BACK TO LIFE

Is extinction forever? While most would assume that yes, extinction is the ultimate end-point, a fate from which no species can return, Chris Fitch investigates the small but growing movement that dares to disagree

PANAIOTIDI

Passenger pigeons were hunted to extinction at the turn of the 20th century

The passenger pigeon was a legendary species. Flying in unfathomably large numbers across North America, with potentially many millions within a single flock, their migration was once one of nature's great spectacles. The 18th century ornithologist Alexander Wilson described a flock of passing passenger pigeons as 'a column, eight or ten miles in length' and on a separate occasion, claims he mistook a flock for 'a tornado, about to overwhelm the house and everything around in destruction.' Thousands of birds would roost together in tree branches.

John Lawson, the 17th century explorer, naturalist and writer, once noted that a flock had 'broke down the limbs of a great many trees all over the woods', while numerous accounts describe trees being toppled by the weight of birds nestling among their branches. There also exist records of terrified villagers fleeing for their lives, with flocks of transiting passenger pigeons 'blotting out the rays of the sun'.

'For me, that's an adrenaline rush,' says geneticist Ben Novak. 'I want to see a biological entity that has the power to create weather. We don't have that today, we have nothing that powerful.'

Sadly, the remarkable passenger pigeon's existence came to an end on 1 September 1914, when 'Martha', the last living *Ectopistes migratorius*, died at Cincinnati Zoo. While estimates of passenger pigeon populations from the 19th century range from three billion to as many as ten billion individuals (with the species believed to have once constituted 25 per cent of the total bird population of the United States), they were hunted to death around the turn of the 20th century (an 'industrial-scale harvest', according to Novak). A few stragglers kept the species alive in captivity, before Martha finally breathed her last.

Novak is Lead Researcher on the Great Passenger Pigeon Comeback, an ambitious project, started in 2012, which aims to bring the passenger pigeon back

AUNTSPRAY

It's being suggested that 2018 could see the start of efforts to reproduce the long-dead woolly mammoth, using Asian elephants as surrogates

to life through an ambitious-sounding process commonly known as 'de-extinction'. Despite how much it sounds like science fiction, de-extinction is, in principle, a genuine and legitimate concept. The basic premise involves using cloning technology (such as that which famously brought us Dolly the sheep two decades ago) to turn the DNA of extinct animals into a fertilised embryo, which can be carried by a surrogate – whatever the nearest living relative is – before being born as a living, breathing animal.

For the Great Passenger Pigeon Comeback, the plan is to use the living and abundant band-tailed pigeon as a surrogate parent for passenger pigeon embryos. 'It's the closest living relative, and it's ecologically very similar,' explains Novak. Then, once the pregnancy has come to term, and the band-tailed surrogate has laid her eggs, they would hatch into the first living passenger pigeon chicks in over a century. 'It's a very simple goal,' he claims. 'We want to recreate passenger pigeons, and put them back out in the wild.'

REPOPULATION

Passenger pigeons are one of the pioneering species in this field, but they are far from the only ones on which this cutting-edge technology is being trialled. From the Pyrenean ibex to the auroch, the heath hen to the gastric-brooding frog, the de-extinction movement is stirring the imaginations of scientists around the world to consider which species could potentially make a return from the void.

In Australia, the thylacine (more commonly known as the Tasmanian tiger) is another extinct creature which genetic scientists are striving to bring back to life. Forced to compete with dingoes for food and survival, driven onto the island of Tasmania, then decimated by hunters upon the arrival of Europeans in the early 1800s, the tragic story of the thylacine, which currently ends with the death of the final individual in Hobart Zoo in 1936, could take a dramatic twist if Michael Archer, Professor at the School of Biological, Earth and Environmental Sciences, UNSW, gets his way. By scouring museum specimens, Archer and colleagues have collected DNA from a range of sources, with attempts to remove any contaminants (such as human DNA) and then successfully sequence the thylacine genome ongoing.

There are a number of criteria that Revive & Restore (a non-profit subsidiary of the Long Now Foundation, with the assigned mission to, 'enhance biodiversity through the genetic rescue of endangered and extinct species') has established should be fulfilled before attempting de-extinction. The first of these asks, understandably, how possible it would actually be. Despite the hopes of many (and probably to the relief of many more), bringing back dinosaurs is off the table since their DNA is many millions of years too old to have survived intact and therefore be able to be sequenced effectively.

If extinct species can be brought back to life, can humanity begin to correct the damage enacted upon the natural world over the past millennia?

However, rough estimates place the length of time which can have elapsed since a species went extinct in order to be able to sequence its DNA in any significant way at around 200,000 years; a time frame which does leave open the possibility of bringing back to life another immensely popular candidate for this technology: the woolly mammoth.

George Church, Professor of Genetics at Harvard Medical School, and co-author of *Regenesis: How Synthetic Biology Will Reinvent Nature and Ourselves*, leads a team working on a project called the Woolly Mammoth Revival. 'It's aimed at developing tools to test ideas that come from genome projects in general,' he explains, 'this one to find out what might be responsible for cold resistance, which is the main distinguishing feature between woolly mammoths and Asian elephants.' By identifying which genetic traits made it possible for mammoths to survive the cold climates of the tundra, the project's ultimate goal is to repopulate the region with brand new mammoths.

'In a way we're ready today, in 2016,' insists Church, 'although we would like to avoid surrogates, because we don't want to interfere with the reproduction of either the African or the Asian elephant.' While alternative, non-surrogate technologies are yet to be fully developed, Church suggests 2018 as a possible date when cloning attempts could begin.

HYBRIDISATION

All this begs the question, if extinct species can be brought back to life, can humanity begin to correct much of the damage enacted upon the natural world over the past few millennia? 'The idea of de-extinction is that we can reverse this process, bringing species that no longer exist back to life,' says Beth Shapiro, Director of Evolutionary Genomics at the University of California Santa Cruz's Genomics Institute, and author of *How to Clone a Mammoth: The Science of De-extinction*. 'I don't think that we can do this. There is no way to bring back something that is 100 per cent identical to a species that went extinct a long time ago. Things that are gone are gone.'

The harsh reality, as Shapiro points out, is that despite the vast improvements made with this technology, the moment a species has become extinct, the reality of bringing that exact same species back to life is basically zero. 'In order to clone something, you need a living cell,' she explains. 'So as soon as something has been dead for a long time, there is no living cell.'

Instead, for de-extinction as we understand it to work, the DNA of existing species needs to be used as a template, ready for the insertion of strands of extinct animal DNA to create something new; a hybrid of two species, based on the living species, but which looks and/or acts like the animal which died out.

TOM REICHNER

Revive & Restore's Heath Hen project makes use of DNA from the extinct bird's closest living relative, the greater prairie chicken (pictured)

This is broadly the same process which has taken place in countless 'de-extinction' projects. The passenger pigeon embryo which could potentially be placed inside a band-tailed surrogate parent would be formed through the editing of band-tailed pigeon DNA to include characteristics which are similar to that of the passenger pigeon. 'We're actually re-writing the genome code, so that it carries the mutations of a passenger pigeon,' explains Ben Novak.

Similarly, attempts to recreate the lost auroch involve the selective sampling of DNA from several existing 'primitive' breeds of cattle, while Revive & Restore's Heath Hen Project significantly utilises the genetic code of the extinct heath hen's closest living relative, the greater prairie chicken.

'We'll never find a living mammoth cell, for example,' explains Shapiro. 'Instead, you would have to take an elephant cell, like George Church's group are doing, and edit that into a mammoth.'

While Asian elephants happen to be genetically even closer to extinct mammoths than they are to living African elephants, the differences between the two are still substantial, and geneticists remain a long way from being able to alter all million and a half base pairs in the genetic code, which would turn an Asian elephant cell into a genetically accurate mammoth cell.

Furthermore, even in the rare cases in which DNA can be extracted and sequenced to the point that an animal could be created with all the A, C, G and T nucleobases in the right places, there would remain the massively complicated challenge of teaching animals with no natural parents, conceived and born in entirely controlled circumstances, often by people who have never seen a real life individual before, how to behave like the extinct animal they are trying to bring back to life.

'We have little way to know how mammoth-like versus elephant-like this animal would be,' continues Shapiro. 'They're going to be born and raised by elephants, they're going to eat an elephant diet, they're going to establish in their guts an elephant microbiome. It's got to be taught how to be a living, breathing, adult social animal by an elephant, not by a mammoth. So, is it going to be a mammoth, or is it going to be an elephant?'

If true extinct animals remain lost from nature's family tree forever, what are the motivations for continuing this field of research?

ECOLOGICAL NICHES

This complicated process and questionable outcome begs the question: what is the actual point of this technology? If true passenger pigeons, mammoths and countless other extinct animals remain, despite our best efforts, lost from nature's family tree forever, then what are the logical motivations behind continuing this field of research?

One leading argument is that the dramatic and relatively recent loss of many species, particularly in the past century, has left several ecological niches unfilled, gaps which we are only recently coming to understand as being somewhat pivotal to the health of the wider ecosystem.

'There is no carnivore now in Tasmania that fills the niche which thylacines once occupied,' explains Michael Archer. He points out that the years since the thylacine went extinct has seen a trophic cascade whereby the lack of competition for Tasmanian devils – the island's other notorious resident – has seen the spread of the 'dangerously debilitating' facial tumour syndrome, which threatens the very existence of Tasmanian devils themselves. 'If that contagious cancer had popped up previously, it would have burned out in whatever region it started. The return of thylacines to Tasmania could help to ensure that devils are never again put at risks of this kind.'

Furthermore, the purpose of recreating the passenger pigeon isn't simply because of a wish to witness flocks of birds blocking out the sun. 'For us, the goal has always been replacing these extinct species with a suitable replacement,' explains Novak. 'Band-tailed pigeons are fiercely territorial breeders. When it comes to breeding, they scatter, and make maybe one or two nests per hectare. Whereas passenger pigeons, they're very social. When they would roost, they would make 10,000 or more nests in one hectare. That disturbance in the forest, that's actually the ecological role that the passenger pigeon played, and nothing alive today can really re-assume that role.'

In the absence of such a keystone species, ecosystems in the eastern US have suffered, as the lack of disturbance of thousands of passenger pigeons wrecking trees and branches means there has been minimal need for regrowth, leaving forests stagnant and therefore unwelcoming to the plants and animals which evolved to help regenerate the forest after a disturbance. A hybridised band-tailed pigeon, with the added nesting habits of a passenger pigeon, could, in theory, reestablish that forest disturbance, and thereby create the diverse habitat necessary for many plants, insects, mammals and other native species to thrive. In those terms, Novak sees highlighting the difference between genuine and hybridised species as just 'nitpicking'.

As well as his principle role on the passenger pigeon project, Novak is also in the very early stages of investigating the possibility of bringing back to the island of Mauritius possibly the world's most famously extinct animal, the dodo, which, as he points out, is basically just a giant pigeon.

'All of the technology developed for passenger pigeons can be leveraged for a dodo bird project,' he explains. 'There might be an ecological importance to a dodo on that island, partly because of how big it is. It's got one of the biggest mouths of the endemic fauna, so it's capable of eating a class of fruits and seeds that other species were not eating. So its role as a key seed disperser is important.'

While there is a consensus that there is little habitat left in which a new dodo species could survive, there is an argument that the interest generated by the potential return of the dodo would provide essential funding. This would go a long way towards speeding up the habitat restoration and removal of invasive species needed on Mauritius both for potential dodos, and, crucially, for living endangered species. 'A dodo bird project could really take off, and hopefully the people of Mauritius think so as well,' he smiles.

'Thinking about things in terms of species is not really the right way think about it,' argues Shapiro. 'If you're just going to get an elephant, have you really brought a mammoth back to life? I think the answer to that depends on your motivation for doing this. If you want to bring a mammoth back to life because you want to put it in a zoo or you think it's cool to be able to bring something back that's dead, then you've failed. If you want to bring something back that maybe is able to fill the niche of a mammoth, then you just need an elephant that can live where mammoths once lived. That is a much more compelling reason to think about de-extinction, in terms of what we can do to help preserve ecosystems, to re-establish functional ecosystems, and re-establish interactions between species that are gone because species have gone extinct. I think that can be an incredibly compelling reason to think about this technology.'

GENETIC RESCUE

While the prospect of bringing back to life extinct animals might capture imaginations, it is, of course, far easier to try to save a living, breathing species which is merely threatened with extinction. 'Many of the technologies that people have in mind when they think about de-extinction can be used as a form of "genetic rescue",' explains Shapiro.

She prefers to focus the debate on how this emerging technology could be used to fully understand why various species went extinct in the first place, and therefore how we could use it to make genetic modifications which could prevent mass extinctions as a result of human activity and climate change in the future. 'This technology – although it doesn't exist yet – could be incredibly useful as a new weapon in what should be a growing arsenal to fight contemporary extinctions,' she insists.

While enabling mammoths (or mammoth-like Asian elephants) to return to the tundra and boreal forests of Eurasia and North America could be a useful factor in reducing carbon emissions – the disruptive impact of elephants punching holes through snow and knocking down trees believed to encourage grass growth, thereby increasing albedo, reducing temperatures, and mitigating emissions from melting permafrost – there is also the significant role such actions could have on the elephants themselves.

'Probably my highest priority would be preserving the endangered Asian elephant,' says George Church, 'expanding their range to the huge ecosystem of the tundra. It's probably the largest ecosystem in the world, and it has the lowest population density of humans.' Necessary adaptations would include smaller ears, thicker hair, and extra insulating fat, all for the purpose of reducing heat loss in the tundra, and all elements contained within the genetic code of the extinct woolly mammoth.

Of course, many extinct animals wouldn't be able to survive in our contemporary environment even if they could be successfully brought back to life. Therefore, another of the Revive & Restore criteria asks why the species initially went extinct, and whether that problem has changed. Is it simply because of over-hunting, which cultural changes may have eliminated? Or are we trying to bring a species back just because it's fun 'playing God'?

The latter is an accusation which geneticists such as Shapiro have had to get used to. 'We are not messing with things,' she counters. 'We, as a species, have been manipulating and directing the evolutionary trajectory of the organisms with which we share this planet for at least the last 30,000 years, which is the first time we find evidence in the archaeological record of grey wolves being domesticated as dogs. We're simply now asking for the capacity to do it in a more directed way.'

One criteria asks why a species went extinct, and whether that has changed. Are we trying to bring a species back just because it's fun 'playing God'?

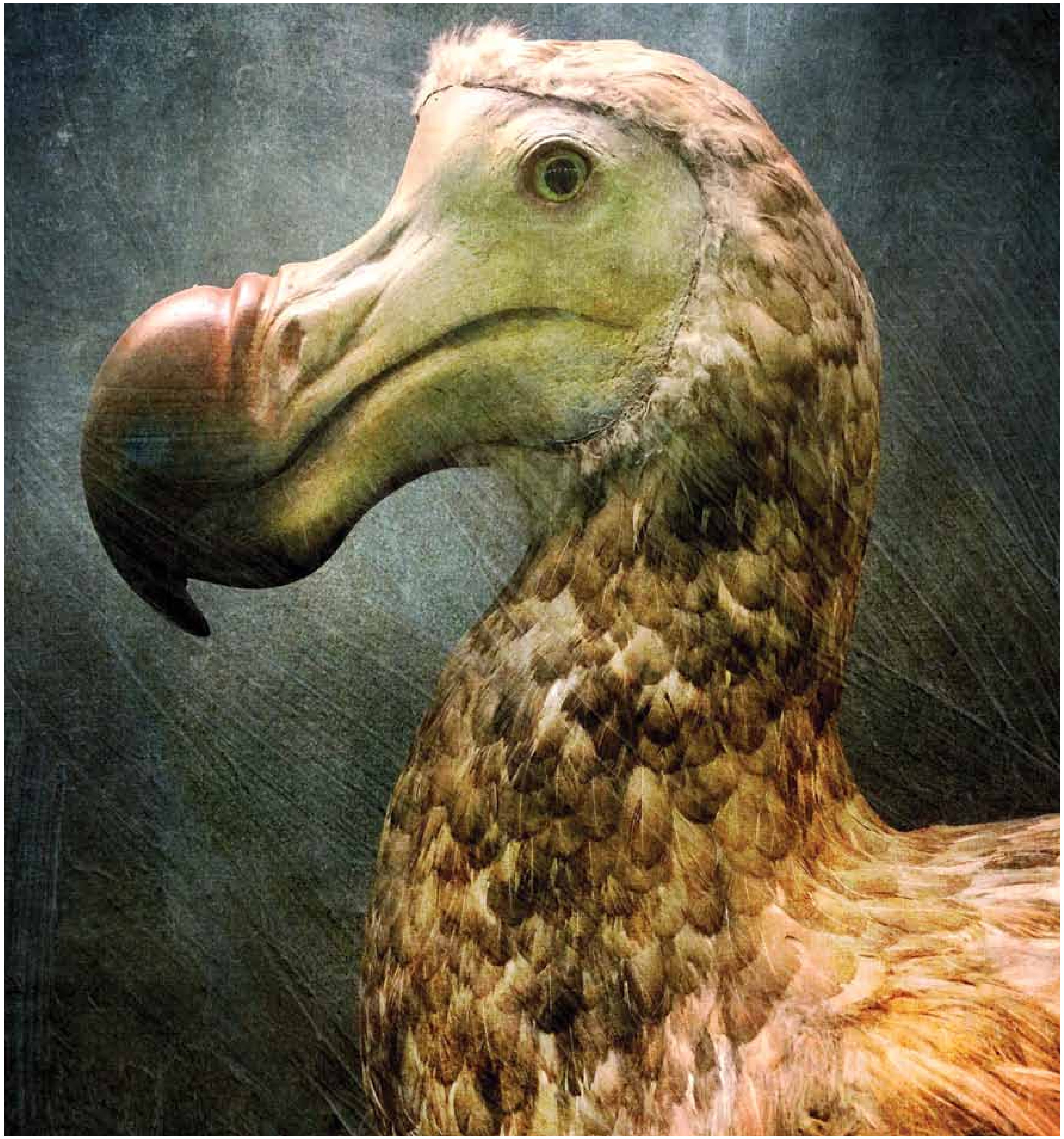
'I would also say there's an incredible moral hazard to not do anything at all,' she continues. 'We know that what we are doing today is not enough, and we have to be willing to take some calculated and measured risks.'

MATTER OF TIME

While genuine de-extinction – the returning of 100 per cent genetically accurate extinct creatures to our environment – remains merely science fiction, the opportunities available as a result of genetic rescue technology potentially offer a difference between survival and complete extinction for many species which could only have been imagined even just a few years ago.

Furthermore, if the ultimate goal is to find a way to fill certain ecological niches which humans have left vacant, then it may not be too long before this ambition is realised for real.

'It's a matter of time and it's a matter of funding,' explains Novak, who anticipates that, with the necessary financial support, a first batch of engineered birds could be hatched by 2022. 'I don't think there will be many billions of passenger pigeons again,' he predicts, 'but we can definitely get up to the millions or hundreds of millions range, and they can block out for sun for a couple of hours again.'



STOCKIMO

Bringing back the famous dodo bird might be as much a tool for publicity as it would be a vital part of the ecosystem of Mauritius