Did the dinosaur extinction lead to the evolution of larger mammals?

Educator guide

PAPER DETAILS

Original title: Exceptional continental record of biotic recovery after the Cretaceous-Paleogene mass extinction

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TABLE OF CONTENTS

DISCUSSION QUESTIONS

	LEARNING STANDARDS
1. How are an asteroid impact, dinosaur extinction, flowering plants, and the rise of mammals related? A diagram or flowchart may be useful in your answer.	**SEP7** **LS4.C** **ESS2.E** **Stability and Change** **RST.9-10.2** **EK2.D.1**
2. What evidence did the authors provide to support the claim that warming intervals influenced post-KPgE biotic recovery?	**ESS2.E** **Cause and Effect** **RST.9-10.5** **RST.9-10.8** **SP6** **EK2.D.3** **VC1**
3. What factors most likely interacted to limit body mass of mammal species prior to the KPgE?	**SEP7** **RST.9-10.8** **SP7** **VC1**
4. How was the authors' development of a high-resolution stratigraphic framework tied to paleomagnetics and the use of radioisotopes?	**SEP4** **PS1.C** **Patterns** **RST.9-10.4** **SP7** **VC4** **NS2**
5. How did the percentages of fossil pollen found in different stratigraphy layers help the authors in determining when there were spikes in different plant populations?	**SEP7** **RST.9-10.1** **VC2** **NS2**
6. What data did the authors collect to support the claim that the body mass and diversity of mammals increased post-KPgE?	**LS4.C** **Structure and Function** **RST.11-12.8** **SP6** **EK2.D.1** **VC2**
7. How might an understanding of post–mass extinction biotic recovery provide a framework for predicting ecosystem recovery following present-day mass extinctions?	**SEP7** **LS4.D** **Patterns** **EK1.C.1** **VC1** **VC4**

ACTIVITIES FOR INTERACTIVE ENGAGEMENT

	LEARNING STANDARDS
Writing an abstract Students write a new abstract for the article at a grade-appropriate reading level.	**RST.11-12.2** **VC1** **NS1**
Locating this study in the larger field Students use the annotated list of references to explain how this research builds on the published work of at least one other independent group of scientists. Students will evaluate whether data from this research supports or contradicts previous conclusions, and reflect on the statement that scientific knowledge is a "community effort."	**RST.9-10.8** **RST.11-12.8** **VC4** **NS3**
The Making of Mass Extinctions This Click & Learn activity from HHMI BioInteractive explores the environmental factors and species involved in Earth's five major mass extinctions, including the dinosaur extinction at the end of the Cretaceous period. https://www.biointeractive.org/classroom-resources/making-mass-extinctions-0 Students may watch a film following paleobiologists Anthony Barnosky and Kaitlin Maguire's efforts to find, collect, and date mammalian fossils. https://www.biointeractive.org/classroom-resources/anthony-barnosky-and-kaitlin-maguire-measure-mammal-extinctions-john-day-fossil	**SEP4** **LS4.C** **LS4.D** **ESS2.E** **Patterns** **EK1.C.1** **VC1**
The Day the Mesozoic Died This film from HHMI BioInteractive tells the story of uncovering the clues to explain the sudden disappearance of dinosaurs at the end of the Cretaceous period. Film: https://www.biointeractive.org/classroom-resources/day-mesozoic-died Guide sheet for film: https://www.biointeractive.org/classroom-resources/following-trail-evidence Activity: https://www.biointeractive.org/classroom-resources/activity-day-mesozoic-died Interactive Assessment: https://www.biointeractive.org/classroom-resources/interactive-assessment-day-mesozoic-died Calculating Iridium Fallout from an Asteroid Impact https://www.biointeractive.org/classroom-resources/calculating-iridium-fallout-asteroid-impact Chemical Signatures of Asteroid Impacts https://www.biointeractive.org/classroom-resources/chemical-signatures-asteroid-impacts Weighing the Evidence for a Mass Extinction: On Land https://www.biointeractive.org/classroom-resources/weighing-evidence-mass-extinction-land	**SEP4** **LS4.C** **LS4.D** **ESS2.E** **Patterns** **Cause and Effect** **Stability and Change** **RST.9-12.2** **RST9-12.4** **RST9-12.9** **SP6** **SP7** **EK1.A.4** **EK2.D.1** **EK2.D.3** **VC1** **NS1** **NS2** **NS3**

ARTICLE OVERVIEW

Article summary (recommended for educator use only)

The array of plant and animal fossils discovered in Colorado helped to answer some of the questions scientists have been asking about the rise of mammals during the first million years after the K-Pg extinction event. Using paleomagnetics and CA-ID-TIMS U-Pb-dated volcanic ash, the authors tied the stratigraphy of the Corral Bluffs area to the Geomagnetic Polarity Time Scale (GPTS). This provided them with a time-calibrated, uninterrupted fossil record of the biotic recovery as it took place. The authors were able to examine how warming trends influenced the adaptive radiation of plants and animals with a primary focus on the increase in body mass of mammals.

Importance of this research

In theory, the extinction of the dinosaurs paved the way for the expansion of mammals as well as other taxa, including plants. However, there are very few direct records of this time period. The researchers describe a new record in Colorado that includes unusually complete vertebrate and plant fossils that describe this event in detail. The authors, representing multiple scientific disciplines, build their work on research performed by scientists from an equally diverse set of disciplines. Lyson *et al.* stated that it is important to know what factors influence ecosystem recovery after a mass extinction. They state that "Detailed records of post-mass extinction biotic recovery … will provide a critical framework for predicting ecosystem recovery following mass extinction events including the one we currently face."

Experimental methods

- Magnetostratigraphy: This is a form of stratigraphy based on the remnant magnetism of rock layers. Stratigraphic divisions are based on changes in paleomagnetic polarity through time.
- CA-ID-TIMS U-Pb Dating: Stands for chemical abrasion-isotope dilution-thermal ionization mass spectrometry of radioactive uranium and lead. This is a procedure using geochronology based on the radioactive decay of ^{238}U and ^{235}U. Using this method, the authors were able to determine the age of the rock strata in which fossilized pollen, spores, and bones were found.
- Differential Global Positioning System (DGPS): A Trimble Juno T41S receiver was used to obtain 3D positioning data that resulted in post-processed data points that had a horizontal and vertical precision of 10 centimeters or less.
- Palynology: An analysis of the pollen and spores provided information about the relative abundances and distribution of plant species present at different times.
- Leaf-estimated mean annual temperature (LMAT): Leaf edges of megafloral specimens were examined and the frequency of serrated- vs. smooth-edged leaves was recorded. The percentage of smooth-margined leaf species at a site strongly correlates with greater mean annual temperature.
- Leaf mass per unit area (LMA): The estimate was conducted using the relationship between the cross-sectional area of the petiole and the mass of the leaf.
- Mammalian body mass determination: Statistical methods were used on the fossil skulls and teeth. In the case of partial crania, a comparison of the relative size of the upper first molar crown area was made to those from more complete crania from each respective taxon.
- Megaflora fossil collection and analysis: Beginning in the 1990s and continuing through 2018, the authors conducted field collections of megaflora fossils. All of these specimens were prepared, identified, and deposited at the Denver Museum of Nature & Science.

- Statistical models:
    - One-way chi-squared tests: Used to determine whether there was a statistically significant difference between the expected frequencies of occurrences for each vertebrate taxon and lithology versus the observed frequencies of occurrence.
    - Least-squares regressions of adult cranial size were done to estimate body mass.
    - Box plots: Used to represent data, including LMA.
    - Regression equations were used to calculate body-mass estimates for the largest specimen known from each meter level.

Conclusions

- The work of Lyson *et al.* has provided insight into how life recovers after a global catastrophe. The fossil plant and animal specimens they have discovered tell a more complete story of the first million years after the K-Pg extinction event.
- Within about 100 thousand years (ka) post-KPgE, the number of mammal species doubled and the maximum body mass of mammals increased to near pre-PKgE levels.
- Within about 300 ka post-KPgE, maximum mammalian body mass tripled and dietary niche specialization occurred. An increase in the richness of megaflora species took place during the same time period.
- About 700 ka post-KPgE, the first *Leguminosae* appeared, along with additional large mammals.
- Warming intervals likely fueled the concurrent plant and mammal evolution and body mass changes. This suggests that climate influenced post-KPgE biotic recovery. The warming periods, correlated with biotic change, demonstrate a strong relationship between the biosphere and the geosphere.
- The Deccan Traps eruptions likely played a role in Earth ecosystem succession and recovery post-KPgE.

LEARNING STANDARDS ALIGNMENT

The following tables provide an overview of the learning standards covered by this article, including the A Framework for K-12 Science Education (Framework), Common Core State Standards English Language Arts-Literacy (CCSS ELA), Common Core State Standards Statistics and Probability (CCSS HSS), AP Science Practices, and Vision and Change for Undergraduate Education. Where applicable, activities and information will be marked with specific standards to which they are linked.

<table>
<tr><th colspan="3">A Framework for K-12 Science Education</th></tr>
<tr><th>Science and Engineering Practices</th><th>Disciplinary Core Ideas</th><th>Crosscutting Concepts</th></tr>
<tr>
<td>Analyzing and Interpreting Data (SEP4)
Analyze data systematically, either to look for salient patterns or to test whether data are consistent with an initial hypothesis. Recognize patterns in data that suggest relationships worth investigating further. Distinguish between causal and correlational relationships.

Engaging in Argument from Evidence (SEP7)
Construct a scientific argument showing how data support a claim.</td>
<td>LS4.C: Adaptation
Species become extinct because they can no longer survive and reproduce in their altered environment. If members cannot adjust to change that is too fast or too drastic, the opportunity for the species' evolution is lost.

LS4.D: Biodiversity and Humans
Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction).

ESS2.E: Biogeology
The many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual co-evolution of Earth's surface and the life that exists on it.

PS1.C: Nuclear Processes
Spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials.</td>
<td>Patterns
Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.

Cause and Effect
Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.

Structure and Function
The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.

Stability and Change
For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.</td>
</tr>
</table>

Common Core State Standards English Language Arts-Literacy		
Key Ideas and Details	Craft and Structure	Integration of Knowledge and Ideas
RST.9-10.1 Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions. **RST.9-10.2** Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text. **RST.11-12.1** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. **RST.11-12.2** Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.	**RST.9-10.4** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics. **RST.9-10.5** Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy). **RST.9-10.6** Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, defining the question the author seeks to address. **RST.11-12.4** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics. **RST.11-12.5** Analyze how the text structures information or ideas into categories or hierarchies, demonstrating understanding of the information or ideas. **RST.11-12.6** Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, identifying important issues that remain unresolved.	**RST.9-10.8** Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem. **RST.9-10.9** Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts. **RST.11-12.8** Evaluate the hypotheses, data, analyses, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. **RST.11-12.9** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

AP Science Standards	
AP Science Practices	AP Biology Content Standards
Science Practice 6 (SP6) The student can work with scientific explanations and theories. **Science Practice 7 (SP7)** The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.	**Essential knowledge 1.A.4 (EK1.A.4)** Biological evolution is supported by scientific evidence from many disciplines, including mathematics. (Scientific evidence of biological evolution uses information from geographical, geological, physical, chemical, and mathematical applications). **Essential knowledge 1.C.1 (EK1.C.1)** Speciation and extinction have occurred throughout Earth's history. **Essential knowledge 2.D.1 (EK2.D.1)** All biological systems from cells and organisms to populations, communities, and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy. **Essential knowledge 2.D.3 (EK2.D.3)** Biological systems are affected by disruptions to their dynamic homeostasis.

Connections to the Nature of Science	
Vision and Change for Undergraduate Biology Education Core Competencies and Disciplinary Practices	A Framework for K-12 Science Education Understandings About the Nature of Science
Ability to apply the process of science (VC1) Biology is an evidence-based discipline. **Ability to use quantitative reasoning (VC2)** Biology relies on application of quantitative analysis and mathematical reasoning. **Ability to tap into the interdisciplinary nature of science (V4)** Apply concepts from other sciences to interpret biological phenomena.	**Scientific Investigations Use a Variety of Methods (NS1)** Scientific inquiry is characterized by a common set of values that include logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings. New technologies advance scientific knowledge. **Scientific Knowledge is Based on Empirical Evidence (NS2)** Science includes the process of coordinatingpatterns of evidence with current theory. Scientific arguments are strengthened by multiple lines of evidence supporting a single explanation. **Scientific Knowledge is Open to Revision in Light of New Evidence (NS3)** Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.