De-Extinction: Restoration or Destruction?

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Summary

De-extinction, the practice of producing animals which are functionally or morphologically analogous to an extinct species, is a multi-faceted prospect carrying much potential for both harm and good, and is in rapid development. In this review, I discuss the pathway towards de-extinction from an integrative perspective, ranging from ecological considerations, such as matters influencing release group success and population dynamics, to the molecular techniques for achieving species recreation, including cloning, back-breeding and genetic engineering. I also outline the ethical and practical aspects of the process of de-extinction, leading to the conclusion that, despite the risks involved, de-extinction remains a useful tool to keep in hand should the need to use it arise.

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Introduction

Extinction is a fundamental evolutionary process that contributes to the delicate balance naturally found in every ecosystem. If a species is unable to adapt after losing its niche due to biotic or abiotic factors, it will eventually cease to exist, giving another the opportunity to replace it. Such internally driven extinction, like many other processes in the natural world, is neither good nor bad – it is an inevitability. Unfortunately, however, a substantial portion of contemporary extinction events is not driven by internal processes, but externally forced by human interference. This has led to the untimely loss of many species throughout both recent and distant history, often to the detriment of the ecosystems that these species were part of. Whether by induction of harsh changes to their physical habitats, introduction of harmful invasive species, or by excessive hunting, humans have irreversibly tipped the balance of multiple delicate ecosystems in one direction or another, compounding the effects of natural extinction.

While the loss of species by extinction has so far been irreversible, recent studies are showing that this may soon no longer be true: in the near future, it may be possible to reintroduce species which have been lost, using techniques such as back breeding, genetic engineering, or cloning, in a process referred to as de-extinction. De-extinction was recently put on the horizon as an imminent reality, when the biotechnology company Colossal Biosciences announced its plans to reintroduce the Dodo in January of 2023.

As dramatic as bringing back long-lost species from the dead may sound, the potential benefits in restoring stability and functionality to ecosystems which would otherwise be at risk make it a lucrative idea to pursue de-extinction in the context of ecological engineering for the purpose of restoration. Note that de-extinction in this context does not necessarily require the resurrection of a lost species as a faithful replica, but rather the reconstitution of an ecologically functional equivalent of the original extinct species. In recognition of this fact, the 2016 International Union for Conservation of Nature (IUCN) guiding principles on de-extinction coin the products of de-extinction as 'proxy species', to indicate that de-extinction is not a way of 'righting past wrongs' or 'reverting the world to how it once was', but a way to recover declining ecosystems by returning keystone species driven into extinction by anthropogenic involvement. De-extinction for other purposes will not be considered. Many human-caused extinctions throughout history have been driven by a desire to exploit nature for commercial gain, and so using de-extinction for such purposes can only be labelled counter-productive. It is my belief that risking the remaining ecosystems for the sake of making money would not be justifiable.

The prospect of de-extinction does not come without its drawbacks and risks, and so careful consideration into the ethics and potential consequences, as well as its feasibility, must be given. The reintroduction of an extinct species into environments which have been deprived of their presence for potentially tens of thousands of years will raise questions of ecological and evolutionary nature, such as whether they can still fulfil the roles they had previously been performing, and whether there will be unforeseen consequences of their reintroduction in the present-day ecosystem. The practical aspects of producing and preserving populations of artificially manufactured animals require further knowledge of genetics and zoology, presenting questions such as whether viable individuals for a given species can be procured in the first place, and whether development and socialisation is possible in an authentic manner. Ethics are another important aspect to consider, and will have various implications depending on the selected species and method through which the reintroduction would occur.

In the following sections, I will present an overview of the complex interplay of ecological, biotechnological and ethical aspects of de-extinction, and combine these perspective to arrive at an integrative appraisal of the promises and caveats of de-extinction in conservation.

Section 1: Ecological Restoration

In the field of conservation, there exist two separate methods for protecting and restoring ecosystems: ecological restoration and rewilding. Though sharing similarities, they also have distinct goals, with restoration focusing on the 'recovery of a defined historically determined target ecosystem', and rewilding focusing on 'recovery of natural processes with often no target endpoint' (Mutillod et al., 2021). For the purpose of de-extinction, the prior method would be the most suitable, as having a clearly defined target ecosystem state is perhaps the most critical consideration in the process.

A necessary aspect to consider prior to de-extinction is whether the current state of the target species' potential habitat, can still support their population. There are several complications involved with species reintroductions, and a good understanding of the selected environment is essential in ensuring the success of the operation. If the extinguishing force responsible for their disappearance is still present, or if other factors have rendered the environment inhospitable, then that species is likely not a good target for de-extinction. The IUCN released a detailed set of guidelines outlining various principles and considerations involving the prospect of de-extinction in 2016, providing a good foundation for making assessments about environment suitability. Though helpful, it has received its share of criticism, and has yet to prove its efficacy through practice. One of the biggest challenges will be in making sure that the newly introduced population has what it needs to take root and prosper with minimal management. To this end, not only must the minimum viable population size be met, but also an understanding of the critical thresholds and tipping points of the environment must be attained.

Once a novel species is introduced to an environment, regardless of whether it was historically present or not, it may induce significant cascading changes in the ecosystem, highlighting the importance of intentional action. Unless a clear timeline and endpoint are determined, these changes risk being accentuated, leading to potential failure or even harm to the ecosystem. Those wishing to attempt de-extinction must be aware of three key categories of ecological considerations if they hope to succeed.

First, it is crucial to understand how the reintroduced species will impact the ecosystem. This requires knowledge of the critical thresholds at which the state of the environment leans one way or another, which can result in an undesirable yet stable state being maintained despite the reintroduction of the extinct species (Lenton, 2013). Such ecological tipping points could lead to the population failing to establish itself, or even unforeseen detrimental interactions involving the reintroduced species harming the environment. In order to get a full picture of the state of an ecosystem, multiple methods must be used. Statistical analyses, computer modelling, and field observations are all effective in gathering and processing information on stability, resilience, and sensitivity. Field observations are essential to any restoration procedure, as they provide direct data on the most fundamental aspects of the target environment such as biodiversity, environmental conditions, and interspecies interactions. Doing so will allow a food chain to be modelled, uncovering the impact made by the extinction of the target species and how it can be amended. Computer models are a useful tool for predicting the impact of a number of variables. Depending on the species being reintroduced, a variety of factors including climate change, population dynamics, and even foraging windows, could be at play determining their potential success. To process the data obtained from models and observations, statistics is used, converting raw data into more digestible formats and allowing further inferences to be made, leading to mathematically supported conclusions. Having such precise information would allow ecological engineering to be performed with much greater efficacy. It would also enable decisions to be made as to whether the habitat should be reformed or avoided. The current condition of the release habitat will be the biggest determinant of the release group's success, and so it needs to be ensured that it is still fitting for reintroduction. If the driving factor for the target species' extinction is still present, it must be addressed. An example of this would be the Yangtze river dolphin: though they are good de-extinction candidates in theory, their habitat is still inhospitable due to pollution, fishing, and poor protection efforts (Seddon et al., 2014)

A second factor to consider for successful de-extinction is that re-introduced species tend to be particularly vulnerable shortly after individuals have been first released and population size is still low, even if conditions permit the persistence of a stable, large population. These negative effects caused by low population density, which are collectively referred to as Allee effects, may occur in different ways. For example, if the population is dispersed or too small, individuals may not be be able to find a mate easily, preventing successful reintroduction, even under ecologically favourable conditions. Three different strategies can be employed to minimize Allee effects: bolstering of the release group, management of post-release mortality & dispersal, and direct management of Allee effects (Armstrong & Wittmer, 2011). The first strategy is the most intuitive, and involves increasing the population size so that the initial population density is high. Altering the composition of the group would also contribute to increasing its effective size, with factors such as having an optimal sex ratio or having attractive individuals being significant contributors. The second strategy, requiring an intermediate amount of management, aims to keep the population density high by reducing mortality and minimizing dispersal. Species reintroduction is often stressful for the release group, and leads to a higher initial mortality rate, making efforts to oppose this appear lucrative. Practical applications of this approach, however, have proven its inefficiency, and often achieve the opposite of what was intended. The third method, direct management of the Allee effects, requires the most amount of management, and requires having an understanding of the interactions between the target species and the environment. This would involve protection for animals prone to predation, or food supplementation for animals which struggle with feeding. This would present challenges for the introduction of extinct species, as less information is present on their potential vulnerabilities to the Allee effects, but it hold the advantage of avoiding the ecosystem disruptions large releases could bring.

Apart from Allee effects, the early stage of species reintroduction requires several additional considerations. For instance, the method of translocation holds importance, with hard-release and soft-release being two different approaches with different levels of support for the individuals. Soft-release involves a period of acclimatization for the animals, with pre-release cages containing food and water near the site of translocation providing gradually diminishing aid to ensure their success. Hard-release foregoes this step and instead relies on the animal's own ability to survive and establish a stable population. There is no clear consensus on which of the two provides the released population with the best chance of success, suggesting it depends on the unique characteristics of the species being released (Resende et al., 2021). For the reintroduction of extinct species, soft-release would provide the best start, due to a variety of factors which may negatively impact their chances of establishing themselves as a wild population would. Furthermore, the capacity of newly made individuals to operate may be hindered by inadequate knowledge of survival strategies. Since there will be no previous generation to socialize the neonates, new populations may fail to establish themselves into the appropriate ecological niche, leading to inadequate feeding and out competition by others (Shapiro, 2017). It is possible to circumvent this by employing maternal females from a sister or analogous species to serve the role of parent, but this may not always be accurate or possible.

The third, and final category of ecological considerations that must be taken into account relates to the phase after successful re-introduction and establishment, and concerns the long-term persistence and adaptive potential of the population. Long-term persistence requires a sufficiently high population size and genetic diversity. The minimum viable population size (MVP) is the smallest size of a population of a given species which could survive in the wild. Ensuring that newly released populations meet this standard of numbers and helps spare them from the effects of detrimental evolutionary forces such as genetic drift or inbreeding depression (Robert et al., 2017). For extinct species with no extant populations, the minimum viable population size can be determined either by referencing historical records of population data, or by drawing comparisons to other analogous species. One way to counteract the effects of inbreeding and ensure a sufficiently healthy population would be through the use of genetic engineering to identify and expunge detrimental alleles (Richmond et al., 2016). Another similar, but less precise, method would be to forcefully induce random mutations within a number of individuals, supplying the population with genetic diversity, but at the risk of introducing new potentially harmful genes. Recreated species will also suffer from lower disease resistance, as they will not have had the time to adapt to any pathogens that may be present in their new habitat. This could have disastrous consequences not only for the created population, but also for the native animal and human communities, as the proxy species may become a vector for new or existing diseases to be spread.

Accounting for all of these factors requires a management plan which can account for not only the individual requirements of the target species being brought back, but also for the unpredictability which employing novel, untested techniques entail. On top of the described co-evolutionary challenges, obstacles of economical, political, and even cultural natures are bound to be present. Adaptive management is a concept based on flexibility to overcome uncertainty, and involves the adoption of multiple alternative strategies, which are modified, replaced, or discarded regularly. It also aims to incorporate “new scientific and programmatic information into the implementation of a project”. Having been used in several major ecosystem restoration efforts to date, including the Colorado and Platte rivers, it boasts several potential benefits such as providing direction in ambiguous situations, and providing additional data on the progress of ecosystem restoration, which would be an indicator on the released species’ success.

Section 2: Performing De-Extinction

Three potential pathways exist for de-extinction: back-breeding, cloning, and genetic engineering. Though varying in complexity and fidelity to the original, they all aim to recreate a functionally similar animal capable of filling the niche left after the extinction of its predecessor.

One of the most straightforward and lowest accuracy methods, back breeding, presents a purely pragmatic way of replacing lost species. Through selective breeding, specific ancestral traits linked to the desired function, which were lost or diluted over time, are able to be reinstituted in populations (Shapiro, 2017). After determining the phylogeny of the target species, their closest living relatives are chosen as a starting point for the process, and multiple mating pairs are formed. The offspring of these pairs are then sorted based on the presence of the target functional phenotype, and mate to produce the next generation. A well-known example of this would be the back-breeding programme held in Germany as an attempt to bring back the extinct species of cattle, the aurochs. After them having gone extinct in the 1600s, the Heck brothers used selective breeding on their various European descendants to produce offspring with phenotypes similar to how they envisioned the aurochs. Though the final product could not be considered the same species as the still extinct aurochs, they had a morphology resembling them. This method is not guaranteed to result in a faithful recreation of the target species, however, and would also not work if their phylogeny is ambiguous.

Another example of back breeding being used for de-extinction would be the Quagga Project taking place in South Africa. The quagga is a subspecies of the Plains Zebra which went extinct in 1883 due to hunting, resulting in a loss of biodiversity and thus stability in the South African wilderness (The Quagga Project : Official Website). The aim of the project is to release a population of zebra demonstrating the distinctive coat-pattern characteristics, which are the best estimate available for authenticity to the Quagga due to limited knowledge on their genome, into the wild. Restoration of a culturally significant entity seems to be the driving motivation behind the Quagga Project, drawing into question whether the ecological impact they would incite is well-considered. Further criticism of this project has pointed out that if the original Quagga possessed non-morphological traits unique from its cousins, then the animals produced by the selective breeding programme will not be genuine. This emphasizes the significance of ensuring that there is sufficient data on the genome and phylogeny of the species being brought back. QTL (Quantitative Trait Locus) mapping is a genetic technique used to identify regions in the genome associated with quantitative traits, and can be used to decipher the relationship between genotype and phenotype for a given species. For the purpose of back breeding, QT mapping provides a systematic and targeted approach for fixing desired quantitative traits in a population, accelerating the back-breeding process (Cui et al., 2015) With the help of QT mapping, other secondary traits influencing individual fitness such as disease resistance or increased fecundity may also be included in order to better the release group's chances of survival.

Cloning, i.e., producing a direct copy of the target animal, offers a more precise approach to de-extinction. It has the advantage of ensuring that the reconstituted species be as close to the original as possible, as well as skipping the need for breeding multiple generations, but does not come without its drawbacks. In fact, cloning for the purpose of de-extinction has seen limited success so far, with the only cloned extinct animal, a bucardo, dying shortly after birth. In fact, typically less than 5% of potential clones developing into live offspring (Cowl et al., 2024). Another drawback would be the need for intact living cells which, depending on how long ago the target species went extinct, may not be available. The various methods of cloning each have their characteristics influencing suitability for de-extinction purposes.

Early methods of cloning included monozygotic twinning and embryo splitting. Occurring naturally, monozygotic twinning is where a single embryo undergoes a splitting phase early on, resulting in two or more genetically identical copies of itself being produced. This phenomenon is also replicable in vitro, either by physically separating the blastomeres of early embryos, or by bisecting later stage embryos through embryo splitting. Unfortunately, however, given that this procedure is highly complex and difficult to perform, as well as the fact that it has not been proven to work beyond a limited number of domestic species, it appears unsuitable for conservation purposes (Cowl et al., 2024).

Modern approaches to cloning using methods such as SCNT (somatic cell nuclear transfer) or in vitro gametogenesis. Somatic cell nuclear transfer is at present the method most commonly associated with cloning. In SCNT, the nucleus of an egg cell from a host species is replaced by the nucleus of a somatic cell from the target species, and reprogrammed to revert to an undifferentiated pluripotent stem cell. The reconstructed egg cell is then stimulated to begin cell division, and implanted in a surrogate mother as an embryo (Cowl et al., 2024). Famously, Dolly the sheep was the first animal cloned from an adult, and reportedly survived until adulthood without defect and was able to reproduce. SCNT is widely used domestically, for purposes such as agriculture or racehorse breeding, making it a tested and familiar method of cloning. This makes it an obvious candidate for de-extinction, though limited to non-egg laying animals due to there being no way of inserting the somatic cell nucleus without killing the egg itself.

In vitro gametogenesis involves inducing iPSCs (induced pluripotent stem cells) to differentiate into gametes through blastocyst complementation. Similarly to SCNT, this method involves removing the original contents of a host cell and replacing them with the genetic material to be cloned, with blastocysts being used instead of egg cells. The advantage of this method is that it produces gametes which conserve genetic diversity in subsequent offspring, making it a lucrative technique for conservation, though it has yet to be replicated in species beyond mice (Cowl et al., 2024).

Mammals are currently the best class to work with for cloning due to their compatibility with SCNT. Since the process requires direct access to the egg cell, oviparous classes such as birds and reptiles introduce the challenge of penetrating the eggshell without harming the embryo. While methods for overcoming this barrier have been mentioned (Shapiro, 2017), they still remain theoretical or proprietary. At present, only a few examples exist of practical applications of cloning for the purpose of de-extinction (Novak, 2018). The bucardo, also known as the Pyrenean ibex, was one of four subspecies of Iberian wild goat inhabiting the Pyrenees up until the 20th century, until they were driven into extinction through hunting. Though the last individual of this species, a female named Celia, died in 2000, cryopreserved samples secured from her body were used to form a culture of fibroblasts in 2003. The cloned kid marked the first de-extinction of an evolutionarily torpid species, but died 7 minutes after birth due to a collapsed lung.

Genetic engineering presents what some believe to be the most plausible route to de-extinction, using a combination of gene editing technology and cloning to recreate the target species using their closest living ancestor as a base (Shapiro, 2017). To begin the process, first the full genome of the target species must be sequenced from tissue samples. DNA decays slower than the cell it inhabits, so it is possible to collect samples from long-dead animals, granted they have been adequately preserved. Though initially DNA was only able to be harvested from tissue that had been preserved in cold environments, new advancements in ancient DNA methodologies have opened the doors to processing samples subjected a variety of conditions. Once the genome is acquired, it is analysed and compared to the genome of the nearest living relative. For efficiency, only the sites responsible for phenotypical change are selected, and modifications are made to a cell from the extant species, which is then used in cloning. This method holds the advantage of having the ability to make direct modifications to the genes of the target species for purposes such as removing deleterious mutations or inducing genetic diversity. It also enables the use of gene drive systems to assist in the spread of particularly useful alleles of genes modified so as to provide release groups with better odds of survival.

Out of the three pathways to de-extinction discussed, genetic engineering presents the most options. On top of its ability to produce high-fidelity copies of the target species, it also provides the ability to combat the various genetic and ecological challenges released populations would typically face such as inbreeding depression or habitat unsuitability.

Section 3: Ethics and Practicality

Ultimately, the question of "is it worth it?" will need to be answered by means of ethical and practical considerations. Through recent advancements of technology in the biological sciences, the discrepancy between what can be done and what should be done has grown, with genetics in particular being a field with much potential, both good and bad. It is important to keep an open mind in such a time, and consider the benefits and detriments in an unbiased manner.

Once the pathway towards de-extinction has been determined, a number of practical and ethical aspects must also be considered. The advantages of reintroducing the extinct species must outweigh the potential disadvantages it may pose for it to be justifiably carried out, and so every step of the project, including those coming after reconstitution and initial release of the target species, must be accounted for. This would include awareness of the potential to introduce risk to the ecosystem or surrounding human communities, as well as changes to their environment due to global warming, the introduction of new competition, or even the species' own absence. An adherence to ethical standards will help ensure that unnecessary cruelty is avoided, and is necessary to avoid public outcry and secure support for potential projects.

In 2016, the IUCN released a set of guiding principles on de-extinction for the purpose of conservation, including sections on candidate selection and release. Given the serious implications spearheading de-extinction carries, it must be established that no other options are available. Alternative ecological replacements for the extinct species must be explored, as if a suitable stand-in is found, it will greatly reduce the risks and costs of the conservation process. If no such species exists, the practicality of the reintroduction must then be assessed. Factors such as the potential for invasiveness, conflict with native wildlife or humans, ease or difficulty in management, and ultimate conservation benefits all serve as criteria for this assessment, and require a comprehensive understanding of the ecosystem and the animal being reintroduced (*IUCN SSC Guiding Principles on Creating Proxies of Extinct Species for Conservation Benefit*, 2016).

The social and economic circumstances as well as the attitude of the residential human communities must also be considered. If the local government is unable or unwilling to implement protective measures to support the reintroduction, such as designation of the species and their environment as protected, poaching, pollution or even disputes over land may present obstacles to the project. A lack of public support would also lead to similar problems.

Another important factor to consider in candidate selection is the potential risks involved in reintroduction. To this end, a formal risk assessment must be undertaken. The ecological risks involved are primarily centred around the possibility for harm to the extant species and processes present in the environment. Interactions such as interspecies competition, hybridization, and predation all present ways in which the proxy species could disrupt the ecosystem. This consequence will be more accentuated based on the amount of time passed since the extinction took place, as there will be a greater discrepancy between the species' natural and current environments.

Various socioeconomic risks could also potentially threaten the viability of the reintroduction process. If there is a chance that the reconstituted species could pose a risk to the safety or livelihood of local communities, this may sour public opinion towards the project, even if it was favourable starting out. In order to be able to deal with any potential dangers, it must be ensured that a viable plan for reversal exists, such as recapturing or culling of the released species. This will be a greater task for animals with greater ranges of dispersal or better sheltering strategies, making them less fitting targets for de-extinction (*IUCN SSC Guiding Principles on Creating Proxies of Extinct Species for Conservation Benefit*, 2016).

One of the more fundamental aspects of de-extinction for conservation being discussed are of ethics, with perspectives both for and against the prospect making use of various moral and practical considerations. One argument in favour of de-extinction comes from the concept of restorative justice, which urges compensation in cases of harm being done to one moral agent by another. In cases where humans are responsible for the extinction of a species, such as the woolly mammoth or passenger pigeon, the idea is that they must take measures to rectify their actions (Odenbaugh, 2023). This perspective can be described as idealistic, as it fails to factor in whether this will be to the benefit or detriment of the existing ecosystem, sourced from a lack of a clear goal. The moral argument presented is also controvertible, as both the victims and perpetrators of the wrongdoing, the humans which caused the extinction and the species subject to it, are no longer around. De-extinction would not bring back the dead animals nor would it absolve any surviving humans from guilt. A more convincing argument for the use of de-extinction is that it supports conservation and biodiversity, and thus should be utilised (Odenbaugh, 2023). The moral basis of this assertion draws from both human reverence of nature, and of the practical advantages greater biodiversity brings. Having the power to cause major changes in global wildlife is only a recent accomplishment, and has created a world where the natural balance of many ecosystems have been disrupted to great consequence. This makes restoration and conservation efforts seem more lucrative in the eyes of the public, as it presents the ideal of a world free of such devastation. Reintroduction through de-extinction also carries the potential to save dying ecosystems which lost a keystone species and has no available replacement, highlighting the great gain to biodiversity the method provides. Increased biodiversity carries various advantages, such as increasing the stability of the ecosystem and granting access to potentially useful biochemical compounds.

Those opposing de-extinction may mention animal welfare in their arguments. The claim is that de-extinction causes unnecessary animal suffering, and is therefore morally impermissible. Indeed, in one of the only cases of de-extinction actually being performed, the cloning of a bucardo, resulted in the short and painful existence of a single kid suffering from a birth defect. It is stated that the "miscarriage, stillbirth, early death, genetic abnormality and chronic disease" resulting from the cloning process make it cruel (Browning, 2018). The problem with this approach is that it fails to consider the fact that all conservation efforts involve a balance between the gain and death of life- invasive species, for example, are culled so that native species may prosper, with methods such as trapping or poisoning. Another argument against de-extinction is that it takes away attention and funding from other conservation prospects. Statistical analyses performed by Bennett et al. have demonstrated that, even in optimal conditions with external sponsorship, the use of de-extinction for conservation would negatively impact the total number of species able to be protected, making it less suitable than conservation of extant endangered species (Bennett et al., 2017). Though convincing, this perspective does not take into account the fact that de-extinction, as a tool, serves to present more options. While it may have additional complications attached, the individual benefit it provides by allowing the recovery of lost species means that in some cases, it may be well worth the cost. Not all animals are equal in terms of their importance to their respective ecosystem, and there are certain to be scenarios where de-extinction may be the only option. Technology scepticism presents a more abstract reasoning for opposing de-extinction. Going off of the fact that many of the problems humanity faces today originates from our own actions, this viewpoint argues that further innovations should be restricted unless their consequences are perfectly understood. While the idea of limiting the usage of novel technologies in order to prevent potential catastrophes is agreeable, it is not always possible to predict the implications that these new technologies will entail, and this is especially true when it comes to de-extinction. Though methods and models exist in ecology for predicting the outcome of a species reintroduction, the exact consequences of doing so are too complex and chaotic to be 'perfectly understood'. Not only that, but technology scepticism assumes that abstinence from rapid innovation is enough to right the trajectory humanity has been going on. It is my belief, however, that this trajectory has already been so far skewed away from a sustainable end point, that the only way to correct it would be to further lean into technology. Hesitation could, in fact, harm our chances of bettering our future.

Discussion and Conclusion

Though much of the mystique revolves around if and how it can be performed, de-extinction is as much of an ecological process as it is molecular. Producing a number of breeding individuals is merely the first step along an arduous journey involving habitat assessment, pre-release conditioning and population monitoring. Under the perspective of conservation, it is made clear that a solid understanding of the complexities of species re-introduction is necessary for any successful de-extinction operations. This implies familiarity with both the environment and the animal being released, with considerations such as environmental tipping points, minimum viable population sizes and Allee effects coming into play.

Knowledge on the specific molecular methods available will afford any potential de-extinction undertakings with the wisdom to choose the best route available. Back-breeding is a cheap and easy method of creating a species with ancestral ecological functions, but has the drawbacks of being low-accuracy and requiring information on the phylogeny of the target species. Cloning produces genetically identical copies of any given animal, so as long as tissue samples are available. Genetic engineering provides the most comprehensive solution, being able to replicate the target species even with sections of the genome missing, and provides the opportunity to fortify release groups while minimizing the impact of detrimental ecological effects.

De-extinction holds potential to be a precedent setting tool through which humans will have more control over nature. Through the advent of the industrial revolution, the rate at which anthropogenic activity influences ecosystems around the world has accelerated. This has created a scenario where human societies are in constant competition with their surrounding wildlife, in a fight which is both mutually detrimental and one sided. The many human-driven extinction events which took place throughout history serve as indicators to the scale at which we have caused irreversible damage to the world. Given the widespread use of other technologies labelled hubristic, such as genetic modification or biometric surveillance, ideas of technological conservatism serve only to hinder the progress towards de-extinction. Through pieces of media such as Jurassic Park and The Island, public perception towards new technologies, especially in the field of biology, have taken on a negative connotation. Concerns about these advancements typically state that humanity is ‘tampering with nature’ or ‘playing god’, and although the concern is understandable, they assume that restraint equals safety. We have been living in a world with genetically modified organisms being sold in supermarkets and domestic cats inhabiting almost every part of the globe. We have collectively already started down a road with no return, and so we must focus our gaze on the next horizons to prepare for the worst and bring about the best. Issues such as global warming and mass pollution must be solved through decisive action, and technology is one of the only tools we have at our disposal to do so. It is my belief that the answer to these problems lies in further encouraging innovation, and that adopting a greater sense of urgency will allow us to better make use of the limited time we have left.

Though the potential for disaster remains, venturing into unexplored waters will serve as a learning experience for humankind, and with knowledge comes power. Unfortunately we have progressed to a level of advancement where we can no longer rely on the sanctity and abundance of nature, and the time to take matters into our own hands draws closer. Though opinions towards technology, my own included, remain mixed, it has now become an unavoidable part of life on planet earth. We must accept this reality and plan for a world where technology and nature can co-exist. In an ideal future, collaborative efforts would halt the advancement of global warming and limit the impact human living has on nature. Should the way forward not be deviated, however, further catastrophes could necessitate the usage of novel, untested technologies as a last resort. This is why it is highly advisable that de-extinction be further explored and that existing or potential projects be given adequate support.

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