The Living Earth: Unit 1

Background for Teachers and Instructional Suggestions

An ecosystem is a biological system. A ***system*** includes component parts, interactions between those parts, and exchanges of ***energy and matter*** 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, whose components are so complicated that 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***:

- Atmosphere: gas around the Earth
- 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 course centers on the biosphere and examines how it interacts with each of the other Earth systems.

Systems are characterized by the ***flow of matter and energy*** between their components. At the middle grade level, 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 constructing more detailed **mathematical models** of ecosystems, including the size 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.

There are two general types of factors that limit population growth: density dependent factors that vary based on competition for resources and numbers of individuals and density independent factors that result in altering the number of individuals in a population regardless of its current size. Density dependent factors are the focus of this instructional segment. Density independent factors often relate to interactions with other parts of the earth system, such as weather patterns changes or catastrophic events, like hurricanes, floods, earthquakes, volcanoes, etc. Those factors are discussed more fully in instructional segment 6. Nonetheless, introducing these two categories together can help students understand ***proportion and quantity*** in density dependent cases and how that is eliminated in density independent cases. The California Education and the Environment Initiative (EEI) Curriculum can be used in conjunction with this instructional segment (for example, *Ecosystem Change in California* focuses on changes in a grassland ecosystem in the state).[1] This covers EPCs II and IV as students make connections to human impacts on ecosystem resources both in a positive and a negative way. Both density dependent and independent factors affect the ***flow of energy and matter*** within and into a system, which is ultimately the way in which they affect the size of populations.

Using **mathematical modeling** we can predict the effect certain interdependent factors have on the size of a population over time. The numbers of individuals within a population are dependent on flow into and out of the system (immigration and emigration) and changes within the system (birth rates and death rates). Population growth rates can be determined by the change in numbers of individuals (ΔN) divided by the change over time (Δt). Populations continue to grow exponentially over time until they reach a maximum load that the environment in which they live in can handle. Many factors are density dependent, therefore the bigger the population the more food resources, space, nesting sites or water need to be available. These resources are limited and can often change from year to year. The limitations set the parameters for how large a population can get in an ecosystem, this is known as the carrying capacity. Students can collect data using simulations and graph the results, which will model how different parameters affect populations[2]. Some of these simulations can demonstrate the adverse effect of running low on a resource and what that does to a population. The

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[1] http://www.californiaeei.org/ there are curriculum units that cover some of the NGSS bundles outlined in this chapter.

[2] 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 generate data that they can then use to graph and analyze results.

graphs can then pictorially show these types of changes. Initially growth will be exponential but eventually N will increase to a point where there will be competition for the resources and the graphs will level off indicating the carrying capacity of that population or, if resources are depleted the line on the graph will turn back down and move towards zero.

One of the resources organisms compete for is the food from which they obtain their energy. Organisms store energy within the chemical bonds of the matter in their bodies. As individual organisms and populations grow more plentiful, more total energy is stored. Another way to measure the productivity of populations in an ecosystem besides their N is in terms of biomass, the dry weight of all of the living organisms in an ecosystem, which is related to the amount of energy available for these organisms. As a general rule of thumb, when an animal eats, it is only able to store about 10% 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 utilized 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% of 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** of this energy pyramid, scientists find that very large populations of producers are required to support much smaller populations of tertiary consumers for the ecosystem to remain ***stable***. **Mathematical models** utilize this principle to predict the size of populations given the size of populations at other trophic levels. Students can explore many computer simulations and hands on demonstrations that make the connection between energy consumption and population size.

The way that ***energy flows*** from abiotic (non-living forms) to biotic (living) forms in an ecosystem is through matter: producers take energy from the Sun (usually) and use it to convert inorganic compounds into organic materials that make up their bodies, and then that matter cycles up through consumers and decomposers. Most nutrients (matter) are in a form that is 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 restructuring from abiotic to biotic forms involves living processes. For carbon it is photosynthesis and cellular respiration (discussed in Instructional segment 2 and the figure below), and for nitrogen it is through nitrogen fixing bacteria changing it into nitrates and then changing again from ammonia and nitrates into nitrogen through bacteria decomposers. In rare cases, abiotic processes can do a similar job; rain drops can carry nitrogen from the air into the soil where lightning strikes can add the necessary energy to fix the molecules into nitrates. All nutrients required by living organisms are involved in similar nutrient cycles with inorganic materials that can be discussed in association with relevant processes (such as the phosphorous cycle during a discussion of DNA or the calcium cycle during a discussion of climate change and hard-shelled marine organisms). Students can develop **models** on paper, with technology or as a chemical model using organic chemistry molecule kits and show how simple inorganic molecules are made into larger organic molecules and then how they cycle back to the simple inorganic molecules. Emphasis should be placed on the fact that most matter cycles through the atmosphere into the biosphere as explained above. Engineering practices that involve taking components and building them into bigger components can also be emphasized here, for example using kids building blocks or a chemistry molecule kit to show how smaller pieces are used to make bigger pieces and these organize into a known structure.

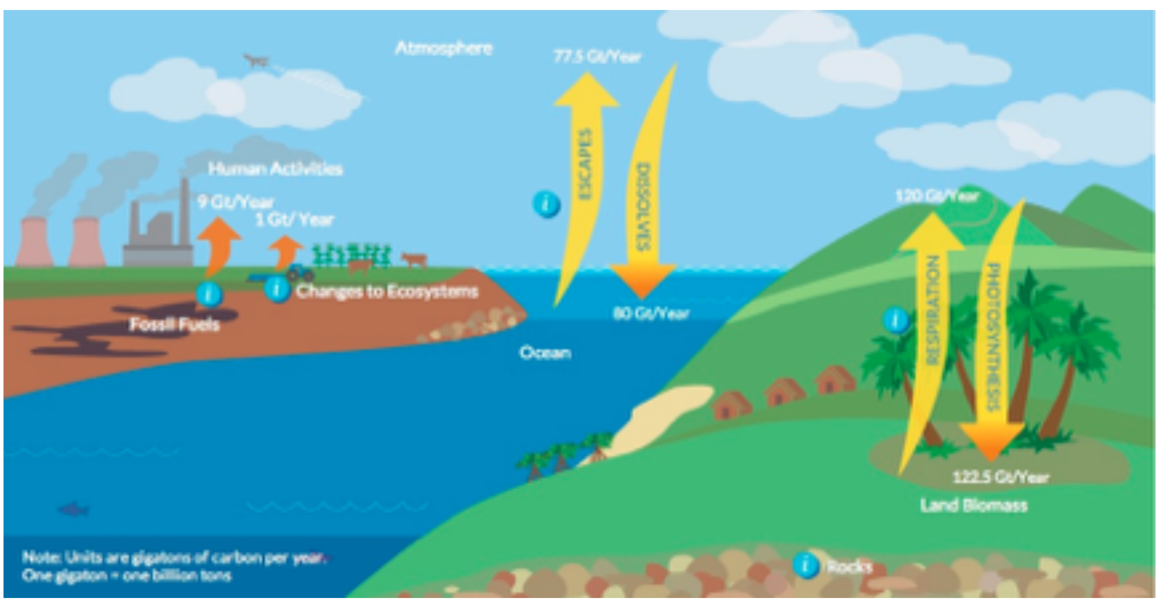

Figure 1. The carbon cycle from abiotic to biotic forms. (Used by permission from Sussman [need year])[3]

Up to this point, this instructional segment has considered how ***energy and matter flow*** between populations in an ecosystem and how that flow helps determine the size of a given population. Now, we zoom in and see how in fact each population itself acts like a system whose members can interact. Students will look closely at the behaviors of populations to assess their impact on survivability. For a population to succeed and not become a genetic dead end, the gene pool of the population (this is the sum of all the alleles in a population and is explained more below) 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.

Viable individuals within populations have the ability to better compete for resources such as food and protected living spaces. Though they still may not have enough food or safety they have some food and safety and are able to reproduce and pass on their alleles. Individuals within some populations rally around the young to help in the raising and protection of the young. It is important that some of the members of the population reproduce but not all need too as long as others help "raise" the young and keep the gene line going. These individuals are known as altruistic. This type of behavior is seen in bees and ants working in colonies, and other animals in herds, flocks, and schools surrounding their young to protect them from predators. This is even seen in human populations where extended family (family members who are biologically related) help raise the young. There may be a kin selection process occurring with these examples where the more genetically related an individual is to the offspring the more likely the individual will "help" (motivated by the possibility of allowing some of its genetic code to persist). Or, it may be that group selection does not require an actual kinship relationship, but instead involves other factors. The actual mechanism that promotes altruism is debated but is definitely based on a cost:benefit ratio where the individual ultimately receives some direct or indirect benefit for its effort. Altruism is seen

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[3] http://www.britannica.com/EBchecked/topic/65875/biogeochemical-cycle

mostly in species that live in social population groups, but there are definitely many populations that are NOT altruistic. Regardless of the theoretical basis for altruism, students can directly observe populations working together (having an ant colony in the classroom or watching videos that demonstrate the hunting and herding behaviors in animals) in order to gather **evidence** that organisms within a population work together to survive and reproduce. Students then use the evidence to write or present an **argument** that altruistic behavior is an important part of survival for some populations.

Living Earth (3 course Model) Snapshot: Does living as a group or individual help you survive?

Mr. T starts class showing a 3 minute YouTube video on Prairie Dogs and how they sound alarms to protect their family instructional segments against snakes as filmed by National Geographic (NatGeoWild 2011). He then asks the students to do a quick write on what behavior the prairie dogs use to protect themselves and how did that behavior help their family?

Students will play a game that is actually a physical **model** of individual and group behavior. Students use their bodies to represent components in a predator-prey ***system***. Since Mr. T has 30 students he designates 2 students who will act as predators. He needs an even number of students as prey, so the 28 students that are left are now prey. Mr. T now randomly hands each prey a white index card that has a color code on it. Each color represents a different genotype. Mr. T set the cards up ahead of time so that there are 4 cards for each color (i.e. 4 blue cards, 4 yellow cards, 4 green cards, 4 red cards, etc.),

For the first round (prey living as *Individuals)* the predators and prey will NOT have knowledge about the individual's genetics (in other words they will not know who is genetically related to whom). Mr. T instructs the 28 prey to randomly wander around the open area and after one minute he signals the predators to "attack". The predators then tag a prey. That individual steps out of the group and the rest of the students continue wandering and again Mr. T signals for "attack" and again each predator selects an individual who then steps out of the group. After 7 attacks 14 individuals should have been tagged (this represents half of the population of prey). Now a recorder can tally all the colors left on a shared class spreadsheet showing how many of each genotype survived (for example, 0 blue, 1 yellow, …)

Now Mr. T assigns two different students as predators and tells them to go sit in the corner and hide their eyes while he re-distributes the index cards to the remaining 28 students who are again the prey. This time he tells the prey students to quietly (so the predators don't know) find the other students who has the same color as they do. These four students have the same genotypes and represent a grouping of kin. The second round (*altruistic prey in groups*) now begins. Since Mr. T has a big open area he will blind-fold the predators. This is so they cannot "learn" about genotypes and relatives within the prey groups. The group instructional segments now randomly wander in the space and again Mr. T signals the predators to "attack". The groups can surround an individual so that when they are tagged the individual prey is "saved" and that prey does not get eliminated. Each genotype/color group gets only ONE save in this round and after that save if anyone in the group is tagged again, they will be eliminated. This rule is designed to simulate the cost: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 continues for a total of 7 "attacks"/rounds. This time there may be less than 14 individuals that were eliminated due to the individuals who were saved by the "herding" effect of their group. Now a recorder can tally all the colors and numbers of individuals for each color left in the group on the shared class spreadsheet.

Mr. T reassigns the roles of each of the students (picking new predators and shuffling the genotype cards) to prevent "learning" by predators. And does each scenario one more time.

After the class completes the four rounds of the game, Mr. T has the students look at the whole class data that has been recorded. He defines the terms
Individual Fitness – Your ability to pass on your genes.
Inclusive Fitness – Your individual fitness plus indirect fitness due to belonging to a group that herds to save individuals.
Mr. T then asks the students to complete a questionnaire about the similarities and

Connections to the CA NGSS:	
Science and engineering practices	**Disciplinary core ideas** **Crosscutting concepts**
Developing and using models	LS2.D: Social Interactions and Group Behavior (Group behavior has evolved because of increase in chance of survival) Cause and Effect
Connections to the CA CCSSM: N/A	
Connections to CA CCSS for ELA/Literacy: RST.9-10.8, RST.11-12.1 RST.11-12.7 RST.11-12.8	
Connection to CA ELD Standards : ELD Pt.I.9-10.1-2, 5, 6b, 9, 10a, 10b. Ex,	
Connections to the CA EP & Cs: N/A	

Students will build on this basic understanding of the ecosystem as a system of interacting components when they return to ecosystem dynamics and human impacts on ecosystems in the final instructional segment of the course (instructional segment 6). It is appropriate to introduce some of the issues in the context of this instructional segment as well. For example, the activities of urbanization, building of dams, and dissemination of invasive species are active parts of the ***energy and matter flow*** within almost all ecosystems, even those that appear relatively ‘undisturbed’ Students can be encouraged to study local ecosystems near their schools to observe populations of plants and animals, identify specific threats to biodiversity, consider alternative proposals to lesson those impacts. Instructional segments 2 through 5 of the course explain many of the mechanisms that drive the processes described in this instructional segment. As they progress through, students should be mindful of the role that these smaller-scale mechanisms can play in solving larger scale problems