Synthetic Biology and the Goals of Conservation

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Word Count: 8316 without References. 10175 with References.

Abstract

The introduction of new genetic material into wild populations, using novel biotechnology, has the potential to fortify populations against existential threats, and, controversially, create wild genetically modified populations. I discuss and problematize, in light of genetic intervention, what I consider the three core goals of conservation: biodiversity, ecosystem services, and wilderness. This uneasy relationship, however, does not forgo the use of such interventions. Instead, it highlights the need for serious intellectual work to be done for us to reconsider our ethical duties to nature at times of global environmental and technological change.

Keywords: Synthetic Biology; Wilderness; Biodiversity; Ecosystem Services; Conservation.

1. Introduction

The Earth is facing multiple environmental crises. Sometimes referred to as the sixth major extinction event, worldwide, the number of wild organisms is rapidly diminishing (Ceballos et al. 2010). As population numbers drop, the extant genetic variation in wild populations is disappearing. This leads to inbreeding, which can contribute to extinction (Frankham 1998). The loss of variation in a population creates further risks. The lack of genetic, morphological, and behavioural variation can make these populations vulnerable to human-induced environmental change. Significant human-driven environmental changes include habitat loss, invasive species, exposure to novel pathogens, and climate change. Larger populations with more genetic variation (and thus more adaptive potential) are better equipped to respond to these stressors, while smaller populations will be highly susceptible.

One way to protect wild populations and allow them to respond to these new stressors is to cultivate phenotypic features that will allow them to avoid extinction. Current conservation programs look to subject a focal population to ‘assisted evolution’. These are selective breeding programs that identify biotic traits in a population that will allow it to survive, and then selectively breed these traits into the wider population of that species. For example: in Australia, there is the Quoll assisted evolution project. The Northern Quoll (*Dasyurus hallucatus*), a marsupial predator, is threatened with extinction by the spread of Cane toads (Braithwaite & Griffiths 1994). Quoll populations have dropped by 75% throughout Australia due to invasive Cane toads poisoning and killing them (Reese 2018). Researchers discovered that some genetic markers in the Quoll population correspond to Cane toad avoidance behaviour in a quoll population that had been heavily exposed to Cane toads (Jolly et al.

2018; Kelly & Phillips 2019). They have since attempted to breed this trait into naïve populations that have not been yet exposed to Cane toads.

Assisted evolution requires standing genetic variation in the species of interest. If there are no genetically-influenced traits that can be bred through the target population, then this method cannot be effectively utilised. A lack of genetic variation in a species is made more likely by small population sizes. Further, selective breeding is inefficient. Recessive or complex traits will require many generations of breeding for the traits to breed true in the wild population and it will take considerable time to isolate these advantageous features. Selective breeding can itself lead to inbreeding as variation in non-associated traits is lost. The individuals that do not carry the selected trait, say Cane toad avoidance in quolls, could have important features which could be lost in the selective breeding process. This is particularly problematic when the species has a small population size and removing multiple individuals from their natural habitat endangers that species further. Finally, selective breeding takes many hours of manual work, driving up the costs of these programs and making them unfeasible in many cases.

These drawbacks make genetically engineering wild populations a tempting option. New DNA editing tools (e.g. CRISPR) allow for the efficient alteration of species' germlines, and scientists are considering using this technology to achieve conservation aims (Church & Regis 2014; Piaggio et al. 2017; Redford & Adams 2021). The efficiency of introducing new variation, and the targeted nature of these alterations, make the process more precise and avoid many of the drawbacks of selective breeding. Projects like the insertion of genes to protect the American Chestnut from Chestnut blight, which was accidentally introduced from Asia, have demonstrated positive effects on the target species with few negative effects (Powell et al. 2019). Other projects, exemplified by the de-extinction research currently underway to create a Thylacine ecotype to be released back into Tasmania, represent radical interventions where numerous changes are being made to the genome. What is shared between these projects is the use of biotechnology to restore or preserve ecosystems through preserving or reintroducing species or ecotypes. Turner (2022) refers to this as Biotechnology Assisted Restoration (BAR).

A major BAR project underway is the attempt to protect coral against climate change. Coral is facing mass die-offs along coastlines due to rising temperatures. Increased temperature leads to coral bleaching, which if sustained will kill the coral. Even if the global temperature increase was maintained at the extremely optimistic projection of 1.5℃, large sections of the earth's coral reefs and their associated habitat will be destroyed. This has led multiple groups of researchers to propose that synthetic biology should be employed to fortify coral reefs against climate change (Antony et al. 2017; Novak et al. 2020). Recently, researchers have aimed to introduce genes for heat shock proteins that will allow coral species to respond to temperature increases (Cleves et al. 2020). This has become an appealing program, with signs of significant public support. A survey of over 1000 members of the public showed that 55% had a positive response to the proposal (Hobman et al. 2022). Given this support and the clear advantages of using synthetic biology, it looks very likely that the genetic modification of wild populations will become a significant tool in conservation in the future.

Given the diversity of projects, there can be many different risks to gauge, both moral and practical. There are strong objections to the use of synthetic biology, both generally and specifically within the context of conservation. Conservation science requires ethical decision-making frameworks for evaluating when radical interventions on the germline DNA of wild species are justified. I will provide reasons why the use of synthetic biology is troubling within conservation science, as compared with its use in medicine and commercial production. I argue that the core difficulty of conceptualizing how synthetic biology should aid conservation science is that it challenges and disrupts the standardly assumed goals of conservation. This is not to say that synthetic biology should not be used, but instead, that the challenges it poses force humanity to deeply consider the values that define the aims of biological conservation in both the short and the long term.

2. Ethical frameworks and Conservation Goals

Three values dominate western conceptions of conservation science. These are the preservation of wilderness, the preservation of biodiversity, and the maintenance of ecosystem services. This is not meant to be exclusive or exclusionary of other conservation practices. Many people in the world, likely the majority of humanity, have a conception of conservation tied to religious or cultural practices. These could be preserving God’s dominion or forms of Animism, where natural features are agents with self-interest who deserve moral consideration. These moral belief systems can be involved with scientific conservation planning and be incorporated into conservation practice (e.g. Blicharska & Mikusiński 2014). Equally, I will not address at length important environmental concepts like intrinsic value, which can connect to the values I discuss, particularly wilderness (McShane 2007). A range of intellectual and social traditions towards the environment are important but, in this paper, I am prioritising an enquiry into how the science of conservation and park planning conceives or has conceived of the goals of conservation. I focus on these three conservation goals, addressing each in turn, and describe how the use of synthetic biology fits uneasily within these ethical frameworks.

3. Wilderness

Wilderness is a concept that emerged from a cultural practice rather than any centralised set of decision-makers, which makes the concepts deployment varied and difficult to delimitate. The word itself, ‘wild’, comes from the same root as ‘willed’, indicating something that is under its own power and intention (Nash 1967). The wilderness concept has changed over time, but it retains this core idea of an area under its own power rather than human governance. This concept took on deep cultural significance during the romantic period, where it was contrasted with the increasingly industrialised society that was emerging. While the self-governed areas were previously viewed as a threat to humans, they were later considered places of value where a person could experience “the sublime”, or areas that inspired combinations of awe, fear, and majesty (Burke 1958 [1757], Kant 2003 [1764]). It was in such spaces that individuals could cultivate their character and find God. The idea of wilderness is deeply embedded in western intellectual history and has motivated preserving areas of aesthetic and biological significance throughout the Western world. Its proponents, e.g. John Muir, argued that land should be kept ‘wild’, motivating the creation of the first national park in the United States of America; Australia shortly followed this lead. These parks were designed to exclude people and administrators did this with good effect and ill, removing the possibility of commercial development and exploitation, but also indigenous peoples who had been the inhabitants to horrific effect.

Wilderness's legacy has been complex. Serious criticisms have been raised against it. These objections include that the concepts ‘Wilderness’ and ‘natural’ are conceptually incoherent as they incorrectly presume a divide between humanity and nature (Ereshefsky 2007). Further, there are strong objections to its political use. It has been used against indigenous peoples, who suffered genocide and removal from their land under the justification of creating wilderness areas (Cronon 1996). But despite this history, it was and remains a significant concept in conservation. It is part of the USA's legislation (Wilderness Act 1964), and it features as a core concern in the public despite variation in how it is interpreted (Cordell et al. 2003; Zoderer et al. 2020), and many still consider it (or similar terms like 'nature') as the primary goal of conservation (Maier 2012; Katz 2022). Many authors have looked to separate the horrific practices that have been done in the name of wilderness from the concept as a goal of conservation (see Petersen & Hultgren 2020 for references). This is due to its role as the primary justification for not allowing land to be economically exploited or developed within Western countries. It has been the primary intellectual lever that has moved the western world toward conservation and was, until the 1980s, a central goal of conservation practice. Given its historical use and continuing role in conservation, it is crucial to consider how new conservation techniques and practices sit within a wilderness conservation framework.

Wilderness conservation, while heavily debated, is intuitive to many who have engaged in conservation practice. As Minteer & Collins (2014) put it, wilderness conservation is based on the following tenants: "1) wild or "pristine" landscapes are the bearers of ethical value and the focal points of advocacy and policy, 2) technological interference in nature should be minimized, and 3) historical integrity is the primary conservation and restoration target." (Pg. 458). Even those who critique wilderness conservation admit that there is some value in this perspective with William Cronon stating (1996: 86) "I also think it no less crucial for us to recognize and honour nonhuman nature as a world we did not create, a world with its own independent, nonhuman reasons for being as it is. The autonomy of nonhuman nature seems to me an indispensable corrective to human arrogance."

The above description of wilderness crystalises the primary difficulty of squaring the use of synthetic biology in conservation: it directly rejects or antagonises tenets 1 and 2. Synthetic biology is the cutting edge of technological innovation and would interfere with nature to produce environmental outcomes that are otherwise impossible or unlikely to be reached. This differs from traditional restoration projects where the character of an ecosystem could be possible or has previously existed, even if these ecosystem features are much less likely to exist without human action. For example, hypothetically one could engineer nitrogen fixation to a microbe symbiotic with a major plant species, such as Spinifex, in a desert ecosystem (which is poor in nitrogen). This would completely change the resource cycle in desert ecosystems and allow for an ecosystem composition unprecedented in the historical records.

This makes synthetic biology a much more radical affront to ‘wilderness’ than traditional restoration, which itself is at times rejected by wilderness proponents because it damages nature. A famous set of arguments introduced by Robert Elliot (1982), developed by Eric Katz (1992), and supported by later environmental philosophers (Siipi 2014), suggests that biological restoration, be it ecological or genomic, degrades or destroys the value of natural systems. These arguments rely on thought experiments or the metaphysics of function to propose that restored biological systems are not of equal value to biological systems which have not experienced human intervention.

These philosophers argue that natural systems are those which are not designed by human intention and that these systems have a unique value. For areas to have a unique conservation value they, therefore, require a particular etiology, one which is autonomous, self-directed, and without human intention. Elliot (1982) supports this claim through the intuition pump of art and art forgeries. Artworks require a direct causal history with their designer to retain their value. While forgeries might be as aesthetically beautiful or striking as originals, they lack the relevant causal history to retain their value. Equally, he argues, the environment has a similar aesthetic and intrinsic value. In the case of nature, rather than an intentional designer its structure is mindlessly self-designed. Katz (1992) focuses on this metaphysics of design to argue natural systems are those which are without function, and this imbues them with *authenticity*. When humans restore ecosystems, he argues, they make biotic systems artefacts rather than natural, removing the distinct value of authenticity. He is a strong eliminativist of natural function arguing that without an intentional designer there is no function present in nature.

These arguments have already been applied to synthetic biology in the context of the de-extinction debate (Siipi 2014, Minter 2015, Turner 2014, Campbell 2016, Campbell 2017, Lean 2020). Exploring the relationship between de-extinction and synthetic biology can therefore help us understand how synthetic biology-based interventions can support or hinder wilderness preservation. By contrasting the two, I suggest that conflict between these types of interventions and wilderness as a value should be considered as a matter of degree, rather than a binary where intervention necessarily leads to wilderness loss. De-extinction represents a series of different technologies to restore biological forms lost through extinction (Sherkow & Greely 2013). It is, however, only with the advent of synthetic biology that de-extinction has reached prominence and been taken seriously as a viable option for restoring biotic variation lost to extinction. De-extinction will not restore species but could restore large sections of genomes lost through extinction through the introduction of these coded genomes into extant species.

An important difference between de-extinction and synthetic biology in conservation is how related the DNA ‘donor’ species is to the recipient. De-extinction involves introducing the genetic variation found in an extinct species or sub-species into one of its closely related living relatives. An example is the proposed introduction of Mammoth DNA into Asian Elephants (Sharpiro 2015). Synthetic biology allows for the introduction of genes from any taxa into another taxon (this is not to say the resulting combination of genes will create a phenotypic effect or a viable individual). This difference could be considered significant. Related species share more of their genomes and ancestral forms of the recipient species may have gone through periods with the ‘donor’ DNA sequence. Given this, the gene introduced would be less foreign and ‘unnatural’ in the case of de-extinction, given these genes could have been in this species or may have been in a distant ancestor. In contrast introductions of genes from phylogenetically distant species may be considered even more unnatural, if one views naturalness as coming in degrees. As such the use of synthetic biology in BAR may be viewed as even more of an affront to the preservation of wilderness and nature than de-extinction.

Under another interpretation, synthetic biology may be viewed as a more permissible intervention. De-extinction involves the introduction of large sections of the extinct population’s genome into the host species, in multiple stages. This is in part to save the variation in this species, for example, Mammoth resurrection has been defended as a means to preserve Asian Elephants whose habitat is located in areas of dense human habitation. Through the Asian Elephant-Mammoth population being able to survive in the less inhabited Tundra areas of the world, it would have more available habitat for survival. The genetic modification in de-extinction is, however, much more directed towards the re-creation of an extinct form rather than preserving existing forms. Synthetic biology is significantly more of a preservationist methodology than de-extinction. The genetic modifications are slighter, often involving only a single protein-coding DNA sequence rather than the introduction of large sections of coding DNA.

My view is that within the wilderness framework there should be some allowance for the BAR of populations despite its prima facie antagonism towards the traditional principles of wilderness preservation. Biological hierarchy is nested, with genes sitting in organisms, organisms in populations, and populations in ecosystems. Interventions by humanity can act to preserve the historical fidelity of features in one level of the biological hierarchy by modifying another. This is true in the case of synthetic biology being used in a targeted manner to preserve endangered populations. The modification of one gene that allows a population to overcome an environmental stressor will change a gene but maintain the rest of the genome, population, and ecosystem in the face of extinction. While this intervention may infringe on the species' authenticity it will allow for it to continue to autonomously evolve and interact with its environment independently from humanity (Rohwer 2022). Given this, I think we should consider the degree of historical continuity within ecosystems and species resulting from human action or inaction rather than think of continuity as an either/or thing. Inaction and not using this technology will result in a more radically different ecosystem than targeted genetic alterations due to species loss. These changes will be ultimately due to human actions such as habitat clearance, the introduction of invasive species, or climate change. If we believe there is a strong connection between the resemblance of an ecological system to its historical form and wilderness, then we should allow for these limited interventions. Therefore, limited interventions could be interpreted as permissible within a nature or wilderness framework when they are conservative (Lean 2022).

The view described here, however, would likely be rejected by many wilderness proponents. The use of synthetic biology in conservation is antagonistic to the goal of preserving wilderness on the first pass, and in turn, the features that are associated with wilderness such as biological autonomy, authenticity, wildness, and naturalness. If the public, conservation scientists, and managers view these features as important conservation goals, then they provide good reasons to limit the use of synthetic biology. One could either reject the use of synthetic biology on these grounds or reject wilderness as a goal of conservation. Considering wilderness as coming in degrees could warrant using synthetic biology in limited cases, however, the caveat is that these changes should aim to maintain as many of the historical features as possible, up and down the biological hierarchy, and aim to create wild populations which do not require constant monitoring. This ameliorative approach, providing an initial attempt to incorporate wilderness-based goals into decision-making around which synthetic biology conservation projects are permissible, will require further refinement as more scholars consider the problems posed by synthetic biology in conservation theory.

4. Biodiversity

Preserving biodiversity emerged as a major goal of conservation within the last 30 years. From the 1970s there was an increasing number of scientists discussing the value of ‘natural diversity’ ‘biotic diversity’ or ‘biotic variety’ (Terbough 1974, Myer 1979, Faith 2021). These terms were codified in the 1980s as biodiversity and by the 1990s it was incorporated by the UN as a global conservation priority for all 160 nations that signed the UN Convention on Biodiversity (Lovejoy 1980, Wilson 1988, CBD 1992). The core idea is that preserving the diverse forms of biotic arrangements will preserve entities desirable both for humanity now and in the future, and preserve features that will allow biotic systems to self-maintain. This differs from the preservation of wilderness because it is seen as a more scientific foundation for conservation, considering the preservation of the biotic features that vary with the natural world rather than areas that are conjectured to have limited human impact.

Standardising the quantification of biotic diversity has been a contested matter, with different accounts emerging. The primary public-facing account of biodiversity can be found in the UN Convention of Biodiversity (1992), which states that biodiversity is “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems”. This broad definition is extremely effective as a political tool in conservation. All biotic features that could be valued by political actors will feature within this definition. This is because diversity within species, between species, and of ecosystems includes all biological phenomena. This, however, creates problems for implementing it within conservation planning. When biodiversity is defined as all of biology, it is difficult to make claims that some areas should be prioritised over others for conservation.

This difficulty has led to the formation of different stances toward biodiversity. Some defend a normative account of biodiversity and either argue biodiversity is equivalent to the biotic features people happen to value, or that we should eliminate the concept of biodiversity and simply focus on preserving systems that people currently value (Maier 2012; Santana 2014, Morar et al. 2015). Some argue for deflationary views of biodiversity, where systematic measures of biodiversity must be selected through a process of stakeholder engagement (Sarkar 2019). Others hold realist views, according to which biodiversity is a measurable objective quantity present in the world. Within the realists there are strong pluralists about which measures best represent biodiversity, arguing there are multiple equally legitimate ways to measure biodiversity (Frank 2016, Burch-Brown & Archer 2017) and those who believe a variety of measures are important in quantifying biodiversity but there is a single priority measure of biodiversity (Maclaurin & Sterelny 2008, Lean & Maclaurin 2017, Lean 2017).

In this paper, I assume that biodiversity includes measurable differences in the biological world rather than the immediate preferences of groups of humans. These will be either taxonomic differences, such as the historical differentiation of lineages or species differences, or feature differences, such as functional differentiation. Such an interpretation follows the rationale that biodiversity conservation is aimed at preserving material differences between biotic forms. The biological world is varied with many different evolved forms, and we should preserve the best range of these forms for both their current use and their future possible use (Arrow & Fisher 1974; Faith 1992; Lean 2017).

The differences shown in modern biota are the result of millions of years of trial and error through natural selection and as such represent ‘irreplaceable design’ that has been imperfectly optimised to survive (Cline 2020). These differences are a material instantiation of the deep history of life, with genetic sequences separated through the splitting of lineages over millions of years (Preston 2018). Given this coded deep history of life, biodiversity is a record of the history of life on earth, holding epistemic utility. This epistemic utility creates heritage value. Just as ancient texts have deep heritage value given, they contain information about the deep history of humanity, biodiversity has heritage value as it reveals the history of life on earth.

Given this understanding of biodiversity, synthetic biology is a disruptive technology for this normative framework. If we alter the genetic sequences of non-cultivated wild populations to preserve biodiversity, we will face some ethical and conceptual problems. For example, in the case of coral, the aim is to preserve coral in the face of a changing climate. But these genetic alterations do not simply preserve biodiversity. They introduce new biodiversity. This can be seen most clearly in the case of de-extinction. The aim of bringing back a Thylacine proxy to the Tasmanian wilderness through the genetic modification of a Numbat is not done to preserve the Numbat population. It is done to reintroduce biological variation lost due to extinction. This will function, however, as a speciation event where the modern numbat lineage is split into Numbats and Thylacine-proxy Numbats. This forced speciation would represent a radical break in the way that biodiversity has been previously formed, not by natural speciation but by conscious artificial speciation (Turner 2017). The imposition of this agency of large-scale natural processes is what Christopher Preston calls the advent of the Synthetic Age (2019).

Synthetic biology projects which look to preserve populations through BAR involve the enhancement or supplementation of biodiversity. This is not just the case within conservation synthetic biology projects but also in synthetic biology more widely. The creation of a minimal genome of *Mycoplasma genitalium* by the Craig Venter lab represents the creation of new biodiversity (Gibson et al. 2010). This is because the genome was modified from the wild-type populations through the removal of coding and non-coding DNA and adding coded 'watermarks' in the DNA that include a web address, the authors of the paper, and three quotes (Sleator 2010). Smaller scope projects which look to modify bacteria to produce new products has already been occurring since the 1970s, such as in the case of *E. coli* which now can produce insulin, have involved the introduction of new variation into these populations (Goeddel et al. 1979).

The enhancement rather than the preservation of biodiversity poses a serious problem for conservation. Is there an ethical equivalency between preserving and creating biodiversity? Gyngell & Savulescu (2017) argue there is. They argue that if we believe that biodiversity provides us with some form of value or goods that are worth preserving, then there is a reason to increase biodiversity to access more of this value or bundles of goods. They claim natural entities' biodiversity value is symmetrical over maintaining features and adding new features. As such, they argue the creation of a population through de-extinction would be equivalent to preserving a species that would have otherwise died out. Equally, increasing genetic diversity through introducing genes would be equivalent to preserving a genetic variant in a sub-population. Initially, the cost inefficiency of the creation of new biodiversity versus preserving biodiversity should make preservation the preferred option but in time creation could become more cost-effective. If one accepts a symmetry between preserving and increasing biodiversity, then increasing biodiversity through synthetic biology could be preferred.

This situation could lead to dangerous norms in how conservation is conducted, with some unfortunate precursors already existing. Many countries have a Biodiversity Offsetting Scheme. When developers want to clear biodiversity-rich habitats they can purchase another area of land as a biodiversity offset to counteract the biodiversity loss in the area being cleared. Often the purchased land is in a more remote area, and in Australia where I am familiar with the local policy, these areas of biodiversity offsetting are often restored ecosystems rather than old-growth habitats. Old-growth habitats tend to have richer more biodiverse assemblages with more endemic species. In such cases, these biodiversity offsetting schemes often result in net biodiversity losses (Bekessy et al. 2010). With the opportunity to restore or increase the diversity of genomes or create new populations we could likely find a recapitulation of this dynamic with biodiversity offsetting becoming genetic. Unique species possessing biotic features millions of years in the making could be allowed to go extinct with the promise, a promise that is unlikely to be fulfilled, that new biodiversity could be created to replace these losses. This can create a ‘moral hazard’ or ‘complacency problem’ where current conservation may be curtailed due to the belief future technology can replace current losses (Turner 2014; Turner 2017).

Moral hazard could result from the novel ability to create biodiversity and, in some sense, regain lost units of biodiversity leading individuals or institutions to claim that they can regain biodiversity that is lost by their actions. Eric Katz (2022) and others raise this objection to the use of de-extinction. De-extinction at this stage cannot recreate species but reintroduces lost genetic variation to create ecological proxies of the extinct species from related extant species. But if one were to claim that a new species was created through de-extinction, and biodiversity is just a count of extant species, then they could claim there has been no net biodiversity loss. If, however, you consider biodiversity to be inclusive of phylogenetic or genetic diversity, as I do, then there is a biodiversity loss. The danger is that to the public's eye, it might look like biodiversity has been restored despite the monumental loss of underlying biotic variation.

A lack of urgency in conservation now will undoubtedly result in extant biodiversity loss. This issue of complacency in the face of the biodiversity crisis is the same as that faced by climate change where, instead of reducing emissions now, governments are increasingly relying on intensive technological interventions to remove carbon from the atmosphere (Kolbert 2021). In both cases, prudent action to stop environmental destruction now is the most effective way to preserve the environment as these new technological interventions will not be perfect or may not be timely. They will create new externalities of risk as their use will be unpredictable and the application will be put in the hands of the powerful, creating new asymmetries of power.

The introduction of synthetic biology into the toolbox of conservation will provide significant methods to overcome environmental stresses that wild populations are subject to. With targeted interventions, it may protect threatened ecosystems, like coral reefs, or introduce genetic variation into highly inbred populations. However, this method complicates grounding conservation in biodiversity. One could accept that there is no asymmetry between biodiversity preservation and biodiversity production, like Gynell & Savalescu (2017), but this would be deeply unacceptable to most of the public and conservation practitioners. This leaves us with the option of explaining why there is this asymmetry or that further considerations mean that enthusiastic biodiversity supplementation has risks that make it undesirable. I believe it is dangerous to treat new biodiversity as equivalent to extant or extinct biodiversity. Just as in biobanking where old growth forests are treated as equivalent to newly less species-rich restored systems, deeply unique species may be treated as being equivalent to recently modified species. This will lead to significant biodiversity loss.

5. Ecosystem Services

The final way I consider normatively grounding conservation is that it is an act based on gaining access to ecosystem services. Ecosystem services are, “the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life” (Daily 1997). This normative framework is the most recent, being created to directly explain nature's value in economic terms to connect conservation with economics and policy. The Millennium Ecosystem Assessment identifies four types of service: provisioning (e.g., wood, food), regulating (e.g., water quality, climate), cultural (e.g., recreation, aesthetic), and supporting (e.g., carbon cycle, soil formation) (Millennium Ecosystem Assessment 2005). To satisfactorily maintain ecological services, one would have to preserve ecosystems, or parts of ecosystems, that provide utility to the public. This is an anthropocentric conception of why we should preserve biological systems and it is subject to changing perceptions of what is valuable in the environment. Ecosystem services, as a conservation framework, have the most potential to support the use of synthetic biology.

Synthetic biology, as it is standardly practised, is conducted with the goal of engineering biology to suit anthropocentric ends. The alteration of genomes and species to produce goods, be they agricultural, medical, or industrial, all correspond to a normative framework where biological systems are valued for the services they produce. Ecosystem services take this anthropocentric stance and extend it across the environment, the only question is to what degree ecosystem services validate the engineering outlook of synthetic biology, where we not only value these systems for the goods and services they provide but actively alter them to produce more. Within the defences of the ecosystem services framework, I perceive a tacit assumption that we are preserving systems rather than engineering them for these goods and services. The novelty of synthetic biology, and its affordances, have not yet led to serious considerations of what these capabilities mean for conservation more widely. But aspects of this engineering stance do appear within conservation science in the discussion of restoration and novel ecosystems.

The restoration of damaged ecosystems necessarily involves human agency and decision-making. Traditional restoration was done with the primary aim of restoring systems to a historical baseline, that is restoring the system to resemble the ecological system that had previously been present. The increasing interest in the value of 'novel ecosystems' has, however, made historical fidelity not the only goal in ecological restoration (Hobbs et al. 2006, Hobbs et al. 2009, Marris 2011). Novel ecosystems, as the name indicates, are ecological arrangements without historical precedent. Novel ecosystems result from human actions altering the local ecological conditions and facilitating population migrations into new spaces creating new ecological arrangements. Within the novel ecosystem literature, their value is often defended by recording the ecosystem services these areas produce (Evers et al. 2018). While initially novel ecosystems were discussed in the context of valuing the novel ecological arrangements that were a by-product of human-influenced ecosystems they have also been discussed in the context of consciously creating novel ecological arrangements (Perring et al. 2013).

The incorporation of novel ecosystems into restoration ecology involves taking a limited engineering approach to ecosystem design where ecosystems are constructed for the goods and services they provide. This, however, is only at the level of ecological arrangements rather than engineering the populations themselves to contribute to these services. But if we accept this engineering stance at the ecological level it would be a natural extension of this moral framework to take an engineering stance on the genetic composition of populations in ‘conservation’ areas. As such, considering ecosystem services as the primary goal of conservation is a moral framework that validates the use of synthetic biology in conservation practice.

There are stark risks involved in combining an ecosystem services framework with synthetic biology. The instrumentalisation of nature to anthropocentric ends could cause significant losses of the features of the environment that many people value, which include its separation from strong human intervention (see Wilderness). Initially, the ecosystem services normative framework aimed to retranslate such values into language amenable to economics and policy (Gómez-Baggethun et al. 2010). This includes all the ways humans value the environment including the aesthetic, spiritual, and cultural valuations of these systems. If taken seriously this will limit the use of synthetic biology in conservation areas as many within the public would oppose it. If the public perceives that these systems are of diminished value due to technological interventions, then the ecosystem services framework would prevent their use. But this is only if the production of ecosystem services is a value-neutral description of current ecological values. I do not think this is the case, by changing the language of conservation into that of treating ecosystems as economic markets producing goods, conservation has opened itself to the bias of an economic worldview.

In treating ecosystems as goods and services producers the ecosystem services framework has introduced a bias in what is valued in ecosystems. This is in part due to the historical research framework which was used to study the relationship between biodiversity and ecosystem services. Much of this research which dominated the early discussion of ecosystem services in the 1990s and 2000s looked to quantify the relationship between species richness, or a local species count, and either biomass production or net primary productivity (Newman et al. 2017). Key position pieces on the value of ecosystem services described biodiversity as being valuable in that it provided a range of ecological functions that could increase productivity (Dasgupta et al. 2013). This shift in language and emphasis pressed that the way ecosystems provided value was through efficient resource cycling and production, just like a business, to the exclusion of other ways of valuing these systems. These ideas were seized by defenders of invasive species in the last decade to argue that invasive species are good for the environment as the features that make them invasive also make them productive, in that they are fecund and efficient resource cyclers (see Lean 2021).

If ecosystem services are treated as the core aim of conservation this bias towards productivity could find its way into wild organismal design. This would create populations that may outcompete populations already existing with the ecological system they are released into. As such, if we incorporate ecosystem services as the goal of synthetic modification, we could implement a bias towards the production of new invasive species. This is in part something recognised and already treated with concern in the literature. After Craig Venter's lab produced the first organism with a synthetic genome (Gibson et al. 2010), concern emerged from the scientific community over whether synthetic organisms could escape the lab and outcompete wild populations (e.g. Kuiken et al. 2014). The uncontrolled spread of these populations could result in wilderness, biodiversity, and ecosystem service loss. These concerns often mirror the original concerns about the release of GM crops and organisms in the 1990s (Gustafsson & Jansson 1993). Scientists and policymakers are actively researching the biosecurity risks involved in synthetic biology. The wild release of modified organisms compounds these risks.

If productivity is part of the design goals of organisms modified to be released, there is a significant possibility for the unexpected displacement of extant species within ecosystems. This concern is shared by the public around the use of synthetic biology in conservation. A survey of the Australian public's reception of the use of synthetic biology in conservation found several individuals referring to the release of cane toads in Australia (Carter et al.

2020). These toads were released as a biocontrol for the cane beetle but spread rapidly poisoning predators and consuming other frogs causing significant species losses in the habitats they invaded (Shine 2010). There is a fear that synthetically altered populations could similarly function as invasive species, particularly if increased efficiency is part of their design principle. So, both the public and scientists recognise the risk that synthetic methods pose for conservation when we aim to produce populations with the potential to have enhanced productivity.

Presenting the acquisition of ecosystem services as the goal of conservation uniquely validates the use of synthetic biology, in contrast to the normative goals of biodiversity or wilderness. The tacit assumption of the maintenance of historical baselines is weaker within ecosystem services, particularly given the increasing prominence of the novel ecosystems concept. This provides opportunities for an ethical outlook where we should be modifying ecosystems to maximise the goods and services they produce. If the bias towards considering these systems as producing more economic value when they are highly productive, as they create biomass or cycle more resources, continues then there are serious dangers in this as a ethical outlook. Ecosystem services could be an intellectual vehicle that validates the production of invasive species which could cause significant environmental destruction. There is a real threat in the creeping normalisation of treating natural systems as being valuable *only* insofar as they are units of economic production. Synthetic biology, if used and marketed unwisely, could exacerbate this issue.

6. A Diagnosis: Preservation and Maximization

The moral frameworks for preserving wilderness, biodiversity, and ecosystem services are complicated by the use of synthetic biology to assist in the restoration of ecosystems and species. This uneasy relationship is derived from the new capacities synthetic biology affords humanity. Conservation historically has been a backwards-looking endeavour, seeking to preserve, maintain, conserve, or restore systems according to some historic baseline. Whether this baseline is a particular species composition at a time, or set of ecological dynamics, or a history of human interaction with the system. The affordances created by synthetic biology allow for conservation to move away from the preservation of biological systems that have existed towards creating new biological systems. This creates a mismatch between our current ethical frameworks and the futures made possible by synthetic biology.

In each case, synthetic biology disrupts these normative frameworks because engaging in its use alters the historical arrangements of biological systems in ways not previously possible. On the first pass, the clearest mismatch is between the use of synthetic biology and wilderness preservation. Wilderness preservation is aimed most directly at maintaining biotic systems while excluding human interference, and synthetic biology is human interference. This, however, somewhat undersells how history plays a significant role in wilderness theory. Wilderness involves a conception of natural systems where the history of these systems has been continuously present for long periods without human influence, and that humanity's intervention is a disruption of this history (whether this history of separation from humanity is real or imagined).

Biodiversity conservation has always been implicitly about preservation, this was dictated by the capacities that we have previously possessed. There was no way to increase biodiversity so there was no reason to engage with the issue of increasing biodiversity intellectually and/or ethically. Synthetic biology creates a capacity that was not even considered when biodiversity was conceptualised as an ethical goal in conservation (Soule 1985; Faith 2021).

The ecosystem services framework has been used to toy with the idea of conservation as a project of maximizing some good rather than preserving that good. This is through the discussion of creating novel ecosystems with ‘functional arrangements’ which are discontinuous with historical systems in the local area. Still, the advent of synthetic biology moves the locus of human influence from the level of ecosystem arrangement to the level of genome arrangement. Synthetic biology provides new possibilities to maximize the yield of biological goods and services, and in doing so makes us confront the implications of a normative framework that is guided by translating the value of biological systems solely into economic values. Economics generally assumes that growth is one of the most desirable features of a market, and in treating ecosystems as markets we import the economic norm of market growth into ecological services. Synthetic biology provides new mechanisms for satisfying this norm of service growth.

The moral framework of maximisation of some moral good differs from the norm of preservation for two reasons. The first is that being able to increase a desirable quantity makes this quantity fungible. This creates a ‘moral hazard’ as the promise of restoring or ‘improving’ biotic systems may lead to diminished actions to preserve existing biotic systems. The second is that without history as a guiding principle for biotic design we are left with questions about what other norms guide the design choices we make and what norms remain to constrain design choices. This creates slippery slope risks of increasingly drastic interventions as synthetic biology is normalised as a method of conservation.

Moral hazard has been discussed earlier in this paper and has been explored in some detail as it applies to de-extinction (Turner 2014; Minteer 2015; Katz 2022). The possibility of recreating lost species diminishes the psychological barrier of the finality of species extinction, which may allow people to believe we can simply recreate the species that are lost. The replacement of lost units of environmental value with some entity of supposedly similar value is not local to just de-extinction using synthetic biology. This will also be true of biodiversity loss and ecosystem service loss. Synthetic biology may be conceived as a mechanism for replacing environmental features of value with entities of similar value. This could ultimately undercut the message of conservation and lead to irreplaceable losses of the biotic world.

The second issue that arises from the use of synthetic biology in conservation is the risks associated with normalising genetic interventions and creating a ‘slippery slope’ for synthetic biology’s usage in natural systems. Preservation uses history to dictate the structure of biological systems. What history to use is debatable and subject to human decision-making. But history will frame what systems are the targeted goals for conservation. Without history, we must question what we are preserving. If we adopted an ethical framework for the maximisation of a conservation good, be it biodiversity or ecosystem services, we must consider what constrains what we create and what other values should influence biotic design.

In moving away from the belief system that conservation is conserving the biotic structures that exist, we leave open the question of what norms should be incorporated into organismal design for wild populations. When changes in organisms are made to maximize biodiversity or ecosystem services, they will aim in part to increase the quantities but the individual making these changes will have many different options for ways to increase the quantities. What decision-making norms will they use to decide on how they increase biodiversity or ecosystem services? They may use social, ethical, or aesthetic norms to make these choices. Selective breeding already heavily involves not just increasing the functional utility of populations but also norms of increasing the aesthetic appeal of these organisms, this is true of not just companion or ornamental organisms but agricultural populations as well. Radical animal welfarists have already considered genetically modifying carnivorous animals to become herbivorous despite the obvious devastating effects on ecosystems and the species themselves (Bramble 2021).

This sudden shift from biotic design being dictated by history to design being dictated by human norms is what I believe drives many of the public's objections to the use of synthetic biology. 'Playing god' can be understood as not just a set of actions but the assumption of decision-making about the structure of a world that was previously a given. Once biotic design is dictated by human choices, we assume a new power over the composition of life which can then be normalised. Early interventions to modify populations will likely be highly conservative looking to only make slight changes to fortify populations from environmental stressors. If these alterations are successful there will likely be more acceptance of these methods and their increasing use. It is from the increasing opportunities to alter populations that we may find a slide towards more radical interventions which could fully embrace human design choices in organismal design and the norm of maximization rather than preservation. Without constraint, biotic design could become deeply discontinuous with the deep history of life on earth (Preston 2014).

This is where arises a slippery slope of a kind where the acceptance of interventions on organismal design could lead to the unconstrained modification of populations. This will create risks for humanity and ecosystems. There is the possibility that changes made by humans could lead the populations to unexpected advantages in ecosystems and act as invasive species. As noted, the public recognises this risk in their reference to the lessons learned from failed biocontrols like cane toads (Carter et al. 2021). Increasing the commonality of genetic recombination could create new opportunities for zoonotic diseases (Kuiken et al. 2014). But there are also risks to justice and equity as it will be primarily wealthy highly educated people from western nations who will make the decisions about what changes should be implemented. This is also a fear articulated by members of the public when they consider the use of synthetic biology in conservation (Carter et al. 2021). These material and social risks warrant caution in utilising this technology.

Synthetic biology is incredibly powerful in its potential to preserve populations at risk. This makes this technology unwise to dismiss, and dangerous to avoid. As such, I cannot agree with hard-line wilderness advocates who reject its use wholesale (Katz 2022). But the incorporation of synthetic biology in the toolset of conservation raises significant questions about how to conceptualise the ethical goals of conservation. This I think warrants deep conservatism in organismal design, the norm of creating organisms that are closely in accord with historical populations should be advocated. Conservatism in design will mitigate the risk of unintended consequences and make synthetic biology conservation projects more acceptable to the public. But importantly it will make synthetic biology's use in conservation correspond to the implicit norms' conservationists have always held. There is considerable work to be done on the moral foundations of conservation. Restraining our actions will provide our moral theories time to develop in response to the new capacities' humanity finds itself in possession of.

7. Conclusion

Synthetic biology has an immense capacity to aid conservation. While this capacity should not be dismissed it raises serious issues for the normative foundations of conservation. The major goals of conservation, as it is currently practised, are all deeply complicated by the use of synthetic biology. I argue it complicates valuing wilderness, biodiversity, and ecosystem service preservation. This is because synthetic biology provides new technological abilities to design biotic systems discontinuous with biotic history. This allows for conservation to move away from an act of preserving what has existed to increasing desirable features in the biotic world. In doing so it allows for other human norms to be incorporated into biotic design and creates risks. These risks will be material, social, and moral in the form of ‘moral hazards’ and risks of a ‘slippery slope’ towards increasingly radical interventions. Significant work remains to be done explaining what constrains organismal design when we utilise synthetic biology for conservation.

Acknowledgements: Thank you to the following people who provided feedback on this paper. Kate Lynch, Yasmin Haddad, Stefan Lindquist, Francois Papale, Rose Novick, Ford Doolittle, and audiences at University of Leeds, Centre for Public Awareness in Science, and the CoESB. This research was conducted by the Australian Research Council Centre of Excellence in Synthetic Biology (project number CE200100029). The views expressed herein are those of the authors and are not necessarily those of the Australian Government or Australian Research Council.

Funding: Australian Research Council Centre of Excellence in Synthetic Biology (project number CE200100029).

Disclosure Statement: The author reports there are no competing interests to declare.

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