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 in population ecology
- Identify efforts and challenges involved in the conservation of biodiversity

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 rainy season.
   
   B. In 1964, Dr. Jay M. Savage and his colleagues encountered hundreds of these golden toads, which had never been formally discovered, 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. A species is a particular type of organism that shares certain characteristics and can breed with one another and produce fertile offspring.
2. A **population** is a group of individuals of a particular species that live in a particular area.

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

4. **Natural selection** is the process by which inherited characteristics 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 independently proposed the concept of natural selection as a mechanism for evolution and as a way to explain the great variety of living things.
   a. Individuals of the same species vary in their characteristics.
   b. Organisms produce more offspring than can possibly survive.
   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.

2. A trait or characteristic 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** and can give rise to genetic variation among individuals. If a mutation occurs in a sperm or egg cell, it may be passed on to the next generation.

2. Most mutations have little effect; some are deadly; others are beneficial.

3. When organisms reproduce sexually they mix, or recombine, their genetic material so that a portion of each parent’s genes contribute to the genes of the offspring.

C. Selective pressures from the environment influence adaptation.

1. Closely related species living in different environments may evolve differently as a result of different selective pressures.

2. Environments change over time and traits that produce success at one time or location may not do so at another.
3. Natural selection helps to elaborate and diversify traits that may lead to new species and new types or organisms.

D. Evidence of natural selection is all around us.
   1. This process of selection conducted under human direction is termed artificial selection.
   2. Many of our domestic pets and food crops are a result of this process.

E. Evolution generates biological diversity.
   1. Biological diversity, or biodiversity, refers to the variety of life across all levels of biological organization, including the diversity of species and their genes, the diversity of populations within a community, and the diversity of communities within an ecosystem.
   2. Scientists have described about 1.8 million species but estimate that 100 million may exist.

F. 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 enough so that even if they come together again they may not be able to interbreed and have become different species.

G. Populations can be separated in many ways.
   1. Geographic isolation, or allotropic speciation – caused by such issues as ice sheet movement, mountain range building, climate change and similar events – is considered to be the main mode of species formation.
   2. Other mechanisms such as hybridization or different feeding and mating characteristics can also result in speciation.

H. We can infer the history of life’s diversification by comparing organisms.
   1. Scientists represent the history of divergence on diagrams called phylogenetic trees. They illustrate hypotheses of how divergence took place by looking at similarities among genes or external characteristics of organisms.
   2. By mapping traits such as flights, swimming, or vocalization on the trees according to which organisms possess them, biologists can infer evolutionary histories.
I. The fossil record teaches us about life’s long history.
   1. Hard parts of organisms are often preserved after death when sediments are compressed into rock and minerals replace the organic material, leaving behind a fossil. Dating these sediments allows scientists to produce a fossil record.
   2. The fossil record shows an evolution of life on Earth over a period of at least 3.5 billion years with a generally increasing number of species over time.
   3. The species living today are a small fraction of those that ever existed, many of which disappeared during episodes of mass extinction.

J. Speciation and extinction together determine Earth’s biodiversity.
   1. The disappearance of a species is called extinction.
   2. The fossil record indicates an average existence of a species on Earth to be 1-10 million years.
   3. Human impact appears to be speeding up extinctions.

K. 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 genetically adapt to the change.
   2. Some species are vulnerable because they are endemic, occurring in only a single place on the planet.

L. Earth has seen several episodes of mass extinction.
   1. There have been five mass extinction events at widely spaced intervals in Earth’s history. Each wiped out anywhere from 50 to 95% of Earth’s species each time.
   2. The best known of these occurred 65 million years ago and brought end to the dinosaurs, but it was not the largest.

M. The sixth mass extinction is upon us.
   1. Many biologists conclude that human activities have caused an extinction rate that is 100-1,000 times greater than the historic background rate.
   2. Amphibians, such as the golden toad, are disappearing at a higher rate than other organisms, with 170 species having disappeared in the last few decades and 30% of their species in danger of extinction.
III. Levels of Ecological Organization

1. Ecology is the study of interactions among organisms and between organisms and their environments.

A. We study ecology at several levels.

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

2. At the level of the organism, ecology describes the relationships between the organism and its physical environment.

3. Population ecology examines the dynamics of population change and the factors that affect its distribution and abundance.

4. Communities are made up of multiple interacting species that live in the same area. Community ecology focuses on species diversity and interactions among species.

5. Ecosystems encompass communities and the abiotic (nonliving) material, and forces with which their members interact. Ecosystem ecology reveals patterns, such as the flows of energy and nutrients, by studying living and non-living components of systems.

B. Each organism has habitat needs.

1. The specific environment in which an organism lives is its habitat, which consists of living and non-living elements around it.

2. Each organism thrives in certain habitats and not others, leading to non-random patterns of habitat use.

3. Mobile organisms can choose where to live by habitat selection. For non-mobile organisms whose young disperse and settle passively, habitat uses result from success in some and failures in others.

4. The habitat needs of many organisms often conflict with those of humans who want to alter or develop habitats for human use.

C. Niche and specialization are key concepts in ecology.

1. A species’ niche reflects its use of resources and its functional role in a community.

2. Species with very specific requirements are said to be specialists.

3. 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. This is often the major consideration for success or failure of mating or food competition.

3. **Population distribution**, or **population dispersion**, is the spatial arrangement of organisms within a particular area. Ecologists define three types: random, uniform, and clumped.

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

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

6. Birth and death rates measure the number of births and deaths per 1,000 individuals for a given time period.

7. The likelihood of death varies with age; this can be graphically shown in **survivorship curves**.

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

1. **Demographers**, scientists who study human populations, use mathematical concepts to study population changes.

2. Population growth or decline is determined by four factors: births, deaths, **immigration** into an area, and **emigration** away from an area.

3. The **natural rate of population growth** is determined by subtracting the death rate from the birth rate.

4. The **population growth rate** equals the crude birth rate plus the immigration rate, minus the crude 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**, an S-shaped curve, shows a population that increases sharply at first and then levels off as it is affected by limiting factors.
E. The influence of some factors on population depends on population density.
   1. The influence of density-dependent factors waxes and wanes according to population density.
   2. Density-independent factors are not affected by population density.

F. Carrying capacities can change.
   1. Limiting factors are diverse and complex, and help keep population levels below carrying capacity.
   2. Some organisms can alter their environment to reduce environmental resistance and increase carrying capacity.
   3. Humans have appropriated immense proportions of the planet’s resources and in the process have reduced the carrying capacities for many other organisms.

G. Reproductive strategies vary among species.
   1. 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.
   2. 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.
   3. K is an abbreviation for carrying capacity, and species that are K-selected species are ones that tend to stabilize over time at or near the carrying capacity.

H. Changes in populations influence the composition of communities.

V. Conserving of Biodiversity
A. Social and economic factors affect species and communities.
   1. Early European immigrants and their descendants viewed Costa Rica’s forests as an obstacle to agricultural and timber development.
   2. Since 1945, Costa Rica’s population quadrupled and pressures on land increased.

B. Costa Rica took steps to protect its environment.
   1. Beginning in 1970, Costa Rica began protecting its land resources. Today over a quarter of the country’s area lies within national parks or other protected reserves.
   2. Tourists now visit Costa Rica for ecotourism.
VI. Conclusion

A. Natural selection, speciation, and extinction help determine Earth’s biodiversity.

B. Many biologists believe that human activities are playing a role in biodiversity loss.

Key Terms

adaptation  habitat
adaptive trait habitat use
age distribution habitat selection
age structure immigration
natural selection
artificial selection K-selected
biodiversity limiting factors
biological diversity logistic growth curve
biosphere mass extinction events
carrying capacity mutations
communities natural selection
community ecology natural rate of population growth
Darwin, Charles niche
demographers phylogenetic trees
density dependent factor population density
density independent factor population dispersion
density independent factor population distribution
ecology population ecology
ecosystem ecology population growth rate
ecosystem ecology population size
ecosystems r-selected
ecotourism sex ratio
emigration specialists
demographers population density
density dependent factor population distribution
density independent factor population ecology
density independent factor population growth rate
demography r-selected
demographers sex ratio
demography specialists
demography population density
demography population dispersion
demography population distribution
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demography population distribution
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demography specialists
demography population density
demography population dispersion
demography population distribution
demography population ecology
demography population growth rate
demography population size
demography r-selected
demography sex ratio
demography specialists

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 biogeological 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 biogeological history took place:

<table>
<thead>
<tr>
<th>Years before Present</th>
<th>Major Event/Position on Meter Stick</th>
</tr>
</thead>
<tbody>
<tr>
<td>4,600,000,000</td>
<td>Origin of Earth/0 cm</td>
</tr>
<tr>
<td>3,500,000,000</td>
<td>Life evolves/24 cm</td>
</tr>
<tr>
<td>458,000,000</td>
<td>First land plants/90 cm</td>
</tr>
<tr>
<td>375,000,000</td>
<td>Amphibians evolve/92 cm</td>
</tr>
<tr>
<td>200,000,000</td>
<td>First mammals/95.7 cm</td>
</tr>
<tr>
<td>60,000,000</td>
<td>First birds/96.5 cm</td>
</tr>
<tr>
<td>65,000,000</td>
<td>Dinosaurs go extinct/99.86 cm</td>
</tr>
<tr>
<td>100,000</td>
<td><em>Homo sapiens</em> appears in the fossil record/99.98 cm</td>
</tr>
</tbody>
</table>

(One of the most misunderstood concepts among the general public is that the dinosaurs and human beings did not co-exist.)

2. Ask students to study information on the *Cloud Forest Alive* website about the Monteverde Cloud Forest (www.cloudforestalive.org). Students can take an online quiz 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 (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. First, ask each student to consider a local environment (a forest, grassland, desert, seashore, or other nearby natural locale). Next ask them to list two or three populations within the community, and to describe some biotic and abiotic components of the ecosystem. Then have them use concepts and terms from the text -- the population distribution, possible density-dependent and density-independent limiting factors, etc. -- on the populations they have listed, and whether these factors are r- or K-selected.
After 2 minutes, ask each student to pair with another student nearby and to share their lists and descriptions. After 2 more minutes ask one or two 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 a lecture as review or in preparation for the lecture, in the middle of a lecture to ensure all students are grasping the elements of a particular topic, or at the end of a lecture as a summary technique.

Additional Resources

Websites

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

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

   This video workshop uses maps, diagrams, and examples to present foundational knowledge for studying biodiversity.

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

   This website provides information, spreadsheet laboratories, and links to websites covering population ecology.

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

Audiovisual Materials

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

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

   Alan Alda follows Charles Darwin’s footsteps to the islands, learning about the animals and birds that inspired Darwin and the efforts to protect the unique biota from alien invaders—including the 60,000 ecotourists who visit every year.

4. David Attenborough’s documentaries
   Attenborough has produced many documentary films that discuss topics in ecology, biodiversity, and evolution. The films are available in both VHS and DVD formats and can be found at a number of different retailers, such as Amazon.com and Barnes and Noble. Relevant titles include:
   
   *The Living Planet*, 2004, WEA
   *The Blue Planet*, 2003, BBC Video
   *The Life of Mammals*, 2003, Warner Home Video
   *The Life of Birds*, 2002, BBC Video
   *The Private Life of Plants*, 1995, Turner Entertainment Video
   *Life on Earth*, 1987, Turner Home Video

**Weighing the Issues: Facts to Consider**

**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 needs, carrying capacities for humans have increased as the limiting factors have been modified. Increasingly sophisticated technologies will keep increasing the carrying capacity for humans 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 an area is rendered unsafe for human habitation at the existing and possibly future technology levels. If this trend continues, the human carrying capacity may indeed be lowered.
How Best to Conserve Biodiversity

Facts to consider: Perspective plays a very important role in biodiversity conservation. For example, humans establish boundaries for national parks and then expect nature to treat the park as a closed system. However, nature does not adhere to human-imposed boundaries, and the boundaries are porous, not impermeable. The problem comes when organisms that are supposed to stay inside park boundaries “invade” private land. This phenomenon has been seen when large predators, for instance, venture into suburban housing communities. Conversely, organisms outside park borders can cross over to affect organisms within the park, as seen with the extinction of the golden toad in Costa Rica. In essence, biodiversity conservation is a “tragedy of the commons” dilemma, but society must understand that the size of the “commons” in terms of biodiversity conservation is much larger than popularly thought.

The Science behind the Stories:
Thinking Like a Scientist
The K-T Mass Extinction

Observation: While investigating Bottaccione Gorge in Italy, Walter Alvarez noticed a band of reddish clay between two limestone layers. The older (lower) limestone layer had an abundance of globotruncan fossils, and the layer above the clay had very few fossils of a type related to globotruncan. The clay layer had no fossils at all, which signified an extinction event. To measure how fast this extinction event took place, Walter and his father Luis decided to determine the concentration of iridium in the clay. Iridium comes from meteorite dust that falls in a constant amount every year. Results from this analysis show that the iridium in this clay layer was at a concentration 30 times higher than that in the surrounding limestone.

Hypothesis: Excess iridium comes from a massive asteroid that hit Earth, causing a global environmental disaster from dust flung up into the atmosphere.

Experiment: The Alvarezes tested for excess iridium at other sites around the world with the red clay layer. Disproving other sources of excess iridium also became a focus of research.
Results: Other red clay sites the Alvarezes investigated had abnormally high iridium levels as well. For example, a layer of red clay in Denmark had 160 times the normal amount of iridium. (Another source of iridium could be seawater; however, chemical analysis and calculations showed that seawater iridium levels are too low to account for the iridium in the clay layers.) After publication of the research, other scientists found high-iridium clay layers around the world that were sometimes laced with two other minerals that form only in thermonuclear explosions and asteroid impacts. Validity of the theory was widely accepted after 1991, when a crater of the correct size was found off the east coast of Mexico.

Climate Change, Disease, and the Amphibians of Monteverde

Observation: The golden toad 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 discovered ocean and atmospheric temperatures warming, which led to an analysis of Costa Rican oceanic and atmospheric temperatures. Warmer ocean and air temperatures 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.

Answers to End-of-Chapter Questions

Testing Your Comprehension

1. Natural selection rests on the premises that more individuals are born into a population than will survive to reproduce; that variation exists within the population; that some of that variation both affects survival and reproduction and is heritable; and that Earth is ancient. Because we know each of these premises to be true, then individuals with favorable characteristics will be more likely to reproduce and pass on the genes for those favorable traits along to the next generation.

2. Evidence of natural selection includes the human breeding of domesticated animals, human selective breeding of crop plants, and laboratory experiments with fast-breeding species such as fruit flies, as well as evidence from numerous evolutionary studies of the natural world, including those on organismal adaptations.
3. When a population is split into two populations that become geographically and reproductively isolated from each other, they may evolve over time, in their different environments and under different selective pressures, into different species. This is called allopatric speciation.

4. The golden toad has apparently gone extinct, probably due to the effects of climate change and disease on an isolated mountaintop population. The passenger pigeon was driven to extinction by market hunting, after many of its forests had been cleared. The last of the dinosaurs went extinct, probably due to the global impact of a gigantic asteroid.

5. The biological species concept defines a species as “groups of actually or potentially interbreeding natural populations that are reproductively isolated from other such groups” (definition from Ernst Mayr). A group of organisms of the same species that live in the same area is a population, whereas a community is made up of the populations of multiple interacting species that live in the same area.

6. The specific environment in which an organism lives is its habitat, whereas its niche is its functional role in a community.

7. The five population characteristics are population size, population density (the number of individuals per unit area), spatial distribution (random, uniform, or clumped), sex ratio, and age structure (distribution of young and old). The dynamics of a population (i.e., how it changes over time) is affected by birth and death rates, which in turn are influenced by each of the five characteristics. The number of births increases in populations: 1) that are large and at sufficiently high density to make finding a mate likely, 2) with equal sex ratios if monogamous, and 3) with a high proportion of the population of reproductive age. Death rates increase when there is overcrowding (high density), when the population size exceeds the carrying capacity, and when there is a predominance of post-reproductive individuals.

8. Such growth will not exceed the carrying capacity of any environment for very long. Starting from a single bacterium that reproduces (doubles) every 20 minutes, an exponentially growing population of bacteria would fill the observable universe in only a few days. There are simply not enough resources or physical space for any organism to undergo exponential growth indefinitely.

9. Physical, chemical, and biological characteristics of the environment that restrain population growth (limiting factors) place an upper bound (carrying capacity) on the size of the population. The population size cannot increase beyond carrying capacity sustainably because the resources that would be required by the added individuals are not available.

10. K-strategists invest heavily in a few offspring with high survival rates, and move toward a stable population near the environment’s carrying capacity, whereas r-strategists invest in producing large numbers of offspring with low survival rates. Whales are K-strategists, and bacteria (see #8, above) are r-strategists.
## Calculating Ecological Footprints

<table>
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<th>Pounds of coffee per year</th>
</tr>
</thead>
<tbody>
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<td>1</td>
<td>0.025</td>
<td>9.0</td>
</tr>
<tr>
<td>Your class</td>
<td>Answers will vary</td>
<td>Answers will vary</td>
<td>Answers will vary</td>
</tr>
<tr>
<td>Your hometown</td>
<td>Answers will vary</td>
<td>Answers will vary</td>
<td>Answers will vary</td>
</tr>
<tr>
<td>Your state</td>
<td>Answers will vary</td>
<td>Answers will vary</td>
<td>Answers will vary</td>
</tr>
<tr>
<td>United States</td>
<td>310,000,000</td>
<td>7,750,000</td>
<td>2,821,000,000</td>
</tr>
</tbody>
</table>

1. Approximately 18% of the coffee is consumed in the United States. Shade-grown production would need to increase to approximately 9 times the current level.
2. Answers will vary.
3. Answers will vary, but an increase of $1.00/pound would generate $2.7 billion additional dollars, and cost only an additional 2.5¢ per person per day.