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opinion

De-extinction in a crisis discipline

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De-extinction, the idea of resurrecting extinct species using genetic engineering, has recently caught the attention of both the scientific community and the wider public (Kumar 2012, Sherkow and Greely 2013, Zimmer 2013). A diverse group of scientists and practitioners, led by long-time environmental proponent Stewart Brand, has been busy articulating a framework for de-extinction and exploring a roadmap forward, including identifying the many challenges that lie ahead. De-extinction may mean different things to different people. The Long Now Foundation defines it as using "genetic technology and DNA from museum specimens or fossils to revive species that have gone totally extinct"[1]. Related discussions are also underway around using genetic engineering to assist populations in adapting to climate change and other extinction drivers (Thomas et al. 2013). De-extinction has sparked a lively debate on biodiversity conservation strategies, one with plenty of detractors who give reasons why it is a bad idea or that it will never deliver on its promise.

There are many unknowns surrounding de-extinction. Whether it will happen or not, however, is likely not to be one of them. It already has, albeit briefly (Folch et al. 2009), and it is likely to become commonplace—sooner rather than later. One main reason for this is the rate of technological innovation, which is currently doubling every decade and accelerating (Kurzwell 2005). Mass adoption of the radio took 30 years, while the World Wide Web required only seven after it was introduced in 1991. The power of information technologies is growing even faster, doubling every year. The cost of sequencing DNA, for example, is outpacing Moore's Law[2]. Using genetic engineering to resurrect extinct species will be just one of hundreds of technological innovations that will happen in the coming decades. Most of them will bring new ethical challenges, and de-extinction may prove to be mild compared to other disruptive innovations coming our way. The pace of de-extinction progress will largely depend on the resources its proponents are able to attract.

Like all intervention-based strategies, there will be risks, costs and benefits to de-extinction. In my view, the potential benefits are profound, while the potential costs and risks are real, but not novel. The risks are similar to other restoration-based approaches to biodiversity conservation, such as the potential for disease transmission and unexpected species interactions (Donlan et al. 2006, Sherkow and Greely 2013). These are familiar issues to conservation science, and the abilities to quantify and successfully mitigate these risks are improving at a steady pace. For example, our ability to manage certain invasive species, particularly mammals, has increased dramatically over the past two decades. There have now been over 900 successful invasive vertebrate eradications from islands worldwide, including from islands larger than 400,000 hectares (Donlan 2008, Veitch et al. 2011). Yet there are still obvious limitations in our ability to manage populations; those limitations and uncertainty should be a major factor in the initial stages of selecting de-extinction prospects—the current ability to manage the taxon. This suggests that vertebrates with slow reproductive rates would make strategic candidates. In sum, risk assessment will be a pivotal factor in the de-extinction process, but the issues involved (e.g. invasiveness, disease transmission, unexpected species interactions) are common

1 http://longnow.org/revive/candidates/revival-criteria/. Last accessed 06 March 2014.
2 Wetterstrand, K.A. (2013) DNA sequencing costs: data from the NHGRI Genome Sequencing Program (GSP). Available at: http://www.genome.gov/sequencingcosts. Last accessed 06 March 2014.

across many biodiversity conservation interventions.

Another common criticism of de-extinction is that it would divert attention and resources away from other biodiversity issues and the strategies to address them, such as endangered species conservation and land-use change (Scientific American Editors 2013, Mark 2013). Will de-extinction become the next new “fad” in biodiversity conservation and shift precious resources away from other strategies (*sensu* Redford et al. 2013)? This argument can be made for any conservation strategy: carbon markets distracting from ecosystem-based approaches, payment for ecosystem services programs distracting from species-based conservation, and working landscapes distracting from protected-area networks (Redford and Adams 2009, Soulé 2013). There is little evidence to support any of these claims, partly because conservation practitioners are notoriously bad at tracking spending and outcomes (Ferraro and Pattanayak 2006, Halpern et al. 2006). Similar to research efforts (Brodie 2009), how conservation funding is allocated is influenced by many factors, including those that have less to do with science or strategy (e.g. a family foundation’s personal interest). Conservation dollars are often not fungible, and novel initiatives can generate new funding sources. If successful, de-extinction will become a relatively specialized tool under the larger umbrella of species’ reintroductions. Thus, one would hope de-extinction will become more complementary than competitive within the larger portfolio of conservation strategies. In my view, a significant diversion of resources is unlikely because conservation strategies are not mutually exclusive—a point conservation scientists tend to overlook. De-extinction work on the Woolly mammoth, anti-poaching programs for forest elephants, and market-based solutions for illegal wildlife trade can and should occur concurrently. And the funding for those initiatives is likely to come from different sources—from different players with different interests across the diverse environmental sector.

A moral hazard argument accompanies the concern of de-extinction acting as a distraction from more “important” activities. Will the ability to bring back extinct species wipe away people’s concern about protecting species alive today? This possibility assumes that conserving species is a major priority for many—although much evidence suggests otherwise (Brook et al. 2003, Sorice et al. 2013). Could de-extinction act as a perverse incentive and political tool to promote activities that harm species and the environment? At a minimum, the answer is probably yes. But environmental policy and conservation strategies are no stranger to perverse incentives. The US Endangered Species Act, for example, is fraught with them (Donlan et al. 2013). In many countries, strong policies already exist to prevent extinction; yet species continue to decline. It seems unlikely that the ability to de-extinct certain species would drastically change the moral landscape around endangered species conservation. Another scenario is also worth considering: rather than acting as a perverse incentive, could de-extinction be used as a strategic policy tool to promote and trigger conservation actions? If the passenger pigeon were resurrected, would there not be a legal case for its protection and the designation of critical habitat under the Endangered Species Act? Moral hazard is no stranger to the field of biodiversity conservation.

While the risks of de-extinction are not new, the challenges are substantial. The laboratory challenges will enjoy the momentum and resources of the biomedical and agricultural sectors. Bringing de-extinction into the “wild” will be less fortunate. We are currently better at manipulating genomes than we are at rewilding landscapes. This will have to change if the benefits of de-extinction are to be fully realized. Moving from a few individuals to a functioning, viable population will probably be the limiting step—presenting a monumental challenge for conservation biologists. Species reintroductions commonly fail, particularly for captive-born individuals (Jule et al. 2008). Allee effects—demographic dynamics of small populations—are more complex than previously appreciated (Hughes 2013, Luque et al. 2013). And for many species for which de-extinction may be highly desirable, the threats that were responsible for their extinction still remain (e.g. habitat destruction and land-use change). Those remaining threats will limit the utility of de-extinction to a subset of extinct species, which calls on conservation biologists to develop a decision framework to guide efforts and priorities. Given the asymmetry in resources between inside and outside the laboratory, the "skin-out" challenges and the innovations needed to overcome them may decide the on-the-ground outcomes of de-extinction.

The de-extinction debate is part of larger discussion around the role of synthetic biology in biodiversity conservation (Redford et al. 2013). Synthetic biology and related fields are already delivering benefits to biodiversity conservation (Ben-Nun et al. 2011, Anthes 2013). The potential implications are as profound for extant species as for extinct ones (Redford et al. 2013, Thomas et al. 2013). Yet, synthetic biology has gone largely unnoticed by conservation scientists, and misinformation and subjectivity appear to be clouding the value proposition of synthetic biology to biodiversity conservation.

I suspect that de-extinction may be serving as more salt on open wounds. Biodiversity conservation is increasingly viewed as a discipline in crisis (Rosner 2013). Over the past decade, new intervention-based and human-centered strategies have been proposed and are gaining support. Some of those approaches are being viewed as incompatible with historical strategies for biodiversity conservation. At one extreme is the view that "wilderness", as we once perceived it, no longer exists and successful conservation strategies will rely heavily on management actions, and will often explicitly integrate human needs (Lalasz et al. 2011). At the other extreme is the view that such an approach runs counter to conservation biology, is fundamentally flawed, and is akin to "gardening" (Soulé 2013). With conservation biology founded on the basis of preservation, some within it are wary of approaches that are not strongly aligned with the ideas of John Muir. As this debate takes up increasingly more ink in academic journals, new insights from palaeoecology challenge our views of what is natural, economic development continues to influence almost every corner of the globe, and technology evolves at an exponential rate. Yet the majority of those in the biodiversity conservation sector seem to ignore public opinion, which is increasingly indifferent to environmental issues (Kareiva and Marvier 2012). Public and subsequently political support for biodiversity conservation is declining. Biodiversity conservation does not need silver bullets; rather, it needs strategies that garner the support and interest of average citizens. De-extinction may be one of them: half of Americans believe "scientists will bring back an extinct animal by cloning it" by 2050 (Pew Research Center 2013).

Will de-extinction revolutionize biodiversity conservation? Unlikely. But let's be honest: our current strategies are not sparking revolutions either. Rather, they are underperforming—all of them. Biodiversity conservation needs all the help and strategies it can muster. Decades ago, Stewart Brand penned an epigram on his *Whole Earth Catalog*: "We are gods and might as well get good at it"—excellent advice for conservationists in the coming decades.

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