Click and Learn

The Anthropocene: Human Impact on the Environment

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Educator Guide

OVERVIEW

This Click and Learn activity supplements the 2014 HHMI Holiday Lectures on Science "Biodiversity in the Age of Humans." The activity uses the interactive version of the poster that supports the lectures and illustrates many ways that humans are affecting Earth.

KEY CONCEPTS

- Recent changes to Earth's biosphere and its ecosystems have led scientists to propose a new geologic epoch, called the Anthropocene.
- Fossil evidence since 200,000 years ago suggests that prehistoric humans altered local habitats and caused extinctions of plants and animals, a process which has greatly accelerated in the 20th century.
- Major human impacts on the environment include but are not limited to climate disruptions, extinctions, loss of ecosystems, and pollution.
- Technological advancements have helped improve the quality of life for humans but have also amplified the negative aspects of human impacts on the environment.

PRIOR KNOWLEDGE

It is helpful for students to

- understand that extinction is a part of the natural pattern of evolution and that the fossil record reveals five mass extinctions during which a large proportion of species went extinct;
- understand that all organisms, including humans, are members of complex networks within their environments, resulting in stability within ecosystems;
- have a basic understanding of natural selection, evolution, and adaptation;
- know that the process of science involves making observations, modeling natural systems and processes, and testing hypotheses and making predictions;
- be able to perform the basic arithmetic functions, carry out calculations involving means, decimals, fractions, percentages, and ratios, and represent and interpret data in the form of bar charts, line graphs, histograms, and graphs involving two variables (scatterplots) that show linear or nonlinear relationships.

TEACHER STRATEGIES FOR USING THIS RESOURCE

- Student teams choose a region from the illustration, explore the related resources, and prepare a presentation to the class: whole group presentations and science fair/round robin formats are both effective.
- Each student is assigned a region to explore and share back with a group of other students who explored other regions.

- Teacher assigns a region in a flipped classroom for students to engage in the material prior to discussion of the topic in class.
- Teacher navigates through each region throughout the year or semester as the topics come up in the curriculum.

BACKGROUND

In the early millennia of human evolution, population sizes were small and impacts on their environments were probably minimal. However, as modern humans arose around 200,000 years ago, their population sizes and their ranges grew and their stone tool technology advanced. These changes led to humans causing measurable and lasting changes in their environments. For example, the fossil record reveals that the timing of the extinction of many large mammals (10 – 1,000 kg) in a geographic region is associated with the arrival of human populations.

Geologists have organized the history of Earth into eras, periods, and epochs. The Mesozoic Era (252 – 66 mya) gave way to the Cenozoic Era with the extinction of the nonavian dinosaurs. Within the Cenozoic, the Quaternary (2.6 mya to present) is the most recent period, and within the Quaternary, the Holocene (12,000 years ago to present) is the most recent epoch, which includes all of human written history.

Many scientists have suggested that recent human activities have permanently and irreversibly altered Earth to such an extent that a new epoch called the Anthropocene (*anthropo*, for "man," and *cene*, for "new") should be added. To date, the Anthropocene has not been formally adopted into the geologic timescale but has been gaining traction as a cultural concept. Similarly, the date marking the start of the Anthropocene is being debated, with possibilities ranging from megafauna extinctions beginning 50,000 years ago, to the origin of farming 8,000 years ago, to the nuclear age of the mid-20th century. Either way, it is clear that as the human population began to surge over the past century, human impacts on Earth's ecosystems have intensified, and indisputable and measurable changes are occurring.

Using the Click and Learn

Students can hover the cursor over a section of the interactive map and click to reveal the impact. Students can also click on the box next to the name of the impact in the menu bar. For most impacts, graphical data summarized from scientific literature will appear at the bottom. Students can then click on the graph thumbnail to learn more about the impact. For the mining and invasive species impacts, clicking on the name of the impact displays a short summary. The cut-away of sediment and fossils is also interactive and reveals the three epochs of the Quaternary Period.

NOTES ON IMPACTS

***Atmosphere*:** Air pollution has many components. The Click and Learn focuses on greenhouse gases. Other factors such as particulate matter, sulfur oxides, toxic metals, and organic compounds are not covered here, but could be good candidates for an extension activity.

Discussion Points

- Students may ask for evidence for the increase in carbon dioxide in the atmosphere over the past 200 years is from burning fossil fuels. There are three main forms (isotopes) of carbon: carbon-12 (^{12}C), carbon-13 (^{13}C), and carbon-14 (^{14}C). Most of the carbon in the atmosphere is ^{12}C, while 1% of it is ^{13}C. ^{14}C occurs in tiny amounts in the atmosphere and radioactively decays to ^{14}N. Plants preferentially incorporate ^{12}C relative to ^{13}C during photosynthesis. In C3 plants, the abundance of ^{13}C is reduced by about 25% to 30%. Thus, plants, animals that eat plants, and fossil plants and animals have a lower ^{13}C:^{12}C ratio than the atmosphere. When carbon is released by burning fossil fuels derived from dead organisms, the ^{13}C:^{12}C ratio in the atmosphere should decline, and that is exactly the effect atmospheric chemists have measured.
- Help students understand that climate change varies across the globe; some regions are warming while others are cooling, and some years might be cooler compared to other years. But the overall average change indicates that Earth as a whole is indeed warming.
- As the average global temperature increases, patterns of precipitation and other factors that define ecosystems also change. Cool-temperature habitats are moving to higher latitudes and/or higher elevations. Ask students to predict the possible impacts these changes could have on the animals that live in these habitats.

Biodiversity

Discussion Points

- Mass extinctions are defined as a loss of over 75% of species in a relatively short period of time. In the fossil record, five mass extinctions have occurred in the past 540 million years.
- Remind students that extinction is a natural part of biological evolution, but the current increase in the extinction rate of plants and animals can be linked to the activity of a single species: humans.
- Ask students to identify the major levels of biodiversity (ecosystem, species, population, genetic). Have students discuss the different types of threats faced by each level of biodiversity and propose different strategies for conservation.
- Help students understand that evolution acts on genetic variability and loss of genetic variability limits the potential of a population of organisms to evolve under changing environmental conditions. If the concept of the extinction vortex is in your curriculum, stress to students that as population size decreases, genetic variability also tends to decrease, leading to the loss of rare alleles, meaning the already-stressed population has fewer tools to withstand future change.

Cities

Discussion Points

- The human needs for power, food, and money are the main causes of human impacts on the environment. Have students work in teams to generate ideas for changing how we consume and generate energy, for how we will feed a growing population, and for how our economic systems can be adjusted to value natural systems. Guide students to consider the services that a particular ecosystem provides humans. Examples include production of natural resources, water retention and/or purification, provisioning (e.g., pollination), and carbon storage.
- Two main threats to biodiversity are climate change and ecosystem transformation and loss. Human population growth is at the heart of both of these threats. Have students research what we know about past population growth and predict future projections.

***Coastal Habitats*:** Coastal waters and nearshore ecosystems are affected by pollution, development, and increased intensity of storms, among other things. The Click and Learn focuses on agricultural runoff.

Discussion Points:

- Discuss with students the process of eutrophication and how it occurs both naturally and unnaturally due to inputs of nitrogen and phosphorus fertilizer from farming systems and the resulting blooms of freshwater algae and marine plankton.
- Students may also find coastal ocean dead zones interesting. Dead zones occur naturally and unnaturally across the globe. The dead zone in the Gulf of Mexico at the mouth of the Mississippi River grows every summer as fertilizer from the Mississippi River watershed (roughly 1/3 of the U.S. lower 48 land area) flows into it. More information can be found at the National Oceanic and Atmospheric Association (http://www.noaa.gov/factsheets/new%20version/dead_zones.pdf).

***Farms*:** Conversion of natural landscapes to agricultural uses has many implications, including habitat loss and increased release of carbon and methane to the atmosphere.

Discussion Points:

- The Food and Agriculture Organization of the United Nations reports that world crop production increased around 126% from 1970 to 2000. Crop production is predicted to increase another 55% from 2000 to 2030 to feed humans and the animals we eat. Today, more than one-half of Earth's land area that is farmable has already been converted to agricultural land. Discuss with students some reasonable changes in human behavior (e.g., a reduction in meat consumption) that could slow the conversion of habitat to agricultural land.

- Explain to students that as land is converted for agricultural uses, biodiversity is often drastically reduced. For example, the remaining tall grass prairie in North America supports as many as 850 species of plants, 250 species of breeding birds, and in one square meter alone can have over 1,800 species of insects – far more than are found in cultivated fields. Have students research the amount of land in North America that has been converted from prairie to row crop agriculture since 1850.

Forests

Discussion Points:

- The spread of human development results not only in loss of habitat but also in fragmentation of the habitat that remains. Help students connect this phenomenon to natural evolutionary processes like gene flow and genetic drift and ask students to propose some conservation strategies that may help reverse the effects of habitat fragmentation. Ideas for conservation may include land preservation, marine protected areas, captive breeding programs, managed ecosystems, conservation corridors to connect habitat fragments, and other projects to increase variability in isolated populations.
- On a positive note, students may be interested to learn that, while the early European settlers in North America cleared much of the eastern forests for agriculture, many of the forests have grown back over the past 150 years as agriculture moved west. However, the replacement forests are usually less diverse than the original forests.

Invasive Species

Discussion Points:

- Distinguish for students the difference between a non-native species and an invasive species. A non-native species is a species that did not evolve in a particular ecosystem but can now be found there. According to the National Invasive Species Council, an invasive species is a non-native species that causes "economic or environmental harm or harm to human health." Environmental harm includes outcompeting native species. Both non-native and invasive species are introduced to the new environment by either purposeful or accidental human action.
- Have students research examples of invasive species in their geographic area and report on current efforts to control or eradicate them.

Mining

Discussion Points:

- This is an opportunity to connect students to the concept of bioaccumulation. For example, copper and mercury mining releases copper and mercury, as well as lead, arsenic, chromium,

and zinc, among other metals, into aquatic ecosystems. Aquatic animals like insect larvae incorporate these metals into their tissues. Predators of these animals may eat hundreds of metal-laced individuals and thereby accumulate the metals in their own tissues. The metals can reach toxic levels that affect an animal's ability to survive and/or reproduce.

- Water flowing out of mining operations can lower the pH of streams to levels below which most aquatic invertebrates can survive. Ask students how low invertebrate biodiversity might affect the food web of the upland ecosystem through which the stream flows.

Ocean

Discussion Points:

- Help students make the connection that some of the carbon dioxide emitted by humans dissolves into the ocean. On the one hand, that helps reduce the greenhouse effect, but it makes the ocean slightly more acidic, which makes it more difficult for invertebrates with calcium-based skeletons to survive.
- Aside from causing climate change and habitat destruction, humans also directly kill many animals for economic benefit. Often this is done in a poorly managed and unsustainable way and occurs both on land and in the sea. Discuss with students the complex nature of international relationships as they relate to harvesting and conserving open ocean fish resources.
- Help students understand that modern reef-building corals have been around for over 250 million years and have survived several mass extinctions. Ask students to hypothesize about why corals and coral reefs are in serious decline. An explanation students may not come up with is that heat can damage the photosynthetic microalgae that live inside coral cells, causing the coral to expel the damaged symbionts and making the corals appear white (coral bleaching). Loss of the symbionts makes it difficult for the corals to survive because the symbionts provide up to 75% of the energy the corals use. Refer to coral bleaching animation.

Water Use

Discussion Points:

- Students may point out that hydropower from dams does not contribute to increasing atmospheric carbon dioxide and is indeed a renewable source of electricity. Help students understand that while dams are an important source of electricity, a heavily dammed river that was once a continuous aquatic ecosystem is now not much different than a series of lakes. Ask students to identify some possible consequences for populations of aquatic organisms and species interactions when a dam is built in a river. Examples of student ideas may include disruption of gene flow, decrease in population sizes and an increase in genetic drift, and disruption of food web interactions.

- Students may be interested in water use data. For example, in 2010, the total volume of water used in the United States for human activities was 355 billion gallons per day (bgpd). Uses included 161 bgpd for thermoelectric power, 115 bgpd for irrigation, 42 bgpd for public supply (e.g., drinking water), and 16 bgpd for industrial uses.

NOTES ON EPOCHS

Pleistocene. The Pleistocene began around 2.6 mya and ended with the Holocene. The epoch is characterized by several ice ages on both hemispheres as well as many large mammal species like the now-extinct mammoth and saber-toothed tiger. The Pleistocene was also the epoch that saw the evolution of the human genus *Homo* and modern humans.

Holocene. The Holocene began with the end of the last ice age around 12,000 years ago, and officially we are still in the Holocene. However, in 2016 the International Commission on Stratigraphy will take up the question of whether the Anthropocene should become a formal part of the geologic timescale. Important criteria for a geologic time division are that it is distinct from preceding divisions and it is worldwide.

Discussion Point:

The table below summarizes potential start dates/events for marking the beginning of the Anthropocene. Have your students discuss and debate the options.

Event	***Date***	***Geographical Extent***	***Geologic Marker***
Megafauna extinction	50,000 – 10,000 yrs ago	Near-global	Fossil megafauna
Origin of farming	~11,000 yrs ago	Southwest Asia, expanding to global	Fossil pollen
Extensive farming	8,000 yrs	Eurasian event, global impact	CO_2 inflection in glacier ice
Rice production	~6,500 yrs ago	Southeast Asia	Increase in methane
New-Old World Collision	1492 – 1800	Eurasia and Americas expanding to global	CO_2 minimum in glacier ice in 1610
Industrial Revolution	1760 to present	Northwest Europe, expanding to global	Ash from coal burning
Nuclear weapon detonation	1945 to present	Local events, global impact	Radionuclides (^{14}C) in tree rings
Persistent industrial chemicals	~1950 to present	Local events, global impact	SF_6 in glacier ice, many other examples

RELATED BIOINTERACTIVE RESOURCES

Lecture Series: Biodiversity in the Age of Humans http://www.hhmi.org/biointeractive/biodiversity-age-humans (Also available on DVD)

Poster: The Anthropocene—Human Impact on the Environment
http://www.hhmi.org/biointeractive/anthropocene-human-impact-environment-0

Poster: The Making of Mass Extinctions http://www.hhmi.org/biointeractive/making-mass-extinctions

Resource Collection: Extinctions http://www.hhmi.org/biointeractive/explore-extinctions

Animation: Coral Bleaching http://www.hhmi.org/biointeractive/coral-bleaching

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