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Lesson

Is Earth Currently Undergoing a Sixth Mass Extinction?

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Abstract

The five Phanerozoic mass extinctions were central in shaping biodiversity on Earth today. Due to increasing biodiversity losses, there is debate about whether we are currently undergoing a sixth mass extinction. To help students better understand these issues and explore the ongoing debate, we developed a lesson that uses active learning approaches including small-group work, poll questions, and whole-class discussion. This lesson provides an overview of major events in Earth's history, an introduction to extinction and mass extinction, and past and present conservation efforts. Students were assessed using two short take-home assignments, in-class poll questions, and quiz questions. Here we provide detail about the lesson and summarize student performance on the assessments.

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Supporting Materials: Supporting Files S1. 6th Mass Extinction–Potential Resources for Teachers; S2. 6th Mass Extinction–Group Work Slides; S3. 6th Mass Extinction–Mass Extinctions Note-Taking Chart; S4. 6th Mass Extinction–Class Session I Slides; S5. 6th Mass Extinction–Class Session II Slides; S6. 6th Mass Extinction–Poll Questions; and S7. 6th Mass Extinction–Quiz Questions

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Learning Goals

- LG-1: Compare and contrast the forces of global change throughout history in the context of extinction.
- LG-2: Evaluate the possibility, implications, and mitigation of a human-mediated mass extinction event.

Learning Objectives

- LO-1: Outline the temporal relationship between major events in Earth's geological and biological history.
- LO-2: Identify defining features of mass extinction events.
- LO-3: Compare and contrast the previous five major extinction events in terms of cause, magnitude, and subsequent impact on biodiversity.
- LO-4: Evaluate evidence for whether current losses in biodiversity should be defined as a mass extinction and explain why defining large losses in biodiversity as a mass extinction is relevant.
- LO-5: Assess the long-term implications of human impacts on the environment and propose practical strategies that humans can implement to slow down current extinction events.

INTRODUCTION

Examining the forces which have historically shaped biodiversity, and which will continue to do so, is imperative to understanding the diversity of life today. The five Phanerozoic mass extinctions (Ordovician, Devonian, Permian, Triassic, and Cretaceous) had monumental ecological impacts, eliminating many lineages while affording others the opportunity to diversify. For example, the devastating Permian extinction wiped out most land animals, setting the stage for dinosaurs to become a dominant group in many ecosystems. Dinosaurs later met the same fate and were largely replaced by a widened diversity of mammals after the Cretaceous extinction (1).

While the Phanerozoic mass extinctions occurred tens to hundreds of millions of years in the past, they provide case studies whose importance extends far beyond purely academic matters, including influencing views about biodiversity loss today (2,3). Thanks in part to the investigation of these events, many scientists now recognize an ongoing sixth mass extinction that threatens a large percentage of living species and could result in similar upheavals to Earth's biodiversity in the future if left unchecked (2, 3). This lesson aims to contextualize modern, human-mediated extinction using previous large-scale losses of biodiversity.

Biodiversity is a frequently misunderstood concept among the general public (4,5). Historically, the public has not grasped the level of severity of ongoing losses in biodiversity or the causes of loss in biodiversity (6). In addition, there are many misunderstandings around deep time (i.e., the immense history of Earth prior to humans). For example, over half of Americans falsely believe that the earliest humans lived at the same time as dinosaurs (7). Such misunderstandings about Earth's history are also prevalent in the undergraduate population. In a survey of undergraduate students, many respondents provided dates for prehistoric events that were off by multiple orders of magnitude (8). Other misunderstandings include the conflation of widely separated events, such as the extinction of non-avian dinosaurs and the Late Cenozoic ice age (9). Although deep time has been identified as an important but difficult-to-grasp concept (10), there is little college-level pedagogical material and few publications on the subject (11). This lesson seeks to fill these gaps by providing students with an understanding of the history of life and the major events which shaped it, as well as the factors causing the current global decline in biodiversity.

In the first part of this lesson, students examine key events in the history of life and place them on our planet's four-billion-year timeline. These include all five Phanerozoic mass extinctions. Students investigate their potential causes, their commonalities and differences, and the most significantly impacted taxa of each mass extinction event. Students also learn how mass extinctions are identified, preparing them for the next part of the lesson.

During the second half of the lesson, students explore the ongoing loss of global biodiversity before critically evaluating and debating its categorization as a sixth mass extinction. The major drivers of present-day extinctions are addressed through case studies (including the passenger pigeon, golden toad, and Yangtze river dolphin). Throughout both sections, this module incorporates active learning techniques for synchronous online environments such as live poll questions, group discussions, and two short take-home assignments. We also make suggestions for how to teach this lesson in the in-person and asynchronous online environments.

Intended Audience

This lesson is designed for an introductory undergraduate evolution course offered through Cornell University's Department of Ecology and Evolutionary Biology. The lesson is intended for students who are not pursuing biology majors, though it could easily be adapted for an introductory majors course as well. Students who participated in the lesson varied in undergraduate education level, but most had not taken any post-secondary biology coursework. The content of this lesson should be appropriate for any class size and type of post-secondary institution, though we implemented this lesson in a synchronous online class of 65 students. The lesson was taught during a synchronous online class due to the COVID-19 pandemic, but all incorporated activities are possible with either online or in-person teaching.

Required Learning Time

This lesson is designed to be given over two 75-minute class sessions. We also include a short out-of-class activity to be assigned between 75-minute classes and an online discussion board activity after the second day of class. A lesson timeline is provided in Table 1.

Prerequisite Student Knowledge

This lesson requires relatively little prior knowledge of the associated topics. Students should be generally familiar with the idea of extinction and the concept of geological time, but no specific prerequisite knowledge is needed. In general, all potentially new terms are clearly defined within the lesson. For the lesson described here, students had previously learned about the mechanisms of evolution, phylogenetic trees, and fossils, which may provide useful background but are not strictly necessary.

Prerequisite Teacher Knowledge

It is recommended that instructors for this lesson be broadly familiar with the basics of Earth's geological history and the major events therein. Supplementary books, articles, and web resources are provided in Supporting File S1. 6th Mass Extinction–Potential Resources for Teachers. We suggest that educators familiarize themselves with the concept of mass extinctions, both by reviewing information on the five unambiguous Phanerozoic mass extinction events and by examining arguments for and against the categorization of ongoing biodiversity loss as the sixth mass extinction. Additionally, some familiarity with the current biodiversity crisis, major factors in human-mediated extinction, and related topics would be beneficial. Instructors should also be familiar with at least one student polling system, such as clickers or PollEverywhere, to facilitate these activities during the lesson.

SCIENTIFIC TEACHING THEMES

Active Learning

Throughout this lesson, students engage in a variety of active learning activities including answering poll questions individually and in groups, participating in small group discussions, and completing note-taking worksheets that accompany the lecture slides. When we taught this lesson, small group discussions (4 or 5 students) were held in breakout rooms. If students had a question, they could signal to a course instructor that they needed help and the instructor could visit their breakout room. If students could not attend the synchronous portion of the online class, they could watch the video of the class period and provide answers and explanations to each poll question. This asynchronous assignment needed to be completed within 48 hours of when the class ended.

Outside of class, students are asked to research an endangered species and submit a reflection about the potential cause of extinction for that species. They are also asked to participate in a discussion board and respond to peers about possible human interventions to prevent the extinction of an endangered species.

Assessment

During class, students are assessed in a variety of ways. Students are asked to respond to poll questions both individually and based on small-group discussion in breakout rooms (Supporting File S6. 6th Mass Extinction–Poll Questions). They are also encouraged to work through several collaborative and individual worksheet activities including placing events on a timeline to outline deep time, filling in a chart to identify common features of mass extinctions, and completing a Venn diagram examining influencing factors for modern extinctions (Supporting Files S2. 6th Mass Extinction–Group Work Slides and S3. 6th Mass Extinction–Mass Extinctions Note-Taking Chart).

These activities provide immediate feedback to the instructors and students alike. After the lesson, several questions relating to key concepts are included in a quiz (Supporting File S7. 6th Mass Extinction–Quiz Questions). The instructor may also consider highlighting key concepts in future exam questions. Student performance on these assessments are included in the Teaching Discussion and Supporting Materials. This research was considered exempt from institutional review: Cornell University protocol 1802007733.

Inclusive Teaching

This lesson focuses on several inclusive teaching practices related to community building. Students are asked to work collaboratively in small groups and to discuss poll questions. Poll questions are graded based on participation rather than selection of the correct answer. This grading policy encourages students to seek help when they are incorrect, rather than be concerned about their grade (12). Throughout the lesson, students are encouraged to share their opinions and unique perspectives on how to combat various societal challenges, including conservation and climate change, while respecting peers who may hold perspectives and opinions different from their own. When we taught this lesson, students disagreed regarding whether current biodiversity losses amount to a mass extinction event. Students also held differing views about the role of government in conservation. Despite these differences, discussion remained respectful, and students were receptive to alternative viewpoints. We encourage instructors to remind students to be respectful throughout the semester and to consider creating community guidelines for appropriate discussion behaviors.

Student socioeconomic diversity was also considered throughout the design of this lesson. To prevent economic barriers, students are not required to purchase any textbooks or other supplementary materials to participate in this lesson. Additionally, all assessment questions can be answered based on information provided on lecture slides and do not require outside resources. We also expose students to the work of under-acknowledged scientists. For example, we present the efforts of Marjorie Courtenay-Latimer, who was one of few woman museum curators in the early 1900s, toward preserving a coelacanth specimen (Supporting File S4. 6th Mass Extinction–Class Session I Slides, Slide 16) with the goal of highlighting scientific contributions made by individuals of varied backgrounds (13).

Finally, students are provided with multiple means to achieve the desired learning objectives including discussion, writing, images and diagrams, and poll questions. Similarly, students are offered multiple formats of assessment questions including written and multiple choice to provide an opportunity for each student to display their knowledge of key concepts.

LESSON PLAN

The aim of this lesson is to introduce students to the concepts of deep time and extinction. Students are exposed to an overview of Earth's history focused on the five Phanerozoic mass extinction events. Students also consider endangered species and recently extinct species to evaluate whether they believe Earth is currently experiencing a sixth mass extinction event. Finally, students reflect on possible solutions and conservation efforts that can be made to prevent further biodiversity loss.

Pre-Class Preparation

Prior to teaching the lesson, the instructor should enter the poll questions into an appropriate polling software. The instructor should also prepare a shared document (e.g., Google Slides) with three slides for each group: a slide with the timeline activity, a slide with response prompts about the extinct organism assignment, and a slide with the Venn diagram activity (Supporting File S2. 6th Mass Extinction–Group Work Slides). The instructor should also provide the mass extinction note-taking chart found in Supporting File S3. 6th Mass Extinction–Mass Extinctions Note-Taking Chart.

Class Session I

Deep time and key events in Earth's history

The lesson begins with the instructor introducing the concept of deep time using a set of slides presented to all students in the main room (Supporting File S4. 6th Mass Extinction–Class Session I Slides). Students individually answer a poll question about the age of the Earth to prime their thinking (Supporting File S6. 6th Mass Extinction–Poll Questions, PQ1). The instructor shows NPR's Skunk Bear video "Earth's Entire History (Visualized On A Football Field)" to provide further details about the timing of some highlights in Earth's history. Because there could be potential bandwidth issues with students viewing the video through Zoom, the instructor can put the video link in the chat and ask the students to take a moment to view the video.

Students are assigned to small groups of four or five and, while working together in breakout rooms, are asked to place a selection of significant events in Earth's history on a timeline in the shared Google document provided (Supporting File S2. 6th Mass Extinction–Group Work Slides, Slide 1). The instructor can watch student progress by viewing the Google documents. After the groups place the events on their timeline, the students come back to the main room and are asked to answer an individual poll question indicating which of three possible timelines looks most like their group's timeline (Supporting File S6. 6th Mass Extinction–Poll Questions, PQ2). The instructor asks students to consider how the three timeline options differ and asks for volunteers to explain to the whole class what prompted their group to choose their selected timeline. When selecting volunteers to share, we encourage you to consider using equitable approaches that encourage all students to participate, such as assigning reporters for each group or waiting for multiple hands to be raised before calling on someone (14).

Introduction to extinction and mass extinction

The instructor defines extinction and describes possible causes of extinction. The students are placed into small groups in breakout rooms and asked to consider two questions: "What percentage of all species that have ever existed are alive today?" and "How do we know if a species has gone extinct?". Students return to the main room and are asked to answer an individual poll for the first question (Supporting File S6. 6th Mass Extinction–Poll Questions, PQ3). The instructor then asks for volunteers to share their responses to the second question. The instructor describes the challenges in determining whether a species has gone extinct and the lack of clarity in defining and studying extinction of individual species. The instructor encourages students to further consider extinction by asking another individual poll question showing various groups of organisms and asking students to consider which is most at risk of extinction (Supporting File S6. 6th Mass Extinction–Poll

Questions, PQ4). After answering the poll question, students are asked to share their reasoning for their response. Finally, the instructor further illustrates the challenges of defining and tracking extinctions by sharing an example of a species that was declared extinct then later rediscovered; in 1938, Marjorie Courtenay-Latimer came across a coelacanth, which was thought to have gone extinct 65 million years prior.

The instructor defines mass extinction and then uses the polling software to ask students to individually click on a timeline diagram and indicate the time point where they believe the most mass extinctions occurred (Figure 1). The instructor shows the results and discusses that there are a variety of ideas in the classroom. Students are encouraged to keep this timeline in mind as they learn more about the timing of mass extinction events. The instructor explains background extinction and how it is used as a baseline when defining mass extinction events and then describes the criteria used to define mass extinctions.

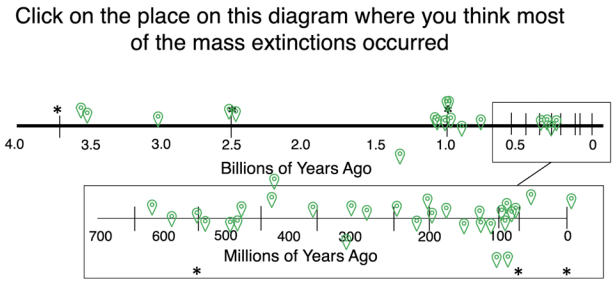

Figure 1. Timeline of student predictions for timing of mass extinction events. Student responses spanned several billion years of Earth's history.

Mass extinctions throughout Earth's history

Students are provided with a chart (Supporting File S3. 6th Mass Extinction–Mass Extinctions Note-Taking Chart) to help them record key information about each of the previous mass extinction events. The instructor describes five periods of Earth's history (Ordovician, Devonian, Permian, Triassic, and Cretaceous Periods) followed by a description of the subsequent mass extinction event. After the expansion of plant life during the Devonian Period is described, students are asked to consider two diagrams explaining the relationship between photosynthetic organisms (e.g., plants) and oxygen. One diagram depicts carbon dioxide and sunlight being used to produce biomass and the release of oxygen while the other depicts oxygen and sunlight being used to produce biomass and the release of carbon dioxide. Students are asked to discuss the question in small breakout room groups and then select a diagram in the group poll question (Supporting File S6. 6th Mass Extinction–Poll Questions, PQ5). The students then return to the main room and the instructor asks students to describe their reasoning for selecting their diagram and explains the process of photosynthesis. The Permian extinction was in part characterized by decreased ocean pH, so during this section the instructor describes the chemistry causing ocean acidification and its relevance today.

After all five Phanerozoic mass extinctions have been described, the students are asked to answer a series of individual poll questions to assess their knowledge about mass extinction events: "Which of the following ranges most accurately represents the percentage of species that went extinct during each of the five major extinction events?", "Which of the following is not a proposed cause of three or more previous mass extinctions?", and "Which of the following do you think is correct? A mass extinction is when..." (Supporting File S6. 6th Mass Extinction–Poll Questions, PQ6-8). For the first two questions, students are asked to volunteer to describe why they selected their answers. The students are placed in small breakout room groups to discuss the third question prior to sharing their thoughts with the whole class and responding to the poll again (Supporting File S6. 6th Mass Extinction–Poll Questions, PQ9). Finally, students are asked to answer a poll indicating whether they think Earth is currently experiencing a sixth mass extinction event (Supporting File S6. 6th Mass Extinction–Poll Questions, PQ10) and 63% of our respondents said yes. The instructor concludes by pointing out that this is currently being debated and provides sources representing arguments for both sides.

Extinct Organism Assignment

After class session I and before session II, students are asked to submit an assignment using a course management system. Students are asked to submit a photo of an organism that is in danger of becoming extinct. They are also asked to write one to three sentences describing the organism and list one to three causes that are likely driving the extinction (Supporting File. 6th Mass Extinction–Class Session I Slides, Slide 50). The organisms selected are summarized in Table 2.

Class Session II

Extinction and biodiversity loss

The instructor begins by explaining the distinction between a biodiversity crisis and mass extinction event and reminds the students of the criteria that define a mass extinction using a set of slides (Supporting File S5. 6th Mass Extinction–Class Session II Slides). The instructor shares a slide of the photos submitted by the students for the extinct organism assignment (Supporting File S5. 6th Mass Extinction–Class Session II Slides, photos should be inserted on Slide 3). In this course, the images were primarily of charismatic fauna–large mammals and vertebrates with traits attractive to humans, such as intelligence, beauty, valor, singularity or a strong symbolism (15). The students are placed into small breakout room groups and asked to discuss the following questions and take notes on the shared document provided: "What do you notice about the photos?", "What types of organisms are pictured?", and "What is surprising?" (Supporting File S2. 6th Mass Extinction–Group Work Slides, Slide 2). When the students return to the main room, the instructor asks volunteers to share what their groups discussed.

Next, the instructor shares a slide of additional extinct organisms that were not included in student responses and points out how these organisms differ from the student-selected organisms. For example, the instructor might point out that plants, insects, or gastropods were absent from the student submissions. The instructor asks for student volunteers to speculate why these organisms were not included in the student submissions and points out that most student submissions are of charismatic fauna. To further illustrate this bias toward awareness about extinction and conservation efforts of charismatic fauna, the instructor describes the example of the extinction of a louse species after the California Condor captive breeding program began and the birds were deloused when they were brought into captivity (Supporting File S5. 6th Mass Extinction–Class Session II Slides, Slide 6) (16).

Common drivers of extinction

The students are asked to respond to an individual poll question identifying which of three pie charts represents the breakdown of common drivers of extinction (Supporting File S6. 6th Mass Extinction–Poll Questions, PQ11). After the students have answered the poll question, the instructor asks the students to consider how these drivers may shift in the future and points out that climate change is expected to play a more significant role in the future. The instructor further introduces the leading drivers of extinction including exploitation, habitat destruction, climate change, invasive species, pollution, and disease. The instructor points out that these drivers do not act in isolation and often multiple causes are involved in the extinction of a species.

The instructor describes three case studies and introduces an optional Venn diagram students can use to individually take notes about the case studies (Supporting File S2. 6th Mass Extinction–Group Work Slides, Slide 3). Later students will be asked to work on the same Venn diagram in small groups. First, the passenger pigeon, which once constituted an estimated 25-40% of the total bird population in the United States, was driven to extinction by deforestation and hunting (17). Second, the golden toad was driven to extinction by climate-induced drought and disease caused by the chytrid fungus, which has caused the extinction of many other species of frogs and amphibians as well (18). Third, the Yangtze river dolphin went extinct directly due to human activity including fishing and pollution (19). After describing the case studies, the instructor assigns students to small breakout room groups and asks the students to consider the causes of extinction in these case studies by filling in the Venn diagram on the shared document provided (Supporting File S2.6th Mass Extinction–Group Work Slides, Slide 3). When the students return to the main room, the instructor asks the students to respond to a poll question indicating which of three possible Venn diagrams is most like their group's diagram (Supporting File S6. 6th Mass Extinction–Poll Questions, PQ12) then asks volunteers to describe their logic in choosing their selected diagram.

What can humans do to help?

The instructor provides several historic examples of human conservation efforts in the United States. Yellowstone National Park was established as the second protected natural area in the world and today 14% of land area is protected in State or National Parks (20). Students are asked to respond to an individual poll question about this topic: "Which of the following best describes the original motivation for the creation of national parks in the United States?" (Supporting File S6. 6th Mass Extinction–Poll Questions, PQ13). The instructor provides another example: pollution prevention in the 1960s following the publication of Rachel Carson's *Silent Spring* (21) which highlighted the damaging impacts of the pesticide dichlorodiphenyltrichloroethane (DDT) on insect, bird, and fish populations and influenced the passing of the Clean Air and Clean Water Acts and the creation of the Environmental Protection Agency. The instructor explains how after DDT was banned, bald eagle populations recovered due to specific targeted measures including captive breeding.

The instructor also highlights several examples outside the United States. African elephant populations in several countries recovered after the ivory trade was banned. Students are placed in their breakout rooms and asked to respond to a group poll question exploring possible non-governmental action to combat illegal ivory trade by considering actions the World Wildlife Fund could take (Supporting File S6. 6th Mass Extinction–Poll Questions, PQ14). When the students return to the main room, the instructor prompts students to share the highlights from their group discussion and challenges in considering each ivory trade prevention approach. Finally, the instructor describes the global threat of climate change and necessary actions to reduce its impact including reducing energy consumption, developing clean energy sources, and preserving forest lands. Students are asked to respond to a group poll question evaluating the feasibility of various approaches to reducing carbon emissions (Supporting File S6. 6th Mass Extinction–Poll Questions, PQ15) and volunteers are asked to share their responses with the class. Finally, students are asked to consider again in an individual poll question whether they believe Earth is currently experiencing a mass extinction to assess if student opinion has shifted over the course of the lesson (Supporting File S6. 6th Mass Extinction–Poll Questions, PQ16). In this course, the percentage of students who responded yes increased slightly to 67%. Students were invited to share their opinions with the entire class. Some students felt there is no way to determine if we are experiencing a mass extinction event until we reflect on species loss many thousands of years in the future. Other students felt classifying current biodiversity losses as a possible sixth mass extinction event is an important warning to encourage people to make changes that positively impact the environment.

Post-Lesson Discussion Board

After class session II, students complete the endangered species discussion board assignment (Supporting File S5. 6th Mass Extinction–Class Session II Slides, Slide 37-40) which asks them to consider an endangered species and what actions could be taken to protect that species. Students can choose from three example species including the Bactrian camel, Mediterranean monk seal, and the rusty patched bumblebee or select a species that interests them. Students are instructed to write an initial post and respond to posts written by two of their peers. Student responses are summarized in Table 3.

Post-Lesson Followup

Five quiz questions to assess student knowledge of the learning objectives are included in Supporting File S7. 6th Mass Extinction–Quiz Questions.

Adaptations for In-Person Teaching

For in-person teaching, the instructor could provide printed versions of the timeline activity and Venn diagram activity and ask students to write down their responses to the group discussion prompts about the extinct organism assignment (Supporting File S2. 6th Mass Extinction–Group Work Slides). The instructor should also provide students with copies of the mass extinction note-taking chart found in Supporting File S3. 6th Mass Extinction–Mass Extinctions Note-Taking Chart. When instructed to use breakout rooms throughout the lesson, the instructor could assign students to in-person discussion groups or ask them to discuss with nearby peers.

Adaptations for Asynchronous Teaching

For asynchronous online teaching, the instructor could record content that goes along with slides and integrate the poll questions into the recording using tools such as Kultra's Video Quiz. Alternatively, the instructor could prompt students to pause the video and answer questions using tools such as Google

Forms. The timeline activity, mass extinction notetaking chart, and Venn diagram activity could be provided as PowerPoint or Google Slides and students could work on the activities individually (Supporting File S2. 6th Mass Extinction–Group Work Slides). When instructed to use breakout rooms throughout the lesson, the instructor could instead prompt students to pause the recording and work on the activity or consider the prompt given individually.

TEACHING DISCUSSION

A variety of methods were used to assess student learning objectives for this lesson, including individual and group poll questions, a written reflection activity, and a discussion board post. In addition, key concepts were assessed via several quiz questions. The assessments were aimed to address all five of the learning objectives (Table 4).

In Class Poll Questions

Overall students came into the class with fairly high levels of prior knowledge about some relevant topics. More than 75% of students were aware of the age of the Earth, what percentage of species that have ever lived are alive today, and the basics of photosynthesis (Supporting File S6. 6th Mass Extinction–Poll Questions, PQ1, PQ3, and PQ5). However, students were less familiar with extinction and conservation-related concepts including common drivers of extinction and the reasoning behind protecting land (Supporting File S6. 6th Mass Extinction–Poll Questions, PQ11 and PQ13).

Overall students had a strong understanding of Earth's history after the group timeline activity with 74% of students selecting the correct timeline (Supporting File S6. 6th Mass Extinction–Poll Questions, PQ2). However, some groups still had the misunderstanding that multicellular life arose prior to the oxygenation of Earth even though oxygen is often credited for the rise of complex multicellular life. The poll questions also revealed that most students incorrectly viewed mammals as the group at greatest risk of extinction prior to discussion (Supporting File S6. 6th Mass Extinction–Poll Questions, PQ4).

LO-2 requires that students have a strong understanding of what defines a mass extinction event. Group discussion appears to aid in student understanding of this topic. The number of students selecting the correct response in a poll question on this topic rose substantially from 62% in individual responses to 90% after group discussion (Supporting File S6. 6th Mass Extinction–Poll Questions, PQ8-9). A complete summary of responses to in-class poll questions can be found in Supporting File S6. 6th Mass Extinction–Poll Questions.

Student Opinion: Is Earth Currently Undergoing a Sixth Mass Extinction?

At the end of class sessions I and II students were asked to respond to an opinion-based poll question regarding whether we are currently experiencing a mass extinction (Supporting File S6. 6th Mass Extinction–Poll Questions, PQ10 and PQ16). The goal was to determine if class discussion about biodiversity losses, tracking extinction, and conservation efforts would impact student opinion. The overall frequency of yes and no answers did not change much between the two timepoints. After class session I, 63% of students responded yes, and after class session II, 67% of students responded yes. Among students that responded to the poll after both class sessions, the majority did not change their answers. These results are summarized in Figure 2.

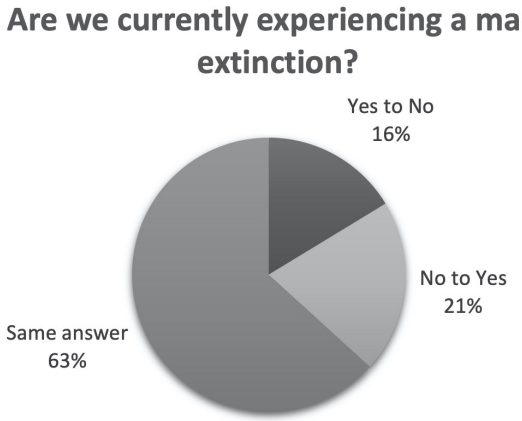

Figure 2. Student opinion about whether we are currently experiencing a mass extinction. Based on responses after class session I and II, most students did not change their answer (31 of 49). Of those who changed their response, 8 of 18 changed from yes to no and 10 of 18 changed from no to yes. Students who only answered once were excluded from this analysis.

Extinct Organism Activity Themes

Between class session I and II, when asked to submit information about an organism in danger of becoming extinct, the majority of students submitted pictures of charismatic fauna–large mammals and vertebrates with traits attractive to humans, such as intelligence, beauty, valor, singularity or a strong symbolism (15). Only two submissions were of non-charismatic fauna (rocket frog and tri-spine horseshoe crab). The submissions were also heavily biased toward mammals with 34 of 52 students submitting a mammal. The remaining submissions were primarily of other vertebrates. Only one student submitted an invertebrate, the tri-spine horseshoe crab. None of the students submitted a plant. Several specific organisms were frequently submitted including green sea turtles (5 submissions), giant armadillos (3 submissions), Ethiopian wolves (3 submissions), and polar bears (3 submissions). A summary of the animal groups submitted can be found in Table 2.

Discussion Board Post Themes

Students were asked to consider one of three provided endangered species (Bactrian camel, Mediterranean monk seal, and the rusty patched bumblebee) or another endangered species they are interested in and propose actions that can be taken to protect that species. Students were expected to post and respond to two peers' posts. The majority of students (25 of 48) selected animals other than the provided example species. For the species given, 13 students selected the Mediterranean monk seal, six selected the Bactrian camel, and four selected the rusty patched bumblebee. Any organisms other than the provided examples were chosen by no more than two students. Most organisms selected by the students were charismatic fauna. However, one student selected a plant (Wollemi pine) and two students selected non-charismatic fauna (desert rain frog and central rock rat).

In their posts, students focused on a wide variety of problems and potential solutions. The student responses can be summarized by 8 major categories of problems (e.g., pollution) and 6 major categories of solutions (e.g., political and regulatory). The problems and solutions are outlined in Table 3.

A common theme reflected in the posts was the nuanced and difficult conflict between humans and endangered species. For example, students indicated that balancing human welfare, income, and food security is a challenge presented by conservation efforts. Students also identified that endangered species often interact with people who are living in poverty, resulting in conservation efforts potentially impacting people's livelihoods. In addition, some species have cultural significance so regulating their relationships with humans is challenging. Overall, many students considered how people can work together with conservationists without jeopardizing the wellbeing of local peoples.

In terms of solutions, students highlighted the importance of education and outreach to both the general public and those who interact with an endangered species. Many students suggested public relations campaigns, perhaps highlighting their views of the role of social media in communication. Another key theme was the role of governments in conservation including regulating hunting and fishing and slowing habitat loss. In particular, students highlighted the importance of governments working together for species with wide habitat ranges which cross country borders or for issues related to climate change.

Quiz Questions

After the lesson, students were assessed on the lesson material in a quiz. A summary of quiz questions relevant to this lesson can be found in Supporting File S7. 6th Mass Extinction–Quiz Questions. Overall students performed well on the quiz questions, but some misunderstandings remained. About 16% of students maintained the thinking that many of Earth's mass extinction events happened billions of years ago (Supporting File S7. 6th Mass Extinction–Quiz Questions, QQ1). In addition, 16% of students appear to be unclear about the criteria that define a mass extinction event and selected answers that correspond with extinctions rather than mass extinctions (Supporting File S7. 6th Mass Extinction–Quiz Questions, QQ3). However, students appear to have attained a strong understanding of common causes and features of past mass extinction events with 95% of respondents correctly identifying changes in climate as the most common feature (Supporting File S7. 6th Mass Extinction–Quiz Questions, QQ2).

CONCLUSIONS

In this lesson, students are introduced to the concepts of deep time and extinction. Students are also asked to consider endangered species and recently extinct species to evaluate whether they believe Earth is currently experiencing a sixth mass extinction. Finally, students are encouraged to reflect on possible solutions and conservation efforts that can be made to prevent further biodiversity loss. A variety of active learning approaches are employed in this lesson including answering poll questions individually and in groups, participating in small-group discussion, and completing note-taking worksheets that accompany the lecture slides. Students are also asked to discuss various societal issues including conservation and climate change while respecting peers who may hold perspectives and opinions different from their own. Overall, students performed well on poll and quiz questions indicating knowledge across all five learning objectives. This lesson provides students with context to evaluate and understand globally relevant issues relating to biodiversity loss and conservation efforts, which are likely to be of increasing importance in the future.

SUPPORTING MATERIALS

- S1. 6th Mass Extinction–Potential Resources for Teachers
- S2. 6th Mass Extinction–Group Work Slides
- S3. 6th Mass Extinction–Mass Extinctions Note-Taking Chart
- S4. 6th Mass Extinction–Class Session I Slides
- S5. 6th Mass Extinction–Class Session II Slides
- S6. 6th Mass Extinction–Poll Questions
- S7. 6th Mass Extinction–Quiz Questions

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Table 1. Lesson timeline.

Activity	Description	Estimated Time	Notes
Preparation for Class			
Instructor preparation	1. Review lesson materials and relevant literature cited 2. Make an online document of the timeline activity, mass extinction chart, and Venn diagram 3. Enter poll questions into your polling software of choice 4. Create online prompt for the endangered animal photo submission and discussion board assignments	60-120 minutes	• Lesson files and a list of resources can be found in Supporting Files S1-7 • For poll questions, consider using PollEverywhere or a similar online software • For online collaboration, consider producing documents in Google Slides to allow live editing by student groups
Class Session I (75 minutes)			
Deep time and key events in Earth's history	1. Introduce the concept of deep time 2. Show NPR's Skunk Bear video "Earth's Entire History (Visualized On A Football Field)" 3. Timeline activity in small groups	15-20 minutes	• Lesson slides in Supporting File S4, Slides 1-8 • Group timeline activity in Supporting File S2
Introduction to extinction and mass extinction	1. Introduce extinction and causes 2. Place students in small groups for discussion 3. Describe the challenges of defining when a species is extinct 4. Introduce mass extinction	15-20 minutes	• Lesson slides in Supporting File S4, Slides 9-21
Mass extinctions throughout Earth's history	1. Introduce students to prior mass extinction events and provide the note taking chart 2. Administer poll questions about mass extinctions	35-40 minutes	• Lesson slides in Supporting File S4, Slides 22-49 • Mass extinction note taking chart in Supporting File S3
Extinct organism assignment	1. Introduce the assignment 2. Students submit photos of endangered organisms and causes driving the extinction	1 minutes	• Share the prompt with the students in class, see Supporting File S4, Slide 50 • Summary of student responses is in Table 2
Class Session II (75 minutes)			
Extinction and biodiversity loss	1. Explain the difference between biodiversity loss and mass extinction 2. Share images submitted in the extinct organism assignment 3. Discuss bias toward charismatic fauna in conservation efforts	15-20 minutes	• Lesson slides in Supporting File S5, Slides 1-6
Common drivers of extinction	1. Ask students to consider current and future drivers of extinction 2. Describe three case studies and provide students with optional individual Venn diagram 3. Place students in small groups to fill in Venn diagram	25-30 minutes	• Lesson slides in Supporting File S5, Slides 7-23 • Individual Venn diagram in Supporting File S3 • Group Venn diagram in Supporting File S2
What can humans do to help?	1. Describe conservation examples from the United States (state parks, legislation, and Bald Eagles) and student discussion 2. Introduce conservation globally (ivory trade, climate change) and group poll question	25-30 minutes	• Lesson slides are in Supporting File S5, Slides 24-36
Endangered species discussion board	1. Introduce the discussion board assignment 2. Prompt students to consider possible strategies for protecting an endangered species by writing an initial post and responding to two peer posts	2 minutes	• Share the prompt with the students in class, see Supporting File S5, Slide 37-40 • Summary of student responses is in Table 3

Table 2. Summary of student submissions to extinct organism assignment.

Animal Group	Number of Responses
Mammals	34
Birds	3
Reptiles	8
Amphibians	3
Fish	3
Invertebrates	1

Table 3. Summary of student responses to discussion board activity.

Description	Number of Responses*
Problems	
Cultural conflict – conflict due to cultural dependance on some resource	8
Resource conflict – conflict based on land use, shared resources, or other resource	33
Climate change or natural disaster	9
Habitat loss and degradation	31
Exploitation – hunting, poaching, harvesting, etc.	28
Pollution	5
Exotics – pathogens, domesticated animals, invasive species, etc.	7
Genetic diversity – hybridization or low genetic diversity	5
Solutions	
Education and research – outreach, ecotourism, campaigns	17
Political and regulatory – catch limits, gear restrictions, global cooperation, legislation	33
Captive breeding of species	4
Relocation of species	1
Land preservation and protected areas	27
Community support – community would need to assist in conservation	3

*Student responses were counted toward multiple themes when applicable.

Table 4. Summary of learning objectives and corresponding assessment questions.

	LO1: Outline the temporal relationship between major events in Earth's geological and biological history	LO2: Identify defining features of mass extinction events.	LO3: Compare and contrast the previous five major extinction events in terms of cause, magnitude, and subsequent impact on biodiversity.	LO4: Evaluate evidence for whether current losses in biodiversity should be defined as a mass extinction and explain why defining large losses in biodiversity as a mass extinction is relevant.	LO5: Assess the long-term implications of human impacts on the environment and propose practical strategies that humans can implement to slow down current extinction events.
Poll Questions	PQ1 PQ2	PQ6 PQ8 PQ9	PQ6 PQ7	PQ4 PQ10 PQ16	PQ11 PQ12 PQ13 PQ14 PQ15
Quiz Questions	QQ1	QQ3	QQ2	QQ4	QQ5