High School Three-Course Model Living Earth Snapshot 7.4: How Did We Eradicate Diseases in the US?

California students, are part of this process. No individual factor is the singular cause of this health revolution. Ms. H led a whole-class discussion during which they generated a collaborative concept map representing society as a **system [CCC-4]** in which changes to different components result in the revolutionary overall system behavior where infectious disease no longer dominates our lives and deaths.

IS6

Living Earth Instructional Segment 6: Ecosystem Stability and the Response to Climate Change

In this instructional segment students will study the effects of natural and human-induced changes on ecosystems and the populations within them. In the middle grades, 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). They now build on that knowledge to explore more complicated changes, many relating to shifts in global climate.

LIVING EARTH INSTRUCTIONAL SEGMENT 6: ECOSYSTEM STABILITY AND THE RESPONSE TO CLIMATE CHANGE

Guiding Questions

- What effects changes in ecosystems that ultimately effect populations?
- What are the changes that are happening in the climate and what effects are those having on life?
- How are human activities impacting Earth's systems and how does that affect life on Earth?
- What can humans do to mitigate their negative impact on the environment?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. [Clarification Statement: Examples of changes in ecosystem conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood; and extreme changes, such as volcanic eruption or sea level rise.]

HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.* [Clarification Statement: Examples of human activities can include urbanization, building dams, and dissemination of invasive species.]

LIVING EARTH INSTRUCTIONAL SEGMENT 6: ECOSYSTEM STABILITY AND THE RESPONSE TO CLIMATE CHANGE

HS-LS4-5. Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species. [Clarification Statement: Emphasis is on determining cause and effect relationships for how changes to the environment such as deforestation, fishing, application of fertilizers, drought, flood, and the rate of change of the environment affect distribution or disappearance of traits in species.]

HS-LS4-6. Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.* [Clarification Statement: Emphasis is on designing solutions for a proposed problem related to threatened or endangered species, or to genetic variation of organisms for multiple species.]

HS-ESS3-5. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems. [Clarification Statement: Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition).] *[Assessment Boundary: Assessment is limited to one example of a climate change and its associated impacts.]*

HS-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity. [Clarification Statement: Examples of Earth systems to be considered are the hydrosphere, atmosphere, cryosphere, geosphere, and/or biosphere. An example of the far-reaching impacts from a human activity is how an increase in atmospheric carbon dioxide results in an increase in photosynthetic biomass on land and an increase in ocean acidification, with resulting impacts on sea organism health and marine populations.] *[Assessment Boundary: Assessment does not include running computational representations but is limited to using the published results of scientific computational models.]*

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

HS-ETS1-4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a practice or disciplinary core idea.

LIVING EARTH INSTRUCTIONAL SEGMENT 6: ECOSYSTEM STABILITY AND THE RESPONSE TO CLIMATE CHANGE

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-1] Asking Questions and Defining Problems [SEP-4] Analyzing and Interpreting Data [SEP-5] Using Mathematics and Computational Thinking [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence	LS2.C: Ecosystem Dynamics, Functioning, and Resilience LS4.C: Adaptation LS4.D: Biodiversity and Humans ESS2.D: Weather and Climate ESS3.D: Global Climate Change ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-4] Systems and System Models [CCC-7] Stability and Change Influence of Science, Engineering, and Technology on Society and the Natural World

Highlighted California Environmental Principles and Concepts:

Principle I The continuation and health of individual human lives and of human communities and societies depend on the health of the natural systems that provide essential goods and ecosystem services.

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

Principle III Natural systems proceed through cycles that humans depend upon, benefit from and can alter.

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

Principle V Decisions affecting resources and natural systems are based on a wide range of considerations and decision-making processes.

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

CA CCSS for ELA/Literacy Connections: RST.9–10.8; RST.11–12.1, 2, 7, 8; WHST.9–12.2.a–e, 7, 8, 9

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

In high school, students confront complicated chains of **cause and effect [CCC-2]** that can work within ecosystems. For example, many human-induced **changes [CCC-7]** in ecosystems have unintended consequences, meaning humans did something to an ecosystem for one reason without realizing that there would be changes to other components of the ecosystem, or they had to balance other priorities (EP&C V). In other cases, natural changes to the physical system can cause cascading impacts on the living populations within ecosystems. A flood might drown many of the animals that live within the floodplain area (a density-independent factor), but this may in turn cause other animals to migrate and compete for resources or territory (density-dependent factors). 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. Students can observe these changes through data-rich case studies and through computer simulations. Once they have developed conceptual models of ecosystem changes, they should be able to **evaluate different claims [SEP-7]** about the impacts of a new, hypothetical change (HS-LS2-6).

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 population given 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 produce living offspring are said to have the advantageous phenotype. The advantageous phenotype that survived while others disappeared is called an *adaptation*.

The majority of this instructional segment centers on how populations respond to the varied stresses due to climate change. What sort of changes will occur in ecosystems? What sort of variations will be beneficial to populations?

Climate Change Background

Many of the changes facing ecosystems today are related to changes in abiotic factors caused by climate change. Before understanding the effects of climate change, it is important to first examine the causes. While the details of global climate change are 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;
- the effects of human activities, especially the combustion of fossil fuels.

Students can make a conceptual model of Earth's energy budget using an analogy of the line for a ride at an amusement park. The constant stream of eager visitors arriving at the end of the line represents solar radiation. As visitors get on the ride at the front of the line, they act like energy radiating out into space. Earth's global average temperature measures the amount of heat stored internally in Earth's system and so it is like the number of people waiting in line at any given time. The line will remain the same length if people get on the ride as quickly as new people arrive at the end of the line. Earth's temperature will remain **stable [CCC-7]** as long as the energy input and output remain unchanged.

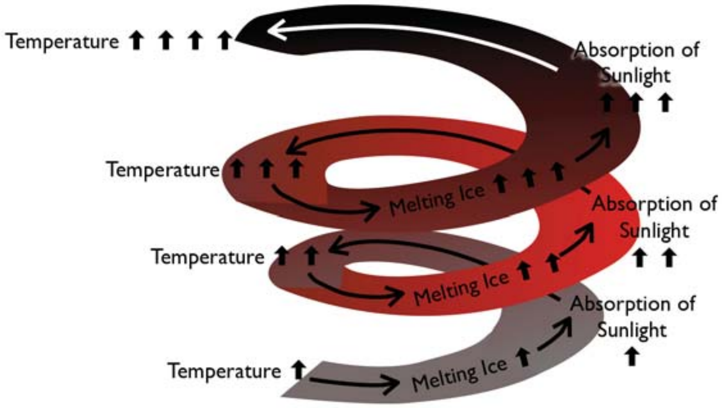
Earth's energy input comes almost entirely from the Sun. While a small amount of radioactive decay within Earth's interior generates heat, the flow of solar energy to Earth's surface is about 4,000 times greater than the flow of energy from Earth's interior to its surface. Relatively small changes in the solar input can result in an Ice Age or the melting of all of Earth's ice, much like the sudden arrival of a large group at an amusement ride can cause the line to quickly grow longer. The line will stabilize at this new length (without continuing to grow) as long as the influx of people returns back to its original rate. Planets can do the same thing, maintaining their temperature at a new value after a temporary disturbance.

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 radiate right back into space as infrared radiation (like an unpopular amusement park ride where people get on as soon as they arrive because there is no line). Gases in the atmosphere, such as CO_2, absorb infrared energy heading into space and cause it to remain within the Earth's system for a longer period of time. Because these gases have the same effect as a greenhouse, with heat trapped inside the system, gases like CO_2 are referred to as *greenhouse gases*. Calculations by scientists show that if Earth had no greenhouse gases, its surface temperature would be near 0°F (or -18°C) instead of its current value of a much warmer 59°F (15°C). The energy coming into the Earth is still balanced almost exactly by what is leaving the planet, but there is enough heat trapped in the system to allow life to thrive (like the amusement park ride whose line is always the same length).

By increasing the amount of greenhouse gases in the atmosphere, human activities are increasing the greenhouse effect and warming Earth's climate. In a given year, less energy leaves Earth than arrives. It is like one of the seatbelts breaking on the amusement park ride and fewer people are able to get on the ride. All of a sudden, the line gets longer and longer as new people arrive because people are not able to leave the line as quickly at the front. At the amusement park, this might lead to impatient children. On Earth, the imbalance in energy flows leads to an overall rise in average temperature.

Amusement parks and planets are **systems [CCC-4]** with complicated inner workings. When lines for one ride at an amusement park get too long, visitors inside the park may respond by going to another ride or park operators may add additional workers or cars to help move people through more quickly. Similar changes happen in Earth's web of systems. While the greenhouse effect seems like a simple **cause and effect [CCC-2]** relationship viewed from outside the system, interactions *within* the system 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 global warming is clearly reducing the amount of ice on our planet. Glaciers around the world are shrinking in size and even disappearing. The amount of ice covering the ocean in summer and fall is also shrinking. As the ice melts, the surface beneath it is darker in color and absorbs more incoming sunlight. More absorption causes more heating, and this heating causes even more absorption of sunlight (figure 7.11). This kind of feedback loop amplifies or reinforces the change, and the distinction between cause and effect begins to blur as each effect causes more change. The clarification statements in the CA NGSS and many scientists use the term *positive feedback*, but because many forms of feedback have very negative outcomes, the term positive feedback often leads to confusion. This term could be replaced by a more descriptive term, such as *reinforcing feedback*.

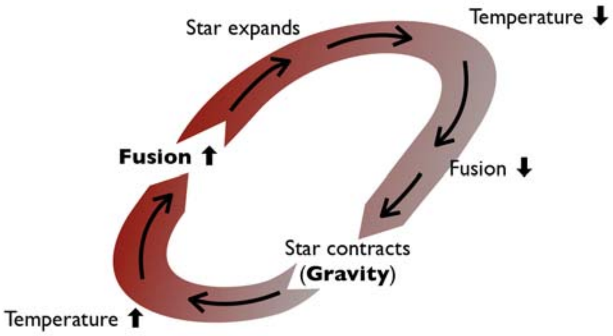
Figure 7.11. A Reinforcing Feedback in Earth's Climate



A reinforcing feedback in Earth's climate system. As the planet warms, more ice will melt, which will expose darker ground surfaces that absorb more sunlight, which will in turn make temperatures rise even more. Diagram by M. d'Alessio and A. Sussman

A counterbalancing feedback loop reduces the amount of change (figure 7.12). For example, warmer temperatures cause more water to evaporate which enables more clouds to form. Clouds reflect sunlight back into space; therefore, more clouds cause more incoming solar energy to be reflected before the planet can absorb it. This causes decreasing global temperatures. More warming could cause more cloud formation and reflection, which would then lead to less warming again.[6] These changes are opposite and can balance each other out.

Figure 7.12. A Counterbalancing Feedback in Earth's Climate System



Temperature changes cause changes to the number of clouds because of evaporation. Clouds, in turn, reflect light. Diagram by M. d'Alessio and A. Sussman

Predicting Climate Change Impacts on Ecosystems

Many of the feedbacks in climate change involve ecosystems as part of the chain of events, resulting in 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 [CCC-4]**, the impacts extend to all of Earth's systems (figure 7.13 shows an example of a few of these linkages).

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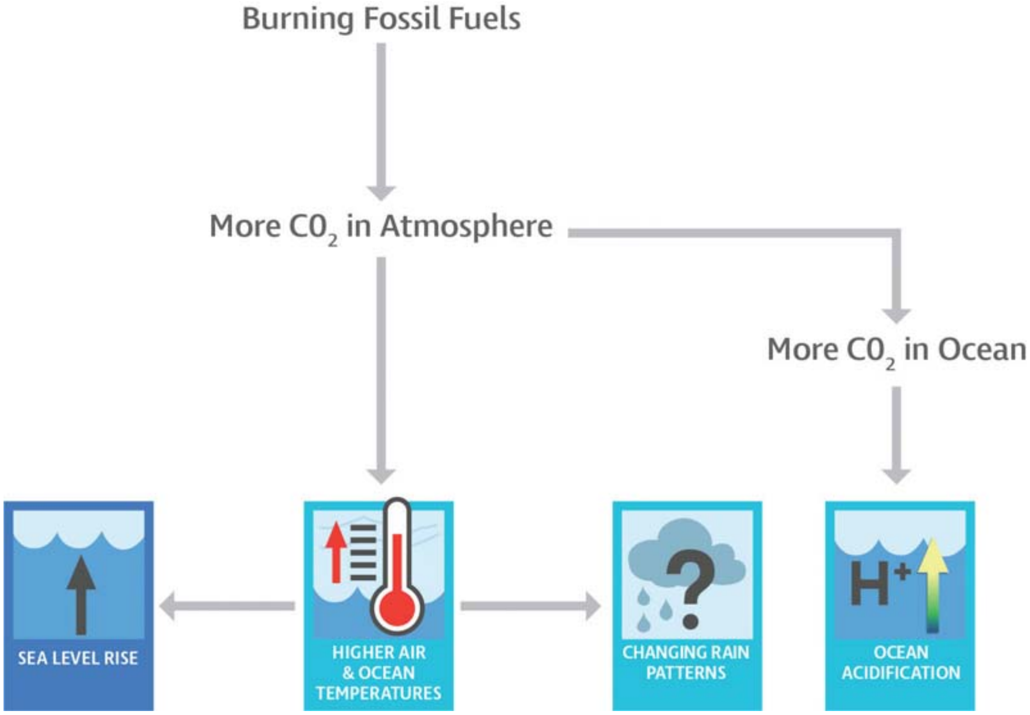
[6] Even though this example describes a counterbalancing feedback involving clouds, clouds are also involved in a reinforcing feedback where they trap more heat, causing more evaporation, and more clouds that trap more heat. Both of these mechanisms occur on Earth. The question researchers are currently trying to answer is, "Which feedback loop is more powerful, reinforcing or counterbalancing?" **Cause and effect [CCC-2]** gets very complicated in the Earth system

Figure 7.13. Human Impacts on the Earth System Related to Climate Change



One example of how humans affect the climate, which impacts all parts of Earth's systems. Illustration by Dr. Art Sussman, WestEd, and Lisa Rosenthal, WGBH n.d.

Models [SEP-2] 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 (see UC Santa Cruz, "Sea Star Wasting Syndrome" at http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link15). 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 [SEP-2]** 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. Students can use the model to assess the impact on coastal tide pool populations that are infected by the bacteria (HS-LS2-6). Other similar problems can be modeled such as the rise in malaria as mosquitoes extend their range to higher elevations or changing growing conditions suitable for rice, wheat, and other food staples (due to changes in rainfall and temperature). The chemistry section of the High School Four-Course Model (chapter 8) describes a similar simulation exploring the impact of ocean acidification on plankton species. Fully meeting 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).

High School Three-Course Model Living Earth Snapshot 7.5: Food Diaries

Everyday phenomenon: Different people eat different foods each day.

Ms. M partnered with the health teacher at her school to have students record everything they ate and drank for three days. Students entered their diets into an online tool (USDA “Supertracker” at http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link16) that reported their intake of different nutrients and they examined their individual diets in the health class. In Ms. M’s class, they used a different online tool to calculate the total carbon emissions from the production and transport of their food (CleanMetrics “Food Carbon Emissions Calculator” at http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link17). Students then entered all their data into a single online spreadsheet to compare each student’s carbon footprint from food and intake of nutrients like fat, sodium, carbohydrates, and fiber (though Ms. M hid the column with student names). The class **analyzed the data [SEP-4]** and noticed several **patterns [CCC-1]**, such as students that ate more vegetables and less meat had lower carbon footprints. Ms. M. asked students to create an infographic illustrating the foods that are both healthy for people and healthy for the climate. They prepared a presentation **communicating [SEP-8]** their findings to the people that ran the school lunch program and posted their infographic in the cafeteria.

Engineering Connection: Conservation Biology

When conservation biologists develop strategies to save endangered and threatened species, they are engaging in one form of engineering design. Conservation biologists help save these species by (1) supporting the use of wildlife corridors, which link large areas of land to other large areas so animals can migrate safely; (2) developing breeding programs for protecting endangered species; (3) identifying specific hotspots of species-rich regions worthy of extra protection and determining plans that provide sufficient protection; (4) arguing for the maintenance of larger environment regions instead of habitat fragmentation; (5) observing genetic diversity in small populations; and (6) monitoring the 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 pathways 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 [SEP-6]** in an ecosystem using the tools and strategies of conservation biology. As they **obtain more information [SEP-8]**, including the needs of people as well as plants and other animals, they refine their solution (EP&C V; HS-LS2-7).

High School Three-Course Model Living Earth Snapshot 7.6: Shrinking Pika Habitat

Anchoring phenomenon: Pikas live only at high elevations (and are adorable).

Mr. R started class off by showing a slideshow of adorable creatures called pikas that live in the eastern Sierra Nevada and other mountains around the world. Pikas' bodies are so well adapted to the colder climates of higher elevations that they can overheat in warm temperatures and die in temperatures as low as 80°F after a few hours. While other animals can relocate to higher locations in the mountains, pikas already live at the highest elevations and they could not survive the migration down from one high peak to another. The pikas serve a unique role in the high-altitude ecosystems where 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 interwoven nature of life with the Earth's systems it is hard to justify what all the fuss is about for a single small organism.

High School Three-Course Model Living Earth Snapshot 7.6: Shrinking Pika Habitat

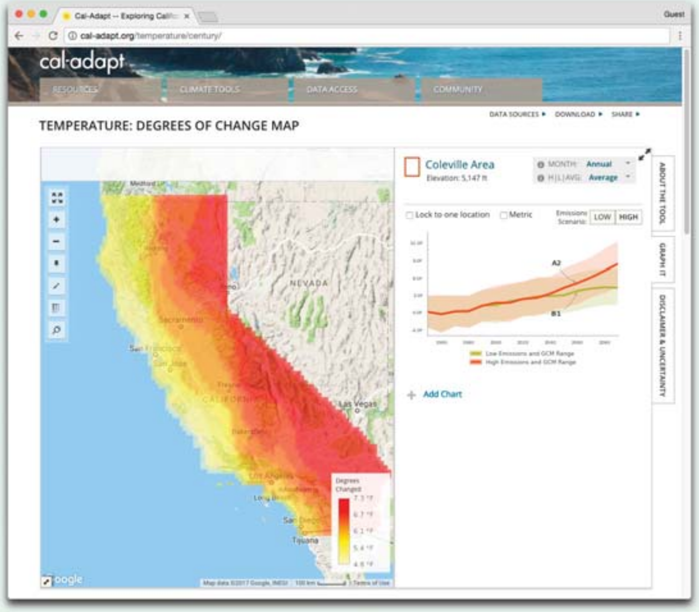
Investigative phenomenon: Global warming will increase the temperatures at high elevations.

Mr. R told students that they would be making a kinesthetic **model [SEP-2]**, a model using their bodies, demonstrating the effects of climate change on pikas. Mr. R scattered a supply of wooden sticks on the soccer field before class to represent plants that the pikas would collect for their winter food supplies. He placed orange cones 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 where pikas could survive. If they strayed below that line, they would overheat and could die. Each person played the part of a pika and had to collect sticks and bring them back to their burrow, one at a time (pikas cannot carry much). By the time winter came, they had to have collected 10 sticks. Students ran around frantically collecting sticks until Mr. R announced the coming of winter. He then shrank the area enclosed by the cones announcing that global warming had reduced the area. Students found that there were insufficient sticks for all of them to survive. He repeated 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 returned to the computer lab and Mr. R showed them a computer simulation of the exact situation that they encountered in the kinesthetic activity (HS-ETS1-4). He emphasized that both were examples of **models [SEP-2]**. Students could adjust the temperature and watch how the size of the pika habitat shrank and grew. The simulation was sophisticated and students could adjust the temperature month-by-month. They could explore the **effect [CCC-2]** of longer summers and see how that affected vegetation growth (so that pikas had more food available) or warmer winters, in which pikas needed less food to survive. Students then visited the California Energy Commissions, Cal-Adapt Web site (http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link18) and found specific temperature forecasts for the habitat of the pika in the Eastern Sierra (HS-ESS3-5). They saw that the average temperature in August was expected to rise by 10°F between 2000 and 2100 under one scenario, but only 3°F if humans emit less carbon dioxide from their use of fossil fuels (figure 7.14). Students quickly entered the temperature changes into their simulator to explore the impact of the predictions on the pika.

High School Three-Course Model Living Earth Snapshot 7.6: Shrinking Pika Habitat

Figure 7.14: Temperature Forecast for Habitat of the Pika



Source: California Energy Commission 2015

Investigative phenomenon: What can people do to protect pikas and the rest of their ecosystem?

Students recognize from the simulator that pikas do much better under the low-emission scenario than the high-emissions scenario (HS-ESS3-6). Students can analyze the problem and identify protection of the entire ecosystem as part of their criteria for their solution (HS-ETS1-1). As the environment warms what can humans do to help the pikas and their ecosystem? Students need to break the problem down into smaller, more manageable problems (HS-ETS1-2), identifying criteria and constraints for successful solutions, and then comparing alternative solutions against the criteria and constraints to determine which is most likely be successful. They then modify the computer simulation they used earlier to include the effects of their solution (HS-LS4-6). How can they parameterize their solution in computer code? How much does it benefit the pikas?

Source: Inspired by Parks Climate Challenge 2009

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 the chemistry and physics sections of the High School Four-Course Model (chapter 8) 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.*

Teachers of the high school biology course may want to culminate with a project in which students apply what they have learned about how organisms maintain life. For example, students could compare and contrast how a few different organisms maintain life (e.g. human, redwood tree, and *E. coli*). The students should use **evidence [SEP-7]** to support their **explanations [SEP-6]** and they should effectively **communicate [SEP-8]** their **models [SEP-2]**.

LIVING EARTH VIGNETTE 7.1: ANALYZING THE PAST, PRESENT, AND FUTURE OF MARINE MAMMAL EVOLUTION

Performance Expectations

Students who demonstrate understanding can do the following:

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-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. [Clarification Statement: Examples of changes in ecosystem conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood; and extreme changes, such as volcanic eruption or sea level rise.]

HS-LS4-1. Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence. [Clarification Statement: Emphasis is on a conceptual understanding of the role each line of evidence has relating to common ancestry and biological evolution. Examples of evidence could include similarities in DNA sequences, anatomical structures, and order of appearance of structures in embryological development.]

HS-LS4-5. Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species. [Clarification Statement: Emphasis is on determining cause and effect relationships for how changes to the environment such as deforestation, fishing, application of fertilizers, drought, flood, and the rate of change of the environment affect distribution or disappearance of traits in species.]

HS-ESS2-7. Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth. [Clarification Statement: Emphasis is on the dynamic causes, effects, and feedbacks between the biosphere and Earth's other systems, whereby geoscience factors control the evolution of life, which in turn continuously alters Earth's surface. Examples include how photosynthetic life altered the atmosphere through the production of oxygen, which in turn increased weathering rates and allowed for the evolution of animal life; how microbial life on land increased the formation of soil, which in turn allowed for the evolution of land plants; or how the evolution of corals created reefs that altered patterns of erosion and deposition along coastlines and provided habitats for the evolution of new life forms.] *[Assessment Boundary: Assessment does not include a comprehensive understanding of the mechanisms of how the biosphere interacts with all of Earth's other systems.]*

HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.* [Clarification Statement: Examples of data on the impacts of human activities could include the quantities and types of pollutants released, changes to biomass and species diversity, or areal changes in land surface use (such as for urban development, agriculture and livestock, or surface mining). Examples for limiting future impacts could range

LIVING EARTH VIGNETTE 7.1: ANALYZING THE PAST, PRESENT, AND FUTURE OF MARINE MAMMAL EVOLUTION

from local efforts (such as reducing, reusing, and recycling resources) to large-scale geoengineering design solutions (such as altering global temperatures by making large changes to the atmosphere or ocean).]

HS-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.* [Clarification Statement: Examples of Earth systems to be considered are the hydrosphere, atmosphere, cryosphere, geosphere, and/or biosphere. An example of the far-reaching impacts from a human activity is how an increase in atmospheric carbon dioxide results in an increase in photosynthetic biomass on land and an increase in ocean acidification, with resulting impacts on sea organism health and marine populations.] *[Assessment Boundary: Assessment does not include running computational representations but is limited to using the published results of scientific computational models.]*

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a practice or disciplinary core idea.

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-5] Using Mathematics and Computational Thinking [SEP-6] Constructing Explanations (for science) and Designing Explanations (for engineering) [SEP-7] Engaging in Argument from Evidence [SEP-8] Obtaining, Evaluating, and Communicating Information	LS2.A: Interdependent Relationships in Ecosystems LS2.C: Ecosystem Dynamics, Functioning, and Resilience LS4.A: Evidence of Common Ancestry and Diversity LS4.C: Adaptation ESS2.D: Weather and Climate ESS2.E Biogeology ESS3.C: Human Impacts on Earth Systems ESS3.D: Global Climate Change ETS1.B: Developing Possible Solutions	[CCC-1] Patterns [CCC-2] Cause and Effect [CCC-3] Scale, Proportion and Quantity [CCC-4] System and System Models [CCC-7] Stability and Change

LIVING EARTH VIGNETTE 7.1: ANALYZING THE PAST, PRESENT, AND FUTURE OF MARINE MAMMAL EVOLUTION

Highlighted California Environmental Principles and Concepts:

Principle I The continuation and health of individual human lives and of human communities and societies depend on the health of the natural systems that provide essential goods and ecosystem services.

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

Principle III Natural systems proceed through cycles that humans depend upon, benefit from and can alter.

Principle V Decisions affecting resources and natural systems are based on a wide range of considerations and decision-making processes.

CA CCSS Math Connections: S-ID.1, 6, 9; S-IC.6; MP.1, MP.2, MP.4, MP.7

CA CCSS for ELA/Literacy Connections: W.9–10.1a–f, 6; SL.9–10.1a–d, 4; RST.9–10.1, 3, 7, 9; WHST.9–10.1a–e, 6, 7, 9

CA ELD Connections: ELD.9–10.P1.1, 3, 6, 10

Introduction

Climate is an environmental factor from the geosphere that has a strong impact on populations in the biosphere. In this vignette, students examine how both year-to-year fluctuations in weather conditions and longer-term trends in climate have affected marine mammal populations. They analyze a variety of data sets, including fossils, amino acid sequences, population census, and temperature reconstructions over geologic time to identify patterns and correlations that provide clues to cause and effect relationships. Students are expected to integrate their knowledge of Earth systems and ecosystems as the changes introduced involve complex interactions among plate motions, climate, human activities, evolution, and population dynamics. While the data sets provide clues, there are no easy answers in this vignette—evidence supports many possible interpretations and no simple model is sufficient to explain all the observations. This complexity and uncertainty make the vignette an ideal culmination of the Living Earth course.

Length and position in course: This vignette describes two to three weeks of instruction that integrate many aspects of the Living Earth course.

Teacher background: Marine mammals include three different types: whales and dolphins (infraorder *Cetacea*), manatees and dugongs (order *Sirenea*), and seals and sea lions (clade *Pinnipedia*). Each type occurs at a different level of taxonomy. For simplicity, this activity refers to each by their common names. Despite their many similarities, these organisms evolved independently from different land mammals around the same times and in response to the same environmental conditions.

5E Lesson Design: This sequence is based on an iterative 5E model. See chapter 11 on instructional strategies in this framework for tips on implementing 5E lessons.

LIVING EARTH VIGNETTE 7.1: ANALYZING THE PAST, PRESENT, AND FUTURE OF MARINE MAMMAL EVOLUTION

Day 1: Problems Affecting Diverse Marine Mammals

Students are introduced to local challenges to marine mammals. They obtain and evaluate information about three different types of marine mammals. They ask questions about whether their similarities were inherited from a common ancestor.

Day 2: Fossil Evidence for Evolution

Students analyze a sequence of fossils, using patterns to trace the evolution of different marine mammals back to different land-dwelling ancestors.

Day 3: DNA Evidence for Evolution

Students analyze sequences of amino acids to determine relative similarity between the DNA of different marine and land-dwelling animals. DNA evidence confirms that the three different marine mammal species evolved separately from one another.

Days 4–5: Animals Evolve in Response to Climate Change

Students ask questions about the influence of climate changes on the evolution and biodiversity of different marine mammal species. They obtain information to support claims about complex cause and effect chains: changes caused by plate motion in the shape of ocean basins that caused changes in ocean currents that caused changes in climate that influenced evolution.

Days 6–7: Predicting Future Climate Impacts

Knowing that marine mammal species have been so strongly influenced by climate changes in the past, students analyze data about shorter-term impacts from El Niño on sea lion populations.

Days 8–10: Human Impacts and Human Solutions

Students obtain information about the extinct Steller’s sea cow to debate whether climate changes or human impacts caused its downfall. They evaluate different design solutions to protect modern day marine mammal populations.

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Day 1: Problems Affecting Diverse Marine Mammals (Engage)

Anchoring phenomenon: In 2015, marine mammal experts rescued three times the usual number of stranded sea lion pups on Southern California beaches.

Students watched a video that introduced the anchoring phenomenon about record numbers of sea lion pups rescued on Southern California beaches. The movie claimed that the mystery remains unsolved, but climate change may be to blame. Students discussed initial ideas about how climate change could have played a role. On the road to evaluating this claim during subsequent days, students investigated how marine mammals responded to ancient climate shifts and then analyzed recent trends.

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To ensure that students had some basic background knowledge about the diversity of marine mammals, Mr. T organized a jigsaw during which each student **obtained information [SEP-8]** to become experts about one of the three major types of marine mammals: seals (*Pinnapedia*), whales and dolphins (*Cetacea*), and manatees (*Sirenia*). Experts shared all sorts of facts: where they live, what they eat, how they gather food, how big they are, how they sleep, how they breathe, their mating habits, and more. Groups with an expert on each type **evaluated their combined information [SEP-8]** by making a Venn diagram comparing the three types. Mr. T then had students **develop questions [SEP-1]** about the evolutionary history of marine mammals by looking at the diagram. When did each type of marine mammal evolve? What environmental factors caused them to evolve this way? How do marine mammals relate to regular land dwelling mammals? Is it possible that all these organisms evolved from a common ancestor that had the features at the center of the Venn diagram?

Day 2: Fossil Evidence for Evolution (Explore)

Investigative phenomenon: The ancestors of ancient marine mammals have slowly changed over time (in both body shape and the shapes of external structures).

Scientists trace the evolutionary history of animals using a range of tools, including fossils. On day 2, students reconstructed the evolutionary sequence of each type of marine mammal. Mr. T provided each expert team a stack of cards. Each one showed a diagram of a complete skeleton of an ancestor to the team's marine mammal. The top card was the modern-day skeleton but all the rest of the fossils were in random order; the students had to put them in their correct evolutionary sequence. Mr. T explained that this process was quite different from the way paleontologists complete their work—each fossil came from a layer of rock in a known sequence and often a known age. The jumbled sequence, he explained, helps students pay close attention to the gradual progressions that exemplify many evolutionary changes. Students related these gradual progressions back to the initial questions they developed in day 1. Students did not need to understand much about marine mammal anatomy—their goal was to **analyze [SEP-4]** **patterns [CCC-1]** such as the tail is getting longer or the teeth are shrinking.

Mr. T had them tape their cards along the wall in sequence and add sticky notes to emphasize features that changed from frame to frame. Students then returned to their mixed jigsaw groups to lead tours of their fossil sequence to experts from other groups. Mr. T asked the students to evaluate if all the fossil sequences started from a common ancestor. They discovered that all three of these marine mammals evolved from land mammals that walked on four legs and had long tails, each one from a distinctly different looking creature. Seals evolved from something like an otter while the ancestor of the whale was the size and shape of something like a cross between a dog and a very large rat. Students ended the day by reflecting on what they had discovered by writing a brief **argument [SEP-7]** refuting the statement, "Whales, manatees, and seals all evolved from a common ancestor." What

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evidence would they expect to find if this statement were true? Did they find that evidence? The shared traits of these different marine mammals exemplify convergent evolution.

Day 3: DNA Evidence for Evolution (Explore)

Convergent evolution is easy to notice, but how does it happen? On day 3, students learned how genome mapping illustrates the evolutionary history of organisms. To review what students learned earlier in the year about DNA and heritability, Mr. T wore a geeky science t-shirt that said: “98 percent Chimpanzee” on the front and “50 percent banana” on the back. He began class by asking students to explain the shirt’s joke. He then had students do a think-pair-share in which they responded to the questions: What are the implications of humans being 98 percent chimpanzee? What does this information allow us to predict about humans and chimps.

Investigative phenomenon: The amino acid sequence in the protein cytochrome C is similar for many animals, but there are notable differences.

Mr. T informed them that they would do some simple analysis of DNA sequences to see how numbers like these percentages on his t-shirt were constructed. He gave a short mini lecture on genome mapping and genetic barcoding. Students needed enough basic background to interpret data from genome mapping of marine mammals to infer how closely related two organisms were. He provided lab teams with amino acid sequences of a protein common to many organisms, cytochrome C.[7] The list contains about two-dozen animals. The DNA of a grey whale was identified at the top of the list, but the rest were simply labeled “Organism A, B, C, etc.” Like the previous day, they focused on the **pattern [CCC-1]** of the amino acids rather than trying to understand the details. Students tried to arrange the organisms in order of how closely related they were to the grey whale. Mr. T then revealed the actual organisms (including fungus, wheat, dog, and penguin). Students discovered that, at least for this one protein, the grey whale is more closely related to cows than it is to seals or manatees. While this is just one small section of DNA, it confirms the fossil evidence that the organisms evolved from different species of land animals rather than a single common marine ancestor. Mr. T had students return to their previous day’s **argument [SEP-7]** and extend it with the new DNA evidence (HS-LS4-1).

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[7] Evolution & the Nature of Science Institutes. 2001. “The Cytochrome-C Lab.” http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link167; Students can also learn to access proteins from mapped genomes directly from the National Center for Biotechnology, “Cytochrome C Southern Elephant Seal.” http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link168

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Days 4–5: Animals Evolve in Response to Climate Change (Explain)

Investigative Phenomenon: Three separate species of land mammals all evolved to become entirely aquatic organisms.

Whatever the genetic mechanism, three separate species of land animals all evolved to become entirely aquatic organisms. Why? The general trend in evolution has been for organisms to emerge from the water, so what conditions led the three marine mammal types to return? Mr. T had students begin by writing a short story that described a possible scenario that would explain why separate land animals returned to the ocean. He invited them to be creative with their ideas, but they needed to be consistent with the previous concepts they had learned in the class. What sort of evidence did they expect to find if their story is true? They revisited their story at the end of this activity.

Investigative Phenomenon: The diversity of marine mammals has shrunk and grown over the last 60 million years.

Students returned to fossil evidence to look at when each species evolved. They plotted and **analyzed data [SEP-4]** showing the number of genera of each type of marine mammal alive at different points in geologic time (figure 7.15). Students analyzed one marine mammal in jigsaw groups before coming together to compare them.

Figure 7.15. Diversity of Marine Mammals Over the Last 60 Million Years

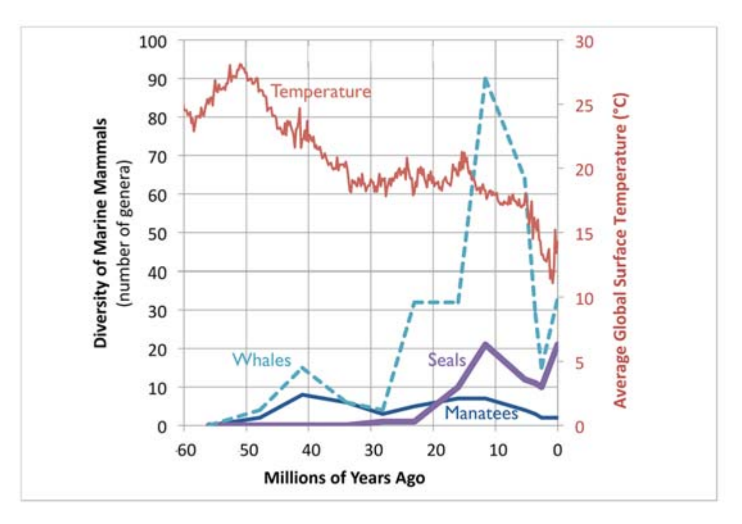

Chart by M. d'Alessio with data from Uhen 2007 and Hansen et al. 2013

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Students found that whales and manatees evolved at nearly the exact same time ~50 million years ago, thrived for about 10 million years, and then started to die off. The diversity then exploded dramatically to a peak around 10 million years ago (around the same time that seals first evolved), only to have all three types of marine mammals collapse simultaneously a few million years later. Mr. T invited students to ask testable questions about why these creatures shared such a similar history even though they evolved independently. Groups asked things like, “Did they evolve at the same time because a new food source evolved in the ocean?” and “Did they start to die out because of an asteroid?” Mr. T focused on the group that asked, “Was there something about the environment that changed at 50 million years ago?” He asked them what sort of physical changes could occur, and climate was one possibility.

Investigative Phenomenon: Some of the changes in marine mammal diversity occur at the same time as major changes in global temperature.

Mr. T provided the class with another graph showing a reconstruction of global temperatures. Students used the graphs to present possible explanations of some of the changes in biodiversity (HS-LS2-2, HS-LS4-5). Could whales and manatees have escaped into the water to avoid exceptionally high temperatures at the time? Or did the warmer temperatures simply make food sources more abundant in the ocean? Could the expansion of all marine mammals starting around 18 million years ago (Ma) be related to a slight warming known as the Middle Miocene Climatic Optimum (perhaps causing an explosion in ocean productivity)? Could the collapse shortly thereafter be related to the cooling trend a few million years later? Students read some short articles and Mr. T provided a mini-lecture to help students understand the relationship between temperature and marine biological productivity and how this relates to what may have happened during the Middle Miocene Climate Optimum. Mr. T had students draw a concept map (a pictorial **model [SEP-2]**) illustrating some of the cause and effect relationships they saw in the data (figure 7.16).

Figure 7.16. Concept Map Illustrating Cause-and-Effect Relationships

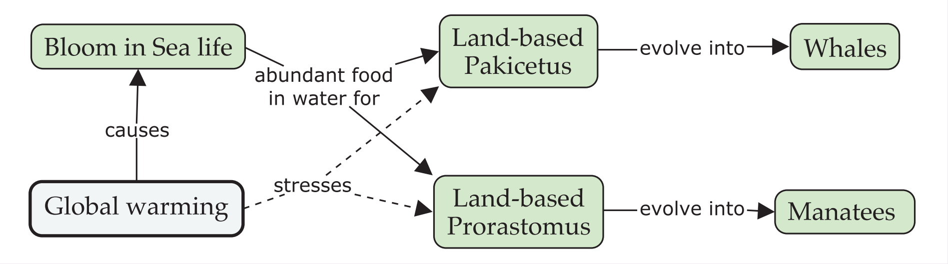

Diagram by M. d’Alessio

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When students saw cause and effect relationships between climate change and biodiversity, they also wondered about what caused such dramatic climate fluctuations. Mr. T had students discuss an article that described some surprising ties between the motion of Earth's tectonic plates and climate. For example, when the Tethys Sea closed sometime between 20 and 15 Ma, it may have disrupted global wind and ocean currents so much that the planet began a dramatic cooling. That cooling affected marine mammal diversity. After the reading, Mr. T had students extend their concept map model (figure 7.17) showing the complex chain of **cause and effect [CCC-2]** (7.17A and B). He had them use their diagrams to **debate the claim [SEP-7]** that "whales would not have evolved without plate tectonics." (HS-ESS2-7). Students finished the activity by returning to their stories from the beginning of day 4. Did their stories match the evidence?

Figure 7.17. Extended Concept Map Showing Chains of Cause and Effect

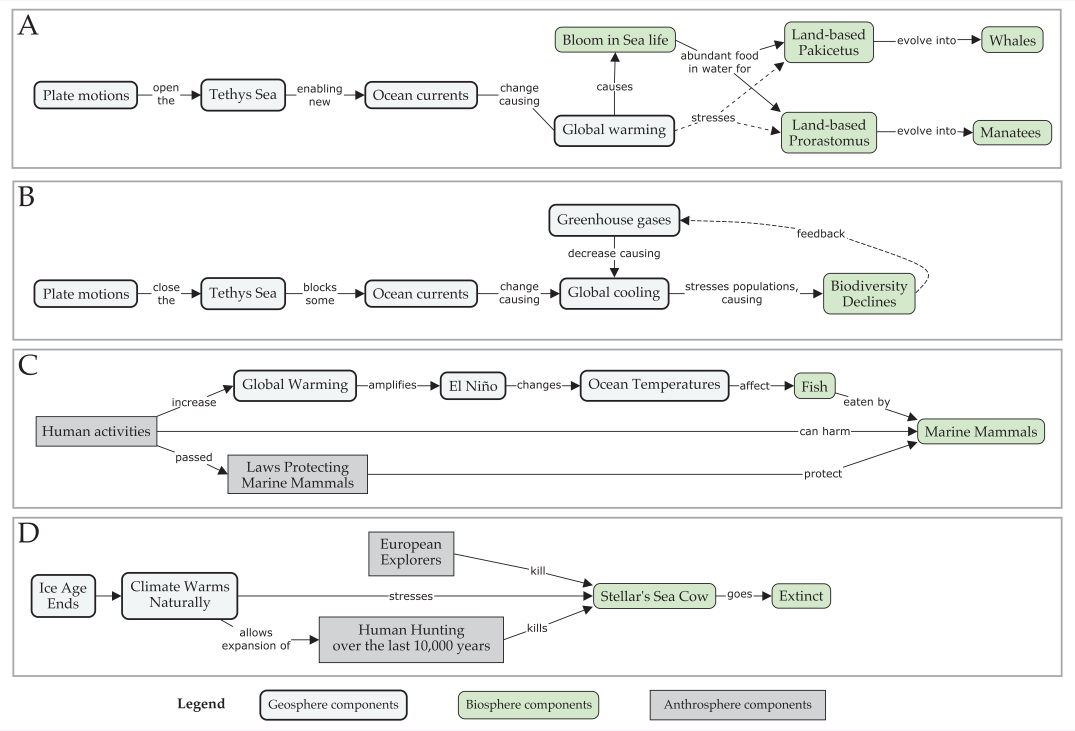

Diagram by M. d'Alessio

Days 6–7: Predicting Future Climate Impacts (Explain)

The entire history of marine mammals in the past depends in part on changes in the climate, but how will future climate change affect today's populations? While the effects of long-term climate change are hard to model, short-term changes to global temperature are becoming increasingly common due to El Niño. Examining the effects of these short-term changes provides insight into the ways ecosystems might respond to longer-term changes. Students

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returned to questions from day 1 about sea lion populations. They used a spreadsheet to plot and **analyze [SEP-4]** sea lion population over the last 40 years (figure 7.18).

Figure 7.18. Sea Lion Pup Population and El Niño Intensity

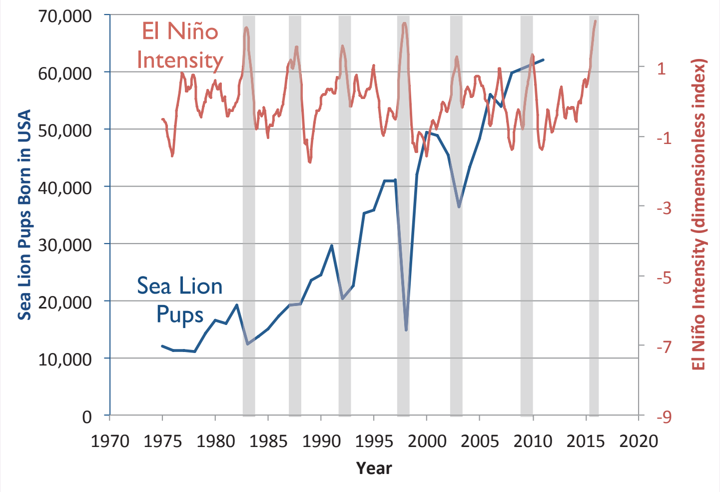

Chart by M. d'Alessio with data from National Oceanic and Atmospheric Administration Fisheries 2015 and Climate Prediction Center 2015

Investigative Phenomenon: Sea lion populations have increased over the last 40 years but seem to undergo population collapses every few years.

Students recognized two important features in the data: (1) sea lion populations have generally increased since the mid-1970s; and (2) every few years, there is a sudden reduction in the number of sea lion pups. They considered the overall growth trend on day 7, but on day 6 they focused on the **cause [CCC-2]** of the periodic reductions. Students discovered that sea lion pups tend to suffer severe die-offs in years when El Niño is extreme. They began to create a model for the exact mechanism by which El Niño affects sea lions by graphing the availability of their favorite food sources, fish such as sardines and anchovies (see California Academy of Sciences 2015). Since the cause and effect chains have many steps, students continued to use concept maps to record their understanding, building part of 7.17C. They used their model to evaluate the claim that El Niño's fluctuations have caused changes in the sea lion populations (HS-LS2-6). Students plotted data from the amount of fish caught by commercial fishermen, so Mr. T also led a discussion about how these changes not only impact sea lions, but they also impact human populations (EP&C I).

Students then read articles to **obtain information [SEP-8]** about computer simulations that predict how El Niño would change as climate changes. Some models show that El Niño would probably not occur more frequently, but the intensity of El Niño and La Niña might

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increase, causing larger fluctuations from year to year (HS-ESS3-6; EP&C III). Will sea lions be able to adapt to these **unstable [CCC-7]** conditions? Students added their new understanding of cause and effect to their concept map models.

Day 8: Human Impacts (Elaborate)

Students noticed that the population of sea lions in the United States had been growing steadily since the 1970s. Could this be related to climate change? The small but steady temperature increases in the ocean were unlikely to be strong enough to have such a dramatic impact. What besides climate could have such a dramatic impact on animal populations? Human activities. The United States Congress passed the Marine Mammal Protection Act in 1972, which makes marine mammal conservation a priority. Mr. T told students that this act was put in place in time to protect sea lion populations, but it was not early enough to save all of California's marine mammals. The fossil record reveals one more exciting surprise.

Investigative Phenomenon: Fossils indicate that Steller's sea cows, giant manatees, once lived off of California. These organisms were last seen alive by explorers in the 1700s near a remote island in Alaska but have since become extinct.

Students reviewed videos and Internet resources to **obtain information [SEP-8]** about the Steller's sea cow, finding that it is the largest manatee species known (growing up to 9 meters long—nearly three times the size of Florida's well known manatees). When explorers first encountered it in 1741, it was abundant but only found in a few isolated pockets around uninhabited islands off the far western tip of the Aleutian Islands near Russia. Within 27 years of its discovery by Europeans, it was hunted to extinction. The Steller's sea cow was the last branch of a genetic tree that diverged from the rest of the manatee and dugong family more than 20 million years ago. As recently as 20,000 years ago, it extended along the rim of the North Pacific as far south as Japan and Monterey Bay in California. Since they only survived in places without human civilization, some scientists speculate that human hunting in the last 10,000 years contributed to their demise. Others note a number of other species also died out in that time period because of a major shift in climate at the end of the last ice age. Students **collected evidence and engaged in a debate [SEP-7]** about whether early humans, European explorers, or natural climate change were most responsible for their extinction (EP&C II). To prepare for the debate, students constructed a concept map model to represent the different possible causes of the extinction (7.17D). Mr. T also prompted students to investigate the rate of **change [CCC-7]** in the last 10,000 years versus some of the other changes in the evolution of marine mammals they learned about on previous days.

Days 9–10: Human Solutions (Evaluate)

Students had been posting their concept map diagrams and their data plots on the walls around the classroom throughout the week. To evaluate whether or not students could link

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their evidence to their model, Mr. T highlighted one specific relationship on a concept map and asked a student to point to the specific feature in a specific graph or informational article that provided evidence for this link. He repeated this prompt for a variety of linkages on the concept maps and then reversed the process by holding up a graph and asking students to identify where its interpretation was represented on the concept map models.

Investigative Phenomenon: How can people reduce their impact on marine mammal populations? .

Students finished this instructional segment evaluating competing design solutions for reducing human impacts on marine mammal populations (HS-ESS3-4, HS-ETS1-3). Mr. T asked his students to decide between two possible challenges: preserving habitat for seals and sea lions in coastal California or managing overfishing in the waters of the Gulf of California where humpback whales birth their calves. He presented teams with handouts that allowed them to **define the problem [SEP-1]**, including pressures from human activities and climate change. Different teams received handouts identifying one of several different alternatives and students created a presentation **communicating [SEP-8]** the pros and cons of the plan (EP&C V). The students continued this activity the following week.

Vignette Debrief

As the culmination of the entire course, this vignette showed how the biosphere, geosphere, and anthrosphere interact.

SEPs. A major focus of the vignette was on having students **analyze [SEP-4]** different data sets and notice that they exhibit **patterns [CCC-1]**. These correlations invited students to **ask questions [SEP-1]** about possible **cause and effect relationships [CCC-2]**. The evolution of marine mammals presented sequences of complex chains of cause and effect relationships, so the vignette relied on concept maps as pictorial **models [SEP-2]** to represent them. Students used these models to help structure **arguments [SEP-7]** such as the debate on day 8 and the assessment on day 9.

DCIs. Students examined evidence of common ancestry from homologous structures, fossil sequences, and DNA similarity (LS4.A) in the first 3 days of the lesson. They then sought to explain the evolutionary sequence of land mammals migrating to the ocean in terms of adapting to environmental changes (LS2.C, LS4.C). Many of these changes were related to human impacts (ESS3.C) on global climate (ESS2.D, ESS3.D), and they used computer simulations to predict future changes to marine mammal populations on days 6 and 7 given different climate change scenarios. While the lesson emphasized how earth systems influence the evolution of biological systems, it also briefly touched upon the role biodiversity plays in maintaining the concentration of greenhouse gases in the atmosphere (fig. 7.17B; ESS3.E).

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CCCs. While students comprehend cause and effect from a very early age, the analyses in this lesson sequence demonstrated the rich and complex understanding of **cause and effect [CCC-2]** at the high school level. Students learned to use evidence to distinguish between several possible causal mechanisms and recognized that several factors may contribute with different amounts of influence. They also could model complex chains of cause and effect (as in figures 7.16 and 7.17) that also included feedback loops (as in figure 7.17D) that could reinforce or counterbalance **change [CCC-7]**. This lesson also illustrated how high school students could integrate evidence from a range of different **timescales [CCC-3]**, noticing that the short-term changes in ocean temperature from El Niño from year to year and the slow changes in global climate over millions of years can both influence populations and survival via the same basic mechanism. Abrupt changes from year to year can add up to a steady evolutionary **change [CCC-7]**.

EP&Cs. Humans have the capacity to affect marine mammals in so many ways. Humans can directly hunt and kill animals as they did with the Steller's sea cow (day 8, EP&C II), but they can also alter natural systems (EP&C III) so strongly that they influence the climate. In addition to having to adapt to the changes in their own living conditions, climate change can also disrupt food supplies such as marine fish such that humanity suffers much like the sea lions pups (EP&C I). As students explored some of these impacts on days 8–10, they designed solutions that had to meet the long-term needs of society and the ecosystem as well as being tolerable in the short term for society (EP&C V).

CA CCSS Connections to English Language Arts and Mathematics. Throughout the instructional sequence, students participated in pair, group, and whole class discussions (SL.9–10.1a–d). They engaged in reading informational texts to identify key pieces of evidence (RST.9–10.1, 3, 7, 9). The students also produced several types of writing including an argument and a short story (WHST.9–10.1a–e, 6, 7, 9). In the vignette, students were also asked to analyze several data sets looking for patterns and possible causes for population changes (S-ID 1, 6, 9; S-IC 6) Students were also asked to create a formal presentation to exhibit their findings (SL-9–10.4.a).

Resources:

Climate Prediction Center. 2015. Oceanic Nino Index. http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link19

Hansen, James, Makiko Sato, Gary Russell, and Pushker Kharecha. 2013. "Climate Sensitivity, Sea Level and Atmospheric Carbon Dioxide." *Philosophical Transactions of the Royal Society A* 371 (2001).

National Oceanic and Atmospheric Administration Fisheries. 2015. "California Sea Lion (Zalophus Californianus): U.S. Stock." Silver Springs, MD: NOAA Fisheries. http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link20

Uhen, Mark D. 2007. "Evolution of Marine Mammals: Back to the Sea after 300 Million Years." *The Anatomical Record: Advances in Integrative Anatomy and Evolutionary Biology* 290 (6): 514–522.