IS1 Living Earth Instructional Segment 1: Ecosystem Interactions and Energy

An ecosystem is a biological system, and the first instructional segment (IS1) begins with a systems-based approach to ecosystems. Students focus on both biotic and abiotic conditions in a way that integrates life science and Earth and space science DCIs.

LIVING EARTH INSTRUCTIONAL SEGMENT 1: ECOSYSTEM INTERACTIONS AND ENERGY

Guiding Questions

- What factors affect the size of populations within an ecosystem?
- What are common threats to remaining natural ecosystems and biodiversity? How can these threats be reduced?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-LS2-1. Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales. [Clarification Statement: Emphasis is on quantitative analysis and comparison of the relationships among interdependent factors including boundaries, resources, climate, and competition. Examples of mathematical comparisons could include graphs, charts, histograms, and population changes gathered from simulations or historical data sets.] *[Assessment Boundary: Assessment does not include deriving mathematical equations to make comparisons.]*

HS-LS2-2. Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. [Clarification Statement: Examples of mathematical representations include finding the average, determining trends, and using graphical comparisons of multiple sets of data.] *[Assessment Boundary: Assessment is limited to provided data.]*

HS-LS2-4. Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem. [Clarification Statement: Emphasis is on using a mathematical model of stored energy in biomass to describe the transfer of energy from one trophic level to another and that matter and energy are conserved as matter cycles and energy flows through ecosystems. Emphasis is on atoms and molecules such as carbon, oxygen, hydrogen and nitrogen being conserved as they move through an ecosystem.] *[Assessment Boundary: Assessment is limited to proportional reasoning to describe the cycling of matter and flow of energy.]*

HS-LS2-8. Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce. [Clarification Statement: Emphasis is on: (1) distinguishing between group and individual behavior, (2) identifying evidence supporting the outcomes of group behavior, and (3) developing logical and reasonable arguments based on evidence. Examples of group behaviors could include flocking, schooling, herding, and cooperative behaviors such as hunting, migrating, and swarming.]

HIGH SCHOOL THREE-COURSE MODEL LIVING EARTH INSTRUCTIONAL SEGMENT 1: ECOSYSTEM INTERACTIONS AND ENERGY

The bundle of performance expectations above focuses on the following elements from the NRC document *A Framework for K–12 Science Education*:

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-5] Using Mathematics and Computational Thinking [SEP-7] Engaging in Argument from Evidence	LS2.A: Interdependent Relationships in Ecosystems LS2.C: Ecosystem Dynamics, Functioning, and Resilience LS2.D: Social Interactions and Group Behavior	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-3] Scale, Proportion, and Quantity [CCC-4] Systems and System Models [CCC-5] Energy and Matter: Flows, Cycles, and Conservation

Highlighted California Environmental Principles and Concepts:

Principle II The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human societies.

Principle IV The exchange of matter between natural systems and human societies affects the long-term functioning of both.

CA CCSS Math Connections: N-Q.1–3; S-ID.1; S-IC.1, 6; MP.2, MP.4

CA CCSS for ELA/Literacy Connections: RST.9–10.8; RST.11–12.1, 7, 8; WHST.9–12.2a–e

CA ELD Connections: ELD.PI.11–12.1, 5, 6a–b, 9, 10, 11a

A **system [CCC-4]** includes component parts, interactions between those parts, and exchanges of **energy and matter [CCC-5]** to the world outside the system. Ecosystems contain living and non-living components that influence one another. In a way, an ecosystem is a microcosm of the entire Earth, with components that are so complicated it is often referred to as a system of systems. To help organize thinking about these sub-systems, scientists have divided up Earth materials and processes into five general groupings, each of which is shaped by its own internal workings and its interactions with the other **systems [CCC-4]**:

- Atmosphere: gases around the Earth (i.e., our air)
- Hydrosphere: all the water (sometimes ice is separated out into the cryosphere)
- Biosphere: all life

- Geosphere: inorganic rocks and minerals
- Anthrosphere: humanity and all of its creations (This sphere is not specifically mentioned in the *NRC Framework* [2012] because it is primarily part of the biosphere. Separating this sphere out emphasizes the significant influences humans have on the rest of Earth's systems and is consistent with California's EP&Cs).

This course centers on the biosphere and examines how it interacts with each of the other Earth systems. Teachers can introduce the biosphere by taking students to local ecosystems (either physically or virtually) to observe populations of plants and animals, to identify specific threats to biodiversity, and to consider alternative proposals to lessen those impacts. This local context can be a thread throughout the course.

Systems [CCC-4] are characterized by the **flow of energy and cycling of matter [CCC-5]** between their components. In the middle grades, students constructed models of these flows (MS-LS2-3), analyzed data about resource availability within a system (MS-LS2-1), and explained patterns in the way organisms interact (MS-LS2-2). This instructional segment builds on that understanding by using more detailed mathematical **models [SEP-2]** of ecosystems, including the sizes of different populations. Biologists use a specific definition of *population*: a group of individuals from the same species living together in the same geographical area at the same time.

Using **mathematical and computational thinking [SEP-5]** and **modeling [SEP-2]**, students can predict the effect certain interdependent factors have on the size of a population over time. The number of individuals within a population depends on birth rates, death rates, immigration, and emigration. Population growth rate is defined as the change in numbers of individuals (ΔN) divided by time (Δt). While some populations grow very quickly, populations cannot continue to grow exponentially forever. At some point they reach a maximum load that the environment they live in can support, called the *carrying capacity*. Students can use computer simulations[1] to **conduct investigations [SEP-3]** that test how different parameters **change [CCC-7]** population sizes, and then **analyze their findings [SEP-4]** (HS-LS2-1). Graphing their results, they can describe the population changes **mathematically [SEP-5]** (HS-LS2-2). Initially growth will be exponential, but students should be able to recognize the point on the graph where competition for resources begins to dramatically impact the population size.

1. There are many simulation/games available online that allow students to manipulate certain parameters that affect populations, example might be food resources or overcrowding.

Students can use simulations to recognize two general types of factors that limit population growth: Density-dependent factors and density-independent factors. Many factors are *density dependent*, such as food resources, space, nesting sites, and water, meaning that the amount of these resources required depends on the population size. *Density-independent* factors alter the number of individuals in a population regardless of how many individuals already exist. Instructional segment 1 focuses on density-dependent factors while IS6 introduces density-independent factors that often relate to interactions with other parts of the Earth system, such as weather pattern changes or catastrophic events like hurricanes, floods, landslides, volcanoes, etc. Nonetheless, introducing these two categories together can help students understand how **proportion and quantity [CCC-3]** are essential to describing density-dependent cases but not relevant in density-independent cases. Both density-dependent and density-independent factors affect the **flow of energy and matter [CCC-5]** within and into a system, which is ultimately the way in which they **affect [CCC-2]** the sizes of populations.

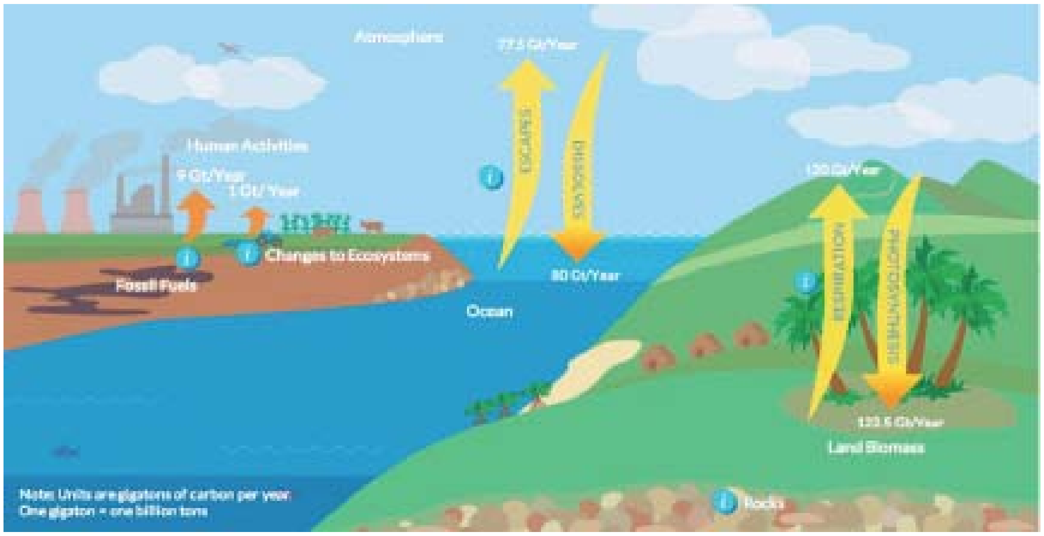
Many times, humans alter the availability of resources and change the landscape. For example, if a new freeway is built dividing a population's territory in half and limiting its migration, how will this cause both density-dependent and density-independent changes to the ecosystem? Human-induced changes to climate also cause changes to ecosystems. The Education and the Environment Initiative (EEI) Curriculum unit *Ecosystem Change in California,* which focuses on changes in a grassland ecosystem in the state provides guidance teaching EP&Cs II and IV as students obtain information about both the positive and negative ways humans influence ecosystem resources.

One of the resources organisms compete for is the food from which they obtain their energy. Organisms store potential energy within the chemical bonds of the matter in their bodies. As individual organisms grow and when populations become more plentiful, more total energy is stored. Biomass is the dry weight of all of the living organisms in an ecosystem and is related to the amount of energy available for these organisms. As a general rule, when an animal eats, it is only able to store about 10 percent of the energy from its food to build up its own energy stores. The rest of the energy is lost due to inefficient digestive processes or used in respiration to keep the animal alive long enough to eat again. As a result, each higher trophic level ends up with available energy that is just 10 percent the size of the level below it, creating a pyramid-like structure in population sizes with the lowest trophic levels at the base of the pyramid.

Using the conceptual **model [SEP-2]** of this energy pyramid, students find that very large populations of producers are required to support much smaller populations of tertiary consumers for the ecosystem to remain **stable [CCC-7]**. Mathematical **models [SEP-2]** use this principle to predict the size of a predator population given known populations of prey at other trophic levels. Students can explore many computer simulations and hands-on demonstrations so that they are able to support claims about the relative amounts of energy in different trophic levels (HS-LS2-4).

Energy flows from abiotic (nonliving forms) to biotic (living) forms, starting with sunlight or other light sources and inorganic compounds in producers and moving through consumers and decomposers. Nutrients (matter) cycle in the same manner. They can exist in forms that are largely abiotic, such as carbon dioxide (CO_2) and nitrogen (N_2), and move into living organisms (biotic) in a different form such as glucose ($C_6H_{12}O_6$) or starch (many joined glucoses) and nitrates (NO_3-). The movement from abiotic to biotic molecular forms involves living processes. For carbon (figure 7.2), these processes are photosynthesis and cellular respiration (discussed in IS2). For nitrogen, nitrogen-fixing bacteria change nitrogen gas into nitrates while bacterial decomposers change ammonia and nitrates back into nitrogen. In some cases, abiotic processes can do a similar job. When a lightning bolt travels through the atmosphere, its energy can break apart molecules of nitrogen in the air; free nitrogen atoms bond with oxygen to create nitrate that gets carried to the soil by raindrops. Other nutrients are involved in similar cycles (such as the phosphorous cycle as it relates to DNA or how climate change alters the calcium cycle and therefore affects hard-shelled marine organisms). Students can develop **models [SEP-2]** on paper, with technology, using their body moving around the room to represent the flow through different processes, or as a chemical model using organic chemistry molecule kits. The models show how simple inorganic molecules are made into larger organic molecules and then how they cycle back to the simple inorganic molecules.

Figure 7.2. The Carbon Cycle includes Biotic and Abiotic Processes



Source: WGBH n.d.

While carbon and nitrogen are essential nutrients, toxic material also cycles through the ecosystem. Humans are major sources of disruptions to nutrient cycles, including adding toxins. Students can **obtain information [SEP-8]** about how mercury accumulates in certain fish species and learn about the impacts this can have on human health. Human activities such as operating coal power plants have added significant amounts of mercury to the environment (EP&Cs III and IV).

Up to this point, this instructional segment has considered how **flow of energy and matter [CCC-5]** moves between populations in an ecosystem and how that flow helps determine the size of a given population. Now, students zoom in and see how each population itself acts like a **system [CCC-4]** with interacting members. Students will look closely at the specific behaviors of populations that help those populations survive (HS-LS2-8). For a population to succeed and not become a genetic dead end, the gene pool (the set of all the different genes) of the population must be passed on to the next generation. Producing a new generation of healthy offspring capable of successful reproduction is important for a population's survival.

High School Three-Course Model Living Earth Snapshot 7.1: Does Living as a Group or Individual Help You Survive?

Anchoring phenomenon: Prairie dogs squeak and communicate to one another as they work together to fight off a snake that intrudes into their colony.

Mr. T started class showing a short video clip on prairie dogs and how they sound alarms to protect their family units against snakes (for example, NatGeoWild, Prairie Dog Snake Alarm: http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link3). He then asked the students to do a quickwrite on what behavior the prairie dogs used to protect themselves and how that behavior helped their family.

Later, the students played a game that was actually a physical **model [SEP-2]** of individual and group behavior. Students used their bodies to represent components in a **system [CCC-4]** with a predator-prey relationship. He needed an even number of students as prey; since Mr. T had 30 students, he designated two students to act as predators, leaving 28 students to act as prey. Mr. T randomly handed each prey a white index card that had a color code on it, with each color representing a different genotype. Mr. T set up the cards ahead of time so that there were four cards for each color (i.e., four blue cards, four yellow cards, four green cards, four red cards, etc.).

For the first round (prey living as individuals) the predators and prey did not have knowledge about the individual's genetics (in other words they did not know who was genetically related to whom). Mr. T instructed the 28 prey to randomly wander around the open area and after one minute he signaled the predators to attack. The predators then tagged a prey. That individual stepped out of the group and the rest of the students continued wandering; again Mr. T signaled for attack and again each predator tagged an individual who dropped out of the group. After seven attacks, half the prey (14 individuals) had been tagged. At that point, a recorder tallied all the colors left on a shared class spreadsheet showing how many of each genotype survived (for example, 0 blue, one yellow, etc.).

Then Mr. T assigned two different students to act as predators and told them to go sit in the corner and hide their eyes while he redistributed the index cards to the remaining 28 students who were again the prey. This time he told the prey students to quietly (so the predators don't know) find the other students who shared their color. These four students had the same genotypes and represented a kin group. The second round (altruistic prey in groups) began. Since Mr. T had a big open area, he blindfolded the predators. This was so they would not know about genotypes and relatives within the prey groups. The group units now randomly wandered in the space and again Mr. T signaled the predators to attack. Each kin group could surround an individual so that when they were tagged the individual prey was saved and did not get eliminated. Each genotype/ color group received only one save in this round, after that save had been used, anyone

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in the group who was tagged again, was eliminated. This rule is designed to simulate the cost to benefit ratio of altruism. Saving a member of your group incurs an individual cost because it means your group will not be able to save you during the next attack. The benefit is that the group to which you belong is more likely to survive as a whole. The game continued for a total of seven attacks. This time there were fewer than 14 individuals eliminated because some individuals were saved by the herding effect of their group. Then a recorder used the shared class spreadsheet to tally the number of individuals left in each color group.

Mr. T reassigned the roles of each student (picking new predators and shuffling the genotype cards) to prevent learning by predators. The class enacted each scenario one more time.

After the class completed the four rounds of the game, Mr. T had the students look at the whole class data that had been recorded. He defined the terms *individual fitness* (your ability to pass on your genes) and *inclusive fitness* (your individual fitness plus indirect fitness when you belong to a group that herds to save individuals). Mr. T then asked the students to use these terms to describe the similarities and differences they saw between the two scenarios and **explain [SEP-6]** how inclusive behavior (group behavior) could be advantageous for some populations (HS-LS2-8). Mr. T wanted the students to specifically address what the action of saving an individual meant in the altruistic group scenario. Students were expected to use examples of animals that they knew that used *inclusive fitness behaviors*. The students talked about the prairie dogs (as in the video), dolphin pods, rabbit colonies, bird flocks, monkey troops, and other social, family, or group behavior. Mr. T ended class with a video clip showing how water buffalo work as a group to counter-attack lions that have surrounded an individual water buffalo (for example, NatGeoWild, Buffalo Herd Counter Attack: http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link4). What was the individual fitness of the animal being attacked? How does its fitness change because of the behavior of the group?

The rest of this course zooms in to explain many of the mechanisms that drive the processes described in this instructional segment. At the end of the course (IS6), students will return to ecosystems and human impacts to revisit their models and address more complex ecosystem interactions. As preparation, IS1 can introduce the idea that urbanization, the building of dams, and dissemination of invasive species are active parts of the **flow of energy and cycling of matter [CCC-5]** within almost all ecosystems, even those that appear relatively undisturbed (EP&Cs II, IV).