Living Earth Unit 6

Ecosystem Stability & the Response to Climate Change

Background for Teachers and Instructional Suggestions

In this instructional segment, students will study the effects of natural or human induced changes on ecosystems, and relate these changes to the effects they have on population interactions. In the previous instructional segments students expanded on their knowledge of natural factors like food, habitat resources, and weather that can affect the size of a population. At the middle grade level, students learned that any change, either physical or biological, to an ecosystem can lead to a change in populations living in that ecosystem (*MS-LS2-4*). Many of the human-induced changes in ecosystems have unintended consequences, possibly because humans ***caused*** a ***change*** to an ecosystem for one reason without thinking through the long term ***effects*** on other aspects of the ecosystem, or because of other priorities (*EP&Cs Principle V*). For example, humans clear-cut the tropical rainforests in order to provide more land for farming. This change to the cycling of matter in the forest caused infertile soil and flooding, thus farming can no longer happen and the forest is gone. Other negative changes to an ecosystem can be natural and might or might not affect living populations within the ecosystem. If the negative change results in competition for resources, food or shelter, then the impact on population size will be density dependent. This pressure could cause a shift in the ecosystem as a whole; if the population ends up depleting or eliminating resources then the ecosystem may not be able to recover to its original state.

Populations with variation in their gene pool are more often able to withstand selective pressures as long as some of the individuals' phenotypes are advantageous for the environment. Often, there are many variations in a population that do not confer particular advantages at the moment. However, if there is a change in the environment, these phenotypes may then have an advantage. Those individuals that survive and reproduce living offspring have the advantageous phenotype. The advantageous phenotype that survived while others disappeared is called an adaptation. It is important for students to understand that the scientific definition of adaptation is genetically based. The environment does not “cause” an organism to change its genotype or “adapt” to its new environment, rather the variant already exists and becomes advantageous for survival and reproduction in a changing environment.

Biologists do not just consider these adaptations qualitatively. Building on the mathematical reasoning learned in middle school for looking at probability and statistics students can generate more complex **mathematical models**. These can expand on the data collected and **analyzed** in instructional segment 4 by continuing to look at trends of inheritance ***patterns*** of certain traits over time. More than one trait can be followed to determine whether there is significant selective pressures on a specific phenotype (Phenotype I) or whether the changes observed are linked to another phenotype (Phenotype II) that is more favorable (and Phenotype I is brought along because the genes are linked on the same chromosome). Models allow hypotheses to be generated and predictions made. Testing the generated hypothesis with computer simulations or looking at several generations of data can provide evidence that suggests the type of selective pressure affecting a population (e.g., natural selection, immigration, selective mating, population size or introduction of new mutations), and further analysis can lead to a conclusion about what is happening in a particular population.

Climate Change Background

Many of the changes facing ecosystems today are related to changes in abiotic factors due to climate change. Before understanding the effects of climate change, it’s important to first examine the causes. While the details of global climate change can be very complex and technical, the underlying science is fundamentally simple and has been known for a long time. The main ideas relate to:

- the flows of energy into, within and out of the Earth system;
- Earth’s cycles of matter, especially the carbon cycle; and
- the effects of human activities, especially the combustion of fossil fuels.

Students can make a conceptual model of Earth’s energy budget by thinking about it like a family’s budget and bank account where money flows in, is saved, and can flow out. Solar radiation represents the income. Earth’s global average temperature measures the amount of heat stored internally in Earth's system and so it is like the account balance, and energy radiates out into space much like a family spends money. As long as the income matches the expenses, the account balance remains steady. Cutting back on spending causes the account balance to increase.

Most of the sunlight that reaches Earth is absorbed and is transformed to thermal energy. If there were no atmosphere to hold that energy, it would heat radiate right back out into space as infrared radiation, a lot like a family without a bank account is likely to spend money as fast as it is earned. Gases in the atmosphere, such as CO_2, absorb infrared energy heading into space and cause it to remain within the Earth system for a longer period of time. Because these gases have the same effect as a greenhouse where heat is trapped inside the system, gases like CO_2 are referred to as 'greenhouse gases.' By increasing the amount of greenhouse gases in the atmosphere, human activities are increasing the greenhouse effect and warming Earth's climate.

The link between increasing greenhouse gases and more heat trapped in the Earth is a simple ***cause and effect*** relationship, but ***systems*** with complicated inner workings like the Earth's system of systems can often give rise to more complicated chains of ***cause and effect*** referred to as feedbacks. Climate scientists are particularly concerned about feedback effects that could increase the amount and rate of global climate change. One example is that warmer temperatures lead to higher rates of forest fires. As forests burn, they release CO_2 into the atmosphere, which leads to more warming. This kind of feedback loop amplifies or reinforces the change, and the distinction between 'cause' and 'effect' begins to blur. The clarification statements in the *CA NGSS* and many scientists use the term 'positive feedback', but this term should be replaced because it leads to confusion, as many reinforcing feedbacks have very negative outcomes.

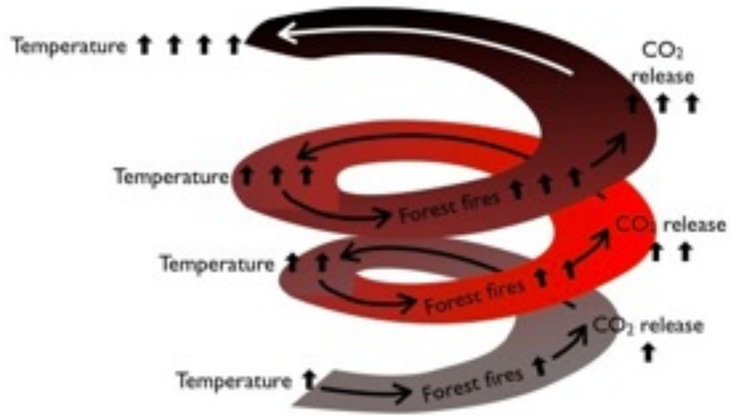

Figure 8. A reinforcing ('positive') feedback in Earth's climate system. As the planet warms, forest fires will grow in frequency and extent, which will release more CO_2 into the atmosphere which will in turn make temperatures rise even more. Image credit: (CC-BY-NC-SA) by M. d'Alessio, based on a draft by A. Sussmann)

A different kind of feedback loop reduces the amount of change. For example, forest fires not only release CO_2, but they also release aerosols (dust) in the atmosphere. That dust causes more of incoming solar energy to be reflected before it has a chance to be absorbed by the planet, thereby decreasing global temperatures. More warming could cause more reflection, which would then lead to less warming again. This kind of feedback balances out changes.

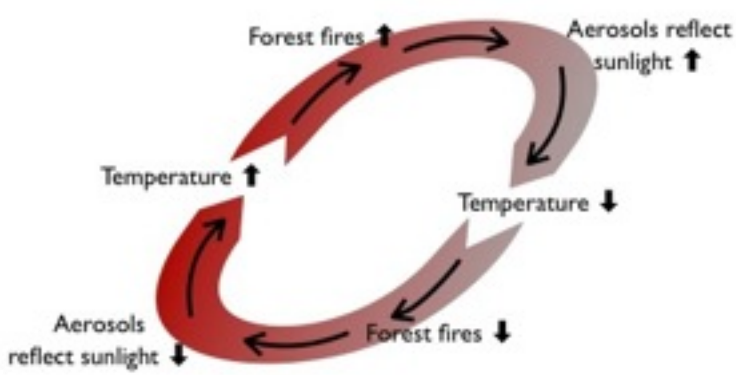

Figure 9. Counter-balancing ('negative') feedback. Global warming may increase the extent and frequency of forest fires. These fires release aerosols (dust) that reflect more sunlight, thereby causing temperatures to decrease. Temperatures stabilize, as when an

air conditioner turns on and off to control the temperature in a climate controlled house. Image credit: (CC-BY-NC-SA) by M. d'Alessio based on a draft by A. Sussman

Predicting Climate Change Impacts on Ecosystems

Many of the feedbacks in climate change involve ecosystems as part of the chain of events and will cause drastic changes to the abiotic conditions. How much will ecosystems change? Global climate models allow scientists and students to see how the climate is expected to change as greenhouse gases trap more energy in the atmosphere. Because of the linkages between different components of Earth's ***systems***, the impacts extend to all of Earth's systems (Figure 4 shows an example of a few of these linkages).

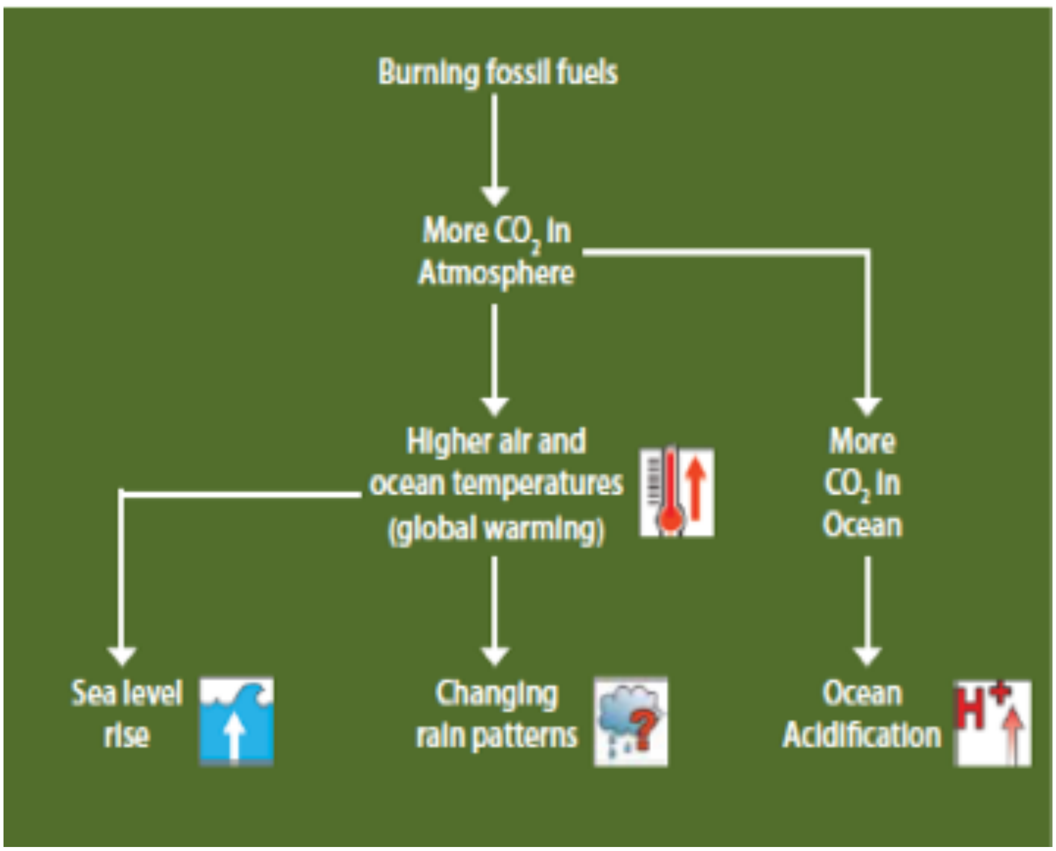

Figure 4. One example of how humans affect the climate, which impacts all parts of Earth's systems. Image credit: (Figure by A. Sussmann)

Models can help scientists predict how a climate change can effect populations within an ecosystem, especially over time. Students can employ simple computational simulations to explore real world population impacts (*HS-ESS3-6, HS-LS2-1*). For example, sea stars in California's coastal tide pools have seen a recent spike in an illness called 'wasting disease' that causes death in a matter of a few days. The problem is dramatic and students can even report observations of afflicted organisms to a long-term monitoring project online.[1] The cause is currently unknown, but one hypothesis is that a species of *Vibrio* bacteria may infect them. Bacteria thrive in warmer temperatures, so seasonal cooling is an important moderator of bacteria populations. Climate forecasts predict that winter temperatures will increase. Will this cause a *Vibrio* bacteria population explosion? Students can design a computer **model** by looking up laboratory experiments on bacteria growth (freely available online) and have their model mimic bacteria growth in ocean water temperatures that match climate forecasts. The model could also include the impact on coastal tide pool populations that can be infected by the bacteria. Other similar problems can be modeled such as the rise in malaria due to mosquitos extending their range to higher elevations or changing growing conditions suitable for rice, wheat, and other food staples. The High School Four Course Model - Chemistry section describes a similar simulation exploring the impact of ocean acidification on plankton species. Fully meeting the PE *HS-ESS3-6* requires that students not only obtain information about the problem, but also use simulations of the interaction of different Earth systems (including the biosphere) to demonstrate the specific impacts of human activities. They can also use these computer simulations to evaluate potential solutions to these problems (*HS-ETS1-4*), as described below.

How can humans design solutions to the growing impact of climate change and its effect on ecosystems and populations? Conservation biology focuses on ways of saving endangered and threatened species (both animal and plant species), and is in essence a form of engineering. Conservation biologists support the use of wildlife

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[1] http://www.eeb.ucsc.edu/pacificrockyintertidal/data-products/sea-star-wasting/

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corridors (these link large areas of land to other large areas so animals can migrate safely), habitat restoration, protection of endangered species, protection of hotspots of species rich regions, maintenance of larger environment regions instead of habitat fragmentation, observing genetic diversity in small populations and effects of climate change on all ecosystems. As climate shifts, some organisms might need to migrate to new locations during part or all of the year, but their pathway could be interrupted by a freeway, fence, or other obstacle. Teachers can present students with a challenge to evaluate several possible plans for a wildlife corridor beneath a freeway and the possible expansion of a protected open space, which would allow them to use engineering design practices to solve a real-world problem in an ecosystem using the tools and strategies of conservation biology.

Living Earth (Three Course Model) Snapshot: Shrinking Pika Habitat

Mr. R starts class off by showing a slideshow of adorable creatures called pikas that live in the eastern Sierra Nevada mountains and other mountains around the world. Pikas' bodies are so well adapted to the colder climates of higher elevation that they can overheat in certain temperatures and die in temperatures as low as 80 degrees for a few hours. While other animals can relocate higher up in the mountains, pikas already live at the highest elevations and they couldn't survive the migration down from one high peak to another. The pikas serve a unique role in the high altitude ecosystems in which they live: they build piles of grass that help fertilize the soil and fix nitrogen and they are also a food source for larger predators within the sparsely populated high altitude regions. Without an understanding of the interweaving of life with the Earth's systems it is hard to justify "what all the fuss is about" for a single small organism.

Mr. R tells students that they will be making a kinesthetic **model**, a model using their bodies, of the effects of climate change on pikas. Mr. R scattered wooden sticks supplies outside on the soccer field before class to represent plants that the pikas will collect for their winter food supplies. He placed orange cones out in a triangle shape with the peak of the triangle representing the peak of a mountain and the long side representing the lowest point on the mountain that pikas can survive. If they stray below the line, they will overheat and could die. Each person plays the part of a pika and must collect sticks and bring them back to their burrow, one at a time (pikas cannot carry much). By the time winter comes, they must have collected 10 sticks. Students run around and frantically collect the sticks until Mr. R announces the coming of winter. He then shrinks areas enclosed by the cones announcing that global warming has limited the area. Students find that there are insufficient sticks for all of them to survive. He repeats the process a third time, keeping the size of the mountain constant but giving students more time to search for sticks, representing a longer summer. More of the pikas survive.

Students return to the computer lab and Mr. R shows them a computer simulation of the exact situation that they encountered in the kinesthetic activity. He emphasizes that both are examples of **models**. Students can adjust the temperature and watch how the size of the pika habitat shrinks and grows. The simulation is sophisticated and

Connections to the CA NGSS: **Science and engineering practices** **Disciplinary core ideas** **Crosscutting concepts** Analyzing Data Defining problems LS2.C Ecosystem Dynamics, Functioning, and Resilience LS4.D Biodiversity and Humans ESS2.D Weather and Climate ESS2.E Biogeology ESS3.C Human Impacts on the Earth System ESS3.D Global Climate Change ETS1.A Defining and Delimiting Engineering Problems Cause and Effect
Connections to the CA CCSSM: < CDE, please add connections>
Connections to CA CCSS for ELA/Literacy: < CDE, please add connections>
Connection to CA ELD Standards : < CDE, please add connections>
Connections to the CA EP & Cs: < CDE, please add connections>

Many solutions to these problems may focus on addressing the causes of climate change, such as the global reliance on fossil fuels for energy generation. Both High School Four Course Model – Chemistry and Physics sections consider these questions and links should be made to those courses. In the past comparative costs of different energy sources have been based on dollar cost to the consumer, but new studies have taken into account a wider variety of costs including degradation of natural ecosystems, health impacts, and water and air pollution. This course on the Living Earth is uniquely positioned to emphasize the importance of these measures when evaluating competing design solutions in all disciplines (HS-ETS1-3). Content from the EEI curriculum helps support many of these concepts, including the lessons on Biodiversity: *The Keystone to Life on Earth and the Greenhouse Effect on natural systems.*

This instructional segment is the last instructional segment taught in the course and can include a culminating project that looks at how organisms maintain life, how life relates to the rest of Earth's systems, and then how humans (including the student themselves) can slow down or reverse some of the damage they have done by changing those systems. The students should use **evidence** for their **explanations** and **arguments**, and include designing solutions. They might research the impacts on a specific organism or compare different organisms (for example a human, redwood tree and/or *E. coli*). Using multiple resources and multiple ways of presenting explanations can be integrated into students English Language Arts courses, providing opportunities for work on writing skills and library searching. The projects should use government resources such as the Environmental Protection Agency website, which will help students use evidence in their writing.