Tips

1. It is very difficult to understand the vastness of geologic time. To gain a better appreciation for Earth's history, assign students to design a geologic time scale analogy. In this exercise, students compare the geologic history of Earth with something measurable in time, length, weight, or distance. For example, Earth's history could be compared to a meter stick. Calculations are made to determine at what points along the meter stick major events in Earth's history took place:

$$\frac{\text{Known age of past event}}{\text{Unknown equivalent}} = \frac{\text{Known age of Earth 100 cm}}{\text{100 cm}}$$

Years before Present	**Major Event**
4,600,000,000	Origin of Earth
3,500,000,000	Life evolves
458,000,000	First land plants
375,000,000	Amphibians evolve
200,000,000	First mammals
160,000,000	First birds
65,000,000	Dinosaurs go extinct
100,000	*Homo sapiens* appears in the fossil record

In the meter stick analogy,

The origin of Earth took place at 0 cm

Life evolved at 24 cm

The first land plants evolved at 90 cm

Amphibians evolved at 92 cm

The first mammals occurred at 95.7 cm

The first birds occurred at 96.5 cm

Dinosaurs went extinct at 99.86 cm

Homo sapiens appeared at 99.98 cm

2. Ask students to study information on the "Cloud Forest Alive" website about the Monteverde cloud forest at www.cloudforestalive.org. There is an online quiz that students can take to test their knowledge.

3. Species in danger of extinction are protected under the Endangered Species Act of 1973. The U.S. Fish and Wildlife Service is the agency that protects listed terrestrial and freshwater species. Information about endangered and threatened species can be found on the U.S.F.W.S. Endangered Species Program website at http://endangered.fws.gov. Using the website, students should be able to provide information about local species that are on the list.

4. Get students active in any size class with a "Think-Pair-Share" activity, first developed by Professor Frank Lyman at the University of Maryland in 1981. Ask each student to consider a local environment (a forest, grassland, desert, seashore, or other nearby natural locale) and to list two or three populations within the community, and to describe some biotic and abiotic components of the ecosystem, using the ideas and terms from the text, such as the population distribution, possible density-dependent and density-independent limiting factors on the populations they have listed, and whether they are r- or K-selected. After 2 minutes ask each student to pair with another student nearby, and share their list and descriptions. After 2 more minutes ask 1 or 2 groups to share aloud. This is an excellent method to check for student understanding of a concept, and to get them actively involved with the material. Try this before beginning a lecture as review or as preparation, in the middle of a lecture to ensure all students are grasping the elements of a particular topic, or at the end of a lesson as a summary technique.

Additional Resources

Websites

1. *Speciation and Biodiversity: Interview with Edward O. Wilson, Ph.D.*, 2002, Action Bioscience (www.actionbioscience.org/biodiversity/wilson.html).

   An interview with Dr. Wilson, world-renowned expert on biodiversity, is provided on this website. Links to other websites are included.

2. *Monteverde Cloud Forest Preserve* (http://www.cct.or.cr/en/menu_mtv.htm).

   This is the official website of the preserve and offers information about the history of the preserve and species that live there.

3. *Evolution*, 2001, PBS *Evolution* Program Website (http://www.pbs.org/wgbh/evolution/index.html).

   This website is the gateway for information and teaching resources designed for the PBS video program *Evolution*.

4. *Population Ecology*, 1996, Virginia Polytechnic Institute and State University (http://www.gypsymoth.ento.vt.edu/~sharov/popechome/welcome.html).

This website provides information, spreadsheet laboratories, and links about population ecology.

5. *Extinction!*, 2001, PBS *Evolution* Program Website (http://www.pbs.org/wgbh/evolution/extinction/index.html).

   This website gives background information about past and possible current mass extinctions.

6. *The Wildlands Project.* (www.wildlandsproject.org).

   A non-profit organization comprised of conservation biologists, restoration ecologists and many other professional and interested amateurs dedicated to "restoring, reconnecting, and rewilding" the American landscape from Alaska to Mexico. International in scope, this group has "boots on the ground" researching, documenting, and inventorying biodiversity and putting forth recovery plans for those plants, animals, and ecosystems that are in peril. Students can review this website for the latest information on biological hot spots, featured species currently under study for habitat recovery and much more.

Audiovisual Materials

1. *Evolution*, 2001, PBS Home Video (www.shop.pbs.org).

   This program contains 7 videotapes that discuss the history, science, and controversy surrounding the theory of evolution. Each videotape has its own website with information and teaching resources.

2. *A History of Evolutionary Thought*, Museum of Paleontology, University of California Berkeley (www.ucmp.berkeley.edu/history/evothought.html).

   The U.C. Berkeley Museum of Paleontology provides a list of scientists and philosophers who have contributed to the understanding of evolution. It is organized according to themes of evolutionary thought, and provides links to other resources.

3. *America's Endangered Species: Don't Say Goodbye*, 1998, National Geographic Video (http://shop.nationalgeographic.com).

   In this video, two photographers travel across the country learning about and photographing endangered species.

4. David Attenborough's documentaries. Attenborough has produced many documentary films that discuss topics in ecology, biodiversity, and evolution. The films are in both VHS and DVD and can be found at a variety of sellers such as Amazon.com and Barnes and Noble. Relevant titles are:

   Life on Earth, 1987, Turner Home Video
   The Private Life of Plants, 1995, Turner Entertainment Video

The Life of Birds, 2002, BBC Video
The Blue Planet, 2003, BBC Video
The Life of Mammals, 2003, Warner Home Video
The Living Planet, 2004, WEA

5. E.O. Wilson & Dan L. Perlman. (2000). *Conserving Earth's Biodiversity*. An interactive learning experience for studying conservation biology and environmental science. Island Press, the Environmental Publisher. Washington, D.C. An authoritative, interactive experience for students from the "Father of Biodiversity," as E. O. Wilson is often called. The CD-ROM format includes 10 interactive models from population growth rates, habitat fragmentation, in-depth case studies and video clips of Dr. Wilson posing questions and discussing current data, fifteen world maps showing vegetation cover of the world's major biomes, Lights at Night, Conservation Hot Spots, and more.

Weighing the Issues: Suggested Answers

Should We Care about Extinction?

Facts to consider: There are a variety of philosophies. Preservationists would want to preserve species for their own sake as well as for the spiritual, aesthetic, and recreational benefits. Conservationists may stress that species should be conserved because human beings might learn to use them or learn from them how to improve human health and well-being. Finally, the more anthropocentric view is that organisms are simply resources for exploitation and that there is no real need to worry about extinction. The benefits of biodiversity to people, and reasons to care about extinction, are examined further in Chapter 8.

Carrying Capacity and Human Population Growth

Facts to consider: Human populations are subject to the same types of limiting factors as other organisms; however, we are adept at modifying our habitat to suit our needs. Because humans have become increasingly efficient in fulfilling our needs, carrying capacities for people have increased as the limiting factors have been modified. Increasingly sophisticated technologies may keep increasing our carrying capacity as advances are made in agriculture and medicine, for example. However, technological progress relies on natural resources, which are becoming increasingly scarce. Natural resource exploitation, in some cases, degrades the environment to such a degree that it negatively impacts our ability to live and thrive. If current trends in environmental degradation continue, and if we fail to develop sustainable solutions to a variety of issues, then the human carrying capacity may indeed be lowered.

The Science behind the Story

Climate Change, Disease, and the Amphibians of Monteverde

Observation: The golden toad and other amphibians recently disappeared from the Monteverde cloud forest. The period between July 1986 and June 1987 was the driest period recorded in Monteverde. Review of climate records revealed an increasing number of dry days and periods from 1973 to 1998.

Hypothesis: Hot, dry climate conditions caused increased adult mortality and breeding problems among golden toads and other amphibians.

Results: Other research established that global ocean and atmospheric temperatures had been warming, which led to an analysis of Costa Rican oceanic and atmospheric temperatures. Warmer ocean and air temperatures in this region resulted in cloud formation at higher altitudes. When the clouds moved inland, they contacted Costa Rican mountain ranges at a higher elevation than previously, robbing the Monteverde cloud forest of the moisture and cooler temperatures needed for successful amphibian survival. Other observations note changes in the community from moisture-dependent species to more dry-tolerant species. Moreover, by making daytime and nighttime temperatures less extreme, climate changes were likely encouraging the proliferation of chytrid fungi that appear to be driving many amphibians extinct. Most recently, research by biologist Karen Lips and others suggests that amphibian die-offs in Central America may be a direct result of the invasive spread of chytrid fungi, and may have little to do with climate change. Further research is needed to resolve these questions—and fast, since so many amphibians are disappearing so quickly.