Geographies of Conservation I:
De-extinction and Precision Conservation

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Abstract

Extinction has long been a central concern in biodiversity conservation. Today, de-extinction offers interesting possibilities of restoring charismatic species and ecosystem function, but also risks and costs. Most de-extinction depends on genetic engineering and synthetic biology. These technologies are also proposed for use in 'gene tweaking' in wild species to enhance their chance of survival. Within conservation, the resulting debates pit an optimistic world of high-tech 'precision conservation' against a more conventional vision of biodiversity conservation achieved primarily through protected areas. De-extinction is a fashionable idea that brings the complex debates about the ethics and wisdom of genetic engineering to a central position within conservation science

Keywords

Conservation, de-extinction, extinction, rewilding, synthetic biology, novel ecosystems, mammoth.

1. Introduction

> 'I had one of the early Thylacines,' said the official glumly. 'A Version 2.1. When we decanted him he had no ears. Stone deaf. No warranty or anything. Bloody liberty I call it'. Jasper Fforde (2001) *The Eyre Affair*, 31-2).
>
> 'Extinct Tasmanian tiger could roar back into life after DNA is implanted into a mouse'. Richard Shears, *MailOnline* 20 May 2008[1].
>
> 'A saber-toothed cat? It would be neat to see one of those.' (Hank Greely, quoted by Zimmer 2013).

In April 2013, the cover of *National Geographic* showed a painting of a mammoth, a sabre-toothed cat, a moa and other extinct megafauna marching out of giant test tube onto a tundra landscape. The issue carried the headline 'Reviving extinct species: we can, but should we?' In the lead article, Carl Zimmer (2013) described scientific work being done to recreate a series of extinct species (including the *bucardo*, a Pyrenean subspecies of the European ibex, the passenger pigeon and the wonderfully-named Lazarus frog from Australia), and recounted the ideas of Russian ecologist Sergey Zimov about restoring megaherbivores to the Siberian Tundra in a 'Pleistocene Park' (Zimov 2005). A linked TEDx event on 15 March at the National Geographic headquarters in Washington DC (organized by Revive & Restore[2], a project of the Long Now Foundation, founded by former hippy entrepreneur Stuart Brand[3]) saw speakers discuss these and other species (including the mammoth, the thylacine or Tasmanian tiger, the heath hen and the less glamorous American chestnut)[4].

As Beth Shapiro (2015) observed in *How to Clone a Mammoth*, these events caused 'de-extinction' to make headlines across the world, generating high levels of excitement, hyperbole, speculation and alarm, rapidly losing contact with the actual state of the science. The question of the 'genetic rescue' of endangered and extinct species (the purpose of Revive and Restore) was catapulted into the role of 'new big idea' for biodiversity conservation. It fell on fallow ground.

The history of conservation can be presented in terms of a sustained attempt to halt or prevent extinction (Adams 2004, Barrow 2009). The establishment of conservation societies in the late Victorian era was stimulated by charismatic extinctions (or near-extinctions). Such extinction stories retain their power (e.g. Paddle (2002) on the thylacine, Turvey (2008) on the Yangtze river dolphin, and Avery (2014) on the passenger pigeon). Elizabeth Kolbert won the Pulitzer prize (and first place in the *Observer* Newspaper's list of the '100 best nonfiction books of all time'[5]) for *The Sixth Extinction* (2014*),* her version of extinction due to human activities (c.f. Wilson 1992, Leakey 1995).

Classification, listing and counting of rare species lie at the heart of global biodiversity protection (Barrow 2009, Turnhout et al. 2013). The IUCN Species Survival Commission publishes an online *Red List of Threatened Species*[6], based now on systematic and quantitative assessments of threat status (Mace and Lande 1991, Mace et al. 2008) to categorize species as extinct, extinct in the wild, critically endangered, endangered, vulnerable, near threatened[7]. Conservation organizations invest considerable effort in the identification of unknown species, to inform protected area selection and management[8]. Many new species are already rare when discovered (e.g. the Myanmar snub-nosed monkey, already Critically Endangered by IUCN criteria when described in 2010)[9]; others are rediscovered, having been thought extinct (e.g. Turvey *et al.* 2012).

Conservation's classic response to biodiversity loss is to set apart protected areas for nature. The geographical character of this strategy is widely noted (e.g. Zimmerer 2006), as are its social impacts (Brockington et al. 2008), and its grand spatial aspirations (Wuerthner et al. 2014, Wilson 2016).

The notion of de-extinction draws attention to conservation strategies aimed directly at biodiversity itself, engaging with the genomes of individual species.

Here I explore the implications for conservation of two such ideas, 'de-extinction' (the recreation or restoration of previously extinct species) and the direct manipulation of genomes of wild species for conservation purposes.

2. De-extinction as technique

In theory, de-extinction can be achieved by a range of methods (Sherkow and Greely 2013, Ogden 2014, Shapiro 2015). None is simple, cheap or foolproof (Shapiro 2015). The simplest is selective or back breeding, used for example to produce a cow that resembles the extinct auroch (Lorimer and Driesssen 2011). This is essentially a version of existing domestic animal breeding. It is slow, and while it can result in a creature that looks like the extinct species, its genetic make-up may be very different (since a relatively small part of the genome may control appearance).

The second method of de-extinction is cloning. This requires the transfer of the nucleus of the adult cell of an extinct species (e.g. from frozen tissue) into the unfertilized egg of a host animal cell from which the nucleus has been removed. This method was used by the Roslin institute to create Dolly the sheep (Wilmut et al. 1997), and to recreate the *bucardo* (Folch et al. 2009), using frozen cells taken in 2000 from the last living animal. Such a method creates a true clone (identical to the parent). However, the rate at which DNA degrades make this only possible with relatively recently extinct animals for which a suitable closely related host is available (so not mammoths, let alone dinosaurs, Shapiro 2015).

The third approach to de-extinction involves genetic engineering, or synthetic biology. Essentially this involves i) working out the complete genome of the target extinct species and the nearest living relative; ii) identifying the differences; iii) synthesising stretches of the extinct species' genome; using gene editing technologies (notably CRISPR-Cas9) to insert this into the target genome. Nuclear transfer from cells with the new DNA then creates living organisms with the characteristics coded by the new DNA. The task is (of course) hugely complex, and the technical challenges of fully reconstructing the genomes of extinct species are immense (Shapiro 2015).

The importance of synthetic biology in de-extinction brings the wider ethical questions associated with these technologies into salience. Synthetic biology is a rapidly developing field (Carlson 2010, Church and Regis 2012). It involves 'the deliberate design and construction of customised biological and biochemical systems to perform new or improved functions' (IAP, the Global Network of Science Academies, May 2014). One way to think of it is that genes are thought of as software that creates its own living hardware in organisms: Gibson (2014) observes that it is now technically feasible to reverse the process of reading genome sequences and begin writing them. The potential revolution in biology is profound.

Synthetic biologists adopt an engineering approach, designing and fabricating genetic 'components' using standardized parts and automatable processes. Thus the International Genetically Engineered Machine (iGEM) Competition, for students, offers BioBricks™ as a standard for interchangable parts that can be assembled to form biological systems in living cells, in turn creating 'useful devices': life that does what its creator wants. Such assembly does not require hugely costly laboratories: as Carlson (2005) noted, we are in an 'era of garage biology', in which 'amateur hobbyists' are 'creating home-brew molecular-biology labs' Ledford (2010, 650).

When, in 2010, Craig Venter announced the successful construction of the first self-replicating, synthetic bacterial cell, it seemed clear that new forms of life (re-designed organisms, wholly new organisms) are perfectly achievable. There is a large literature on the battle lines established around the regulation of synthetic biology and synthetic organisms (e.g. Dana et al. 2012), informed by only very incomplete learning about the nature and importance of public trust (or lack of it) in the evolution of debates about GM crops in Europe (e.g. Erikson et al. 2011, Blanke et al. 2015).

3. De-extinction as a Conservation Strategy

If slowing the rate of species loss seems to be the best conservation can do, conservation could be said to have failed (Kareiva et al. 2012). In such a context, the idea of reversing extinction is clearly one that has potential attractions. There are a number of arguments for and against it.

First, it is argued that it can contribute directly to conservation: both that the restoration of lost species brings genetic diversity back into the stream of evolution (which it does, albeit at a small scale and high cost), but also that it can drive ecosystem recovery by restoring ecological function, re-starting latent ecological processes and restoring lost ecosystems or ecosystem states (e.g. Estes et al. 2016). This argument reflects the idea that ecosystems from which species have been lost (for example the passenger pigeon) are incomplete and their former functioning is impaired. Like many de-extinction scientists, Seddon et al. (2014) argue that the ultimate aim of de-extinction should be 'the establishment of viable free-ranging populations', and therefore the technical ability to resurrect particular species is insufficient reason to do it. Shapiro (2015, 131), in the context of the everlastingly charismatic wooly mammoth, argues that 'we should think of de-extinction not in terms of *which life form* we will bring back but *what ecological interactions* we would like to see restored' (emphasis in the original). This is the core of the diverse concept of 'rewilding' (Lorimer et al. 2015). The original call for 'Pleistocene rewilding' (Donlan et al. 2005, 2006) made the case that the ecology of North America and Eurasia was shaped by extinct mammals, a line of argument extensively developed at a meeting on 'megafauna and ecosystem function' held in Oxford in 2014[10] (e.g. Malhi et al. 2016, Svenning et al. 2016).

Analogues of extinct species can perform similar functions: Monbiot (2013), for lack of the extinct straight-tusked elephant, calls for Indian elephants to graze British woodlands, whose understories are adapted to bulldozer herbivore coppicing. More boldly, Zimov (2005) argues that the introduction of modern large herbivores can restore arctic grasslands (and indeed transform carbon sequestration). In modern parlance, de-extinction provides ecosystem services as well as enhancing biodiversity. Of course, beliefs about the ecosystem engineering effects of extinct species remain somewhat conjectural (Bakker et al. 2015). As with other forms of restoration, historical reference points are necessarily arbitrary. Ecosystems are highly dynamic and past impacts have knock-on effects over multiple generations (Hobbs et al. 2006, Hughes et al. 2012).

Second, de-extinction might increase public support for conservation. Charismatic extinct species might be a source of wonder ('it would surely be very cool to see a woolly mammoth', Sherkow and Greely 2013, p, 33), and hence increase public interest in nature and conservation. The huge cost and effort of reviving an extinct species might itself increase awareness of the value of conservation (Shapiro 2015). On the other hand, as a way to contribute to the global stock of biodiversity, de-extinction is slow and massively expensive: Ehrlich (2014) calls it 'a fascinating but dumb idea' because it could distract from more pressing issues and cost-effective conservation actions.

Third, de-extinction can be argued to be good for science, and hence contribute to wider human benefit. To bring back an extinct species demands a huge amount of knowledge of its genome and ecology, so arguably the effort to bring it back would lead to new scientific knowledge about lost and extant biological systems. This could be useful to conservation, and might contribute to scientific and technical advancement in gene-editing and cloning technologies more generally, and hence bring wider social benefits. To date, conservation has benefitted from efforts in agriculture (chickens for passenger pigeons, or sheep for the *bucardo*), and in medicine. Work on wild species is a small side-shoot of medical research (Shapiro 2015), but conceivably learning could flow the other way.

4. Managing de-extinction

Practical questions beset attempts at de-extinction. The choice of species for de-extinction reflects the lure of charismatic species, particularly mammals, for conservationists (Lorimer 2007, Seddon et al. 2014). Such species 'increase the public and corporate interest in the conservation of wild nature' (Jones 2014, 22). lants seem to lack the necessary charisma. Animals that reproduce quickly (like the passenger pigeon) are easier scientific targets than those with long gestation periods (like a mammoth or a woolly rhinoceros, Shapiro 2015). Given the importance of release and establishment in the wild, a critical factor in choosing species is the availability of suitable habitat (not necessarily easy with large mammals, or flocks of passenger pigeons), and freedom from the factors that caused extinction in the first place (hunting or habitat loss, for example). It is no accident that there is overlap between proposals for de-extinction, and for rewilding (Carey 2016) over large areas (Donlan et al. 2005, Zimov 2005, Donlan et al. 2006, Wuerthner et al. 2015).

The status of de-extinct species is complex and interesting. Organisms subject to de-extinction using genetic engineering (or back breeding) may look like lost species, but they will not be genetically identical. In an exchange with Paul Ehrlich (2014), Stewart Brand (2014) argues 'If it looks like a passenger pigeon and flies like one, is it the original bird?', but he is disingenuous: it will be a mixture of the host genome and sections that have been reconstructed.

That means that the organism will not be classified as the original species, either in law or by the various bureaucratic processes of conservation and biological regulation. Indeed, different agencies (and certainly different agencies in different jurisdictions) may classify the de-extinct organism differently (Friese and Marris 2014). Carlin et al. (2013) explore the legal status of a de-extinct species in the USA: would it be regulated as an endangered species under the US Endangered Species Act, as a project requiring a permit under the National Environmental Policy Act either for its possible environmental impacts, or as a genetically Modified Organism (GMO)? Should its welfare be regulated as a wild or domesticated species? N o existing framework (set up to protect species and ecosystems deemed to have emerged as a consequence of evolution) is entirely suited to de-extinct species. One response may be to treat de-extinct species by extending existing rules about species reintroductions (Jørgensen 2013), such as the 2013 IUCN Guidelines on Reintroductions and other Conservation Translocations (Seddon et al. (2014)[11]. In 2015, IUCN duly began drafting a set of *Guiding Principles on De-extinction for Conservation Benefit*.

One thing that is clear about de-extinction through genetic engineering: under US patent laws, de-extinct species will be patentable, and their genetic code and bodies are likely to be private property. Because of the costs, de-extinction experiments are already dependent on private charitable investment. One likely future outcome is corporate investment, with restored species displayed in private zoos or parks for profit, as part of a bizarre and novel nature tourism industry (the *Jurassic Park* model, of course, Crichton 1990). Such an industry would have implications for current arguments about close and supportive relations between nature tourism and conservation (Whittle et al. 2015), as well as obvious ethical issues.

The ethics of de-extinction are complex (Sandler 2013, Cohen 2014): as Minteer (2014, 261) notes, we have a 'tendency to let our gadgets get out in front of our ethics'. Calls for de-extinction tend to have a strong (if sometimes implicit) moral basis in deontological ethics, an obligation to restorative justice, on the argument that humans have a responsibility to reintroduce species that their actions have caused to go extinct (Cohen 2014). The extent of human involvement, human design and intention on de-extinction undermines arguments about the authenticity of nature (Dudley 2011). On the other hand, there are clear ethical questions about the making and use of living animals in de-extinction attempts (Friese and Marris 2014): animals are 'moral patients' capable of suffering (Cohen 2014). These concerns are exacerbated by the high death rate of captive wild animals in cloning (Shapiro 2015): the young cloned *bucardo* lived only seven minutes, having a genetic malformation (Ogden 2014).

5. Tweaking Genomes

De-extinction holds the headlines, but for conservationists it is only the end member of a continuum of techniques that involve the deliberate manipulation of the genomes of wild species. The same techniques of genetic engineering can be used to 'tweak' the genomes of extant species (Thomas et al. 2013, Redford et al. 2013, 2014). They are being used in this way in public health (e.g. to deliver sustained control of disease-carrying mosquitos (Alphey 2014). In conservation, possible applications include 'facilitated adaptation' to anthropogenic environmental change (Thomas et al. 2013). for example 'human-assisted evolution' of coral reefs, using genetic engineering to insert genes from heat-tolerant coral species into others as part of reef restoration efforts (Mascarelli 2014). Other ideas are the engineering of microbial consortia to enhance bioremediation of polluted sites (Brune and Bayer 2012), the use of CRISPR technologies to develop species-specific biological control of invasive alien species by incorporating some disadvantageous feature such as reduced fertility or chemical sensitivity (Webber et al. 2015) or engineering of resistance to fungal diseases such as white nose syndrome in North American bats or chytridiomycosis in amphibians (Redford et al. 2014).

As Esvelt et al (2014a, 2014b) observe 'we may soon be able to alter not just domesticated species, but entire wild populations and ecosystems'. The challenge for conservationists is to work out whether, when, why and how genetic engineering might legitimately and safely be applied (c.f. Redford et al. 2013, 2014). Synthetic biologists are mostly comfortable with the notion of the design and construction of entirely synthetic species (Moreno 2012): something not quite achieved by Craig Venter in 2010, although he came close. The importance of good design in synthetic biology is recognised (Ginsberg et al. 2014), but ambition is expansive. There is interest in the synthesis of whole ecological communities ('microbial communities with desirable properties', Frederiskson 2015) and large-scale interventions in global environmental systems: Sole´ et al. (2015) speculate about the role of 'synthetic circuit designs for earth terraformation'. They note, with characteristic and presumably accidental understatement, that 'history shows us that modification of ecosystems needs to be done carefully' (p.10).

The capacity of synthetic biology to reshape organisms, ecosystems (up to the scale of the biosphere, and potentially on other planets) awakens familiar controversies in conservation. 'Tweaking' genomes is simpler than attempting de-extinction, and the technology may therefore be applied faster, more cheaply and more widely. Conservationists viewing the prospect are strongly focused on pragmatic questions of cost/benefit, environmental and non-target species impact, and the potential of engineered traits to 'leak' into non-target species and spaces (as genes from genetically modified Atlantic salmon have done, Oke et al. 2013).

Risks are certainly recognised. Webber et al (2015) note that genetic engineering of pest species might seem cheaper and have less potential for collateral damage than conventional control methods using poison or traps, but the global reach of invasive species creates a risk of spread of the deleterious trait. On the other hand, some argue that since human exploitation of nature already influences the genomes of wild species inadvertently, causing changes in evolutionary trajectories (Sarrazin and Lecompte 2016), conservationists should consider managing genomes actively as well as passively (Redford 2014). Deliberate genetic manipulation (without direct engineering) is already practiced in conservation. Thus Bletz et al. (2013) analyse the potential for 'bioaugmentation' of the skin bacteria of amphibians to improve defences against chytridiomycosis, while itken and Whitlock (2013) and Kelly and Phiullips (2015) explore the potential of 'assisted' or 'augmented' gene flow to promote climate change adaptation or mitigation,where conservation managers translocate individuals pre-adapted to changed or changing conditions.

6. Conclusions: precision conservation?

Ehrlich (2014) suggests de-extinction is 'extremely unlikely to succeed on a planet continually being vastly transformed by human action'. Donlan (2014,

25) is probably more prescient seeing it as ‘likely to become commonplace’. The question is then whether conservationists should follow Latour’s injunction (2011) to ‘love your monsters’.

Love of genetic technology is certainly widely urged on conservation. Brand (2015) welcomes the use of genetic engineering to develop ‘precision conservation techniques based on minimalist tweaking of wildlife gene pools’. Such a bold strategy would demand a new vision for the ‘crisis discipline’ of conservation biology, one which embraces evolutionary biology and seeks to help ecosystems tolerate increasing global change (Hellman and Pfrender 2011). To that end, Charo and Greely (2015) ask whether ‘CRISPR critters’ are really any different from the unexpected effects of human expansion, while Jeschke et al (2012) argue that all organisms novel in biology or location (genetically modified organisms, synthetic organisms, invasive species and emergent pathogens) need to be thought about within a common framework. Redford (2014, 2) urges conservationists to ‘engage directly with synthetic biology and other technologies’ and try to instil conservation values and concerns.

De-extinction and the ‘precision conservation’ that arguably is allowed by synthetic biology puts pressure on an important fracture zone in conservation, between the idea of conservation as the task of curating novel ecosystems, or as gardening (Hobbs et al 2013, Marris 2010), and the conventional and long-established idea of conservation as wilderness protection (e.g. Soulé 2013, Wuerthner et al. 2014, Wilson 2015). This dispute extends out into the debate about the so-called ‘new conservation’, and the way conservationists respond to the idea and environmental changes of the ‘Anthropocene’ (Soulé 2013, Corlett 2014, Kareiva 2014, Lennon 2015).

To follow McKibben (1990), the idea that a nature could exist that was not influenced by humankind is gone. This has significant implications for conservationists: Lorimer (2011, 7) asks ‘when one can no longer make recourse to Nature, what forms and trajectories of difference matter? There is increasing interest in the evidence for and significance of ‘novel’, ‘emerging’ or ‘noanalogue' ecosystems that differ in composition and/or function from present or past systems (Hobbs et al. 2009, 2013). Kareiva et al. (2007) speak of global nature as 'domesticated'. Head (2008, 273) argues the concept of 'human impacts is 'neither conceptually or empirically strong enough for the complex networks of humans and non-humans now evident, in prehistoric as well as contemporary time frames'. Ellis (2009) asks whether 'it is 'time for a "postnatural" environmentalism'?

Anthropocene science displays 'a panicked political imperative to intervene more vocally and aggressively in an earth run amok' (Robbins and Moore 2012, p. 9). Associated environmentalisms are criticised as reflecting a technocratic, coercive and neoliberal model of protecting nature against humanity. Just as ideas of nature-society hybrids challenge conservation thinking (Lorimer 2011, 2015, Lorimer and Driessen 2014), so, most especially, do the burgeoning human capacities to synthesise nature, inside as well as outside conservation. Just as the conventional distinction between conservation *in situ* (in the field) and *ex situ* (in zoos and collections) is being eroded (Braverman 2014, 2015), so too is the idea of nature as self-organising at the level of the genome.

There is clearly an urgent need for informed and open debate about synthetic biology in conservation, whether done to 'save' biodiversity or for quite other purposes, and about how it can and should be regulated (Webber et al. 2015). These go well beyond the question of de-extinction, but this brings the issues onto the public agenda in a powerful way. The question Friese and Marris (2014, 2) ask, 'what kind of nature does de-extinction seek to make?' needs to be broadened to address all aspects of synthetic biology. Minteer (2014, 261) argues that 'it cuts against the progressive aims of science to say it, but there can be wisdom in taking our foot off the gas, in resisting the impulse to further control and manipulate; to fix nature'. Conservationists face the question whether to heed or ignore this advice.

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Notes

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[1] http://www.dailymail.co.uk/sciencetech/article-1020675/Extinct-Tasmanian-tiger-roar-life-DNA-implanted-mouse.html, accessed 19 March 2016

[2] http://longnow.org/revive/

[3] The Long Now Foundation was established in 1996 (or 01996 as they would prefer it), 'to foster long-term thinking and responsibility in the framework of the next 10,000 years' http://longnow.org/. Their projects include a clock designed to tick for 10,000 years. (http://longnow.org/clock/).

[4] Videos of all the TEDx talks are available online at: http://longnow.org/revive/events/tedxdeextinction/

[5] http://www.theguardian.com/books/2016/feb/01/100-best-nonfiction-books-of-all-time-the-sixth-extinction-elizabeth-kolbert (accessed 5 March 2015)

[6] www.redlist.org/info/introduction.html

[7] http://www.iucnredlist.org/

[8] Thus since 1990 the US NGO Conservation International's Rapid Assessment Program (RAP), has organized intense field collecting expeditions to field sites, discovering more than 1,400 new species and supporting the creation, expansion and improved management of more than 20 million hectares of marine and terrestrial protected areashttp://www.conservation.org/projects/Pages/Rapid-Assessment-Program.aspx

[9] http://www.fauna-flora.org/news/fauna-flora-international-discovers-new-species-of-snub-nosed-monkey/

[10] http:// megafauna.weebly.com/
[11] http://www.iucn.org/news_homepage/news_by_date/?13377/New-Guidelines-on-conservation-translocations-published-by-IUCN