3

Evolution, Biodiversity, and Population Ecology

Chapter Objectives

This chapter will help students:

- Explain natural selection and cite evidence for this process
- Describe how 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 Study: Saving Hawaii's Native Forest Birds

A. Half of Hawaii's native bird species (70 of 140) have gone extinct in recent times, and the percentage of species that teeter on the brink of extinction here today is higher than anywhere else in the world.

B. The aki is one of 30 species of endangered birds remaining on the Hawaiian Islands. It is a type of Hawaiian honeycreeper, a group of birds numbering 18 living species (and at least 38 species recently extinct), all of which originated from individuals of a single ancestral species that reached Hawaii several million years ago.

C. Hawaii's honeycreepers thrived for several million years in the island's forests, amid a unique community of plants.

D. Today native Hawaiian forests are under siege.

E. Newly introduced organisms wreaked havoc because native Hawaiian organisms were unprepared to resist them.

F. With the arrival of people, domestic animals, and invasive plants also came diseases.

G. Today few native forest birds exist anywhere on the Hawaiian Islands below 1500 m (4500 ft) in elevation.

H. Conservation biologists and managers have worked hard to keep the Hakalau Forest protected. Young restored native forest is now regrowing on thousands of acres. More birds are using this restored forest year by year.

I. Today global climate change is throwing up a new challenge.

J. Plenty of challenges remain, but the restoration successes at Hakalau Forest so far provide hope that through responsible management we can save Hawaii's native flora and fauna and preserve the priceless bounty of millions of years of evolution on this extraordinary chain of islands.

II. Evolution: The Source of Earth's Biodiversity

1. A **species** is a particular type of organism or, more precisely, a population or group of populations whose members share characteristics and can freely 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. **Evolution** in the broad sense means change over time, and biological evolution consists of change in populations of 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 than those that do not, 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.
2. The idea of natural selection follows logically from a few straightforward premises that are readily apparent to anyone who observes the life around us.

a. Organisms face a constant struggle to survive and reproduce.

b. Organisms tend to produce more offspring than can survive.

c. Individuals of a species vary in their characteristics.

3. Variation is due to differences in genes, the environments in which genes are expressed, and the interactions between genes and environment. As a result of this variation, some individuals of a species will be better suited to their environment than others and will be better able to reproduce.

4. From one generation to another through time, characteristics, or traits, that lead to better and better reproductive success in a given environment will evolve in the population. This is termed **adaptation**, and a trait that promotes success is also called an **adaptation** or an **adaptive trait**.

B. Selection acts on genetic variation.

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

2. Genetic variation is also generated as organisms mix their genetic material through *recombination* during sexual reproduction.

3. Because evolutionary change generally requires a great deal of time, a species cannot always adapt to environmental conditions that change quickly.

4. However, genetic variation can sometimes help protect a population against novel challenges.

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. Conversely, sometimes very unrelated species may acquire similar traits as they adapt to selective pressures from similar environments; this is called **convergent evolution**.

2. Environments change over time and traits that produce success at one time or location may not do so at another.

D. Evidence of selection is all around us.

1. Scientists have demonstrated the rapid evolution of traits by selection in countless lab experiments, mostly with fast-reproducing organisms such as bacteria, yeast, and fruit flies.

2. Through *selective breeding*, we have been able to augment particular traits we prefer.

3. This process of selection conducted under human direction is termed **artificial selection**.
4. 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, genes, populations, and communities.
2. Scientists have described about 1.8 million species but estimate that 100 million may exist.

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

1. The process by which new species are generated is termed **speciation**. The main mode is generally thought to be *allopatric speciation*, whereby species form from populations that become physically separated over some geographic distance.
2. When a mutation arises in the DNA of an organism in one of these newly isolated populations, it cannot spread to the other populations.

G. Populations can be separated in many ways.

1. Populations can undergo long-term geographic isolation in various ways.
2. Alternatively, sometimes new areas are created and organisms colonize them, establishing isolated populations.
3. For speciation to occur, populations must remain isolated for a very long time, generally thousands of generations.

H. We can infer the history of life's diversification by comparing organisms.

1. Evolutionary biologists study patterns, examining how groups of organisms arose and how they evolved the characteristics they show.
2. Scientists represent the history of divergence by using branching, tree-like diagrams called **phylogenetic trees**.
3. Once we have a phylogenetic tree, we can map traits onto the tree according to which organisms possess them, and we can thereby trace how the traits have evolved.
4. *Taxonomists* use an organism's physical appearance and genetic makeup to determine its species. Related species are grouped together into *genera* (singular, *genus*), related genera are grouped into families, and so on.

5. Today biologists use evolutionary information from phylogenetic trees to help classify organisms under the Linnaean system's rules.

I. The fossil record teaches us about life's long history.

1. As organisms die, some are buried by sediment. Hard parts of their bodies—such as bones, shells, and teeth—may be preserved, as sediments are compressed into rock. Minerals replace the organic material, leaving behind a **fossil**, an imprint in stone of the dead organism. The cumulative body of fossils worldwide is known as the **fossil record**.

2. The fossil record shows that:

   a. Life has existed on Earth for at least 3.5 billion years.

   b. Earlier types of organisms evolved into later ones.

   c. The number of species existing at any one time has generally increased through time.

   d. The species living today are a small fraction of those that ever lived; the vast majority are extinct.

   e. There have been several episodes of *mass extinction*, or simultaneous loss of great numbers of species.

J. Speciation and extinction together determine Earth's biodiversity.

1. The disappearance of a species from Earth is called **extinction**.

2. Extinction occurs naturally, but human impact can profoundly affect the rate at which it occurs.

K. Some species are especially vulnerable to extinction.

1. Small populations are vulnerable to extinction because fluctuations in their size could, by chance, bring the population size to zero. Species narrowly specialized to some particular resource or way of life are also vulnerable because environmental changes that make that resource or way of life unavailable can doom them. Species that are **endemic** to a region, meaning that they occur nowhere else on the planet, also face elevated risks of extinction because all their members belong to a single, sometimes small, population.

2. Island-dwelling species are frequently vulnerable.

3. On a mainland, "islands" of habitat can host endemic species that are vulnerable to extinction.

L. Earth has seen several episodes of mass extinction.

1. These episodes, called **mass extinction events**, have occurred at widely spaced intervals in Earth's history and have wiped out 50–95% of our planet's species each time.
2. The best-known mass extinction occurred 65 million years ago and brought an end to the dinosaurs.

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.

III. Levels of Ecological Organization

1. **Ecology** is the scientific study of the distribution and abundance of organisms, the interactions among organisms, and the relationships between organisms and their environments.

A. We study ecology at several levels.

1. Life exists 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. At the level of the organism, ecology describes the relationships between the organism and its physical environment. In contrast, **population ecology** examines the dynamics of population change and the factors that affect the distribution and abundance of members of a population.
3. A **community** consists of an assemblage of populations of interacting species. **Community ecology** focuses on patterns of species diversity and on interactions among species, ranging from one-to-one interactions to complex interrelationships involving the entire community.
4. **Ecosystems** encompass communities and the abiotic (nonliving) material, and forces with which community members interact. **Ecosystem ecology** reveals patterns, such as the flow of energy and nutrients, by studying living and non-living components of systems in conjunction.

B. Each organism has habitat needs.

1. The specific environment in which an organism lives is its **habitat**.
2. Each organism thrives in certain habitats and not others, leading to non-random patterns of **habitat use**. Mobile organisms actively

select habitats in which to live from among the range of options they encounter, a process called **habitat selection**.

3. Habitats are scale dependent.
4. The criteria by which organisms favor some habitats over others can vary greatly.
5. Habitat use is important in environmental science because the availability and quality of habitat are crucial to an organism's well-being.

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 narrow breadth, and thus very specific requirements, are said to be **specialists**. Those with broad tolerances, able to use a wide array of resources, are **generalists**.
3. Specialists succeed over evolutionary time by being extremely good at the things they do, but they are vulnerable when conditions change and threaten the habitat or resource on which they have specialized. Generalists succeed by being able to live in many different places and to withstand variable conditions, but they may not thrive in any one situation as much as a specialist would.

IV. Population Ecology

A. Populations show characteristics that help predict their dynamics.

1. **Population size** is expressed as the number of individual organisms present at a given time, and may increase, decrease, undergo cyclical change, or remain stable.
2. **Population density** describes the number of individuals in a population per unit area.
3. **Population distribution** describes the spatial arrangement of organisms in an area.
   a. In a *random distribution*, individuals are located haphazardly in no particular pattern.
   b. A *uniform distribution* is one in which individuals are evenly spaced.
   c. In a *clumped distribution*, the pattern most common in nature, organisms arrange themselves according to the availability of resources they need to survive.

4. A population's **sex ratio** is its proportion of males to females, and this can influence whether the population will increase or decrease in size over time.
5. **Age distribution**, or **age structure**, describes the relative numbers of organisms of each age within a population.
6. To show how the likelihood of survival varies with age, ecologists use graphs called **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 (*natality*), deaths (*mortality*), **immigration** into an area, and **emigration** away from an area.
3. Births and immigration add individuals to a population, whereas deaths and emigration remove individuals. A convenient way to express rates of birth and death is to measure the number of births and deaths per 1,000 individuals per year. These rates are termed the *crude birth rate* and the *crude death rate*.
4. The **rate of natural increase** is determined by subtracting the crude death rate from the crude birth rate.
5. 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**. A J-shaped curve shows this type of growth.
2. Populations of organisms increase exponentially unless they meet constraints.
3. Normally, exponential growth occurs in nature only when a population is small, competition is minimal, and environmental conditions are ideal for the organism in question.

D. Limiting factors restrain population growth.

1. Every population is eventually contained by **limiting factors—** physical, chemical, and biological attributes of the environment that restrain physical growth. These limiting factors determine the **carrying capacity**, the maximum population size of a species that a given environment can sustain.

2. 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.

3. Many factors influence a population's growth rate and carrying capacity.

E. The influence of some factors depends on population density.

1. The influence of **density-dependent factors** waxes and wanes according to population density.

2. **Density-independent factors** are limiting factors whose influence is not affected by population density.

3. The logistic curve is a simplified model, and real populations in nature can behave differently.

F. Carrying capacities can change.

G. Reproductive strategies vary among species.

1. Organisms differ in their *biotic potential*, or capacity 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.

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.

4. It is important to note, however, that *these are two extremes on a continuum* and that most species fall somewhere between the extremes of r-selected and K-selected species.

V. Conserving of Biodiversity

A. Introduced species pose challenges for native populations and communities.

B. Innovative solutions are working.

1. Wildlife and natural areas draw tourists from around the world, a phenomenon called **ecotourism**.

C. Climate change now poses an extra challenge.

VI. Conclusion

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