ICE AGE MAMMALS COLONIZE NEW YORK:

A STEM LAB DERIVED FROM COLLECTIONS-BASED RESEARCH AT THE NEW YORK STATE MUSEUM

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Andrew L. Kozlowski, Ph.D.

New York State Museum Education Leaflet 37

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New York State Museum
Albany, NY

New York State Museum Education Leaflet 37

ISBN: 978-1-55557-2723

ISSN: 0735-4401

Dear Educators,

The New York State Museum is happy to present you with Education Leaflet No. 37, Ice Age Mammals Colonize New York: A STEM Lab Derived From Collections-Based Research at the New York State Museum. Below you will find readings intended for the non-specialist as well as sample assessment questions to use with students in the classroom, perhaps used in combination with a reading of the scientific article from which this Education Leaflet is based:

Feranec, R.S., and Kozlowski, A.L. 2016. Implications of a Bayesian radiocarbon calibration of colonization ages for mammalian megafauna in glaciated New York State after the Last Glacial Maximum. Quaternary Research 85(2):262-270; doi:10.1016/j.yqres.2016.01.003

This Education Leaflet is aligned with the New York State P-12 Draft Science Learning Standards and is appropriate for Grades 8–12.

New York State P-12 Draft Science Learning Standards:

MS-LS2-2. Construct an explanation that predicts patterns of interactions among organisms in a variety of ecosystems.

MS-LS2-5. Evaluate competing design solutions for maintaining biodiversity and protecting ecosystem stability.

MS-LS4-1. Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past.

MS-LS4-2. Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships.

MS-ESS1-4. Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year-old history.

MS-ESS2-2. Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying temporal and spatial scales.

MS-ESS3-4. Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.

Acknowledgements
We would like to thank K. Feranec for graphic design and layout of the Education Leaflet. We thank J. Hart and K. Feranec for editorial comments that improved the manuscript. We thank D. Crast, a Master Teacher at Durgee Junior High School, Baldwinsville, NY, for peer review and examining this Education Leaflet with students prior to publication. His comments and suggestions improved the manuscript. Funding for the original research integrated into this Education Leaflet was provided by the Great Lakes Geological Mapping Coalition (Grant: G13AC00338) and the STATEMAP program (Grant: G14AC00360) of the National Cooperative Geological Mapping Program of the United States Geological Survey, and the New York State Museum.

THE PURPOSE OF THIS LEAFLET

is to provide information to primary and secondary school educators and students relating to collections-based research at the New York State Museum addressing the question:

"After the last Ice Age, when did species first colonize New York?"

The information provided below is intended for the non-specialist, and is derived from the publication, "Implications of a Bayesian radiocarbon calibration of colonization ages for mammalian megafauna in glaciated New York State after the Last Glacial Maximum." *Quaternary Research* (2016) 85(2):262 270; doi:10.1016/j.yqres.2016.01.003.

For educators, sample assessment questions can be found on the final pages of this leaflet.

THE ICE AGES

The Pleistocene Epoch, 2.588 million years ago to 11,700 years ago (0.0117 million years ago), is characterized by fluctuations in global climate where cold glacial periods (-12 to -4 degrees Celsius compared to today) are followed by warm interglacial periods (average temperatures similar to today). Currently, the Earth is in an interglacial period. But, twenty five thousand years ago, the Earth was entering the height of the last Ice Age.

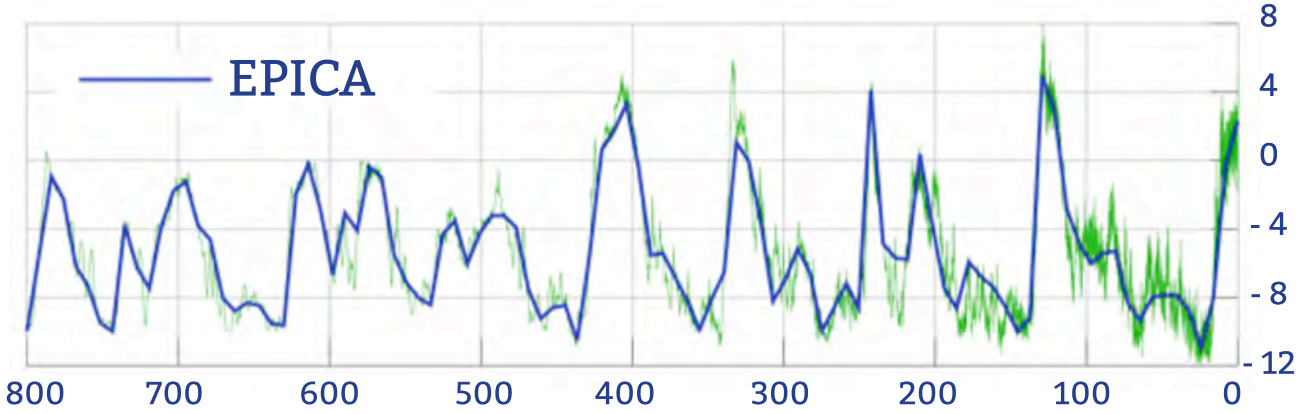


Figure 1. Temperature difference over the past 800,000 years obtained from the EPICA ice core (Antarctica). Interglacials are represented by high temperatures, and glacial periods by low temperatures. (Source: Delphi234; CC-BY-SA 3.0)

LAST GLACIAL MAXIMUM

Earth's last ice age, more appropriately called the Last Glacial Maximum (LGM), was a time of extreme cold. During this period, an enormous ice sheet, called the Laurentide Ice Sheet (LIS), covered much of northern North America, including most of what would become New York.

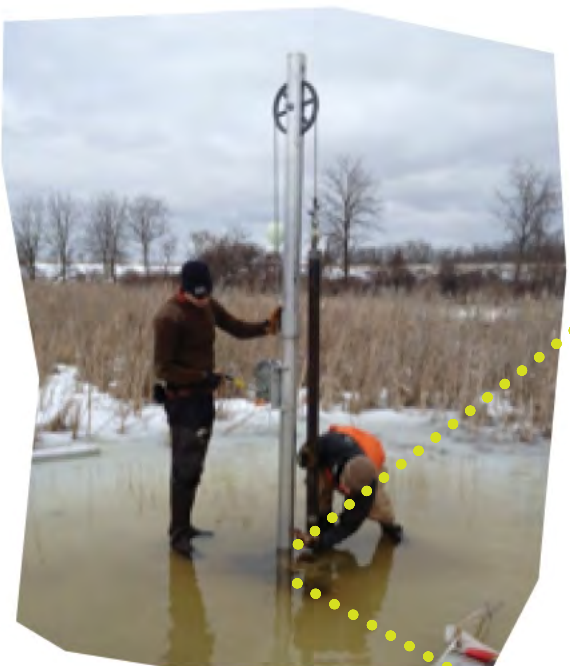
The only areas left uncovered in New York included a small portion in the west where present-day Allegany State Park is located and the southernmost part of Long Island. Geological data show that even New York's highest mountain peak in the Adirondack Mountains, Mount Marcy (1629 m high), was covered by the LIS. However, as the climate warmed, the LIS began to melt and plants and animals were able to re-colonize the areas of New York once covered by the ice.

PLANTS FROM THE PAST

By analyzing pollen found in ancient sediments, researchers have been able to identify the presence of specific plant species at a particular place and time in the past.

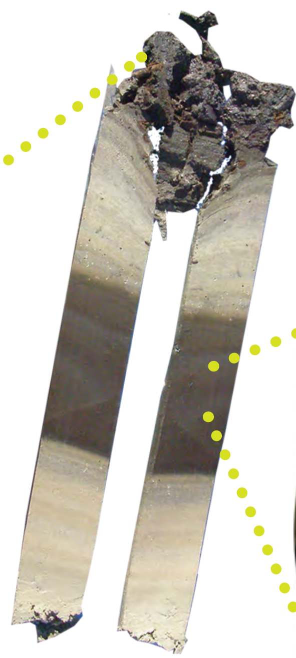
STEP 1.

New York State Museum scientists obtain sediment cores from the Dummond Wetland in Cayuga County, NY. *(Source: A. Kozlowski, 2015)*



STEP 2.

The different colored layers observed in the sediment core are identified and measured. Each new layer represents a period of time from hundreds to thousands, and sometimes millions of years ago, depending on the depth from which the core was taken. The deeper the extraction point, the older the material. *(Source: A. Kozlowski, 2015)*



STEP 3.

Each section of the sediment core is then examined for evidence of fossils, soil type, and, in this case, microscopic particles, such as pollen. The spruce pollen grains pictured here are about 100 microns across. *(Source: Martin D. Adamiker; CC BY-SA 4.0)*

HABITATS
IN POST-ICE AGE NEW YORK

Using data extracted from sediment cores throughout New York, researchers are able to reconstruct what habitats existed at each study site as well as how these habitats changed over time.

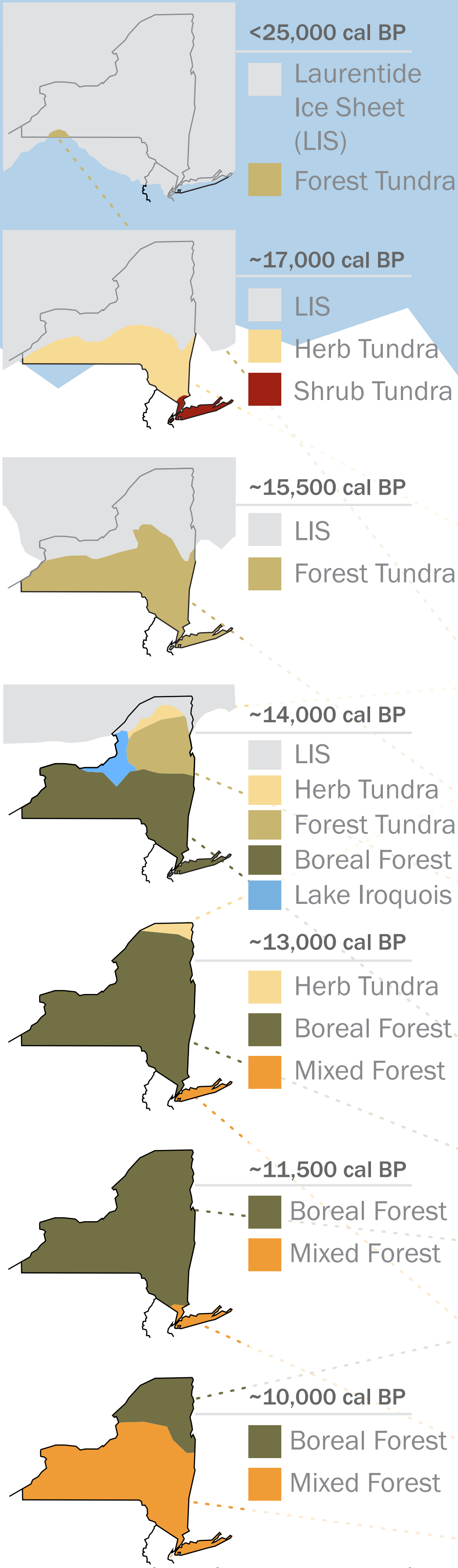
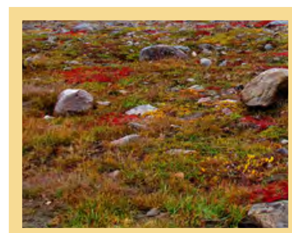


Figure 2. Habitat changes in New York after the LGM.

THE FOUR MAJOR HABITATS to occur in New York after deglaciation from the LGM include:

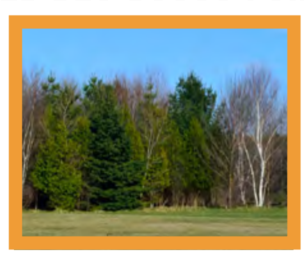
HERB/SHRUB TUNDRA



FOREST TUNDRA

BOREAL FOREST

MIXED DECIDUOUS FOREST



Modern tundra - Nunavut, Canada
(Source: ADialla; CC BY 2.0)

HERB/SHRUB TUNDRA

When the glaciers retreat, the first habitat to appear is the tundra, a cold windy, treeless environment with little rain and a short growing season. Plants that grow in this harsh environment are usually small and have adapted to conserve water and survive the cold and wind.

Tundra flora include sedges, grasses, forbs (e.g., *Dryas integrifolia*) as well as low-lying willow and birch.

Extant caribou *(Rangifer tarandus)* in modern day tundra habitat. *(Source: A, Dean Biggins; US Fish and Wildlife Service; public domain)*

Dryas integrifolia, a typical tundra plant found abundantly in New York after the Last Glacial Maximum. *(Source: Kim Hansen; CC-BY-SA 3.0)*

FOREST TUNDRA

The next habitat, forest tundra, typically occurs between the herb/shrub tundra habitats and boreal forest. Forest tundra contains herbs and shrubs but also has stands of conifer trees, typically spruce.

Glacier National Park, Montana
(Source: Jeffrey Mehlhorn, 2012. Public Domain)

Modern boreal forest in Canada
(Source: peupleloup; CC BY-SA 2.0)

BOREAL FOREST

Spruce, larch, and fir trees are the dominant plants in the boreal forest, although smaller herbaceous plants, mosses, and grasses can be found. Lakes and other smaller water bodies are also abundant. Today, boreal forest is the largest **biome** in the world, making up 29% of all forest cover. Boreal forests are present throughout much of Canada and are still found in the Adirondack Mountains.

Norway Spruce (*Picea abies)*
(Source: A, MPF, CC BY-SA 3.0)

Larch (*Larix decidua***)**
(Source: Peter O'Connor; CC BY-SA 2.0)

MIXED DECIDUOUS FOREST

Unlike the evergreen trees of the Boreal Forest, deciduous trees lose their leaves each year and are found in areas with warm, moist summers and mild winters. Most of present-day New York State is occupied by Mixed Deciduous Forest, where both evergreens and broad-leaf deciduous trees like maple and oak coexist.

Modern mixed deciduous forest in Canada
(Source: Raysonho CC0 1.0 Universal Public Domain Dedication)

ANIMALS
IN POST-ICE AGE NEW YORK

Pleistocene-aged fossils of many different animal species have been found throughout New York. Some species, like muskox and caribou, are **extant**, meaning they are still around today, while others, such as Woolly mammoth, are **extinct**, indicating their species is no longer alive anywhere on Earth.

American mastodon, peccary, and caribou
(Source: Detail from New York State Museum Ice Ages Mural. Beth Zaiken, artist.)

Based on the fossil record, three of the most abundant **taxa** present during the late Pleistocene of New York included the American mastodon, the Woolly mammoth, and caribou. Ground sloths, giant beaver, flat-headed peccary, and stag moose are also present in the state.

AMERICAN MASTODON

This animal may have looked like a hairy elephant, but American mastodon were only distantly related to modern elephants. Features of this species' skeleton, most notably the large cusps on their teeth (Figure 3), show that they were actually quite different from elephants.

Fossils of American mastodon have been found across North America, but were particularly abundant around the Great Lakes, including New York. Interestingly, Orange County, New York has an extraordinarily high density of American mastodon fossils. Research from these sites has shown that American mastodon preferred to live in spruce forests. In fact, gut contents of American mastodon indicate that this species liked eating spruce and other conifer needles, twigs, and cones.

Extinct American mastodon (*Mammut americanum)*
(Source: Detail from New York State Museum Ice Ages Mural. Beth Zaiken, artist.)

Extinct Woolly mammoth (*Mammuthus primigenius*)
(Source: Flying Puffin; CC BY-SA 2.0)

WOOLLY MAMMOTH

Mammoths were also present in New York during the late Pleistocene. Although similar in appearance to American mastodon, mammoth were much more closely related to modern elephants, specifically Asian elephants. This similarity can be seen in dental comparisons (Figure 3).

New York had at least two, and possibly three species of mammoth during the late Pleistocene: the Woolly mammoth, the Columbian mammoth, and the Jefferson's mammoth. To identify the species from fossils, specific characteristics of teeth or genetic tests are needed.

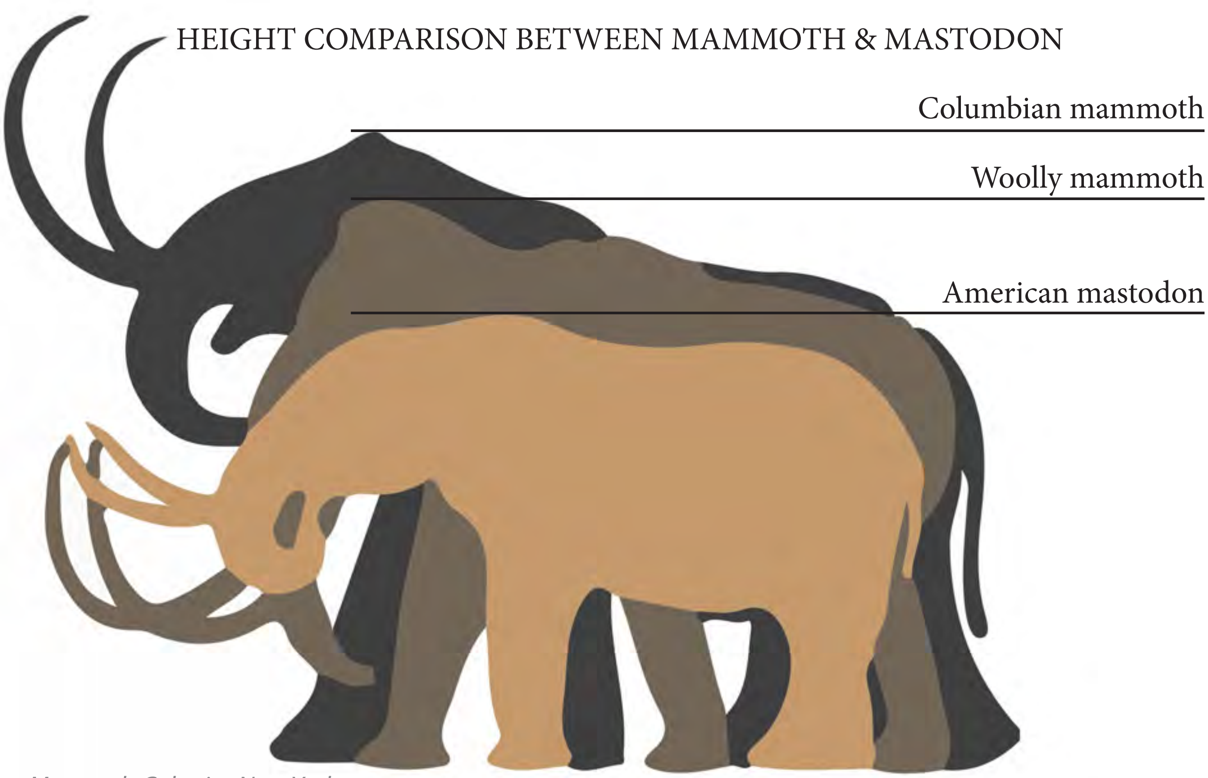
Woolly mammoth migrated to North America from Eurasia during the late Pleistocene. Woolly mammoth were globally wide-spread, but their remains have never been found south of 36.5N latitude (e.g., south of Kentucky or Virginia), most likely due to climate. This species appears to have preferred cooler temperatures and feeding on low-lying plants in tundra or boreal forest habitats.

Columbian mammoth were closely related to Woolly mammoth, but had less hair. Columbian mammoths were native to North America, and appear to have preferred feeding on low-lying plants in grasslands or **steppe** habitats.

Jefferson's mammoth was a possible third species of mammoth present in New York after the LGM. Paleontologists are still debating whether Jefferson's mammoth was a true species. Some research suggests that this species was a hybrid of Woolly mammoth and Columbian mammoth.

DNA analyses showed that each of these species were capable of interbreeding with each other and producing viable offspring. All of these mammoth taxa were grazers, animals that consumed grasses, sedges, and low-lying tundra plants.

HEIGHT COMPARISON BETWEEN MAMMOTH & MASTODON



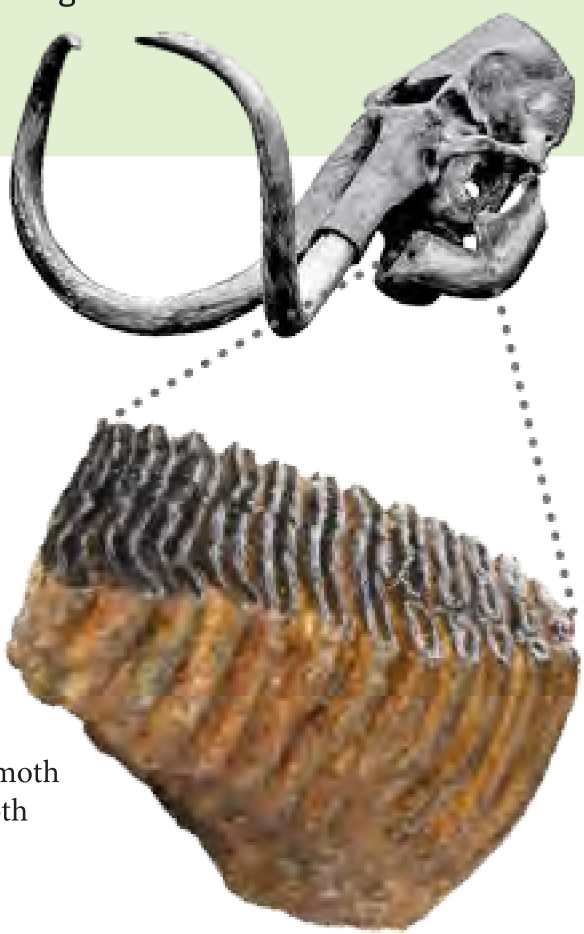
DENTAL COMPARISON

Figure 3.

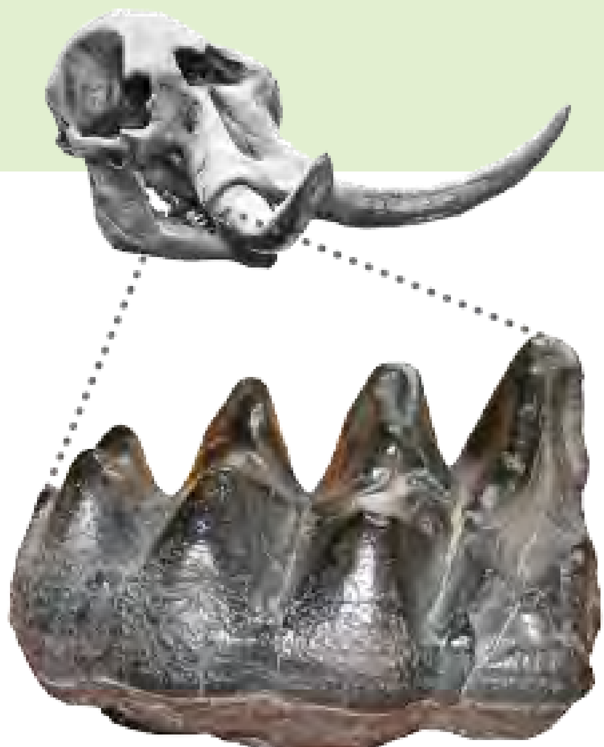
Tooth of modern elephant (*Loxodonta africana*)

Similar to modern elephants, mammoth teeth were flat and covered with ridges of enamel that would grind and pulverize grasses and lichens in a forward/backward sliding motion.

On the other hand, the molars of mastodon had deep cusps that were used to chew and crush plants like pine needles and twigs.



Mammoth tooth



Tooth of American mastodon (*Mammut americanum*)

Extant caribou (*Rangifer tarandus*) in modern day tundra habitat.
(Source: A, Dean Biggins; US Fish and Wildlife Service)

CARIBOU

Caribou were also abundant in New York after the LGM. In contrast to the species mentioned above (i.e., American mastodon and mammoth), caribou are still alive today, although they were **extirpated** from New York in the 1700s.

Caribou are known to inhabit tundra and boreal forest habitats, and like to eat lichens, a common tundra plant, particularly in winter. Caribou have also been observed eating grasses, sedges, and the leaves of willow and birch.

CARBON DATING

Carbon dating is a method of determining the age of something that lived in the past using the radioactive properties of ^{14}C (generally said, "Carbon-14"). It is commonly used in archaeology and paleontology. The age limits of carbon dating currently go back about 50,000 years before present (yr BP).

^{14}C is radioactive, meaning after a certain period of time it converts into a more stable product. By measuring the amount of ^{14}C in a sample of plant or animal, scientists can determine when it died. ^{14}C is continually being created as cosmic rays hit nitrogen gas in the upper atmosphere. The ^{14}C then combines with oxygen to create a radioactive molecule of carbon dioxide ($^{14}CO_2$). Some of this $^{14}CO_2$ is taken into plants during photosynthesis, and then incorporated into animals when the plants are eaten.

When the plant or animal dies, it stops absorbing the ^{14}C, and over time the ^{14}C converts back to stable atmospheric nitrogen gas, at a half-life of 5,730 years. Thus, after 5,730 years, half of the ^{14}C incorporated into the plant or animal during its life has converted to stable nitrogen. After another 5,730 years, half of the remaining ^{14}C (i.e., 25% of the original ^{14}C) remains. And, after yet another 5,730 years, half of that ^{14}C remains (i.e., 12.5%), and so on.

Based on the rate of conversion (generally called, "decay") of ^{14}C to nitrogen, the percentage of ^{14}C remaining in a fossil sample compared to a modern sample (called, "fraction modern") can be used to calculate a radiocarbon age. For example, using Figure 4 below, a specimen analyzed to have 10% of its ^{14}C is calculated to have been 19,035 radiocarbon years old.

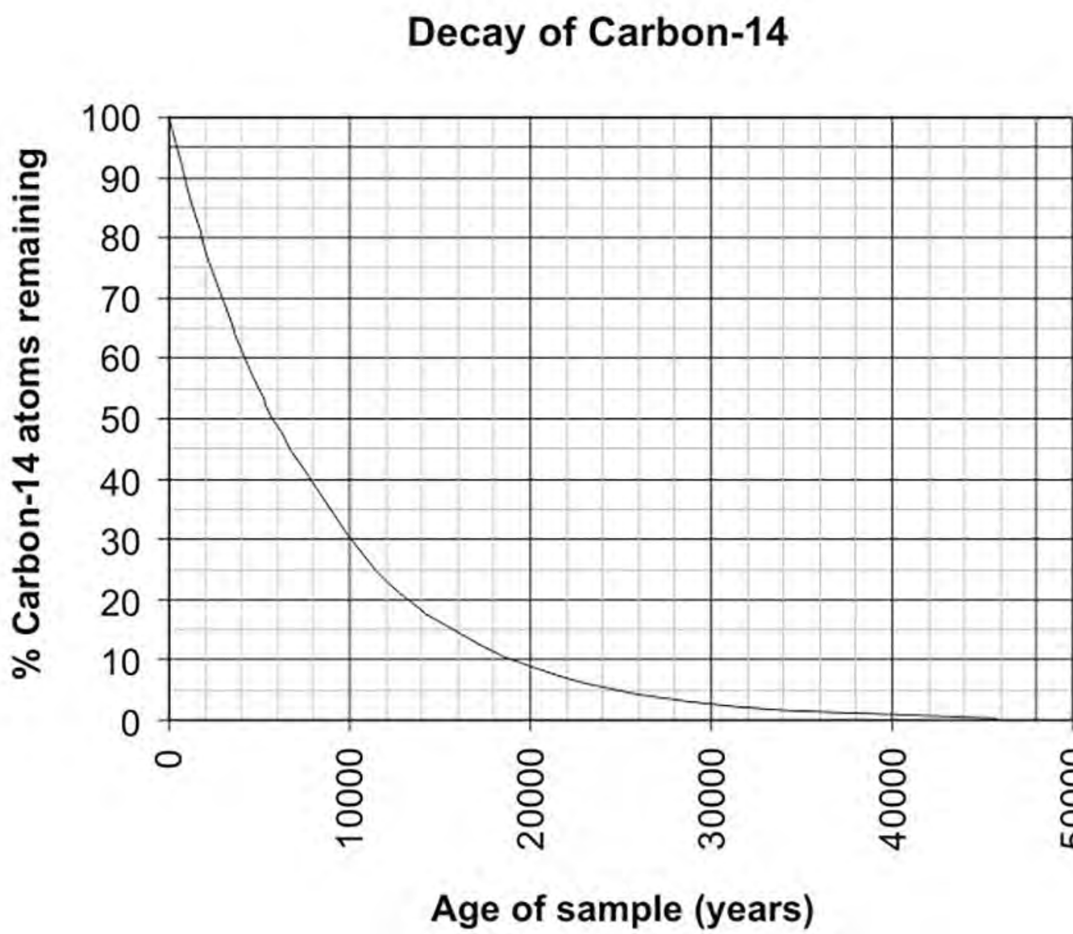


Figure 4. Radioactive decay of ^{14}C. Fraction of ^{14}C atoms remaining in an ancient sample based on age. (*Source: Kurt Rosenkrantz; CC BY-SA 3.0*).

CALIBRATION

Tree rings grow every year, and the rings can be matched from different individual trees to create a tree-ring record back in time. Similar to trees, some corals in the ocean also grow forming yearly bands, and these bands can also be matched to create a record back in time. Scientists have now created a record back about 50,000 years.

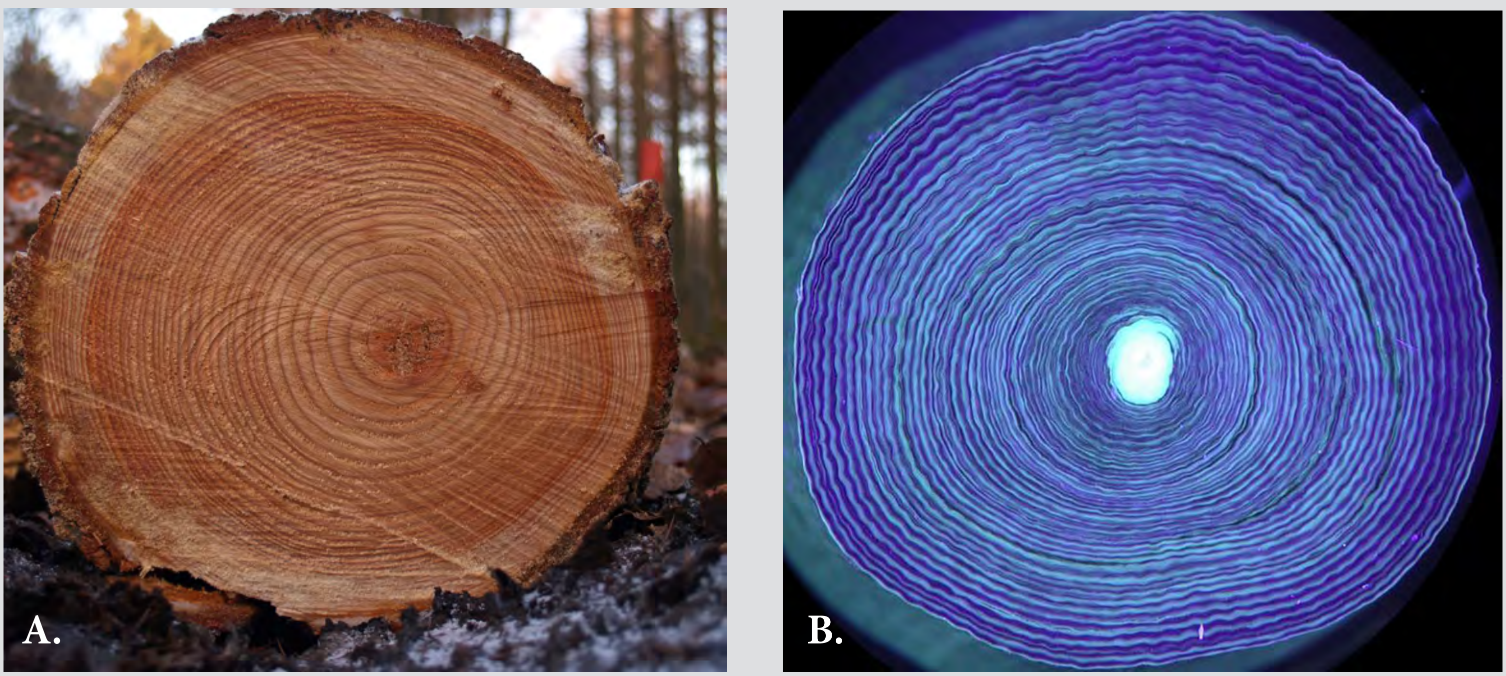


Figure 5. Figure showing the growth rings of (A) tree and (B) coral. The rings can be correlated between individuals allowing scientists to create a record of the past. At present, scientists have growth-ring records dating back to about 50,000 yr BP. The rings can be used to measure the amount of ^{14}C remaining from a specific year. (*Sources: A, Arnoldius; CC BY-SA 2.5; B, Owen Sherwood, Smithsonian Institution 2015*).

Over time, the amount of ^{14}C in the atmosphere has changed, which complicates using the ^{14}C half-life in calculating accurate ages for ancient samples. More or less ^{14}C in the atmosphere may result in younger or older ages being calculated. But, tree and coral ring records can be used to calculate exactly how much ^{14}C is expected to be left from a given year in the past. Scientists use the ^{14}C tree and coral ring records to “calibrate” ages based on the amount of ^{14}C that remains in an ancient sample.

Carbon dates based on just the ^{14}C half-life are reported as “years before present” (yr BP; e.g., 5,730 yr BP), with the present designated as 1950, by convention. To designate a date that has been calibrated, dates are reported as “calibrated years before present” (cal yr BP; e.g., 5,730 cal yr BP). Sometimes, “cal” is referred to as “calendar” rather than “calibrated”.

In general, specific calendar years are not possible to calculate because of the uncertainty in the measurement of ^{14}C in the ancient sample as well as in the tree ring record. Calibrated dates are usually given as ranges. With technological and laboratory improvements over the last few years, the uncertainty of age ranges continues to narrow for ^{14}C dates.

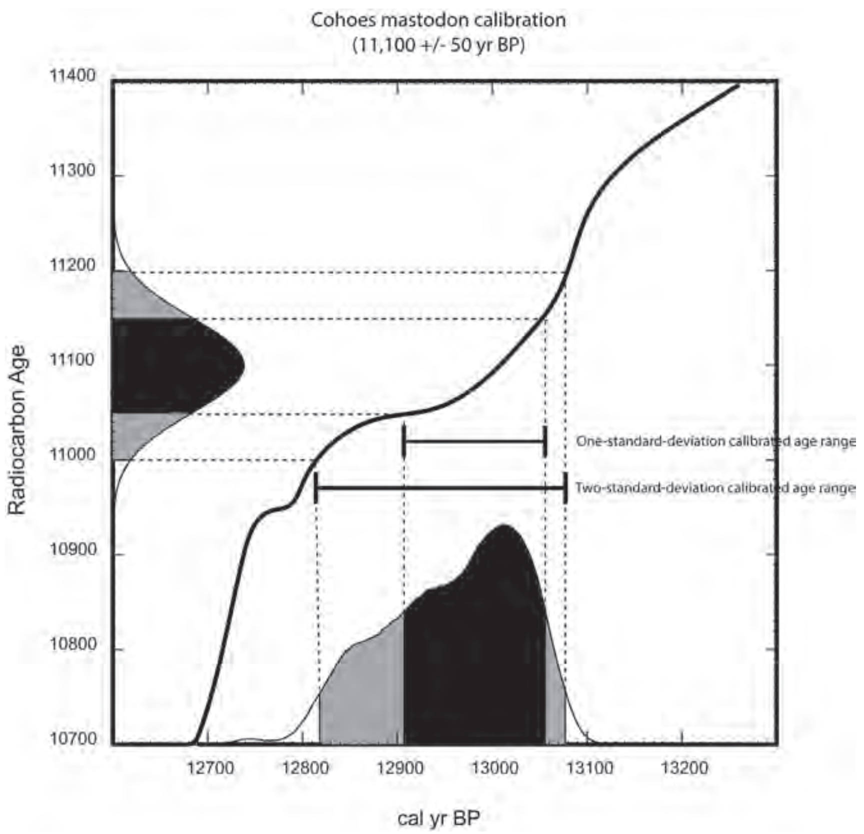
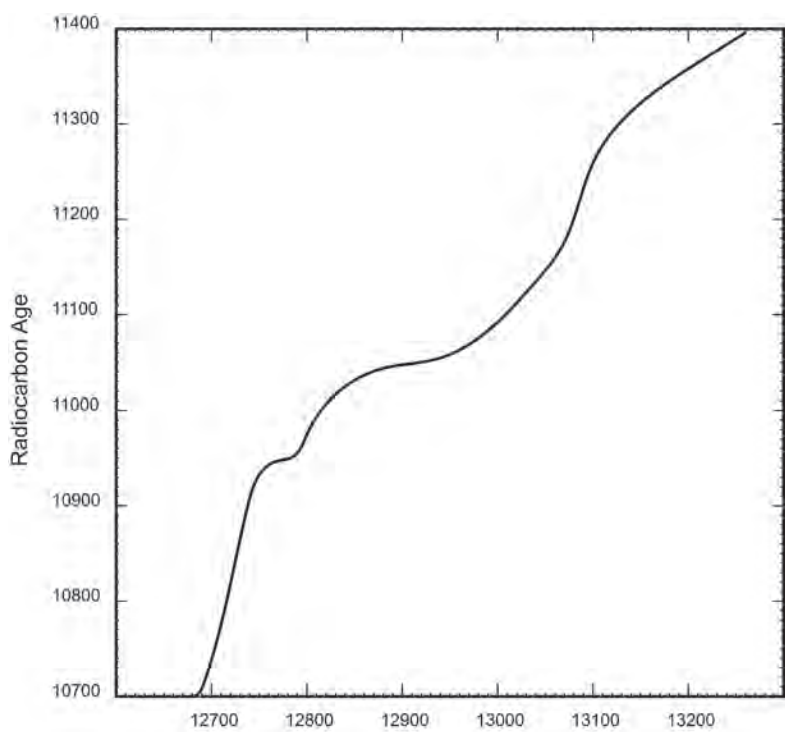


Figure 6.

Calibration of the Cohoes mastodon. Data from the left femur and a tooth root provided a radiocarbon age of 11,100 ± 50 yr BP for this individual. The error provided with carbon dates (e.g., ± 50 yr BP for the Cohoes mastodon) is one standard deviation. When reporting calibrated ages, it is best to report the two-**standard-deviation** calibrated age ranges.

Figure 7.

Radiocarbon calibration curve between 12,800 and 13,300 cal yr BP.



DISCUSSION

Table 1. Ranges for the dates of earliest and latest occurrences of caribou (*Rangifer tarandus*), mammoth (*Mammuthus sp.*) and American mastodon (*Mammut americanum*) within New York State.

Species	Number of Specimens	Range of Earliest Occurrence (cal yr BP)	Range of Latest Occurrence (cal yr BP)
Caribou *(Rangifer tarandus)*	11	17970—16450	~200
Mammoth *(Mammuthus sp.)*	7	17600-15230	12240-10190
American Mastodon *(Mammut americanum)*	21	14540-14090	12460-11930

Examining the range of earliest occurrence dates from Table 1 (above) shows that caribou and mammoth colonized New York in the thousand years or so after 18,000 years ago, and this was followed by mastodons colonizing the state about 14,000 years ago. Comparing these colonization dates to the habitats that were present in New York upon their arrival shows that caribou and mammoth colonized when tundra was present, while American mastodon arrived when boreal forest was first present in the state. These habitats provided the preferred food for these species.

Interestingly, both mammoth and mastodon go extinct in New York only a few thousand years after their arrival. The range of last occurrence dates, that is, the date of extinction, for these two species is around 12,000 years ago in the state. A big debate that is still on-going in paleontology is whether the extinction of large mammals, such as mammoth and mastodon, at the end of the last Ice Age was caused primarily by changes in climate, which would have caused habitats to change as global temperatures warmed, or whether human hunting was the major cause.

Humans first colonize North America after the Last Glacial Maximum. Although remains of the initial human colonizers of New York have yet to be recovered, evidence in the form of fluted points and other stone tools found at early archaeological sites suggest a Native American arrival in the state about 13,000 years ago. At the time of extinction of mammoth and mastodon in New York, both boreal forest and tundra habitats were still present suggesting humans played a significant role in the extinction of the species in New York.

Early Paleoindian fluted point, Lamb site, Darien, Genesee County, New York.
(Source: New York State Museum)

CONCLUSIONS

From this and other similar studies, it is evident that habitats moved north as the climate warmed. Additionally, the data collected from Ice Age mammoth, mastodon, and caribou of New York indicate that as climates changed, mammal populations migrated with or to their preferred habitats rather than stay put and try to adjust to new temperatures and/or the changed environment. This implies that with current climatic warming, habitats and animal populations from southern areas will begin to move northward.

Therefore, if we value these habitats and animals, steps should be put into place to assist with possible enivornental and faunal migrations north. For example, environmental corridors such as land bridges would be necessary for animals to safely move across the landscape (e.g., reducing roadkill). And because it may be hard for certain species, like deer, to establish populations in large cities, more park reserves and designated areas would need to be available so that habitats and animals could re-establish.

Ultimately, by examining the climate, environment, and animals of the past, we not only learn more about our prehistory, but we can use that information to arrive at a better understanding of our world today and how current events may shape the world of tomorrow.

VOCABULARY

Biomes: large regions of the world characterized by major vegetation types and animals, which are typically controlled by climate.

Deglaciation: the retreat of a glacier or ice sheet (e.g., Laurentide Ice Sheet) that results in the exposure of land.

Extant: currently living as a species

Extinct: the end of a species. Occurs when the last individual of a species dies.

Extirpate: extinction of a species in a particular area. Species are extant in other areas.

Glacial period: sometimes referred to as just "glacial"; a time interval characterized by colder temperatures and the growth of glaciers.

Half-life: the time required for half of an amount of radioactive atoms to convert to a more stable set of atoms.

Interglacial: sometimes referred to as just "interglacial"; a time interval between glacial periods characterized by warmer temperatures.

Last Glacial Maximum (LGM): the most recent period in Earth's history (about 25,000 years ago) when continental ice sheets were at their greatest extension.

Laurentide Ice Sheet (LIS): massive ice sheet that covered much of northern North America, including most of Canada and portions of the United States, during the latest Pleistocene.

Lichen: an organism that occurs through a symbiotic relationship between an algae and a fungus.

Megafauna: Species whose individual animals average over 100 lbs/45kgs, e.g., caribou, mammoth, and mastodon.

Pleistocene: geological epoch, typically referred to as the Ice Age, which lasted from 2,588,000 to 11,700 years ago.

Standard Deviation: a statistical measure used to quantify the amount of variation in a set of data values. A low standard deviation indicates that the data points tend to be close to the average value, while a high standard deviation indicates that the data points are more spread out.

Steppe: an ecological region characterized by grassland plains.

Taxa: group of one or more populations of an organism forming a taxonomic unit, such as population, species, genus, family, etc.

ASSESSMENT QUESTIONS:

1. Using Figure 2, what major habitat type was present where you currently live in New York 14,000 cal yr BP?

2. Summarize how the habitats of New York changed from the Last Glacial Maximum to the end of the Pleistocene where you live.

3. Use Figure 4 above to answer the following: A fossil bone from a grave site in the United Kingdom showed that it had 80% of its ^{14}C atoms remaining. What is the age of the sample?

4. Use Figure 4 above to answer the following. Using the information about the Last Glacial Maximum of New York, explain why you might be skeptical that a fossil from near Lake Champlain had 5% of its ^{14}C atoms remaining?

5. Use Figure 4 above to answer the following: After ten half-lives, the number of ^{14}C atoms is so few that most carbon dating machines can't precisely measure them anymore. Based on this, what is the oldest date that most carbon dating labs can provide?

6. Using Figure 6, what is the calibrated age range for the Cohoes mastodon?

7. Using the calibration curve from Figure 7, a sample with a ^{14}C date of 10,900 +/- 50 yr BP would calibrate to what two-standard-deviation age range. NOTE: the error of radiocarbon dates is always provided as one-standard deviation.

8. Using the calibration curve from Figure 7, a sample with a ^{14}C date of 11,040 +/- 40 yr BP would calibrate to what two-standard-deviation age range.

9. Examine Figure 7. What happens to the calibrated age range of a radiocarbon date that falls on a portion of the calibration line that is flat compared to one that occurs where the calibration line is steep. Use your answers from B and C above to help with this question. (Hint: which sample had the smallest calibrated age range?)

For Questions 10-14, refer to the following table of data from Feranec and Kozlowski (2016):

Ranges for the dates of earliest and latest occurrences of caribou (*Rangifer tarandus*), mammoth (*Mammuthus sp.*) and American mastodon (*Mammut americanum*) within New York State.

Species	Number of Specimens	Range of Earliest Occurrence (cal yr BP)	Range of Latest Occurrence (cal yr BP)
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American Mastodon *(Mammut americanum)*	21	14540-14090	12460-11930

10. Examining the dates of earliest occurrence for **megafauna** (e.g., caribou, mammoth, and mastodon) in New York compare the timing of arrival to the major habitats present in the state (from Fig. 2).

11. Based on your reading, do these species colonize New York when their preferred resources (e.g., habitat, food) were available?

12. Examining the dates of latest occurrence for megafauna in New York compare the timing of extinction/extirpation to the major habitats present in the state (from Fig. 2).

13. Based on your reading, do these megafauna go extinct in New York when preferred resources (e.g., habitat, food) were available?

14. Humans are suspected to have colonized New York about 13,000 cal yr BP. Based on this timing, discuss whether or not humans could have been involved in causing the megafaunal extinction. In your explanation make sure to mention the following: the timing of extinction in New York at the end of the Pleistocene, climate change after the LGM, climate change over the whole of the Pleistocene, and dietary/habitat preferences of the megafauna. Use data from the text and figures above to help answer this question.

NOTES

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