Conservation Biology

Essay

The ethics of genetic engineering and gene drives in conservation

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Abstract: The ethical issues associated with using genetic engineering and gene drives in conservation are typically described as consisting of risk assessment and management, public engagement and acceptance, opportunity costs, risk and benefit distributions, and oversight. These are important, but the ethical concerns extend beyond them because the use of genetic engineering has the potential to significantly alter the practices, concepts, and value commitments of conservation. I sought to elucidate the broader set of ethical issues connected with a potential genetic engineering turn in conservation and provide an approach to ethical analysis of novel conservation technologies. The primary rationales offered in support of using genetic engineering and gene drives in conservation are efficiency and necessity for achieving conservation goals. The instrumentalist ethical perspective associated with these rationales involves assessing novel technologies as a means to accomplish desired ends. For powerful emerging technologies the instrumentalist perspective needs to be complemented by a form-of-life perspective frequently applied in the philosophy of technology. The form-of-life perspective involves considering how novel technologies restructure the activities into which they are introduced. When the form-of-life perspective is applied to creative genetic engineering in conservation, it brings into focus a set of ethical issues, such as those associated with power, meaning, relationships, and values, that are not captured by the instrumentalist perspective. It also illuminates why the use of gene drives in conservation is so ethically and philosophically interesting.

Keywords: conservation philosophy, ethical issues, genetic modification, responsible development, synthetic biology, technology assessment

Ética de la Ingeniería Genética y la Transmisión de Genes en la Conservación

Resumen: Los temas éticos asociados con el uso de la ingeniería genética y la transmisión de genes en la conservación están típicamente descritos como evaluación y manejo de riesgos, participación pública y aceptación, costos de oportunidad, distribuciones de riesgos y beneficios, y omisiones. Todo lo anterior es importante, pero las preocupaciones éticas se extienden más allá de los temas previos porque el uso de la ingeniería genética tiene el potencial de alterar significativamente las prácticas, conceptos y compromisos de valor de la conservación. Busqué elucidar los temas éticos conectados con un giro potencial hacia la ingeniería genética en la conservación y también proporcionar una estrategia para el análisis ético de las novedosas tecnologías para la conservación. Las razones principales ofrecidas como apoyo para el uso de la ingeniería genética y la transmisión de genes en la conservación son la eficacia y la necesidad de lograr los objetivos de conservación. La perspectiva ética instrumentalista asociada con estas razones involucra la evaluación de las tecnologías novedosas como medio para obtener los fines deseados. Para las emergentes tecnologías poderosas, la perspectiva instrumentalista necesita estar complementada con una perspectiva de forma de vida, la cual se aplica frecuentemente en la filosofía de la tecnología. La perspectiva de forma de vida involucra la consideración de cómo las tecnologías novedosas reestructuran las actividades a las cuales son introducidas. Cuando en la conservación se aplica la perspectiva de forma de vida a la ingeniería genética creativa, trae hacia el foco un conjunto de temas éticos, como aquellos asociados con el poder, el significado, las relaciones y los valores, que no captura la perspectiva instrumentalista. Esta perspectiva también ilustra sobre el por qué el uso de la transmisión de genes en la conservación es tan interesante ética y filosóficamente.

***Article impact statement**: Genetic engineering and novel technology use in conservation warrant both instrumentalist and form-of-life ethical analyses.*

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Palabras Clave: biología sintética, desarrollo responsable, filosofía de la conservación, evaluación de la tecnología, modificación genética, temas éticos

摘要: 在保护中使用基因工程和基因驱动技术存在的伦理问题通常包括风险评估和管理, 公众参与和公众接受, 机会成本、风险和利益的分配, 以及监督管理。这些问题都很重要, 但值得关注的伦理问题并不仅限于此, 因为基因工程的使用还可能大大改变保护的实践、概念和价值承诺。本文旨在阐明保护中潜在的基因工程转向有关的、更宽泛的伦理问题, 并为新的保护技术的伦理分析提供方法。支持在保护中使用基因工程和基因驱动技术的首要理由是其在实现保护目标中的有效性和必要性。而相关的工具主义伦理视角涉及对于新技术作为实现预期目标手段的评估。对于这种强大的新兴科技, 工具主义视角还需要技术哲学常用的生命形式视角作为补充, 包括思考新技术如何重构它们所参与的保护行动。在物种保护的创造性基因工程中, 应用生命形式视角可以引发对一系列伦理问题的关注, 如与权力、意义、关系和价值相关的问题, 而这些都是工具主义视角没有关注的; 这也解释了为什么保护中基因驱动技术的应用会激发伦理和哲学上的思考。**【翻译: 胡怡思; 审校: 聂永刚】**

关键词: 伦理问题, 合成生物学, 遗传修饰, 负责任的开发, 技术评估, 保护哲学

Introduction

The idea of engineering genetic changes into wild populations to pursue conservation aims is gaining proponents (e.g., Champer et al. 2016; Johnson et al. 2016; Dearden et al. 2017; Piaggio et al. 2017; Owens 2017; Rohwer 2018; Phelps et al. 2019). The genetic analysis, synthesis, and editing techniques that underlie this possibility are developing quickly (Mei et al. 2016; Knott & Doudna 2018; Grunwald et al. 2019; IUCN 2019). What is not developing nearly so fast is the capacity to analyze and evaluate the significance of adopting these powerful technologies in conservation contexts (Jasanoff & Hurlbut 2018).

Throughout this article, I use "synthetic biology" to refer to "biotechnology that combines science, technology and engineering to facilitate and accelerate the understanding, design, redesign, manufacture and/or modification of genetic materials, living organisms and biological systems" (UN CBD 2017, 2019). Genetically engineering organisms—intentionally modifying their genetic makeup—is one application of synthetic biology. Engineered gene drives (hereafter, gene drives) are a type of genetic modification that increases the probability that a genetic trait or element will be inherited with greater frequency than the usual Mendelian ratio. Gene drives increase the rate at which a genetic modification spreads through a sexually reproducing population and could enable engineering genetic changes throughout wild populations (IUCN 2019).

Researchers exploring the use of synthetic biology, genetic engineering, and gene drives in conservation typically conceive of the ethics involved as consisting of risk assessment and management, public engagement and acceptance, opportunity costs, risk and benefit distributions, and oversight (e.g., Champer et al. 2016; Bennett et al. 2017; Dearden et al. 2017; Esvelt & Gemmell 2017; Piaggio et al. 2017; Kofler et al. 2018; Phelps et al. 2019). These are important and complex issues. However, they are not exhaustive of the ethical concerns associated with the use of genetic engineering and gene drives in conservation because they have the potential to significantly restructure the practices, concepts, and normative (or value) commitments of conservation. I sought to elucidate the broader set of ethical issues connected with a potential genetic engineering turn in conservation and to provide an approach to ethical analysis of novel conservation technologies.

I considered the primary rationales offered in support of using synthetic biology, genetic engineering, and gene drives in conservation, as well as the instrumentalist ethical perspective associated with them. The instrumentalist perspective involves assessing novel technologies as means to accomplishing desired ends. I argue that for powerful emerging technologies the instrumentalist perspective often needs to be complemented by a form-of-life perspective frequently applied in the philosophy of technology. The form-of-life perspective involves considering how novel technologies restructure the activities into which they are introduced. When the form-of-life perspective is applied to creative genetic engineering in conservation it brings into focus a set of salient issues not captured by the instrumentalist perspective. It also illuminates why the use of gene drives in conservation is so ethically and philosophically interesting.

Application of both the instrumentalist and the form-of-life perspectives to novel technology use in conservation is necessary to identify, analyze, and assess their ethical dimensions.

Ethics of Technologies as Tools

There are 2 primary rationales for adopting novel ecosystem management and species conservation technologies and strategies: efficiency and necessity. The efficiency rationale is that the new technology or strategy enables conservation scientists to accomplish their aims more effectively. The necessity rationale is that unless the novel technique or technology is adopted, the conservation effort will fail. These justifications feature prominently in arguments in favor of assisted migration and rewilding, for example. They are also the core justifications offered in support of using synthetic biology, genetic engineering, and gene drives.

Proponents argue that the use of gene drives to eliminate invasive predators, pests, and disease vectors should be explored because they could be effective in places where current methods are not feasible or have not been successful (Dearden et al. 2017; Liao et al. 2017; Owens 2017; Piaggio et al. 2017). They argue that conservationists should be open to possible genetic modification of threatened tree species to protect them from introduced diseases because it could be the only way to establish resistance in a sufficient timeframe (Powell 2016; NAS 2019). They argue that synthetic biology and cloning should be used to increase the genetic diversity of species with small populations because it is necessary for genetic diversification and long-term viability (Wisely et al. 2015; Phelps et al. 2019). Each of these involves doing the sorts of things that conservation scientists already do and are commonly accepted as worthwhile—promoting resistance to introduced diseases, controlling problematic nonnative species, and increasing genetic diversity in species that have been through a population bottleneck. They simply would employ new genetic tools to accomplish them.

These efficiency and necessity rationales take a paradigmatically instrumentalist view on technology (i.e., technologies function essentially as means to ends). They are tools. This technology-as-tool view has an allied ethical outlook, which is that technologies themselves (the tools) are neither good nor bad, but neutral (Pacey 1983; Winner 1983). The ethics of technology is therefore about how they are used, who uses them (or who controls decision making about using them), and what the outcomes are. This is the ethical logic of tool use.

On this logic, the ethics of synthetic biology, genetic engineering, and gene drives in conservation is primarily about whether they can be employed responsibly, in terms of benefits and risks, opportunity costs, and decision-making processes. If the technology is effective, the risks are acceptable and manageable (and sufficiently foreseeable and properly distributed), the benefits outweigh the costs, the opportunity costs are not too high, oversight is in place, and there is adequate public consultation and support, then synthetic biology, genetic engineering, and gene drives will in some cases provide an instrumentally well-justified means to accomplishing familiar conservation ends, such as invasive species eradication and promoting disease resistance (NAS 2016, 2019; IUCN 2019).

This instrumentalist ethical discourse is important, but it is incomplete because novel technologies are sometimes not just more powerful means to established ends; sometimes their adoption changes the character of the activity.

Ethics of Technologies as Forms of Life

Philosophy of technology studies the nature of technology and the role of technological creation and use in human life. There are a variety of interrelated approaches to studying this (e.g., empirical, analytical, and phenomenological), but on all of them the technology-as-tool model is insufficient (Jonas 1973; Pacey 1983; Winner 1983; Borgmann 1984).

The technology-as-tool view is not wrong per se. An important feature of technology is that it is instrumentally useful. It is a large part of how humans get food, build homes, treat diseases, generate energy, and do just about everything else. Technology is a tool; technologies are means to ends. It does matter how they are used and who uses them. However, that technology is so essential to the human way of accomplishing things – and that all technologies are sociocultural phenomena - has further significance, which is what philosophy of technology aims to draw attention to and understand (Franssen et al. 2018).

One of the implications of the ubiquity and essentiality of technology in human life is that technologies continually reconstitute the material, social, and environmental conditions of human experience. Technologies are not merely used in human activities to pursue goals, they structure the activities. They are not merely an efficient power that enables people to accomplish their ends, they reorganize social and political power. They do not merely allow people to realize their visions for how the world should be; they alter what their visions are. In these and other ways, technologies often reshape us, even while we use them. The classic example of this is the automobile. If one thinks about cars and trucks as merely more efficient means of getting from one place to another and moving goods around in comparison to horses and wagons, then one misses all the ways in which they are socially, culturally, politically, personally, economically, and environmentally transformative (Leopold 1949; Winner 1983).

Technologies and technological systems are forms of life in the sense that as they "are being built and put to use, significant alternations in patterns of human activity and human institutions are already taking place" (Winner 1983). Novel technologies often substantially reconfigure roles, relationships, power dynamics, perspectives, and behaviors. Smart phones and social media transformed social experiences, relationships, and skills. Home appliances helped transform family dynamics and the workforce. Digital media transformed music creation, consumption, and industry. Synthetic fertilizer helped transform food systems, agriculture, and diets. Moreover, because novel technologies often restructure human activities in personally, socially, and politically significant ways, technologies are not merely neutral tools whose goodness and badness is solely in their use and their user. Technologies are themselves often political, value laden, and ethically designed. Adopting them often comes with personal, institutional, environmental, and societal implications (Jonas 1973; Winner 1983; Borgmann 1984; Franssen et al. 2018).

Form-of-life considerations do not always pull against new technology adoption. The way that digital music democratized the music industry and empowered consumers is arguably overall good. The way that home appliances contributed to increasing women's participation in the workplace and occupational opportunities outside the home is definitely good. However, responsible development and adoption of new technologies requires considering whether and how they are likely to reshape the activities and systems into which they are introduced. The form-of-life perspective brings a host of ethical considerations into focus that are often obscured by the technology-as-tool model, including those related to such things as power, meaning, relationships, perspectives, and value (Leopold 1949; Winner 1983; Borgmann 1984; Sandler 2014).

Ethical analysis of powerful emerging technologies is incomplete unless they are considered as both tools and as potentially novel forms of life. This applies to the ethics of synthetic biology, genetic engineering, and gene drives in conservation. These technologies are particularly interesting from a conservation ethics and philosophy perspective because of their potential to reconstitute aspects of conservation practice in ways that have implications for the values, meanings, significance, perspectives, and concept of conservation.

Genetic Engineering and Gene Drives as a Conservation Form of Life

To help see the potential significance of a genetic engineering turn in conservation, consider the concerns that have been raised about genetic selection and modification in human reproduction. Many bioethicists are wary of the increased power that genetic analysis, selection, and modification technologies can afford parents with respect to choosing their children's genetic characteristics. Collectively, the technologies have the potential to restructure reproductive practices and have implications for how parents approach reproduction, their expectations and attitudes about parenting, the child–parent relationship, and even social attitudes regarding ability and disability (e.g. President's Council on Bioethics 2003; Sandel 2009; De Melo-Martin 2014). These worries arise from the way in which the technologies expand parental agency and encourage parents to confront new questions: How should children be at the genetic level? How do I want my child to be?

A genetic engineering turn in conservation—and some uses of gene drives in particular—may generate something analogous. Many applications mooted for synthetic biology and gene drives are intended to undo problematic human impacts by modifying a threat to the conservation target, such as eliminating invasive predators and disease vectors (Piaggio et al. 2017; Liao et al. 2017; Phelps et al. 2019). However, other applications involve modifying the conservation target, such as genetically engineering the American chestnut (*Castanea dentata*) (Powell 2016) or assisted evolution of corals (van Oppen et al. 2015; Cornwall 2019). In these cases, rather than addressing the ecological or social conditions of the target populations, the interventions focus on the biology of the organisms themselves. This involves a new way of conceptualizing a conservation problem. It is not only that habitat has been degraded, but that the biology of the organism is not attuned (or adapted) to its ecological environment.

When genetic engineering and gene drives are considered as a way to modify the characteristics of the conservation target, they appear to offer solutions to what seem intractable conservation problems. They also offer a new model for conservation. Conservation strategies have standardly focused on restricting human activities in a space, improving the ecological conditions for at risk species, and building back populations through breeding and reintroduction. Now, in addition to focusing on the conditions around the conservation target, gene drives make it possible to ask: How can one alter the species so that it is better suited to these conditions? How do these organisms need to be to survive in a human-dominated world? The fix of the ecological problem can be, at least in part, at the level of the species' genome. This is a new question for species conservation (though not for animal and plant engineering in agriculture, where the primary intent is to modify them for human ends and for suitability within human production systems).

The adoption of synthetic biology and gene drives to creatively engineer species at risk of extinction (a switch in focus from ecological conditions to genomic suitability) may create a novel conservation form of life. It involves a new conservation perspective and model. In general, the use of synthetic biology in conservation involves a more gene-oriented analysis of and response to environmental problems. But gene drives are the enabler of this kind of conservation because they allow engineering solutions to reach into wild organisms. This invites thinking about how to adapt the conservation target to humans and to an anthropogenic world, rather than focusing on adapting resource use, lifestyles, and production systems to accommodate them. For this reason, gene drives appear qualitatively different from a form-of-life perspective than some other conservation applications of synthetic biology, such as cloning or deextinction (IUCN 2016; Greely 2017; Sandler 2019). Moreover, engineering wild populations so they are better adapted to anthropogenic changes raises ethical and conservation philosophy issues not captured by the predominant instrumentalist perspective.

Extent to which genetically engineering species is conservation

Populations and ecological systems are dynamic, so conservation properly conceived is not about resisting change or maintaining things as they are. Instead, conservation is associated with mitigating anthropogenic loss, limiting the rate of anthropogenic change, and maintaining human-independent evolutionary and ecological processes (Callicott 2001). Genetically engineering at risk populations involves intentionally creating anthropogenic change. It thereby pushes at the boundaries of what can be considered conservation.

Similar issues arise regarding the recovery of ecologically degraded sites. Proponents of ecological restoration are grappling with the reality that historical reference conditions for assisted recoveries are less likely to be reliable guides for future ecological integrity under conditions of high rate and high magnitude anthropogenic change (e.g., Harris et al. 2006; Hobbs et al. 2009; Higgs et al. 2014). The issue is how to modify restoration concepts, philosophy, and practices in response (e.g., Sandler 2012*b*; Thompson & Bendik-Keymer 2012; Rohwer & Marris 2016). Should restoration involve greater forward-looking design and creativity? Is restoration no longer the appropriate conceptual frame for assisted recovery in these contexts? Or, should recoveries involve less human design and control, and provide more space for ecological systems to reconfigure on their own, thereby prioritizing reestablishing human-independent processes and products?

Synthetic biology and gene drives raise analogous questions with respect to conservation. How genetically creative, forward-looking, and engineering oriented can an intervention be and still be considered conservation? At what point does the conceptual frame no longer apply? Is it necessary to reconceptualize conservation away from prevention of anthropogenic loss and protection of the naturally evolved biological and ecological world? Or, should the concept be maintained and greater emphasis placed on enabling conditions for human-independent evolutionary processes, rather than on engineering human-directed or human-induced adaptation?

Extent to which genetic engineering conserves the value of the species, ecosystems, and ecological processes

A long-standing value commitment associated with conservation is that human-independent ecological and evolutionary processes, and the products of them, have value in themselves or for what they are. There are different views on the basis of this value, such as their spontaneity and creativity (Soule 1985; Rolston 1986), connection to deep time (Preston 2018), wildness and otherness from nature (Cafaro 2001), and encoding of the natural history of the planet (Soule 1985; Rolston 1986). If human independence is valuable in species and ecological systems, then creatively engineering them in ways that increase rather than undo human design, control, and impacts would seem to undermine that value. This is why conservation practices that aim to maintain human-independent ecological and evolutionary relationships and processes (i.e., that remove human impacts and maintain species populations and assemblages in situ) are generally preferable to those that do not (e.g. US 1973; UN 1992; Rolston 1995).

Because novel conservation interventions interact with environmental values in complex ways, it is important to conduct detailed value analyses of them (Sandler 2010; Palmer 2016). Some forms of intervention are more value-preserving than others. To the extent that certain types of values (e.g., cultural, natural, or aesthetic) are based in part on historical and relational properties, an engineering approach to conservation could undermine them. For example, it might be culturally inappropriate to genetically engineer disease resistance into a tree species because of the way it is valued or the role that it plays in a people's practices and narratives (Sandler 2012*a*; NAS 2019).

Effects of genetic engineering on conceptions of and favored approaches to conservation problems

A concern regarding the genetic turn in medicine is that it can invite pathologizing people's genetics and foster a more gene-focused, rather than holistic approach to health problems. This can in turn mislocate the source of health problems and misprioritize types of solutions to them. For example, when researchers began to take a genomics approach to the problem of elevated asthma rates for children in Harlem and Washington Heights in New York City, community activists pushed back against the idea that the problem was with their children's genes. They advocated instead for focusing on the social and environmental factors that were the predominant cause, such as the high concentration of diesel bus depots in their neighborhoods (Di Chiro 2007).

A potential concern regarding a genomic shift in perspective on conservation problems is that it could invite a sort of pathologizing of threatened species. But the problem is that human activities have made the world less hospitable for them. Corals, amphibians, and chestnuts do not have defective genomes. Even if it is possible to use gene drives to engineer wild population so that they are better fitted or adapted to obtaining ecological, social, and economic conditions, this would not address the underlying causes of species declines or reestablish the ecological relationships that are the basis for many types of species value.

Using synthetic biology to engineer adaptation to anthropogenic change exhibits features often associated with a moral hazard or problematic technofix. That is, it could be seen or presented as a way to manage the detrimental effects of degradative practices and activities without addressing the underlying causes of the problems and enabling them to continue under the belief that the effects can be handled technologically. The promised benefits of the engineering solution may also be used to close off close critical evaluation and consideration of the full range of alternatives, even when the claimed benefits are quite speculative (Nordmann 2007; Preston 2020).

Impact of genetic engineering in conservation on the human–nature relationship

An objection likely to be made against the use of synthetic biology and gene drives in conservation is that they are hubristic. Concerns about hubris often arise in the context of both intentional environmental modification and genetic engineering, for example, geoengineering to address climate change (Hamilton 2014), ecosystem engineering in restoration (Katz 2000), genetic modification in agriculture (Comstock 2000), and human germline engineering (Lander et al. 2019; Yaeger 2019). The central component of hubris-oriented concerns is that those who develop, advocate for, or employ the technology overestimate their (or other's) ability to predict the full range of outcomes of the intervention and address problematic unintended effects. This is particularly so when the technologies modify complex, dynamic, and incompletely understood biological and ecological systems.

The logic of hubris concerns can be ambiguous. In one sense, they are instrumentalist, risk-oriented concerns about possible negative environmental and human health outcomes resulting from overconfident or hasty implementation. In another sense, they are form-of-life concerns about proper attitudes and perspectives to have on the human relationship to the biological world, as well as on what roles, powers, and responsibilities it is appropriate to assume. For example, the hubris concerns regarding human germline modification are about both the health and well-being of the children and the attitudes and perspectives of the researchers and clinicians regarding the power to engineer human genetic change.

Analogous issues arise regarding the power to assist or guide evolution in other species (Nuffield Council on Bioethics 2016). Some are about the attitudes and outlooks of researchers regarding their abilities. For example, does the use of gene drives to modify wild populations involve an overestimation of scientists' capacity to anticipate outcomes and address unexpected problems, particularly given evolutionary processes and rapidly shifting climatic and ecological conditions? Other issues are about the appropriate perspective to take regarding the power to modify at the genomic level, quite apart from environment, health, and safety concerns. For example, does the use of gene drives to modify the conservation target express or promote the attitude that humans stand above or apart from nature in a way that licenses problematic human domination or control of the natural world (Preston 2018)? Does it involve a lack of appreciation of or respect for human-independent processes (Crist 2019)? Alternatively, is a willingness to employ the power to remake the biological world a necessary part of embracing the Anthropocene and taking responsibility for the environmental problems humanity has created (Ackerman 2012; Cornwall 2019)? Or is a new conception of the relationship needed, perhaps one more akin to gardening than to either protecting or controlling (Marris 2011; Kaebnick 2017)?

Whether and how to use the power to creatively engineer species requires considering the power's potential to restructure humanity's relationship with the natural world. Adopting it involves taking up roles, responsibilities, attitudes, and outlooks on the human–nature relationship that could carry beyond conservation contexts.

Extent to which the use of synthetic biology and genetic engineering restructures the practice of conservation

As the genomic turn in medicine illustrates, technological restructuring is material, in addition to being perspectival, attitudinal, evaluative, and conceptual. The already-underway genomic turn in conservation involves new infrastructure, expertise, projects, collaborations, and training programs. As the use of synthetic biology expands, and if genetic engineering approaches are adopted, it is likely to draw people into the field with different backgrounds and outlooks. This could result in shifts in the profession, including people's motivations for entering it and their perspectives on it, as well who is empowered and disempowered within it. This, in turn, could carry through to such things as the sorts of projects taken up, where resources are allocated, and the types of solutions that are pursued. It would also change what conservation scientists do (i.e., the day-to-day practice of researchers and practitioners) (Kuiken 2018; Braverman 2018).

Two Perspectives for Analyzing Novel Conservation Technologies

Determining whether a novel technology or technological system is desirable—ethically, practically, professionally, socially, and ecologically—requires employing sufficiently robust analytical and evaluative frameworks, perspectives, and concepts. Discussion of the use of synthetic biology in conservation has been dominated by an instrumentalist perspective on technology. The ethical discussion has therefore focused on risks and benefits, opportunity costs, decision-making processes, and public engagement and acceptance. These are all important. However, there is another perspective on technology—technology as a form of life—that is also crucial to analyzing its social and ethical dimensions. Synthetic biology, particularly when used to intentionally engineer genetic change in wild populations, could constitute a new form of conservation practice. It thereby raises issues connected to power, meaning, values, and worldviews.

My aim here is not to oppose synthetic biology or creative gene drive applications in conservation. It is to elucidate what is novel about them and to identify the sorts of ethical and conservation philosophy issues that they generate when considered as a conservation form of life. The power to drive genetic change through wild populations is significantly different from other conservation approaches. It enables remodeling the biological world at the genomic level in accordance with human beliefs about how organisms ought or need to be. This qualitative difference in the range of human agency warrants attentiveness and carefulness, just as do the risks and uncertainties involved. Comprehensive ethical analyses that include both instrumentalist and form-of-life considerations have been largely absent from the conservation genetic engineering discourse, in general and regarding particular projects. This should perhaps give pause to those who hope to deploy genetic engineering and gene drives in an ethically informed and responsible way.

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Literature Cited

Ackerman D. 2012. The human age: the world shaped by us. Norton, New York.

Bennett J, Maloney R, Steeves T, Brazill-Boast J, Possingham H, Seddon P. 2017. Spending limited resources on de-extinction could lead to net biodiversity loss. Nature Ecology and Evolution **1** https://doi.org/10.1038/s41559-016-0053.

Borgman A. 1984. Technology and the character of contemporary life. University of Chicago Press, Chicago.

Braverman I. 2018. Gene drives, nature, governance: an ethnographic perspective. Pages 55–73 in Braverman I, editor. Gene editing, law, and the environment. Routledge, New York.

Cafaro P. 2001. Thoreau, Leopold, and Carson: toward an environmental virtue ethics. Environmental Ethics **23:**1–17.

Callicott B. 2001. The land ethic. Pages 204–217 in Jamieson D, editor. A companion to environmental philosophy. Blackwell, Malden, Massachusetts.

Champer J, Buchman A, Akbari, O. 2016. Cheating evolution: engineering gene drives to manipulate the fate of wild populations. Nature Reviews Genetics **17:**146–159.

Comstock G. 2000. Vexing nature? On the ethical case against agricultural biotechnology. Kluwer, Boston.

Cornwall W. 2019. The reef builders. Science **363** https://doi.org/10.1126/science.363.6433.1264.

Crist E. 2019. Abundant earth. University of Chicago Press, Chicago.

Dearden P, Gemmell N, Mercier O, Lester P, Scott M, Newcomb R, Buckley T, Jacobs J, Goldson S, Penman D. 2017. The potential for the use of gene drives for pest control in New Zealand: a perspective. Journal of the Royal Society of New Zealand **48:**225–244.

De Melo-Martin I. 2014. The ethics of sex selection. Pages 90–103 in Sandler R, editor. Ethics and emerging technologies. Palgrave Macmillan, Basingstoke, United Kingdom.

Di Chiro G. 2007. Indigenous peoples and biocolonialism: defining the "science of environmental justice" in the century of the gene. Pages 251–284 in Sandler R, Pezzullo P, editors. Environmental justice and environmentalism: the social justice challenge to the environmental movement. MIT Press, Cambridge, Massachusetts.

Esvelt K, Gemmell N. 2017. Conservation demands safe gene drive. PLOS Biology **15** (e2003850). https://doi.org/10.1371/journal.pbio.2003850.

Franssen M, Lokhorst G-J, van de Poel I. 2018. Philosophy of technology. Stanford encyclopedia of philosophy. Center for the Study of Language and Information, Stanford University, Stanford, California. Available from https://plato.stanford.edu/entries/technology/ (accessed September 2019).

Greely H. 2017. Is de-extinction special? The Hasting Center Report, Special Report **47:**S30–S36.

Grunwald H, Gantz V, Poplawski G, Xu X-R, Bier E, Cooper K. 2019. Super-mendelian inheritance mediated by CRISPR-Cas9 in the female mouse germline. Nature **566:**105–109.

Hamilton C. 2014. Ethical anxieties about geoengineering. Pages 439–455 in Sandler R., editor. Ethics and emerging technologies. Palgrave Macmillan, Basingstoke, United Kingdom.

Harris J, Hobbs R, Higgs E, Aronson J. 2006. Ecological restoration and global climate change. Restoration Ecology **17:**170–176.

Higgs E, Falk D, Guerrini A, Hall M, Harris J, Hobbs R, Jackson S, Rhemtulla J, Throop W. 2014. The changing role of history in restoration ecology. Frontiers in Ecology and the Environment **12:**499–506.

Hobbs R, Higgs E, Harris J. 2009. Novel ecosystems: implications for conservation and restoration. Trends in Ecology & Evolution **24:**599–605.

International Union for the Conservation of Nature (IUCN). 2016. IUCN SSC guiding principles on creating proxies for extinct species for conservation benefit. Version 1.0. IUNC Species Survival Commission, Gland, Switzerland. Available from https://portals.iucn.org/library/sites/library/files/documents/Rep-2016-009.pdf (accessed September 2019).

International Union for the Conservation of Nature (IUCN). 2019. Genetic frontiers for conservation: an assessment of synthetic biology and biodiversity conservation. Synthesis and key messages. IUCN, Gland, Switzerland. Available from https://portals.iucn.org/library/node/48408 (accessed September 2019).

Jasanoff S, Hurlbut S. 2018. A global observatory for gene editing. Nature **555:**435.

Johnson J, Altwegg R, Evans D, Ewen J, Gordon I, Pettorelli N, Young J. 2016. Is there a future for genome-editing technologies in conservation? Animal Conservation **19:**97–101.

Jonas H. 1973. Technology and responsibility: reflections on the new tasks of ethics. Social Research **40:**31–54.

Kaebnick G. 2017. The spectacular garden: Where might de-extinction lead? The Hasting Center Report, Special Report **47:**S60–S64.

Katz E. 2000. The big lie. Pages 83–93 in Throop W, editor. Environmental restoration. Humanity Books, Amherst, New York.

Knott G, Doudna J. 2018. CRISPR-Cas guides the future of genetic engineering. Science **361:**866–869.

Kofler N, et al. 2018. Editing nature: local roots of global governance. Science **362:**527–529.

Kuiken T. 2018. Vigilante environmentalism: Are gene drives changing how we value and govern ecosystems? Pages 95–111 in Braverman I, editor. Gene editing, law, and the environment. Routledge, New York.

Lander E, et al. 2019. Adopt a moratorium on heritable genome editing. Nature **567:**165–168.

Leopold A. 1949. A sand county almanac. Oxford University Press, Oxford, United Kingdom.

Liao W, Atkinson C, LaPointe D, Samuel M. 2017. Mitigating future avian malaria threats to Hawaiian forest birds from climate change. PLOS ONE **12** (e0168880). https://doi.org/10.1371/journal.pone.0168880.

Marris E. 2011. The rambunctious garden: saving nature in a post-wild world. Bloomsbury, New York.

Mei Y, Yang Y, Chen H, Sun Z, Ju X-D. 2016. Recent progress in CRISPR/Cas9 technology. Journal of Genetics and Genomics **43:** 63–75.

National Academies of Science, Engineering, and Medicine (NAS). 2019. Forest health and biotechnologies: possibilities and considerations. The National Academies Press, Washington, D.C. Available from https://doi.org/10/17226/25221 (accessed September 2019).

National Academies of Science, Engineering, and Medicine (NAS). 2016. Gene drives on the horizon: advancing science, navigating uncertainty, and aligning research with public values. The National Academies Press, Washington, D.C.

Nordmann A. 2007. If and then: a critique of speculative nanoethics. NanoEthics **1:**31–46.

Nuffield Council on Bioethics. 2016. Genome editing: an ethical review. Nuffield Council on Bioethics, London. Available from http://nuffieldbioethics.org/project/genome-editing/ethical-review-published-september-2016 (accessed September 2019).

Owens B. 2017. Behind New Zealand's wild plan to purge all pests. Nature **541:**148–150.

Pacey A. 1983. The culture of technology. MIT Press, Cambridge, Massachusetts.

Palmer C. 2016. Saving species but losing wildness: should we genetically adapt wild animal species to help them respond to climate change. Midwest Studies in Philosophy **40** https://doi.org/10.1111/misp.12058.

Phelps M, Seeb L, Seeb J. 2019. Transforming ecology and conservation biology through genome editing. Conservation Biology https://doi.org/10.1111/cobi.13292.

Piaggio AJ, et al. 2017. Is it time for synthetic biodiversity conservation? Trends in Ecology & Evolution **32:**97–107.

Powell W. 2016. New genetically engineered American chestnut will help to restore the decimated, iconic tree. The Conversation https://theconversation.com/new-genetically-engineered-american-chestnut-will-help-restore-the-decimated-iconic-tree-52191.

President's Council on Bioethics. 2003. Beyond therapy: biotechnology and the pursuit of happiness. President's Council on Bioethics, Washington, D.C.

Preston C. 2018. The synthetic age. MIT Press, Cambridge, Massachusetts.

Preston C. 2020. Genome tinkering and the rewriting of the evolutionary story. In press in Bovenkerk B, editor. Animals in our midst. Springer, The Netherlands.

Rohwer Y. 2018. A duty to cognitively enhance animals. Environmental Values **27:**137–158.

Rohwer Y, Marris E. 2016. Renaming restoration. Restoration Ecology **24:**674–679.

Rolston H. 1986. Philosophy gone wild: essays in environmental ethics. Prometheus, Amherst, New York.

Rolston H. 1995. Duties to endangered species. Encyclopedia of Environmental Biology **1:**517–528.

Sandel M. 2009. The case against perfection. Belknap Press, Cambridge, Massachusetts.

Sandler R. 2010. The value of species and the ethical foundations of assisted colonization. Conservation Biology **24:**424–431.

Sandler R. 2012*a*. The ethics of species. Cambridge University Press, Cambridge, United Kingdom.

Sandler R. 2012*b*. Global warming and virtues of ecological restoration. Pages 63–79 in Bendik-Keymer J, Thompson A, editors. The virtues of the future: climate change and the challenge of restoring humanity. MIT Press, Cambridge, Massachusetts.

Sandler R. 2014. Technology and ethics. Pages 1–23 in Sandler R, editor. Ethics and emerging technologies. Palgrave Macmillan, Basingstoke, United Kingdom.

Sandler R. 2019. Should we engineer species in order to save them? Environmental Ethics: in press.

Soule M. 1985. What is conservation biology? BioScience **35:**727–734.

Thompson A, Bendik-Keymer J, editors. 2012. The virtues of the future: climate change and the challenge of restoring humanity. MIT Press, Cambridge, Massachusetts.

United Nations (UN). 1992. Convention on biological diversity. UN, New York. Available from https://www.cbd.int/convention/text/default.shtml (accessed September 2019).

United Nations Convention on Biological Diversity (UN CBD). 2017. Decision adopted by the conference of the parties to the convention on biological diversity XIII/17 Synthetic biology. CBD, Montreal. Available from https://bch.cbd.int/synbio/ (accessed September 2019).

United Nations Convention on Biological Diversity (UN CBD). 2019. Report of the ad hoc technical expert group on synthetic biology. CBD, Montreal. Available from https://www.cbd.int/doc/c/b2bb/cf58/b09729bb00be6abf72325a1a/synbio-ahteg-2019-01-03-en.pdf (accessed September 2019).

United States Congress (US). 1973. Endangered species act of 1973, 16 USC 1531–1544.

van Oppen M, Oliver J, Putnam H, Gates R. 2015. Building coral reef resilience through assisted evolution. Proceedings of the National Academy of Sciences **112:**2307–2313.

Winner L. 1983. Technologies as forms of life. Pages 249–263 in Cohen R, Wartofsky M, editors. Epistemology, methodology and the social sciences. Kluwer Academic Publishers, Boston.

Wisely S, Ryder O, Santymire R, Engelhardt J, Novak B. 2015. A road map for 21st century genetic restoration: gene pool enrichment of the black-footed ferret. Journal of Heredity **106:**581–592.

Yaeger A. 2019. Scientists push for a moratorium on human germline editing. New Scientist, 13 March 13. Available from https://www.the-scientist.com/news-opinion/scientists-push-for-a-moratorium-on-human-germline-editing-65593 (accessed September 2019).