

## Ecology Concepts and Learning Activities<sup>1</sup>

Ecology is the study of how organisms interact with each other and their environment. Important concepts for understanding ecology are summarized in two sections:

I. Energy Transfers and Cycles of Matter in Ecosystems (pages 1-4)

II. Dynamics of Populations, Communities and Ecosystems (pages 4-7).

Each of these sections begins with the relevant Disciplinary Core Ideas from the Next Generation Science Standards (NGSS; quoted from <https://ngss.nsta.org/DisciplinaryCoreIdeasMid.aspx?id=2>).

Then, each section presents a more complete set of important relevant concepts. Finally, each of these sections concludes with recommended learning activities for high school students. Each of these activities engages students in analyzing specific examples to learn general ecological principles. These activities also help students understand the complexity of ecological systems; this will counteract common student misconceptions about ecology, most of which involve a failure to appreciate the complexity and diversity of ecological interactions.<sup>2</sup> Many of the recommended learning activities are explicitly aligned with the NGSS.

Section III (pages 7-8) provides links to helpful introductory ecology readings.

### I. Energy Transfers and Cycles of Matter in Ecosystems

#### Disciplinary Core Idea LS2.B, Cycles of Matter and Energy Transfer in Ecosystems

- “Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.”
- “Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved.”
- “Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans and geosphere through chemical, physical, geological, and biological processes.”

#### Additional Concepts

- A producer is an organism that produces all of its own organic molecules from small inorganic molecules, whereas a consumer is an organism that consumes organic molecules produced by other organisms. Consumers can be categorized as primary consumers (herbivores) which eat producers, decomposers which consume dead organic matter, secondary consumers which consume primary consumers or decomposers, tertiary consumers which consume secondary consumers, or trophic omnivores which consume organisms at more than one trophic level.
- In a trophic relationship one organism consumes organic molecules from another organism (or a decomposer consumes organic molecules from dead organic matter). A food chain

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<sup>1</sup> By Dr. Ingrid Waldron, Department of Biology, University of Pennsylvania. © 2023. These Teacher Notes are available at <https://serendipstudio.org/exchange/bioactivities/ecology>.

<sup>2</sup> See Hard-to-Teach Biology Concepts, Chapter 7, by Susan Koba with Anne Tweed, NSTA Press, 2009 and Ecological Misconceptions by Bruce Munson, Journal of Environmental Education, Summer 1994, 25 (4)

shows a simple sequence of trophic relationships (e.g. producer → primary consumer → secondary consumer). A food web shows the multiple complex trophic relationships among organisms in an ecosystem. Food webs are models that show how matter and energy is transferred among different species as they interact within an ecosystem.

- Understanding a food web can help us to understand how changes in the population size of one organism can influence the population size of another organism in an ecosystem. For example, a trophic cascade can occur when an increase in a predator population results in a decrease in an herbivore population which in turn results in increased growth of producers.
- The following general principles apply to all biological processes.
  - The atoms in molecules can be rearranged into other molecules, but atoms cannot be created or destroyed.
  - Energy is neither created nor destroyed by biological processes.
  - Energy can be transformed from one type to another (e.g. during photosynthesis, the energy in sunlight is transformed to chemical energy).
  - During energy transfers and transformations, some of the input energy is transformed to heat energy.
- Carbon atoms are continuously recycled between biological communities and the air, ocean, and other abiotic pools. Biological processes that contribute to the carbon cycle include:
  - photosynthesis, which moves carbon atoms from CO<sub>2</sub> to small organic molecules, and biosynthesis, which produces larger, more complex organic molecules;<sup>3</sup>
  - eating by animals and consumption of dead organic matter by decomposers, which move carbon in organic molecules from one organism to another;
  - cellular respiration, which moves carbon atoms from organic molecules to CO<sub>2</sub>.
- The biomass of an organism is the mass of the organic molecules in the organism. The rate of production of biomass is highest for the producers in an ecosystem and smaller for each higher trophic level in the ecosystem. One major reason why is that much of the biomass eaten by consumers is used for cellular respiration, so carbon atoms are lost as CO<sub>2</sub> is released to the environment. Therefore, the biomass available for consumption decreases at higher trophic levels. The reduced rate of biomass production at higher trophic levels results in a trophic pyramid. One practical implication is that it takes roughly ten times as much land and other resources to produce meat from a primary consumer compared to a similar biomass of plant food.
- Energy flows through ecosystems. Photosynthesis in producers uses the energy in sunlight to produce organic molecules (e.g. glucose). During cellular respiration in producers and consumers, glucose is one input for reactions that provide the energy to make ATP. Hydrolysis of ATP provides the energy for many biological processes. All of these biological processes produce some heat. Heat cannot be used as the input energy for photosynthesis or cellular respiration; instead, heat is ultimately radiated out to space. Thus, the biosphere, with all of the Earth's living organisms, depends on continual input of light energy from the sun. In contrast, the earth does not receive a significant inflow of carbon atoms, and this is not a problem because the carbon cycle constantly recycles carbon atoms.

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<sup>3</sup> I use biosynthesis to refer to the processes that use the products of photosynthesis to make other types of organic molecules. Some sources use the term biosynthesis to include photosynthesis.

## **Recommended Learning Activities for Energy Transfers and Cycles of Matter in Ecosystems**

### **Food Webs, Energy Flow, Carbon Cycle, and Trophic Pyramids**

<https://serendipstudio.org/exchange/bioactivities/foodweb>

To begin this hands-on, minds-on activity, students view a video about ecosystem changes that resulted when wolves were reintroduced to Yellowstone. Then, students learn about food chains and food webs, and they construct and analyze a food web for Yellowstone National Park. Students use what they have learned to understand trophic cascades caused by the return of wolves to Yellowstone. Next, students learn that the biosphere requires a continuous inflow of energy, but does not need an inflow of carbon atoms. To understand why, students analyze how the carbon cycle and energy flow through ecosystems result from photosynthesis, biosynthesis, cellular respiration, and the trophic relationships in food webs. In the final section, students use the concepts they have learned to understand trophic pyramids and phenomena such as the relative population sizes for wolves vs. elk in Yellowstone. Thus, students learn how important ecological phenomena result from processes at the molecular, cellular, and organismal levels. (NGSS)

or

### **Food Webs - Understanding What Happened When Wolves Returned to Yellowstone**

<https://serendipstudio.org/exchange/bioactivities/foodwebRR>

To begin, students view a video about ecosystem changes that resulted when wolves were reintroduced to Yellowstone. Next, students learn about food chains and food webs. They construct and analyze a food web for Yellowstone National Park. Finally, students use what they have learned to understand a trophic cascade caused by the return of wolves to Yellowstone. (NGSS)

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### **Carbon Cycles and Energy Flow through Ecosystems and the Biosphere**

<https://serendipstudio.org/exchange/bioactivities/carbonycycle>

In this analysis and discussion activity, students learn why the biosphere requires a continuous inflow of energy, but does not need an inflow of carbon atoms. Students analyze how the process of photosynthesis illustrates the general principles of conservation of matter and the second Law of Thermodynamics. Then, students analyze how carbon cycles and energy flow through ecosystems result from photosynthesis, biosynthesis, cellular respiration, and the trophic relationships in food webs. Thus, students learn how important ecological phenomena result from processes at the molecular, cellular and organismal levels. (NGSS)

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### **Trophic Pyramids**

<https://serendipstudio.org/exchange/bioactivities/trophicpyr>

To begin this analysis and discussion activity, students review what happens to the atoms in the nearly 2000 pounds of food the average American eats each year. This provides a context for students to figure out why the rate of biomass production is higher for the producers than for the primary consumers in an ecosystem. Then, students construct and analyze trophic pyramids. Finally, they apply what they have learned to understanding why more resources are needed to produce meat than to produce an equivalent amount of plant food.

### **Food and Climate Change – How can we feed a growing world population without increasing global warming?**

<https://serendipstudio.org/exchange/bioactivities/FoodClimateChange>

In this analysis and discussion activity, students learn how food production results in the release of three greenhouse gases – carbon dioxide (CO<sub>2</sub>), nitrous oxide (N<sub>2</sub>O), and methane (CH<sub>4</sub>). Students analyze carbon and nitrogen cycles to understand how agriculture results in increased CO<sub>2</sub> and N<sub>2</sub>O in the atmosphere. Students interpret data concerning the very different amounts of greenhouse gases released during the production of various types of food; they apply concepts related to trophic pyramids and they learn about CH<sub>4</sub> release by ruminants. Finally, students propose, research, and evaluate strategies to reduce the amount of greenhouse gases that will be released during future production of food for the world’s growing population. (NGSS)

### **Marine Food Webs**

<https://www.nationalgeographic.org/activity/marine-food-webs/>

Students analyze the differences between two versions of a trophic pyramid for a marine ecosystem. Then, students analyze a coral reef food web and compare it to the trophic pyramids. Then, each student carries out online research to identify the prey and predators for an organism in a mangrove ecosystem, and the class uses this information to construct a food web for the mangrove ecosystem. Throughout, the teacher guides classroom discussion of general principles.

## **II. Dynamics of Populations, Communities and Ecosystems**

Disciplinary Core Idea LS2.A, Interdependent Relationships in Ecosystems:

- “Ecosystems have carrying capacities, which are limits to the number of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environment and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem.”

Disciplinary Core Idea LS2.C, Ecosystem Dynamics, Functioning and Resilience:

- “A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e. the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability.”
- “Moreover, anthropogenic changes (induced by human activity) in the environment – including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change – can disrupt an ecosystem and threaten the survival of some species.”

Additional Concepts

- A population is a group of individuals of the same species that live in the same area at the same time. When resources are abundant, population growth rate is proportional to population size, and the population shows exponential population growth. As population size approaches the carrying capacity of the environment, increased competition for limited resources results in increased mortality and/or decreased reproduction, so population growth slows and stops as population size approaches the carrying capacity. This results in logistic population growth. The exponential and logistic population growth models depend on assumptions which are often not valid for real populations. For example, population size may decrease due to environmental changes such as severe weather, habitat loss, or competition with a non-native invasive species.

- A biological community consists of all the types of organisms that live in an area. Two types of organisms can interact in a variety of ways, including consumption (+/–, i.e. the interaction benefits one and harms the other), competition (–/–), mutualism (+/+), and commensalism (+/0).
- Although biological communities often appear stable from year to year, major changes are common over periods of many years. A biological community may be disrupted by a disturbance (e.g. due to a natural disaster or human activity). After a disturbance ends, natural processes lead to gradual change in the biological community. This process is called succession and often extends over many decades. During succession, the organisms in a biological community change the environment in ways that may facilitate or inhibit the growth of other organisms. Succession often restores the biological community that was present before a disturbance. However, under some circumstances, succession does not restore the original biological community. For example, disturbance may allow an invasive non-native species to become established which can interfere with restoration of the original biological community.
- An ecosystem includes the physical environment as well as the biological community in an area. The physical environment affects how succession proceeds. For example, in regions with limited precipitation, succession often culminates in grasslands, whereas, in regions with more precipitation, succession often culminates in forests. This explains why the central part of the US has a grassland biome, whereas the eastern part of the US has a forest biome. (A biome is a type of ecosystem observed over large areas of the world, with a characteristic type of vegetation in a characteristic climate and physical environment.)

### **Recommended Learning Activities for Dynamics of Populations, Communities and Ecosystems**

#### **Understanding and Predicting Changes in Population Size – Exponential and Logistic Population Growth Models vs. Complex Reality**

<https://serendipstudio.org/exchange/bioactivities/pop>

In this analysis and discussion activity, students develop their understanding of the exponential and logistic population growth models by analyzing the recovery of endangered species and growth of bacterial populations. Students learn about the processes that cause exponential or logistic population growth, interpret data from several investigations, and apply their understanding to policy questions. Next, students analyze examples where the trends in population size do not match the predictions of the exponential or logistic population growth models. They learn that models are based on simplifying assumptions and a model's predictions are only accurate when the simplifying assumptions are true for the population studied. In the last section, students analyze trends in human population size and some of the factors that affect the earth's carrying capacity for humans. (NGSS)

or (for middle school students)

#### **Some Similarities between the Spread of Infectious Disease and Population Growth**

[http://serendipstudio.org/sci\\_edu/waldron/#infectious](http://serendipstudio.org/sci_edu/waldron/#infectious)

This hands-on activity introduces students to some features of exponential and logistic population growth. First, students analyze a hypothetical example of exponential growth in the number of infected individuals. Then, a class simulation of the spread of an infectious disease shows a trend that approximates logistic growth. Next, students analyze examples of exponential and logistic population growth and learn about the biological processes that result in exponential or logistic population growth. Finally, students analyze how changes in the biotic or abiotic

environment can affect population size; these examples illustrate the limitations of the exponential and logistic population growth models. (NGSS)

### **Stability and Change in Biological Communities**

<https://serendipstudio.org/exchange/bioactivities/succession>

This analysis and discussion activity engages students in understanding how biological communities remain stable and how they change during ecological succession. Students analyze several types of research evidence, including (1) repeated observations of a biological community to assess stability or change over time, (2) analyses of dated fossils in a peat bog, and (3) analyses of how mutualism, competition and trophic relationships contribute to stability or change in biological communities. Students use this evidence to understand the causes of stability and succession in a variety of habitats, including a tropical forest, a new volcanic island, abandoned farm fields, and ponds. Students also analyze the effects of climate and non-native invasive plants. (NGSS)

### **How do small changes make big impacts on ecosystems?**

<https://www.colorado.edu/program/inquiryhub/curricula/inquiryhub-biology> – click on “Go to the iHub Biology Course Materials Google Drive”, and then click on “Ecosystems Unit”

This 24-lesson curriculum begins with 9 lessons (15 50-minute periods) that explore several hypotheses about factors that affect the size of the buffalo population in the Serengeti. (NGSS)

### **How do ecosystems work, and how can understanding them help us protect them?**

<https://www.openscienced.org/instructional-materials/b-1-ecosystem-interactions-dynamics/>

This 11-lesson curriculum is estimated to require 26 days of 50-minute periods. The focus is on conservation, limiting factors and wildebeest migration in the Serengeti. (NGSS)

### **How do small things make a big difference? Activities to Teach about Human-Microbe Interactions**

*American Biology Teacher* 76 (9), 601-608, 2014 and

<https://neuron.illinois.edu/units/how-do-small-things-make-a-big-difference>

This curriculum unit includes six lessons. In the first two lessons students investigate historical changes in scientists’ understanding of evolutionary history, as summarized in the tree of life. The third lesson introduces students to microbes. In the fourth lesson students analyze a microbial ecosystem in a jar (a Winogradsky column). In the fifth lesson, students analyze the microbial communities that live within and on humans. After an introductory video, they develop initial models of human-microbe interactions, then participate in a jigsaw activity to gain relevant information, and then revise their models. In the sixth lesson, students analyze data from a clinical trial of two antibiotics to treat *C. difficile*, one of which is more harmful to commensal bacteria in the gut, and students use this information to explore ecosystem dynamics. (NGSS)

### **Modeling for Ecological Engineering**

*The Science Teacher*, September, 2019, pages 31-39

<https://www.nsta.org/store/search.aspx?action=quicksearch&text=Modeling%20for%20ecological%20engineering>

This article describes a sequence of learning activities, initially focused on the driving question, “Why are recent mountain pine beetle outbreaks worse than those of the past?” Students develop an initial model, learn some basic ecology, and revise their model. Then, they use an engineering process to develop proposals to prevent further devastation of pine forests. (NGSS)

### **Do ant birds help or hinder army ants?**

[https://tiee.esa.org/vol/v4/issues/figure\\_sets/army\\_ants/overview.html](https://tiee.esa.org/vol/v4/issues/figure_sets/army_ants/overview.html)

In this activity, students examine the relationship between an army ant swarm and the birds that follow the foraging swarm. Students design a hypothetical experiment to measure the effects of birds on army ant foraging success and interpret the results of a published experiment. You may want to precede this activity with the video of army ants available at

<https://video.nationalgeographic.com/video/worlds-deadliest/00000144-0a3f-d3cb-a96c-7b3f92d40000>.

### **Scientific Inquiry and Data Analysis Using WildCam Gorongosa**

<https://www.biointeractive.org/classroom-resources/scientific-inquiry-and-data-analysis-using-wildcam-gorongosa>

In this activity, students use trail camera data from Gorongosa National Park in Mozambique to generate a testable question, form a hypothesis and prediction, and choose and analyze the appropriate data to answer the question. Students learn that the location and abundance of animals are determined by the availability of resources and community interactions, such as competition, predation, and human influences.

### **Population Ecology**

<http://landbasedlearning.org/slews-curriculum-es>

This curriculum reviews population ecology and relates population ecology to analysis of invasive species.

### **Disturbance: Invasive Mollusk Impacts**

<https://www.caryinstitute.org/eco-inquiry/teaching-materials/hudson-river-ecology/invasive-species/disturbance-invasive-mollusk>

Students experiment to determine the effects of adding an invasive species, fertilizer runoff, or road runoff to pond water ecosystems in jars.

### **Population Dynamics**

<http://ats.doit.wisc.edu/biology/ec/pd/pd.htm>

This online simulation will reinforce student understanding of basic concepts and the mathematics of population growth.

### **Population Dynamics: Mystery of the Missing Housefly**

[http://mathbench.umd.edu/modules/popn-dynamics\\_housefly/page01.htm](http://mathbench.umd.edu/modules/popn-dynamics_housefly/page01.htm)

This web-based activity provides an entertaining and informative introduction to basic concepts of population growth.

## **III. Background Reading**

The Teacher Notes for the recommended learning activities on Serendip (<https://serendipstudio.org/exchange/bioactivities#ecology>) provide considerable relevant background information.

### **Khan Academy, High School Biology, Ecology**

<https://www.khanacademy.org/science/high-school-biology/hs-ecology>

This informative overview of ecology includes sections on population ecology (including exponential and logistic population growth), community ecology (including biodiversity), ecological relationships (including food webs), biogeochemical cycles, and human impact on ecosystems.

**Ecology and the Biosphere**

<https://tophat.com/marketplace/science-&-math/biology/textbooks/oer-openstax-biology-openstax-content/79/4147>

This chapter of an open source textbook provides a helpful brief overview of ecology and informative introductions to biogeography, biomes and climate change effects.

**Ecosystems and Human Influence**

<http://www.biologymad.com/> (select AS Biology and then A2 Biology from the sidebar menu; then, select Ecosystems and Human Impact)

This source gives a concise and informative overview of multiple aspects of ecology.