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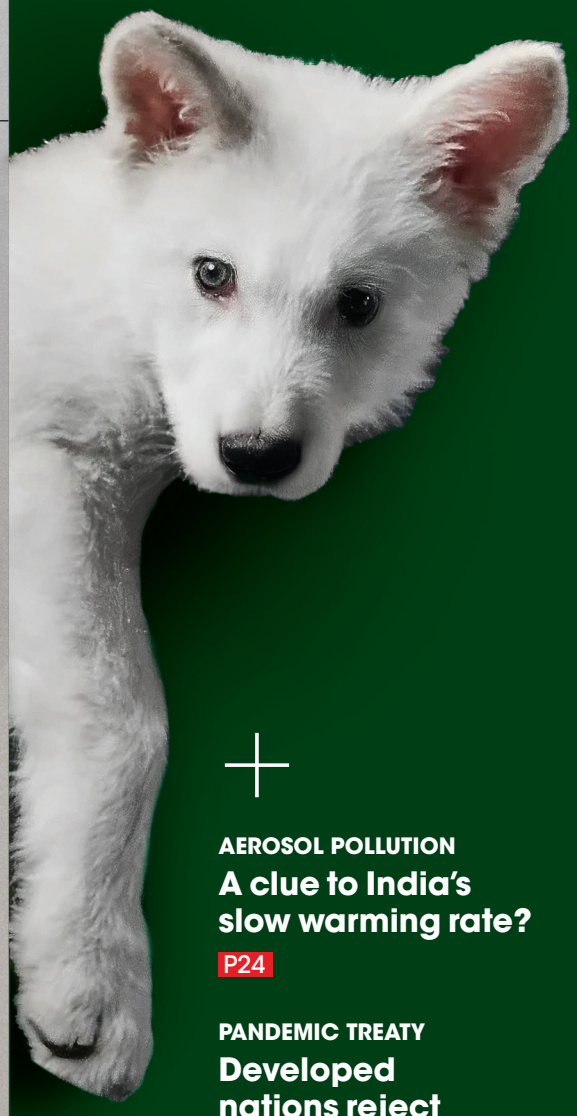
DE-EXTINCT

Scientists bring back dire wolf after 10,000 years.

Is the technology a conservation tool or a show-off?



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A clue to India's slow warming rate?

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Developed nations reject mandatory technology transfer

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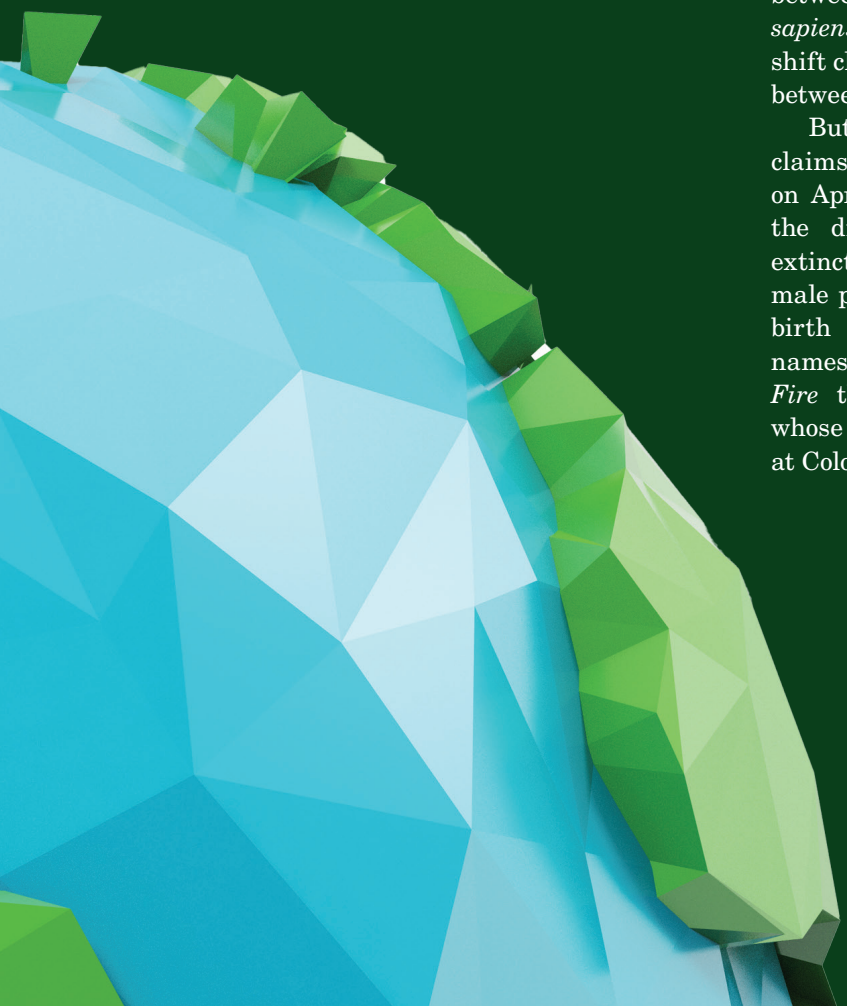
ORIGIN OF PROXIES

The revival of dire wolf by an American biotechnology company proves that it is possible to create proxies of extinct species through cutting-edge genetic editing and cloning technologies. But can this actually fix the extinction crisis? An analysis by

ROHINI KRISHNAMURTHY AND RAJAT GHAI



SOME 2.6 million years ago, when glaciers covered huge parts of the globe, and modern humans had still not evolved, a ferocious, yet social canine roamed the Earth, alongside megafauna like woolly mammoth, ground sloths and sabre-toothed tiger. The canine, dire wolf, also known as *Aenocyon dirus* in scientific lexicon, was as supersized as its contemporaries, hunted in packs and fed on horses, ground sloths and bison. Even as the Earth underwent significant shifts between cold and warm periods during the Ice Age or Pleistocene Epoch that lasted till 11,700 years ago, the canine survived. It in fact changed its physical traits to survive the dramatic climate shifts, adapted to diverse habitats like boreal grasslands, coastal woodlands and tropical wetlands, establishing its range from Alaska in North America to Mexico, Peru and Venezuela in South America. Then Earth entered the current Holocene epoch, marking the end of the Ice Age and shift to a warmer, more stable climate. Several megaherbivores declined, increasing competition for food among packs and possibly between dire wolves and modern humans, the *Homo sapiens*. The canine may have also found the climate shift challenging. Ultimately, dire wolf went extinct between 13,000 and 10,000 years ago.

But only to be resurrected in 2024. At least so claims the US-based Colossal Biosciences Inc, which on April 7, 2025, announced the "resurrection" of the dire wolf, marking the "world's first de-extinction". The company introduced six-month-old male pups Remus and Romulus and confirmed the birth of a two-month-old female, Khaleesi. The names are a nod to the book series *A Song of Ice and Fire* that features dire wolves and incidentally whose author, George R R Martin, is an investor at Colossal.

RESURRECTION BY PROXY

As the "de-extinction" invoked equal amounts of awe and concern *(more on this later)*, Colossal took to public platforms to decode the project. One fact that came to light quickly is that the pups primarily possess the gray wolf DNA, modified to give them the "appearance" of dire wolves. Dire wolves and gray wolves share 99.5 per cent of their DNA, according to Colossal's press release. This was done through gene editing using CRISPR (clustered interspaced short palindromic repeats) technology. In this process, scientists create an RNA sequence that matches the target DNA to be edited. Then an enzyme called Cas 9 is used to make the edits. Scientists can further modify the technology to add a new segment of DNA or individual DNA letters to the edited sequence.

The project, from inception to the birth of the older male pups, took 18 months. The first step, according to a video by the company's chief science officer Beth Shapiro, was recovering ancient dire wolf DNA from well-preserved fossil samples—a 13,000-year-old tooth found in Ohio and 72,000-year-old skull remains from Idaho, both in the US. After extracting the DNA and generating its sequence, the team compared it with the DNA of gray wolves.

The next step was designing the DNA editing tools, followed by making the cuts and inserting parts from dire wolves into the genome. About 20 changes were made to 14 genes. A Colossal press release says one of the edited genes was the Ligand Dependent Nuclear Receptor Corepressor Like gene (LCORL) that controls production of hundreds of genes related to body size and growth. The team also wanted to tweak the genes responsible for coat colour. Analysis of the sequenced dire wolf genome indicated it had a light colour. However, tweaking the genes in gray wolf DNA could have led to blindness or deafness in the pups. So the scientists "silenced" genes that influence expression of dark-coloured coats, resulting in the pups' white coat.

Then came cloning, another technology that makes de-extinction possible. Cloning involves removing the DNA of a body cell from a donor, just as one would remove a skin cell, and transferring it to a developing egg cell to generate a new individual genetically identical to the donor. The first successful, and possibly the most known, mammal cloning bid was of Dolly the sheep in Scotland in 1996.

In Colossal's case, they extracted a rare type of cell from the blood of gray wolves and transferred the edited DNA to an egg cell whose own DNA was removed. In the final step, the embryos were transferred into surrogate maternal hosts (dogs) who eventually birthed the pups. "Romulus and Remus were born at the same time from two different surrogates. Khaleesi came months later. Another pup was born but passed away on day 10, due to a minor infection," Matt James, chief animal officer at Colossal, tells *Down To Earth* (DTE).

The genetic makeup of Colossal's dire wolves has scientists debating facts. "It is not a dire wolf—it is a gray wolf modified to be more like a dire wolf. That is a cool

"It is not a dire wolf—it is a gray wolf modified to be more like a dire wolf. That is a cool achievement but they have not 'brought the dire wolf back'"

— **Alexander Strudwick Young,** assistant professor, Human Genetics Department, University of California, Los Angeles

"Predominantly, the background of these animals is gray wolf, so it would not surprise us if their behaviour resembles that of a gray wolf"

— **Matt James,** chief animal officer, Colossal Biosciences Inc

achievement but they have not 'brought the dire wolf back'," says Alexander Strudwick Young, assistant professor, Human Genetics Department, University of California, Los Angeles, in a post on social media site X (formerly Twitter).

Colossal says on social media that its classification of "de-extinction" is the process of creating an organism that resembles an extinct species, based on the definition by the International Union for Conservation of Nature (IUCN). In an earlier July 2024 video, Shapiro says the company is creating "a modern ecological proxy: a living organism that carries key genetic traits and behaviours of the extinct species." She tells DTE: "You could call the pups Colossal's dire wolves or gray wolves with 20 gene edits that make them resemble some components of the dire wolf."

Nic Rawlence, associate professor at the department of zoology, University of Otago, New Zealand, asks if gene tweaks are enough to make the engineered gray wolves behave like dire wolves. He points out that Colossal has not yet shared information of all 20 edits made to the gray wolf DNA.

James tells DTE it is still early to say if the pups behave like dire wolves. They are skittish and sceptical of new things or people. But they have begun to show some hunting instincts by chasing other animals. "As they get older and we have more data and observational time, we will begin to pick up on specifics of their behaviour. But predominantly, the background of these animals is gray wolf, so it would not surprise us if their behaviour resembles that of a gray wolf," he says. Shapiro adds that they will study consequences of gene editing on the pups' lives and propensity to diseases, but do not plan to release the animals into the wild.

BIOTECHNOLOGY BET

The dire wolf project in a way demonstrates the use of gene editing and cloning for de-extinction. Colossal plans to use these technologies to create and introduce in the wild new breeds of hybrids or "proxies" of extinct species such as the woolly mammoth, which died out 4,000 years ago. The company aims to revive the species using Asian elephants, mammoth's closest living relative that shares 98 per cent of its genetic code. The proxy species "will walk like a woolly mammoth, look like one, sound like one, but most importantly it will be able to inhabit the same ecosystem [the Arctic regions] previously abandoned by the mammoth's extinction," reads the company's project information. Colossal says hybrid-mammoths can help reduce warming with their grazing, which would scrape away layers of snow, allowing the cold air to reach the soil and preventing snow from melting quickly.

But not everyone agrees. "The benefits they claim can happen if you have self-sustaining populations. How many thousands of mammoths are you going to need trampling over Siberia to achieve this? This is a pipe dream," says Rawlence.

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"Cloning is not a natural process in mammals. We do a lot of modifications. If anything goes wrong, the efficiency also drops"

— **Naresh Selokar,** senior scientist, animal biotechnology division, Indian Council for Agricultural Research-National Dairy Research Institute

"We are far ahead of academics in terms of cloning. We keep breakthroughs as commercial secrets. So our success rates are higher"

— **Shawn Walker,** chief science officer, ViaGen Pets and Equine

RESURRECTION LINE UP

Extinct species that have attracted scientists' attention for revival and release into the wild

IVORY-BILLED WOODPECKER | CUBA

Last seen: 1987

Extinct due to: Habitat destruction and hunting/collection

Ecosystem service: Insect control, seed dispersal, nutrient cycling, habitat creation

Revival proponent: Colossal Foundation, a US non-profit

De-extinction technology: CRISPR

AUROCHS | EUROPE

Last seen: 1627

Extinct due to: Hunting by humans

Ecosystem service: Nutrient cycling by dispersing seeds through its range; shaped habitats through grazing and trampling

Revival proponent: Rewilding Europe, a Netherlands-based non-profit, and Grazelands Rewilding

De-extinction technology: Selective breeding

PASSENGER PIGEON | NORTH AMERICA

Last seen: 1914

Extinct due to: Hunting by humans

Ecosystem service: Seed dispersal, provided nutrients to the forest floor through droppings

Revival proponent: Revive and Restore, a US non-profit

De-extinction technology: CRISPR

DODO | MAURITIUS

Last seen: 1662

Extinct due to: Hunting by humans and cats and dogs brought by them

Ecosystem service: Seed dispersal; may have aided decomposition of fallen fruits, other organic matter

Revival proponent: Colossal Biosciences Inc, US

De-extinction technology: CRISPR

WOOLLY MAMMOTH | ACROSS THE GLOBE

Last seen: 4,000 years ago

Extinct due to: Hunting by humans, warming climate

Ecosystem service: Helped maintain grasslands by preventing trees from encroaching; created water sources and wallows by digging the soil; distributed nutrients through its dung; prevented thawing of permafrost which could release greenhouse gases

Revival proponent: Colossal Biosciences Inc, US

De-extinction technology: CRISPR

PYRENEAN IBEX | IBERIAN PENINSULA AND SOUTHERN FRANCE

Last seen: 2000
Extinct due to: Hunting pressure; inability to compete with domestic and wild ungulates
Ecosystem service: Seed dispersal, prevention and mitigation wildfire risk
Revival proponent: Advanced Cell Technology Inc, US
De-extinction technology: Cloning

QUAGGA | SOUTHERN AFRICA

Last seen: 1883
Extinct due to: Hunting by humans
Ecosystem service: Provided nutrient cycling, seed dispersal and food for predator species
Revival Proponent: Project Quagga, a South African non-profit company
De-extinction technology: Selective breeding

THYLACINE OR TASMANIAN TIGER | TASMANIA, AUSTRALIA

Last seen: 1936
Extinct due to: Hunting by humans
Ecosystem service: Regulated populations of wallabies, quolls; controlled overgrazing; helped maintain a healthy balance within the food web
Revival proponent: Colossal Biosciences Inc, US
De-extinction technology: CRISPR

DIRE WOLF | NORTH AMERICA

Last seen: 13,000 years ago
Extinct due to: Reliance on mega herbivores led to their own end as these species died out
Ecosystem service: Kept populations of large herbivores like horses, bison, and mammoths in check
Revival proponent: Colossal Biosciences Inc, US
De-extinction technology: CRISPR

HEATH HEN | NORTH AMERICA

Last seen: 1932
Extinction cause: Hunting, habitat loss, and a devastating wildfire on Martha's Vineyard, US
Ecosystem service: Seed dispersal, nutrient cycling, habitat creation
Revival proponent: Revive and Restore, a US non-profit
De-extinction technology: Gene editing

TECHNOLOGIES USED TO DE-EXTINCT SPECIES

Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR): A technology to edit genes in which specific parts of a living species' DNA are "cut" and inserted with parts of the extinct species' DNA.

Cloning: Cloning involves removing the DNA of a body cell from a donor and transferring it to a developing egg cell to generate a new, genetically identical, individual.

Selective breeding or back breeding: Parents of species that share certain desirable genes of extinct species are bred so the characteristics are passed to offspring, called hybrid.

Source: Media reports; International Union for Conservation of Nature

INTERVIEW

'Project benefits conservation'

The dire wolf revival helps dig into the use of biotechnology for endangered species' rescue and conservation, **BETH SHAPIRO**, chief science officer, Colossal Biosciences Inc, tells **ROHINI KRISHNAMURTHY**

The "de-extinction" of dire wolves took 18 months. What enabled this quick timeline?
There is a lot of science that already exists, because the closest living relative of dire wolves is a gray wolf, which has been extensively studied. We could make progress more quickly on dire wolves than some of our other projects, like the mammoths, where we need to know a lot about elephant animal reproductive biology.

What impact do you see from this project?
We really believe part of the benefit from the dire wolf project is to bring attention to the plight of gray wolves and other species struggling for existence. Our dire wolf project has an immediate conservation impact, especially if we think about how we want to use genetic rescue, the idea of gene editing species, to help living species survive.

Throwing these animals [dire wolf proxies] out into the landscape and seeing what happens would be irresponsible. It is also not what we intended. If we are going to learn about how to use these technologies successfully, we need living animals that we can monitor and ensure are healthy and safe. We want to evaluate the technology for biodiversity conservation.

How do you select which animals to de-extinct?
We think about impact and the tools that exist now, the tools that would be needed to be developed, and their potential impact on conservation of living endangered species. We also think about communities–who would want to help take responsibility when these populations are eventually rewilded? Who wants to collaborate with us on developing plans for rewilding and long-term care? Are these species that communities of people who are impacted want back? For every one of our flagship species, we have local community groups to advise on things like timing, size and scope and help with regulatory questions.

As soon as people realise that we cannot have dinosaurs back, they ask: What about the mammoth? I think this is because it is big and idealistic. It is a really cool idea. It is a species that we as people drove to extinction. It is the icon of a different ice age, and it really would be a showcase of technology if we could bring the animal back.

With the dodo, we knew that we needed to pick a bird because we needed to have tools to protect these species, some of the most endangered around the world. I thought the dodo was a great choice because I have been working in Mauritius for some time, and there are people who I know would be interested in collaborating on the dodo project. For me the dodo was the icon of human-caused extinction, and it is a really sort of sad emblem of the types of horrible things that people have done by accident in a lot of instances to different habitats. It is a good idea if we could reframe the dodo into an icon of the power of biotechnologies to help reverse some of the ways that people have been harming ecosystems around the planet and make them think imaginatively, creatively, and optimistically about a future that includes new tools to help augment what we can do to help protect and preserve species.

How difficult is it to de-extinct birds like dodos?
Birds have different set of technical challenges that need solutions, compared to mammals. Our project on dodos is still in progress. We are collaborating with academics from around the world to try to develop some of these new tools that we need.

Moreover, every species that is a candidate for de-extinction has a different set of challenges, from technical one like getting ancient DNA, making edits, and transforming edited cells into living animals to ecological, regulatory and ethical challenges.

Another animal Colossal is working on is thylacine or Tasmanian tiger or Tasmanian wolf, a marsupial from Australia, which went extinct due to excessive hunting, habitat destruction and disease. Colossal claims bringing it back would control the rampant, invasive rabbit population in Australia that threatens native plant and animal species. Colossal and its collaborators, including University of Melbourne, have extracted and sequenced the thylacine genome. They plan to develop a hybrid by using CRISPR to insert the thylacine genes into the genome of a dasyurid, and grow the egg either artificially or through the womb of a fat-tailed dunnart (dasyurid and dunnart are marsupials related to thylacine).

Colossal is also attempting to resurrect the dodo, one of the most known extinct birds globally. A 2023 *Nature Communications* study shows that dodo, native to Mauritius, was largely responsible for seed dispersal. It died out due to deforestation, hunting and destruction of nests by animals brought by the Dutch. With its disappearance, plants in Mauritius are at risk because only a handful of native animals can carry out the dodo's function. Colossal has sequenced the dodo genome using DNA extracted from a skull preserved in the Natural History Museum of Denmark, and has identified the bright and colourful Nicobar pigeon as one of dodo's closest living relative.

Ben Novak, lead scientist and programme manager of Biotechnology for Bird Conservation at Revive and Restore, a US non-profit, plans to de-extinct passenger pigeons, which went extinct from parts of North America in 1914 due to commercial exploitation for meat and loss of habitat. Passenger pigeons helped in regeneration of forests through "disturbances", like breaking large branches and small trees to open up the canopy. Their droppings also helped fertilise the soil. Revive and Restore thinks the bird's revival would help sustain eastern North America's forests, which now depend on disturbances from storms and fires.

Gene-editing in birds is not the same as in animals, Novak explains. First, scientists would take the egg of a band-tailed pigeon—the closest living relative of passenger pigeons—two days after it has been laid, cut a part of it and remove the blood. They extract germ cells from the blood and grow them in a petri dish, where they develop into reproductive cells. Next, they make edits to genes using CRISPR. They get another egg two days after it is laid, scrape the top portion of it, inject the gene-edited cells and patch it up. The bird that hatches is called a chimera. The offspring of a female and male chimera bird will be a hybrid passenger pigeon.

MYRIAD ATTEMPTS

There are also attempts to revive species using traditional "selective" breeding techniques, without cloning and gene editing. At its core, selective breeding involves choosing parents that possess certain physical or morphological traits and breeding them through several generations, till the offspring appears physically similar to lost species.

Take the quaggas, a subspecies of the plains zebra endemic to South Africa, which died out in the 19th century due to hunting. As the species shared genetic characteristics with plains zebra, South African scientists in 1987 launched a de-extinction effort called The Quagga Project and bred living southern plains zebra populations that showed some quagga characteristics, such as a brownish colour and reduced striping (quaggas possessed brown stripes only on the anterior half of the body, with almost solid-brown hind quarters). The fourth generation of offspring possessed reduced striping of the hind body and legs but lacked the same colouration. Several of these hybrids, called Rau quaggas, have been released in the wild, says the project website.

A similar effort has been undertaken in the Netherlands, where non-profits Rewilding Europe and Taurus Foundation have

selectively bred livestock to "reverse" certain genes and bring back extinct aurochs, the ancestors of all living cattle. The offspring, called "tauros" have been released into the wild since 2023.

De-extinction of plants is also being researched. Unlike animals, extinct plants can be "truly" revived if their seeds are viable for germination, Giulia Albani Rocchetti from Roma Tre University, Italy, tells DTE. She has co-authored a 2022 study published in *Nature Plants* publishing the first list of plant de-extinction candidates, based on availability of seeds in specimens stored in herbaria. The team has identified around 160 candidate species in more than 60 herbaria worldwide. These include the shrubs *Leucopogon cryptanthus* Benth from Australia, and *Hibiscadelphus wilderianus* Rock native to Hawaiian Islands.

But Rocchetti stresses on the need to evaluate the consequences of re-wilding extinct plants, which may have died out for specific reasons—be it lack of pollinators, warm temperatures, or destruction of habitats. "There is also another complication: What if they become invasive?" she asks.

CONSERVATION CLAIMS

De-extinction technologies are also being touted as a way to conserve critically endangered species. On April 7, along with its announcement of the dire wolf pups, Colossal said it used cloning to produce four red wolf pups from red "ghost" wolves of the US' Gulf Coast—canids which are neither coyotes nor dogs but are known to carry ancestral red wolf DNA that was previously considered lost. Red wolves, native to southeastern and central US, are critically endangered with less than 20 individuals in the wild. Their conservation is marred by a major challenge: lack of genetic diversity. Both captive and re-wilded populations descend from only 12 individuals. Colossal plans to increase the diversity by integrating gene alleles from "ghost wolves".

Researchers from the US, Russia and Czech Republic are also attempting to save the endangered Przewalski's horse. All the 3,000 living Przewalski's horses have descended from just 12 individuals. The team is addressing the lack of diversity through cloning. In a 2025 study published in *Animals*, they report the births of two cloned Przewalski's horses in 2020 and 2023 from cells preserved in 1980. Novak and some colleagues in the US have cloned black-footed ferret, one of the most endangered North American mammals. Since 2020, three cloned ferrets have been produced, with one further producing two offspring. Novak is exploring if gene editing can help ferrets resist a fatal sylvatic plague.

The Indian Council for Agricultural Research-National Dairy Research Institute, Karnal, Haryana, has cloned cows and buffaloes, including the indigenous Gir cow. "We have cloned over 25 animals. This technology can be used to increase milk productivity," says Naresh Selokar, senior scientist with the institute's animal biotechnology division. Globally, 56 species and sub-species have been cloned since 1956, as per a 2025 review paper in *Animals*.

But cloning suffers from low efficiency, with a success rate of only 5-10 per cent. "Cloning is not a natural process in mammals. We do a lot of modifications. If anything goes wrong, the efficiency also drops," says Selokar. The 2025 *Animals* review paper says resource limitations (availability of surrogates, sustainable funding) have stagnated the field in academic circles. On the flip side, a private ecosystem has emerged. For example, US-based company ViaGen Pets and Equine clones deceased pet dogs or cats at a cost of $50,000, as per its website. "In the commercial space, we are far ahead of academics. We keep all of our breakthroughs as commercial secrets. So, our success rates in cloning are higher," says Shawn Walker, chief science officer of the company.

"It is true that governments do not have enough money, so public-private partnerships and benefactors might help. But we also need ethical oversight," says Rawlence.

GOD COMPLEX

Does de-extinction provide any conservation benefits or is it just another attempt to show off technical prowess?

THE WORLD'S definition of de-extinction is flawed," screams the dedicated section opener on the website of Colossal Biosciences Inc. The announcement by the US company that it had achieved "revival" of a species last seen 13,000 years ago engendered a furious debate, with some doubting the scientific accuracy of the claim.

What exactly is de-extinction? The International Union for Conservation of Nature (IUCN) problematises the concept. "The term 'de-extinction' is misleading in its implication that extinct species, species for which no viable members remain, can be resurrected in their genetic, behavioural and physiological entirety... 'De-extinction' is therefore here used in a limited sense to apply to any attempt to create some proxy of an extinct species or subspecies," states IUCN's "Guiding Principles on Creating Proxies of Extinct", released in 2016.

"There is a place for use of de-extinction technologies. But these should not be used in place of attempts to preserve existing species"

— **Heather Browning,** lecturer in philosophy, University of Southampton, UK

"Saving species is a scientific, cultural and political challenge. It is a mistake to think of it solely as a scientific problem. De-extinction encourages that mistake"

— **Christopher Preston,** professor of philosophy, University of Montana, US

Colossal Biosciences provides its own definition of "functional de-extinction" on its website: "The process of generating an organism that both resembles and is genetically similar to an extinct species by resurrecting its lost lineage of core genes; engineering natural resistances; and enhancing adaptability that will allow it to thrive in today's environment of climate change, dwindling resources, disease and human interference." The definition does not say what are "core genes" or how "enhancing adaptability" would still ensure replica of the target "de-extinct" species.

Scientists have questioned Colossal Biosciences' claim. The company may have built some ancient genes into wolves and produced an "enhanced" gray wolf, with some genes of the dire wolves, Ronald Goderie, director of Grazelands Rewilding, a Netherlands-based foundation, tells *Down To Earth* (DTE). "But that is something else as claiming to have restored the dire wolf," he says.

Even Colossal Biosciences seems to have backed down from their claim. "Beth Shapiro [chief science officer of Colossal Biosciences] has used the term 'functional essence' of a dire wolf. This means they have some of the interesting characteristics of a dire wolf superimposed on a gray wolf genome," Christopher J Preston, professor of philosophy at University of Montana, US, tells DTE.

Even if one assumes that de-extinction is possible, the concept is loaded with ethical concerns. Sample these. What is the point of bringing back long-lost species? Is it for human entertainment or does it serve some

'REVIVE TRUE PLANTS'

Refine the protocol to find and germinate viable seeds of extinct plant species

GIULIA ALBANI ROCCHETTI

BILLIONS HAVE been invested for de-extinction of animals like woolly mammoth, pigeon or wolf. This is because people are more fascinated by animals, but less aware of the importance of plants. With animals we can bring an equivalent or proxy, but not true extinct species. We can bring back true plants that got lost by germinating seeds.

In conservation, we have species that are "extinct" and those that are "extinct in the wild". The latter may no longer exist in the outside world, but are preserved in some collections. Species which are missing from the wild and from collections are called true extinct species. These are the species we want to recover. To find their seeds, we must look to herbaria. But determining whether seeds from a herbarium are viable is complicated. We need to have protocols because these seeds are rare and precious. In general, each species needs the right temperature, light condition and humidity, chemicals and hormones for germination. But extinct species have no protocol because nobody has tried to germinate them. So we must first try a set of techniques on similar species and refine them.

Another problem is that most techniques to test seed viability are invasive. In general, to check if a seed is alive, one must hydrate it by placing it on a filter paper moistened with water or other substrates (such as agar gel or soil). But this can destroy the seed. We could use X-rays to check for internal damage. But even this could undermine the viability of seeds. They do not work well for species we have selected, such as hawkweed. There is ongoing research on non-invasive techniques.

(Giulia Albani Rocchetti is postdoctoral researcher at Roma Tre University, Italy)

environmental benefits? Could the resources and money spent on de-extinction decrease the same meant for conservation programmes for extant species? These are just a few of the questions scientists and experts have asked in the past few weeks. Ethicists also point out that the discussion of de-extinction could give the impression that extinction is reversible, thereby undermining the seriousness of human actions that lead to extinction of species. They also say that the release of de-extinct species carries the risk of invasiveness, disease transmission and unforeseen species interactions. Moreover, the process of de-extinction and the species created are both "unnatural" with unknown consequences and impacts, especially if the plan is to rewild the de-extinct species.

Goderie says that it is for these reasons that his foundation's Tauros Programme that seeks to bring back the aurochs—the ancestor of all cattle—is named so. "We need fully ecological functioning wild cattle and we call them tauros and not aurochs, since aurochs is extinct and we think—in contrast to Colossal—that you cannot reproduce lost species. In the best case, you can build look-alikes with some of the genes," he says.

Preston, too, points to the nomenclature used by the Tauros Programme to make a pertinent point: "I might say the tauros has the functional essence of the extinct auroch... but not even the people that created the tauros think of it as de-extinction. It adds too much controversy and scientific questions to call it de-extinction."

ADVERSE HEALTH IMPACTS

Apart from the ethical concerns, the bigger and more tangible problems pertain to the welfare of the animal created and the surrogate used in its birth. "De-extinction" can be done through three technological mechanisms: cloning, back breeding or selective breeding and genetic engineering. But all the processes have so far shown to be dangerous to the species created. This was true of the famous Dolly the sheep. Dolly was plagued with arthritis and lung disease, and died at six years, whereas sheep normally live up to 12 years. Similarly, in 2000, a US company cloned a "bucardo" or Pyrenean ibex from the last individual or endling. But the animal died within minutes of birth. "So far, the use of cloning has been problematic for animal welfare, with cloned animals showing rapid aging, ongoing health problems and premature death," wrote Heather Browning, a lecturer in philosophy at the University of Southampton, UK, in a 2018 essay. She also raises concern for the "resurrected" animals "as well as any others who have been used in the testing, cloning, and breeding

process," in an email with DTE. "It is especially worrying given the possible behavioural and cognitive differences from standard wolves that the gene editing may have induced, that could create welfare needs we are not even aware of," she says.

Browning's 2018 essay raises three other critical issues. One, there can be problems in birth, with the target animal being larger or differently shaped than the surrogate, as would be the case with elephants carrying mammoth babies; two, the surrogate could reject the "unusual" offspring; and three, the animals created would grow in absence of elders of their own species, "unlikely to have the required behavioural repertoire and social 'vocabulary' to match their mammoth companions", wrote Browning.

The reintroduction of such "functionally ineffectual eco-zombies" (the term used by Douglas J McCauley and team in a 2017 article) will be a nightmare. First, where will they be released, given that it is quite difficult to find space to even conserve extant species. Then, there is also the question of climate change. For instance, woolly mammoths, which Colossal Biosciences is trying to de-extinct, lived in Ice Age climates, when the average temperatures were up to 12°C colder than today.

Similarly, Colossal Biosciences plans to de-extinct Tasmanian tiger or thylacine, an Australian marsupial species that died in 1936. But the circumstances that led to its extirpation—human hunting—are still present in Australia, wrote philosopher Thom van Dooren, along with the late Australian ethnographer, Deborah Bird Rose in a 2013 article.

ECOSYSTEM BENEFIT ARGUMENT

"The thylacine extinction was entirely human-driven—caused by hunting because of the fear that they might kill sheep. We now know this not to be the case, and that they played an essential role in stabilising their ecosystem. So, we should absolutely bring them back to save many other species in that ecosystem, and the factors do not still exist that led to its extinction," Andrew Pask, epigeneticist and head of the Thylacine Integrated Genomic Restoration Research Laboratory at the University of Melbourne, Australia, tells DTE. Pask also welcomes Colossal Biosciences' dire wolves. "This is a fantastic advance and shows the power of de-extinction technology. This set of new tools is the only hope we have, to reverse the biodiversity crisis," he says.

Agrees Vikash Tatayah, conservation director of Mauritian Wildlife Foundation, Mauritius' largest non-profit, dedicated to saving endangered plant and animal

'OFFER NEW STRATEGIES'

Interventions like gene editing and cloning can help in cases when species lose genetic diversity

BEN NOVAK

THE INTERNATIONAL Union for Conservation of Nature (IUCN) recognises that some 38,000 species are threatened with extinction. A 2019 UN report says one million species may be at danger of extinction. But we do not need to do gene editing for one million species to help them survive. In most cases, habitat protection and restoration can go a long way. As habitat becomes fragmented, populations get more isolated. If we can restore habitat and reconnect populations, we can revive gene flow and increase genetic diversity. But the longer they spend in isolation, small populations start to lose genetic diversity. That is where we need more or heavier intervention methods like moving animals physically to get genes flowing. This is where certain biotechnologies offer new strategies.

Genetic diversity is essential for survival and adaptation to disease. When newly emerging or spreading diseases are added to fragmented and decimated populations, individuals are exposed to pathogens they have never encountered before. They do not have the genetic variability to adapt to and overcome pathogens. That is another situation where gene editing may help. A genome can tell us which population is doing better against a disease and identify naturally occurring genes that respond to the disease, building resistance. This helps us make better decisions about breeding to disseminate the disease resistance gene or connect populations in a way that increases the frequency of disease resistance alleles and not lose genetic diversity. Gene editing and cloning could have value in the present and near future, so we must invest in such research.

(Ben Novak is lead scientist and programme manager, Biotechnology for Bird Conservation, Revive and Restore)

'NO NEED FOR DE-EXTINCTION'

Why bring back extinct species when we do not seem to care for the animals, ecologies still present in our world?

CLEMENS DREISSEN

MY SHORT answer to whether we need de-extinction in today's world is "no". We do not seem to care for the animals and ecologies still present in our worlds. So why bring back species that have gone extinct? Then there are the myriad welfare issues associated with de-extincting—all the failed breeding, the suffering of those artificially inseminated, the disregard for the experiences of non-rare animals that are used as mere incubators. These projects tend to signal instrumentalising non-human life, while they seem merely meant to show off biotechnological prowess rather than express genuine care for the natural world.

Moreover de-extinction tends to reduce the value of the creatures that populate our worlds to the rarity of their "species", defined in terms of a genetic code that is supposed to programme their actions. The idea that bringing a certain genome back into circulation would thereby bring back a full blown animal misses the point of what animals are as the result of millions of years of evolution and often millennia of adaptation to ecological niches and complex relations through which animals make sense of their environments.

But even if new animal cultures emerge, with meaningful learning processes occurring as part of generations finding a place in local ecologies, we can question the impact of this technology on our imagination and see that the idea of possible de-extinction threatens to demotivate conservation.

(Clemens Dreissen is a professor of Cultural Geography at Wageningen University, Netherlands)

species. "In addition to classical conservation, I see de-extinction as another tool which can be used to overcome biodiversity loss, more so to restore ecosystem functions. Very often when an animal goes extinct, its functions in the ecosystem are lost. For instance, dispersal, predation and control of certain plants, pollination," he says.

Tatayah belongs to the Indian Ocean island of Mauritius where Dutch settlement in the 1600s wiped out dodo (*Raphus cucullatus*), a bird from the pigeon family, which has become the emblem of extinction in the centuries since. "I think the dodo should be brought back if there is a possibility of doing so, not from the point of view of nostalgia but from that of restoring lost ecosystem functions. Some want it back for tourism or national pride. But what concerns me the most is that some ecosystem functions are not being done due to the extinction of the dodo," he says.

Though Goderie is against the phrase "de-extinction", he agrees that reintroduction of proxies can provide ecosystem services. The Tauros Programme aims to rewild large depopulated areas, so the herds—together with other large grazing animals—can restore the park-like landscapes that once were very common in Eurasia and had a very high biodiversity, he says.

AYE OR NAY?

All things considered, is it a good idea to recreate lookalikes or proxies of extinct species for a planet in crisis?

Browning, in her paper, quotes Ronald Sandler, a professor of philosophy and director of the Ethics Institute at Northeastern University, US: "Deep de-extinction does not address any pressing ecological or social problems, and it does not make up for the past harms or wrongs. As a result, there is not a very strong ethical case [let alone an ethical imperative] for reviving long extinct species or developing the capacity for doing so…taking on significant costs or risks or funnelling scarce resources to pursue it is not justified…deep de-extinction is in many respects a luxury. It is fine to pursue it if people want, so long as it does not interfere with or compromise ethically important things."

Stephen Louis Brusatte, an American palaeontologist and professor at University of Edinburgh, UK, neatly sums up the debate: "I think the idea of bringing back extinct species is fascinating, and it will be a challenge to push our limits of discovery and exploration. But our world is changing so quickly today that we should prioritise protecting the species that currently exist and are at risk of death, rather than bringing back those that are already dead." DTE

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