

The Scientific Frontier of De-extinction

by Aden Xiao

"There is something missing from our world. The amazing animals that time has left behind. But what if we could bring them back? What if extinction didn't have to be forever?"

– *Prehistoric Park* (2006)¹

I. Introduction

There are many applications for biotechnology and genetics, yet one has seldom heard of de-extinction. When a species is wiped off the face of the Earth, it is gone forever. That is, until we intervene.

In 2009, scientists successfully cloned the extinct Pyrenean Ibex,² also known as the Bucardo. This landmark event would have been a significant turning point in genetics, and animal conservation had the foal not died from respiratory failure. To this day, the Bucardo holds the title of the first and only animal to go extinct twice.³ Nonetheless, de-extinction is a new scientific frontier that has yet to develop out of its infancy. Many candidates have been selected for de-extinction, including the woolly mammoth, the Tasmanian tiger, and the passenger pigeon.⁴ Unlike in *Jurassic Park*, scientists are not creating "genetically engineered theme park monsters"⁵ but rather keystone species to repair ecosystems that once lived.

¹ David Jason, narrator. *Prehistoric Park*, Impossible Pictures Ltd, Released 2006.

² Charles Choi. "First Extinct-Animal Clone Created". *National Geographic*, February 11, 2009, Last Accessed February 24, 2023; <https://www.nationalgeographic.com/science/article/news-bucardo-pyrenean-ibex-deextinction-cloning>

³ Charles Choi. "First Extinct-Animal Clone Created". *National Geographic*, February 11, 2009, Last Accessed February 24, 2023; <https://www.nationalgeographic.com/science/article/news-bucardo-pyrenean-ibex-deextinction-cloning>

⁴ Kara Rogers. "de-extinction". *Encyclopedia Britannica*, Published August 23, 2019. Last Accessed February 24, 2023; <https://www.britannica.com/science/de-extinction>

⁵ Sam Neill, actor. *Jurassic Park III*, Universal Pictures & Amblin Entertainment, Released 2001.

De-extinction is a scientific frontier that deserves equal recognition with other frontiers, such as space travel and AI, due to the significance of its ecological benefits to the environment and technological benefits to humanity.

II. How to De-Extinct an Animal

Contrary to public belief, de-extinction is not about bringing back dinosaurs. It is a branch in zoology and the next step in conservation. De-extinction involves bringing back an extinct species and reintroducing them to their habitats to help restore biodiversity and the ecosystem. In the near future, the developments in this scientific frontier will enable scientists to fill in the ecological gaps extinct organisms leave behind.

De-extinction can be done in three ways. One way is through somatic cell nuclear transfer, or cloning. For this process, a cell from the extinct animal is required. The nucleus of this cell is fused with an enucleated oocyte (immature egg cell) from a close living relative. As a result, fertilization occurs, and an embryo develops in vitro.⁶ In mammals, the embryo will then be implanted into a surrogate mother, its closest living relative, to undergo gestation and eventually, birth. Biobags, artificial wombs are currently being developed and will soon resolve the issue for using endangered species as surrogates, like the Asian elephant for the de-extinction of the mammoth.⁷ This method is suitable for recently extinct animals with preserved, intact cells. The result of this process is a genetically identical copy of the organism that once lived.

Two additional ways are through genetically editing the genome and selective breeding.

⁶“About Cloning”. *Revive and Restore*, Last Accessed February 24, 2023; <https://reviverestore.org/projects/przewalskis-horse/about-cloning/>

⁷ Claire Reilly. “Artificial womb could grow mammoth-elephant hybrid, researchers say”, *CNET*, Published April 29, 2018. Last Accessed, February 24, 2023; <https://www.cnet.com/science/artificial-womb-could-grow-mammoth-elephant-hybrid-harvard-researchers/>

When editing the genome to re-create an extinct organism, scientists modify the genes of a close living relative. For CRISPR-Cas9, a gene editing method, an enzyme is used to make cuts in the DNA for new genes to be spliced. Skin cells from a close relative will be edited to insert the desired genes into the nucleus. The edited nucleus will then be inserted into an enucleated egg generated from stem cells from the living relative.⁸ From there, the process is identical to cloning. Selective breeding to achieve desirable traits is an alternative to genetic engineering, which is currently being used in the de-extinction of the quagga⁹ and auroch.¹⁰ The issue with these methods is the resulting animals will be man-made creations genetically different from the extinct animal.

In all methods, the de-extincted species will eventually be reintroduced to their habitats. This final step in de-extinction is vital. Depending on the length of the species' absence, there is a likelihood that their ecological roles have been refilled. They may potentially damage the ecosystem we are attempting to restore, so this step must be a cautious, planned-out process.

III. Pleistocene Park's Ambitious Rewilding Project

The Pleistocene Park Project in Siberia stands out from the many ongoing de-extinction projects. Sergey Zimov, a Russian geophysicist, and his son, Nikita, aim to restore the mammoth steppe ecosystem, a habitat that has declined since the end of the ice age. The mammoth steppe once spread across Eurasia, from Western Europe to Siberia. Animals such as bison, mammoths, cave lions, wolves, aurochs, horses, saiga, reindeer, elk, and musk ox once roamed these vast

⁸ Molly Campell. "Return from Extinction", *Technology Networks Genomics Research*, Published November 26, 2021. Last Accessed, February 24, 2023; <https://www.technologynetworks.com/genomics/articles/return-from-extinction-356244>

⁹ "The Quagga Revival South Africa", *The Quagga Project*. Last Accessed February 24, 2023; <https://www.quaggaproject.org/>

¹⁰ Diana Hubbell. "The Once-Extinct Aurochs May Soon Roam Europe Again," *Atlas Obscura*, January 26, 2022. Last Accessed, February 24, 2023; <https://www.atlasobscura.com/articles/aurochs-rewilding>

grasslands.¹¹ In other words, an arctic Serengeti.¹² Pleistocene Park aims to reintroduce the animals absent from these lands for thousands of years as well as set up a home for cloned mammoths.

In 1996, the Russian government gave 144 km² of land to the Zimovs and Pleistocene Park began¹³. Since 2010, the Park has introduced musk oxen, bison, yaks, Kalmyk cows, sheep, fur goats, and Bactrian camels. These are all animals that play a role in vegetation shifts and prepare the land for mammoth reintroduction.¹⁴

Zimov argues that the current ecosystem, the tundra, is not productive and the processes that formed this environment are not natural.¹⁵ The lack of large herbivores has slowed the nutrient cycle and negatively impacted the vegetation. Tundra mosses and shrubs outcompeted the grass that grew thousands of years ago since there are no more grazing herbivores.¹⁶ He theorizes the Pleistocene megafauna once trampled on the snow, insulating the permafrost, and stopping it from melting.¹⁷ Today, the permafrost is currently melting at an alarming rate. Permafrost melting is bad news because there are millions of tons of greenhouse gases locked away in the ice for hundreds

¹¹ Věra Pavelková Řičánková, et al. “Ecological structure of recent and last glacial mammalian faunas in northern Eurasia: the case of Altai-Sayan refugium.” *PloS one* vol. 9,1 e85056. 13 Jan. 2014, doi: 10.1371/journal.pone.0085056; <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3890305/>

¹²Jamie Bolam. “A mammoth task: restoring an Ice-Age ecosystem to save the planet,” *Conservation Careers*, Published February 14, 2021. Last Accessed, February 24, 2023. <https://www.conservation-careers.com/conservation-jobs-careers-advice/interviews/a-mammoth-task-restoring-an-ice-age-ecosystem-to-save-the-planet/>

¹³“Pleistocene Park” *Pleistocene Park Foundation*, Last Accessed February 24, 2023; <https://pleistocenepark.org/park/>

¹⁴ “Animals”. *Pleistocene Park*, Last Accessed, February 24, 2023; <https://pleistocenepark.ru/animals/>

¹⁵ Marc Macias-Fauria, et al. “Pleistocene Arctic megafaunal ecological engineering as a natural climate solution?” *Philosophical transactions of the Royal Society of London. Series B, Biological sciences* vol. 375,1794 (2020): 20190122. doi:10.1098/rstb.2019.0122; <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7017769/>

¹⁶ Ned Rozell. “Pleistocene Park an experiment in adventure”, *Geophysical Institute University of Alaska Fairbanks*, Published April 13, 2017, Last Accessed February 24, 2023; <https://www.gi.alaska.edu/alaska-science-forum/pleistocene-park-experiment-adventure>

¹⁷ Scott Pelley “Siberia's Pleistocene Park: Bringing back pieces of the Ice Age to combat climate change”, *CBS News*, Published March 31, 2019. Last Accessed February 24, 2023; <https://www.cbsnews.com/news/siberia-pleistocene-park-bringing-back-pieces-of-the-ice-age-to-combat-climate-change-60-minutes/>

of thousands of years.¹⁸ The insulating snow layer also causes the Albedo effect, where solar radiation is reflected easier by surfaces like ice, reducing the greenhouse effect¹⁹. Data from shows permafrost is colder where heat trapping trees have been cut down²⁰.

By reintroducing the ice age fauna, he believes, he can restore the ecosystem that once was and delay climate change. Until the mammoths are resurrected, Nikita Zimov can only use a vehicle to knock down trees.

IV. Notable Examples of Animal Reintroduction

Scientists debate on whether bringing back extinct fauna in an ecosystem would be beneficial or not. Not all reintroductions have been successful, especially with the Tasmanian Devil on Maria Island.²¹ The scientists intended to release devils onto the island in hopes breeding a healthy population free of DFTD (a cancer transmissible through bites) but failed to foresee the devils wiping out a penguin colony of 6,000. To avoid such a disaster, all animal reintroductions should undergo risk assessments and be carefully evaluated beforehand. Testing this on a small scale like Pleistocene Park will safeguard the ecosystem and contain the organisms should reintroduction go awry.

¹⁸ Michael Ovaska, Prasanta Kumar Dutta, and Clare Baldwin, “How thawing permafrost could fuel climate warming”, *Reuters*, Published October 5, 2020. Last Accessed February 24, 2023; <https://www.reuters.com/graphics/CLIMATE-CHANGE/PERMAFROST/oakveelglvr/>

¹⁹ Mark Serreze. “Why is the Arctic So Sensitive to Climate Change and Why Do We Care?” Published August 28, 2008. Last Accessed February 24, 2023; https://www.pmel.noaa.gov/arctic-zone/essay_serreze.html.

²⁰ Scott Pelley “Siberia's Pleistocene Park: Bringing back pieces of the Ice Age to combat climate change”, *CBS News*, Published March 31, 2019. Last Accessed February 24, 2023; <https://www.cbsnews.com/news/siberia-pleistocene-park-bringing-back-pieces-of-the-ice-age-to-combat-climate-change-60-minutes/>

²¹ Donna Lu. “Tasmanian devils wipe out thousands of penguins on tiny Australian island” *The Guardian*, Published June 21, 2021. Last Accessed February 24, 2023; <https://www.theguardian.com/environment/2021/jun/21/tasmanian-devils-wipe-out-thousands-of-penguins-maria-island-australia>

However, there are many examples of how animal reintroductions have restored the habitats, such as Yellowstone’s wolf reintroduction. In Yellowstone, the wolves were absent for 70 years, causing a collapse in the food chain.²² Elk population exploded, killing off the vegetation. Coyotes became the apex predators, but were too small to hunt elk. After the reintroduction, the food chain restored its balance. Elk and coyote population stabilized once wolves were reintroduced.²³

Animal reintroductions: living, or extinct do the same thing. It involves bringing back what had been absent. Above all, humans are more of an invasive species than the extinct animals reintroduced to the habitats in which they originally lived. In Yellowstone, the wolves were a keystone species, they maintained their environment. In a mammoth steppe, the mammoth and other ice age megafauna knocked down trees and enabled grasses to grow, just like elephants in the Kruger today.²⁴ The absence of the extinct animals caused a decline in biodiversity.

If possible, de-extinction should bring entire groups of animals, e.g. aurochs, cave lions, woolly rhinos for Pleistocene Park along with the mammoth. By doing so, we will complete the ecosystem and rebuild its food chain.

V. Colossal’s Mission

Colossal Biosciences is a company with an ambitious goal, to resurrect the woolly mammoth in 6 years. Since its formation in 2020, George Church, Harvard professor, and Ben

²² “Wolf Restoration”, *National Parks Service Yellowstone*, Updated February 16, 2022. Last Accessed February 24, 2023; <https://www.nps.gov/yell/learn/nature/wolf-restoration.htm>

²³ Christine Peterson. “25 years after returning to Yellowstone, wolves have helped stabilize the ecosystem” Published July 10, 2020. Last Accessed February 24, 2023.

<https://www.nationalgeographic.com/animals/article/yellowstone-wolves-reintroduction-helped-stabilize-ecosystem>

²⁴ teamAG. “Elephants and trees” *Africa Geographic*, Posted on October 9, 2019. Last Accessed, February 24, 2023; <https://africageographic.com/stories/elephants-and-trees/>

Lamm (billionaire) have raised \$200 million to fund their project.²⁵ Church has joined forces with Pleistocene Park to reintroduce the mammoths. He promised Sergey Zimov a herd to help populate the park, which will establish a home base for these prehistoric beasts.²⁶ The company states it also wishes to de-extinct the dodo, the poster child of extinction, and the thylacine. After the successful de-extinction of the mammoth, the techniques used, and technologies developed will set an example for future de-extinction projects.

So far, Church and his team have sequenced the mammoth genome and had begun genetically modifying elephant cell cultures. He aims to design a cold-adapted elephant genome, which is crucial in re-creating the mammoth.²⁷ CRISPR technology is currently being used to edit the genomes of living elephant cell cultures. From these experiments, the feasibility of gene editing for elephant genomes was demonstrated.²⁸

VI. Pros

By bringing back what was lost, we will improve biodiversity in ecosystems and reduce habitat loss. However, the research and data from this scientific field will also greatly benefit us through the development our technology. The application of integrating nature’s designs and systems into our technology, is known as biomimicry or biomimetics (coined by Otto Schmitt). By using extinct species, we will have access to even more innovations. A notable example in

²⁵ Chris Morris. “The company trying to bring back the extinct woolly mammoth also wants to revive the dodo bird—and it’s already raised more than \$200 million” *Fortune*, Published January 31, 2023. Last Accessed February 24, 2023; <https://fortune.com/2023/01/31/dodo-bird-bring-back-extinction-woolly-mammoth/>

²⁶ Ross Anderson. “Welcome to Pleistocene Park.” *The Atlantic*, April 2017. Last Accessed February 24, 2023. <https://www.theatlantic.com/magazine/archive/2017/04/pleistocene-park/517779/>

²⁷ “Woolly Mammoth Revival”, *Revive and Restore*, Last Accessed February 24, 2023. <https://reviverestore.org/projects/woolly-mammoth/history-of-this-project/>

²⁸ “Woolly Mammoth Revival”, *Revive and Restore*, Last Accessed February 24, 2023. <https://reviverestore.org/projects/woolly-mammoth/history-of-this-project/>

using an extinct animal for this is the Trilobite-inspired neural nanophotonic light-field camera.²⁹ Engineers replicated the structure of this trilobite eye, which enabled the trilobite to see light as well as perceive close and far objects simultaneously. Although the trilobite isn't necessarily a suitable de-extinction candidate, it shows we still have much to learn from nature. De-extinction will allow scientists to examine information from animals other than just fossils; their muscles, their scales and their skin, which aren't often fossilized will lead to many useful applications in design.

De-extinction may also create improvements in medicine. 99% of all species that have evolved or lived on Earth are now extinct.³⁰ Out of the remaining species, at least a few of them that died off recently with preserved DNA viable for de-extinction could hold the cure for disease or some undiscovered chemical compound. Their genes or body designs could also tell us how certain species might have adapted to disease. For example, Sharklet AF™ has developed shark skin-like surfaces, which inhibit bacterial growth.³¹ The rough texture on shark skin provides unfavorable conditions for growth for organisms, such as algae and barnacles.

De-extincted animals will also revolutionize fields like paleontology. Paleontology is the study of fossils; scientists can only theorize how an organism would have lived, fed, reproduced, and died by analyzing remains. De-extinction will provide paleontologists a living, breathing example of that animal, expanding our knowledge of the distant past. Fields such as zoology will see a wider range of living organisms to study. Animal behaviors and instincts lost in time will

²⁹ Q. Fan, Xu, W., Hu, X. et al. Trilobite-inspired neural nanophotonic light-field camera with extreme depth-of-field. *Nat Commun* 13, 2130 (2022). <https://doi.org/10.1038/s41467-022-29568-y>

³⁰ Ashley Hamer. "99 Percent Of The Earth's Species Are Extinct—But That's Not The Worst", *Discovery*, August 01, 2019, <https://www.discovery.com/nature/99-Percent-Of-The-Earths-Species-Are-Extinct>

³¹ Rachael Rettner. "Shark Skin-Like Surfaces May Ward Off Hospital Superbugs" *Live Science*, September 17, 2014, <https://www.livescience.com/47870-shark-skin-hospital-superbugs.html>

finally be uncovered. The knowledge gained from resurrecting extinct animals could also help us better prevent further extinctions.

By reaching this genetic power in this frontier, humanity will be able to correct mistakes and prevent them. In other words, should our species possess such an ability, we could redefine what the niche of the human race is on this planet. Rather than being destructive apes laying waste to habitats for unsustainable purposes, we could become a higher being, a species that will fulfill a duty to protect Earth's environment. "Playing god" is not a very strong argument against de-extinction because we were the ones were playing God when we decided to clear habitats, divert, and pollute rivers, and hunt animals to extinction for our own benefit.³²

VII. Cons

One major issue with de-extinction is usually the extinct have been absent from their ecosystems for so long, in an attempt to create an ecosystem they would destroy the current one. Pleistocene Park' critics state Zimov would destroy the tundra to recreate a lost ecosystem.³³ We lack contingency should an extinct animal compete with a present-day animal that evolved to take its place. In addition, they may develop diseases long extinct in the past that may either infect us or destroy the ecosystem.

Another frightening aspect is that extinct animals have no protections or animal rights; they may be exploited. Greedy companies may patent their de-extincted animals as intellectual property and commodities. A question to be raised later is "should nature, something has evolved

³² Scott Pelley "Siberia's Pleistocene Park: Bringing back pieces of the Ice Age to combat climate change", *CBS News*, Published March 31, 2019. Last Accessed February 24, 2023; <https://www.cbsnews.com/news/siberia-pleistocene-park-bringing-back-pieces-of-the-ice-age-to-combat-climate-change-60-minutes/>

³³ Ross Anderson. "Welcome to Pleistocene Park." *The Atlantic*, April 2017. Last Accessed February 24, 2023; <https://www.theatlantic.com/magazine/archive/2017/04/pleistocene-park/517779/>

for millions of years without our influence, really be branded or copyrighted?” The cloning of the mammoth may entice poachers to do the same with endangered elephants. We may never know if black markets decide to fill up their stock with “rare and endangered mammoth ivory” and “dodo soup”. If a species has been extinct for too long, not only would have climate change destroyed its ecosystem, but factors such as pollution, modern day disease, and human predation could drive it extinct again.

De-extinction is an expensive and time-consuming process. Some scientists argue the resources should be used to preserve endangered species rather than bring back extinct ones³⁴. Bringing back animals that no longer have a place on present day earth will bring little to no ecological benefits since their niches have been refilled. Resurrecting animals that would destroy an existing, established, and productive ecosystem to create one that disappeared long ago goes against the whole point of conservation. If we’re not careful, these de-extincted animals’ sole purpose is to stay in zoos as freak show exhibits.

VIII. Conclusion

With conservation efforts renewed, genetic power advanced, and knowledge expanded we set humanity on a new path of healing the environment. As Pleistocene Park continues to collaborate with Colossal, reintroductions of extinct animals will soon be a reality. Certainly, it will be time consuming and expensive, as frontiers are until their implementation is widespread. Imagine in your lifetime, seeing the spectacle of a living, breathing mammoth herd migrating across Siberia on a wildlife safari, coexisting with bison and wild horses. Some restored

³⁴ David Shultz. “Bringing extinct species back from the dead could hurt-not help-conservation efforts”, Science, Published February 27, 2017. Last Accessed February 25, 2023. <https://www.science.org/content/article/bringing-extinct-species-back-dead-could-hurt-not-help-conservation-efforts>

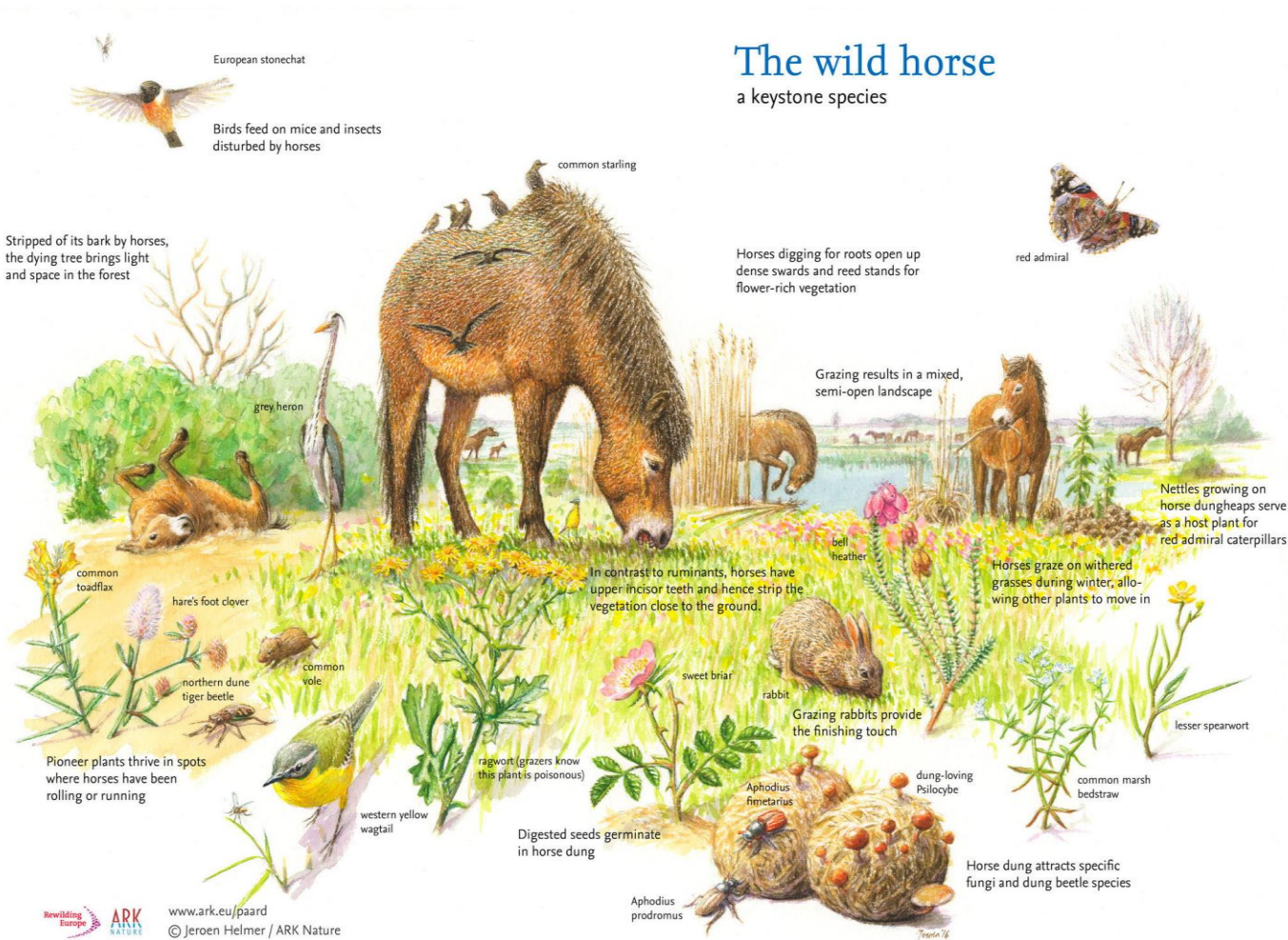
ecosystems will delay climate change, others may benefit their local communities in economic, social ways.

Even though de-extinction has only been tried once, and unsuccessfully, we should not abandon this frontier. Our technology has greatly advanced since the attempted cloning of the bucardo in 2009. With tools like CRISPR and new technologies being developed at this time, combined with adequate funding, de-extinction will develop out of its infancy. We may not be able to co-exist with dinosaurs, but we can with mammoths.

Aden Xiao is a junior at The British School of Nanjing who enjoys studying biology. Aden is a lifelong palaeontology enthusiast and founded his school's Yangtze Porpoise Conservation Club. He is the Student Council Secretary and an Editor for the school's magazine.

Appendix A

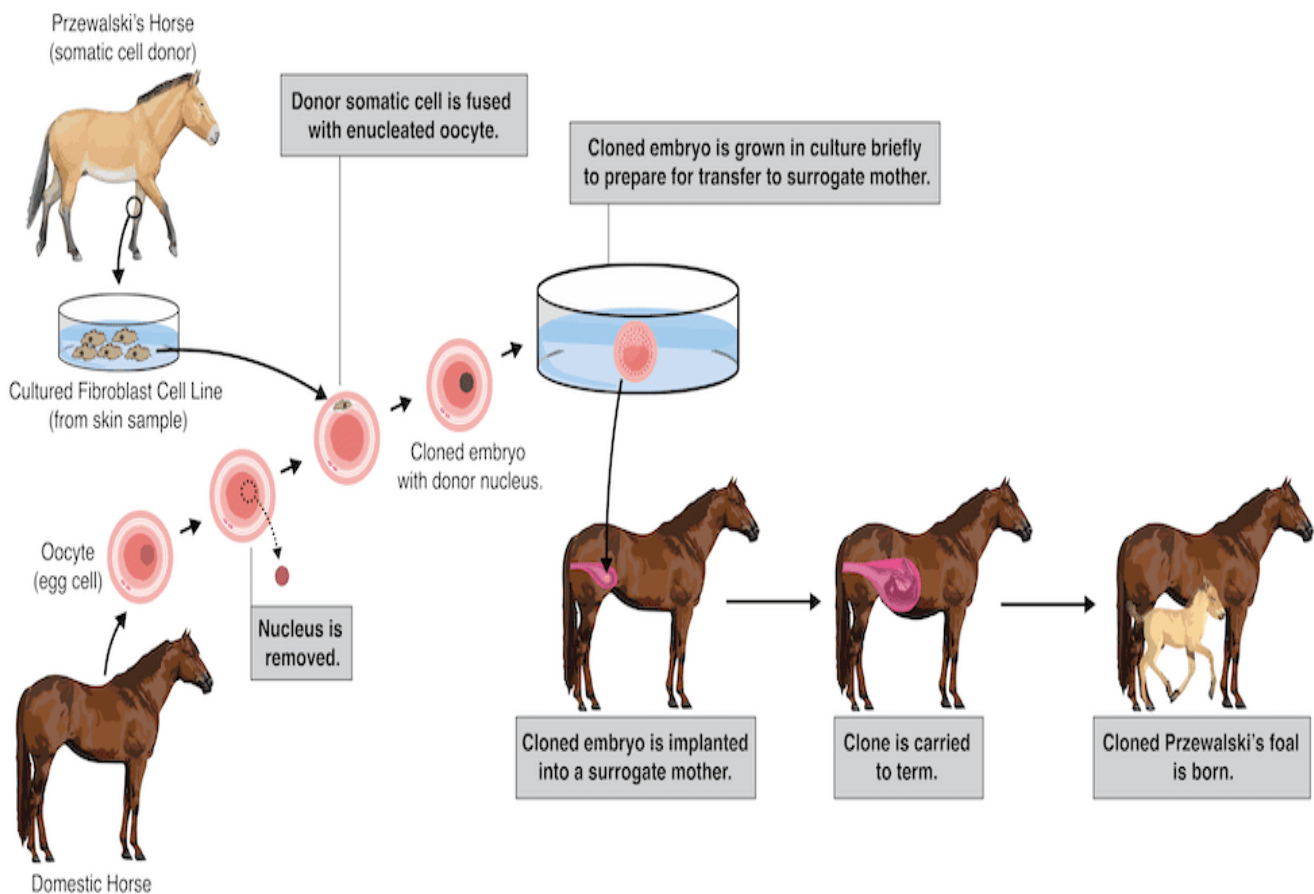
The Wild Horse, A Keystone Species



Rewilding Europe, <https://rewildingeurope.com/rewilding-in-action/wildlife-comeback/wild-horses/> Last accessed February 24, 2023

Appendix B

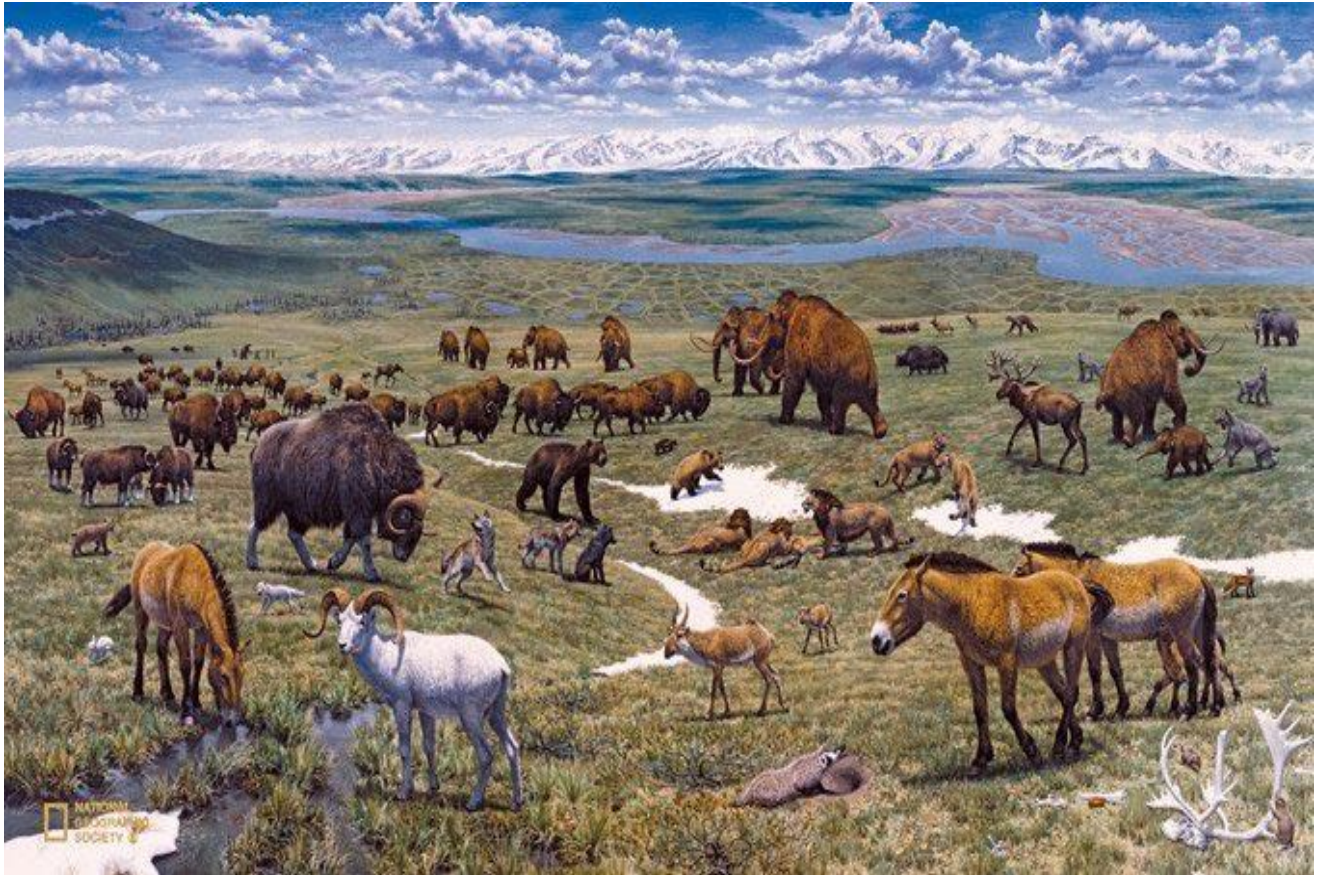
Przewalski's Horse: The Process of Horse Cloning



Revive and Restore, <https://reviverestore.org/projects/przewalskis-horse/about-cloning/foal-mare-graphic-2/>, Last accessed February 24, 2023

Appendix C

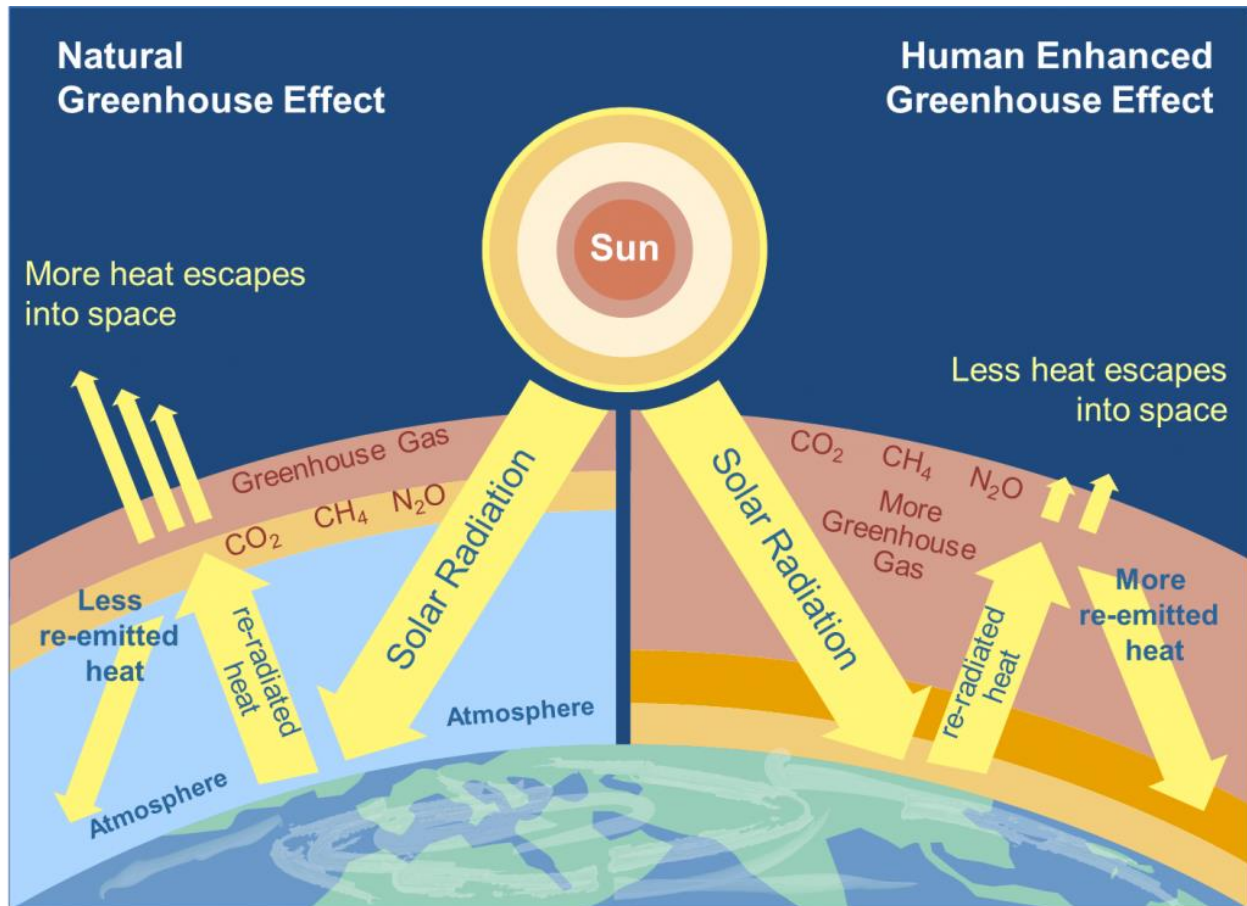
An artist's renderings of the mammoth steppe - *Courtesy Pleistocene Park Foundation*



Revive & Restore: <https://reviverestore.org/pleistocene-patreon/> Last accessed February 24, 2023

Appendix D:

An overview of the greenhouse effect on



Environment Center at University of Colorado Boulder:
<https://www.colorado.edu/center/sites/default/files/styles/large/public/page/greenhouse-effect.jpeg?itok=4X5-u6Iz> Last accessed February 24, 2023

Bibliography

- “About Cloning”. *Revive and Restore*. Last Accessed February 24, 2023.
<https://reviverestore.org/projects/przewalskis-horse/about-cloning/>
- Anderson, Ross. “Welcome to Pleistocene Park.” *The Atlantic*, Issued April 2017. Last Accessed, February 24, 2023.
<https://www.theatlantic.com/magazine/archive/2017/04/pleistocene-park/517779/>
- “Animals”. *Pleistocene Park*. Last Accessed, February 24, 2023
<https://pleistocenepark.ru/animals/>
- Bolam, Jamie. “A mammoth task: restoring an Ice-Age ecosystem to save the planet.” *Conservation Careers*, Published February 14, 2021. Last Accessed, February 24, 2023.
<https://www.conservation-careers.com/conservation-jobs-careers-advice/interviews/a-mammoth-task-restoring-an-ice-age-ecosystem-to-save-the-planet/>
- Campbell, Molly. “Return from Extinction,” *Technology Networks Genomics Research*, Published November 26, 2021. Last Accessed February 24, 2023.
<https://www.technologynetworks.com/genomics/articles/return-from-extinction-356244>
- Choi, Charles. “First Extinct-Animal Clone Created.” *National Geographic*, Published Feb 11, 2009. Last Accessed February 24, 2023.
<https://www.nationalgeographic.com/science/article/news-bucardo-pyrenean-ibex-deextinction-cloning>
- Fan, Q., Xu, W., Hu, X. et al. Trilobite-inspired neural nanophotonic light-field camera with extreme depth-of-field. *Nat Commun* 13, 2130, Published 2022.
<https://doi.org/10.1038/s41467-022-29568-y>
- Hamer, Ashley. “99 Percent of The Earth's Species Are Extinct—But That's Not The Worst”, *Discovery*, Published August 01, 2019. Last Accessed February 24, 2023.
<https://www.discovery.com/nature/99-Percent-Of-The-Earths-Species-Are-Extinct>
- Hubbell, Diana. “The Once-Extinct Aurochs May Soon Roam Europe Again”, *Atlas Obscura*, Published January 26, 2022. Last Accessed February 24, 2023.
<https://www.atlasobscura.com/articles/aurochs-rewilding>
- Jason, David, narrator. *Prehistoric Park*, Impossible Pictures Ltd, Released 2006.
- Kenneally, Christine, “A ‘De-extinction’ Company Wants to Bring Back the Dodo,” *Scientific American*, Published January 31, 2023. Last Accessed February 24, 2023.

- <https://www.scientificamerican.com/article/tech-company-invests-150m-to-bring-back-the-dodo/>
- Lu, Donna. “Tasmanian devils wipe out thousands of penguins on tiny Australian island” *The Guardian*, Published June 21, 2021. Last Accessed February 24, 2023; <https://www.theguardian.com/environment/2021/jun/21/tasmanian-devils-wipe-out-thousands-of-penguins-maria-island-australia>
- Macias-Fauria, Marc et al. “Pleistocene Arctic megafaunal ecological engineering as a natural climate solution?” *Philosophical transactions of the Royal Society of London. Series B, Biological sciences* vol. 375,1794 (2020): 20190122. doi:10.1098/rstb.2019.0122. Published online Jan 27, 2020. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7017769/>
- Morris, Chris. “The company trying to bring back the extinct woolly mammoth also wants to revive the dodo bird—and it’s already raised more than \$200 million” *Fortune*, Published January 31, 2023. Last Accessed February 24, 2023 <https://fortune.com/2023/01/31/dodo-bird-bring-back-extinction-woolly-mammoth/>
- Neill, Sam, actor. *Jurassic Park III*, Universal Pictures & Amblin Entertainment, Released 2001.
- Ovaska, Michael, Dutta, Prasanta Kumar, and Baldwin, Clare. “How thawing permafrost could fuel climate warming”, *Reuters*, Published October 5, 2020. Last Accessed February 24, 2023. <https://www.reuters.com/graphics/CLIMATE-CHANGE/PERMAFROST/oakveelglvr/>
- Pavelková Řičánková, Věra et al. “Ecological structure of recent and last glacial mammalian faunas in northern Eurasia: the case of Altai-Sayan refugium.” *PloS one* vol. 9,1 e85056. Published online Jan 13, 2014, doi: 10.1371/journal.pone. 0085056 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3890305/>
- Pelley, Scott “Siberia's Pleistocene Park: Bringing back pieces of the Ice Age to combat climate change”, Published March 31, 2019. Last Accessed February 24, 2023. <https://www.cbsnews.com/news/siberia-pleistocene-park-bringing-back-pieces-of-the-ice-age-to-combat-climate-change-60-minutes/>
- Peterson, Christine. “25 years after returning to Yellowstone, wolves have helped stabilize the ecosystem” *National Geographic*, Published July 10, 2020. Last Accessed February 24, 2023. <https://www.nationalgeographic.com/animals/article/yellowstone-wolves-reintroduction-helped-stabilize-ecosystem>
- Pleistocene Park Foundation. “Pleistocene Park” Pleistocene Park, Last Accessed February 24, 2023. <https://pleistocenepark.org/park/>

- Reilly, Claire. “Artificial womb could grow mammoth-elephant hybrid, researchers say”, CNET, April 29, 2018. Last Accessed, February 24, 2023.
<https://www.cnet.com/science/artificial-womb-could-grow-mammoth-elephant-hybrid-harvard-researchers/>
- Rettner, Rachael. “Shark Skin-Like Surfaces May Ward Off Hospital Superbugs *Live Science*, Published September 17, 2014, Last accessed February 24, 2023.
<https://www.livescience.com/47870-shark-skin-hospital-superbugs.html>
- “Rewilding Horses in Europe”, Rewilding Europe, Last accessed February 24, 2023
<https://rewildingeuropa.com/rewilding-in-action/wildlife-comeback/wild-horses/>
- Rogers, Kara. "de-extinction". *Encyclopedia Britannica*, Updated Aug 23, 2019. Last Accessed February 24, 2023.
<https://www.britannica.com/science/de-extinction>
- Rozell, Ned. “Pleistocene park an experiment in adventure”, Geophysical Institute University of Alaska Fairbanks, Published April 13, 2017. Last Accessed February 24, 2023.
<https://www.gi.alaska.edu/alaska-science-forum/pleistocene-park-experiment-adventure>
- Serreze, Mark. “Why is the Arctic So Sensitive to Climate Change and Why Do We Care?” August 28, 2008. Last Accessed, February 24, 2023.
https://www.pmel.noaa.gov/arctic-zone/essay_serreze.html
- Shultz, David. “Bringing extinct species back from the dead could hurt-not help-conservation efforts”, *Science*, Published February 27, 2017. Last Accessed February 25, 2023.
<https://www.science.org/content/article/bringing-extinct-species-back-dead-could-hurt-not-help-conservation-efforts>
- teamAG. “Elephants and trees”, *Africa Geographic*, Posted on October 9, 2019. Last Accessed February 24, 2023.
<https://africageographic.com/stories/elephants-and-trees/>
- “The Audacious Experiment of Pleistocene Park” *Revive & Restore*, Published Feb 24, 2020. Last accessed February 24, 2023
<https://reviverestore.org/pleistocene-patreon/>
- “The Quagga Revival South Africa” *The Quagga Project*. Last Accessed, February 24, 2023.
<https://www.quaggaproject.org/>
- “Wolf Restoration”, *National Parks Service Yellowstone*, Updated February 16, 2022. Last Accessed February 24, 2023
<https://www.nps.gov/yell/learn/nature/wolf-restoration.htm>
- “Woolly Mammoth Revival”, *Revive and Restore*, Last Accessed February 24, 2023.
<https://reviverestore.org/projects/woolly-mammoth/history-of-this-project/>

