De-extinction: Who is First?

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0. Abstract

In this final essay in my series on de-extinction, I set out 15 questions surrounding justification, feasibility, likelihood of success and negative impacts, and public acceptance that can be used to assess the suitability of a de-extinction candidate species. I then use these criteria to evaluate the woolly mammoth, passenger pigeon, thylacine, dodo, and aurochs. From my analysis, I conclude that the passenger pigeon and aurochs are the most suitable for de-extinction while the woolly mammoth, thylacine, and dodo are less suitable, although all species have issues and require further research and development, especially regarding animal welfare and the likelihood of success and negative impacts.

1. Introduction:

Of the approximately 4 billion species that have lived on Earth since life first appeared 3.5 billion years ago, 1% survive today[1]. This means that there are approximately 3 960 000 000 extinct species that, theoretically, could be resurrected using de-extinction technologies. Practically, this number is a lot less as the oldest DNA that can be used for de-extinction has been extracted from 700000-year-old bones[2]. Nevertheless, the number of species that have gone extinct in just 700 000 years is incredibly high. This poses an important question to de-extinction practitioners: How will you choose which species to resurrect? Due to the financial, resource, and time costs of reviving one species, the prospect of resurrecting just the 900 species known to have gone extinct in the past 500 years[3] is intimidating. Therefore, guidelines regarding the selection of species for de-extinction are required. Indeed, the IUCN, within their guidelines for the creation of de-extinct creatures, put forth a suggestion for the criteria that should be used for the selection of candidate species, but no specific questions were outlined[4]. For the practice of de-extinction to be well-regulated, understood, and accepted on a global scale, it is necessary for candidate species to be assessed using a specific, simple, and understandable set of criteria which is, unfortunately, not currently available. In this third and final essay in my series on de-extinction, the format of which is inspired by Seddon et al. (2014)[5], I will be creating a list of questions based on those posed by Seddon[5], Shapiro[2], and others, which can be used to evaluate the suitability of a candidate species for de-extinction. I will then use my selection criteria to assess various candidate species and reach personal conclusions regarding their suitability. A summary of my findings will be presented in a table at the end of the essay. For each question I will state yes, no, uncertain, or, if the information is unavailable, unknown, followed by an explanation of my opinion.

2. Selection Criteria:

My de-extinction candidate species selection criteria are separated into five categories: Justification, Biological Feasibility, Likelihood of Success, Likelihood of Negative Impact and Public Acceptance.

Justification:

The questions in this category are focused on the reason why the scientist wishes to resurrect the species.

1. ***Are there environmental/ conservation reasons for de-extinction?***
   As discussed in the second essay in this series – De-extinction: the Good, the Bad, and the Unknown - potential benefits to the environment or conservation of other species are major motivations for de-extinction. This may be through the restoration of species interactions and the filling of ecological roles that have been lost through extinction[1]. Environmental and conservation benefit is most likely to occur when the extinction occurred recently enough for the ecological niche not to be filled, preferably under 70 generations[6]. Furthermore, species that have great impact on their ecosystem such as ecosystem engineers, indicator species, umbrella species, and keystone species, should be prioritised as their absence is likely to have had a great effect on both the environment and other species and so their reintroduction is likely to have the most benefit[7]. The ecosystem into which the de-extinct species will be released should be evaluated for productivity and species and functional diversity to make sure there is a need for the de-extinct species within that ecosystem.

2. ***Is de-extinction the only way to fulfil the objective of a project?***
   De-extinction is often thought of as the last option for conservation. It is less expensive and risky and more ethically acceptable to use living rather than de-extinct species to achieve environmental and conservation goals[3]. Therefore, all other conservation actions should be ruled out before de-extinction is considered. Assisted colonisation and ecological replacement, the release of species outside of their native range to avoid extinction and restore ecological function respectively[8], are forms of conservation translocation that can typically be more easily carried out with living species than de-extinct species. Therefore, extinct species that are most likely to be justified for de-extinction will be those that are evolutionarily and functionally unique[9], with no living close relatives that can act as proxies. Alternatively, close relatives may still be alive but endangered so moving them for conservation reasons may be seen as unethical.

Biological Feasibility:

Some species can be more easily revived than others[10] so it makes sense to prioritise candidate species that will take less time, effort, and money to resurrect, at least for the initial de-extinctions, until the technology has developed further.

3. ***Can usable DNA be obtained?***

   DNA, the key to de-extinction, begins to decay immediately after the death of the individual and has a half-life of 512 years[11]. To be useful for de-extinction purposes, it must be found in fragments longer than 30 base pairs[2]. This means that, theoretically, only individuals that have died in the past 1.5 million years will contain usable DNA[11]. Due to different rates of decay, however, DNA generally becomes unusable after about 100 000 years. It is possible to extract usable DNA from bones as old as 700 000 years, but these are rare occurrences and require optimal conditions. Therefore, species that went extinct within the last 100 000 years should be prioritised as it is most likely to obtain DNA from these species. Furthermore, cold, dry, and climatically consistent conditions are optimal for DNA preservation, so species that lived in these environments should be prioritised[2].

4. ***Has the candidate species, and any other species required for de-extinction, had its genome sequenced?***

   Genome sequencing is a requirement for de-extinction as, for the genome editing method of de-extinction, differences in the genomes of the extinct species and a close relative need to be identified. Unless the synthetic genomes approach to de-extinction is used, the full genome sequence is not required, although a considerable amount of the sequence is required for accurate de-extinction. A detailed explanation of the various de-extinction methods can be found in the first essay in this series – De-extinction: The Science behind the Fiction. If neither the extinct species nor the close relative(s) has had its genome sequenced and it is uncertain whether this may occur in the future, the species may be a poor candidate species due to the cost and lower likelihood of success.

5. ***Are appropriate surrogate and donor species available?***

   In any de-extinction process, living species with a close evolutionary relationship to the extinct species are required to act as donors of eggs and surrogates for the development of the de-extinct individual. The living species must be a close enough relative to the extinct species to avoid incompatibilities between the surrogate and the embryo which could decrease the success of the process. Furthermore, even if the living species is closely related to the extinct species, if there is a large difference in size or developmental environment between the species, success and animal welfare may also be compromised [2, 12]. Therefore, species should be prioritised for de-extinction if they already have, or it is likely to find, appropriate surrogate and donor species. These species will typically be recently extinct and not evolutionarily unique. Additionally, ethical issues may be raised if the surrogate/donor is an endangered species so effort should be taken to avoid this.

Likelihood of Success:

As only 11% of projects that aim to reintroduce living species into ecosystems are deemed successful[13], the likelihood of success of a de-extinction project is likely to be very low. Due to the various costs associated with de-extinction projects, the fear of failure is great and so projects that are the most likely to succeed should be prioritised.

6. ***Will it be possible to breed and raise the species in captivity?***
   Before they establish a self-sustaining population in the wild, de-extinct individuals will be bred and raised in captivity. This means that candidate species must respond well to these conditions, which is not inevitable. Firstly, the surrogate species must be able to breed and carry the embryo healthily to term. Secondly, the de-extinct individuals must be able to learn necessary survival skills in captivity. If the behaviours key to a species are mostly learnt from parents of that species, and these behaviours are different to those exhibited by the surrogate species, de-extinct individuals may be unable to survive when released into the wild[2]. Candidate species that have close relatives that show similar behavioural patterns should be prioritised, as should candidate species that require little parental care, respond well to captivity, and have simple survival and social needs that can be fulfilled easily.

7. ***Does the species have a suitable habitat that will remain suitable into the future?***
   As reintroduction success is greatly determined by the habitat that the species is released into, it is necessary to assess whether a habitat that meets the requirements of the de-extinct species is available[5]. The habitat must be large enough, provide food while excluding competitors and parasites, and be as close to the extinct species habitat as possible[2]. It is preferable for de-extinct species to be released within their native range, however, for long-extinct species and those that went extinct due to habitat loss, this may not be possible. Larger uncertainty regarding species interactions is likely to occur if the release site is outside native ranges, and it is more likely that the de-extinct species will become invasive if they are able to colonise areas beyond these ranges. Additionally, for long term success of projects, the suitability of the habitat must be confirmed for the foreseeable future. Suitable candidate species must have a protected habitat, preferably within their native range, which

is more likely to be found with recently extinct species. Furthermore, species that have 'unique and narrow niches'[14] are less likely to invade neighbouring habitats so should be prioritised[14].

8. ***Have past/future extinction threats been identified/removed/controlled?***
   Re-extinction is a threat for de-extinct populations as they are likely to be small and encountering new environments and species. It is therefore imperative that any causes of the original extinction are removed or controlled, and any new potential threats are identified with plans to address them when/if it becomes necessary[5]. Therefore, candidate species that have known and controllable extinction causes and those that have few future extinction threats should be prioritised, typically recently extinct species that went extinct due to direct human activity and will not face many new threats, such as predators or competitors, in the future.

9. ***Will it be possible to produce enough individuals with adequate genetic diversity?***
   The Allee effect states that for a population to be stable, it must remain larger than a threshold that is specific to that species[2]. It will therefore be necessary to produce enough de-extinct individuals to surpass this threshold, which may be very high for some species. Furthermore, adequate genetic diversity must exist within the population to allow for adaptation to the environment and increase the overall fitness of the population[2]. Consequently, candidate species that have short generation times and large litters should be prioritised[11], as should species where it is possible to obtain DNA from many individuals[2].

10. ***Is the biological knowledge of the species sufficient?***
    For a de-extinct species to be successfully born and raised in captivity and reintroduced into the wild, knowledge about their diet, parental care, interactions, behaviours, and habitat requirements and ranges are required. This information is more likely to be available for recently extinct species however living close relatives and fossilised remains can be helpful for long-extinct species [5, 15].

Likelihood of negative impacts:

No conservation strategy is without risk[2] but new techniques such as de-extinction are commonly seen as riskier than traditional conservation methods. It is therefore necessary to prioritise species that are the least likely to cause negative impacts on the environment and the health of other species, as well as those that are least likely to be negatively impacted by the de-extinction process, to protect the environment and other species and make de-extinction more acceptable to conservationists and the public alike.

11. ***Is there a low risk of the species having negative impacts on the environment and other species?***

    As discussed in the second essay in this series, a possible result of the reintroduction of de-extinct species is environmental harm. This may be through competition, predation or habitat modification which may cause the local extinction of existing species[5]. As the objective of many de-extinction projects is to reintroduce ecosystem engineers to restore ecosystems to more productive levels, some disruption is required, however, if de-extinct species become invasive, the environment may suffer[3]. Selected species should have a low risk of invasion and should be unlikely to harm the ecosystem, which is more likely for recently extinct species which are reintroduced into their native range[15].

12. ***Is there a low risk of the species posing or receiving negative health effects?***[5]

    A risk of introducing into a habitat a species that has not evolved alongside other species is the potential for the spread of disease and parasites both from the de-extinct species to others in the ecosystem and the reverse[5]. It is therefore necessary to evaluate the mutualistic relationships between all species and any parasites present in the ecosystem, as well as the presence of any disease which may be a re-extinction threat for the de-extinct species. Species that are most likely to have a low risk level are those that went extinct recently and can be reintroduced into their native habitat, as less evolution will have occurred in the ecosystem.

13. ***Is there a low risk of the species, or other species involved in its de-extinction, incurring negative welfare effects?***

    The various welfare issues that are possible in de-extinction have been thoroughly discussed in the second essay in this series.

    To reduce welfare issues during the cloning/ production stage, the surrogate and the embryo must be compatible and knowledge regarding the proper breeding and care of the surrogate species should be known[13]. Candidate species that have non-endangered close living relatives should be selected.

    To reduce welfare issues during the captive rearing process, information regarding the developmental needs of the de-extinct species is necessary[13]. Candidate species should be recently extinct or have a close enough relative from which such information can be inferred, and do not form large social groups that may not be possible to maintain in captivity.

To reduce welfare issues during the reintroduction process, knowledge surrounding the behaviours and requirements of the species in the wild. Preparation and training for eventual release must be given in captivity and long-term monitoring may be required[13]. Again, the most suitable species will be those that went extinct recently as this knowledge will be more complete than for those who went extinct further in the past. Furthermore, species that require limited parental care and do not have complex behavioural patterns should be prioritised as these features can be accommodated more easily in captivity training programs.

14. ***Can the species be removed if necessary?***

    Things don't always go to plan and the reintroduction of de-extinct species is unlikely to be successful. Therefore, it may be necessary to remove de-extinct individuals from the environment if they begin to pose an unacceptable risk to that environment. Species that are large and slow moving will be easier to identify and capture, as will those that stay within a reasonably small area which can be accessed by humans, and thus should be prioritised for de-extinction[5].

Public acceptance:

Public acceptance of de-extinction is important for the funding of research and the successful reintroduction of de-extinct species. How specific communities will react to the introduction of a 'new' species in their environment is determined by many factors and needs to be assessed before de-extinction takes place.

15. ***Will the public be accepting of the species?***

    It is possible that the public will be more accepting of species that they are interested in, have a strong cultural connection to, or may provide economic benefits in the form of tourism[5]. This means that large, charismatic species and symbolic species that went extinct recently enough to still be relevant to the community should be prioritised for de-extinction. Additionally, predators, carnivores, and disruptive species are considerably less likely than other species to be accepted if released near humans or livestock[5]. It may be sensible therefore to prioritise herbivores and species that are unlikely to cause problems for neighbouring humans.

Conclusion:

Each candidate species will receive a score out of 15 (1 for yes, 0.5 for uncertain, and 0 for no or unknown). A total score of 5 or less = not suitable for de-extinction, between 6 and 10 = uncertainty of suitability, more than 11 = generally suitable for de-extinction.

3. Candidate Species

The rest of this essay will consist of an evaluation of five species which are the subject of active de-extinction projects - the woolly mammoth, passenger pigeon, thylacine, dodo, and aurochs - using the 15 questions outlined in the previous section. A summary of my evaluations can be found towards the end of the essay.

3.1. Woolly Mammoth:

The woolly mammoth (*Mammuthus primigenius*) was a megaherbivore and ecosystem engineer that lived in the Arctic during the Pleistocene and went extinct approximately 4000 years ago[7]. It is the 'poster child' of the de-extinction movement and as such there are several projects around the world working to resurrect this symbolic animal. The most important of these is the one being undertaken by Colossal Laboratories[16].

1. ***Are there environmental/ conservation reasons for de-extinction?***
   Yes.
   The potential environmental and conservation benefit of mammoth reintroduction into Siberia is emphasised throughout the de-extinction literature. Firstly, the great size of the mammoth means that it is uniquely capable of knocking over trees to be produce more productive and biodiverse grassland ecosystems. Secondly, grazing and trampling of snow-covered grass would make the snow a poorer insulator so the permafrost would remain frozen throughout the winter. This would prevent the release of approximately 1.3 trillion tonnes of carbon into the atmosphere due to permafrost melting which will prevent the acceleration of climate change[3]. Furthermore, expanding the range of endangered elephant species through the production of cold-resistant elephants is a potential conservation benefit of mammoth de-extinction[12].

2. Is de-extinction the only way to fulfil the objective of the project?

No.

The work currently being conducted in Pleistocene Park, Siberia, shows that the permafrost cooling effect can be obtained through the introduction of herbivores such as elk, moose, and bison and without the need for the woolly mammoth[17]. Although the mammoth is the only species of sufficient size to knock down trees, the protection of the permafrost does not require this[3] and it is possible for humans to remove the trees to produce a more open steppe environment. Additionally, it may be possible for non-genetically engineered elephants to be translocated to parts of Europe for conservation purposes[2].

3. Can usable DNA be obtained?

Yes.

Since mammoth remains are commonly found frozen in the permafrost soil of their Arctic habitat, considerable amounts of DNA have been obtained. The size of the mammoth means that the freezing of the body takes time so the DNA begins to decay before full freezing of the body can take place, but the seemingly ideal preservation conditions means that DNA strands between 30 and 90 base pairs in length have been found and can be used for de-extinction[2].

4. Has the candidate species, and any other species required for de-extinction, had its genome sequenced?

Yes.

The genomes of the woolly mammoth[18, 19] and its two closest living relatives the Asian elephant (*Elephas maximus*)[20] and the African savanna elephant (*Loxodonta africana*)[21] have all been sequenced.

5. Are appropriate surrogate and donor species available?

Uncertain.

Although the Asian elephant is a close enough relative to the woolly mammoth to not require too much genome editing (a total of 1.5 million differences[2] in a genome of approximately 4.7 billion bases[18]), both the Asian and African savanna elephants are considered endangered by the IUCN and their populations are still declining[22, 23]. It may not be ethical, therefore, to use these species in risky cloning experiments that have a high likelihood of failure. Further development of de-extinction techniques and technologies should occur before de-extinction involving endangered species takes place.

6. ***Will it be possible to breed and raise the species in captivity?***

   No.

   Although it is known that close relatives can vary in how the respond to life in captivity, it may be inferred from the fact that elephants do not respond well that mammoth will not do so either. One of the biggest problems facing elephants in captivity is that the large social groups and dynamics that they form in the wild cannot be currently replicated in captivity. This could lead to problems when reintroducing individuals into the wild[2]. It is not known how a mammoth would respond to being raised in captivity but if its needs cannot be fulfilled it would be unethical and counterproductive to resurrect the species.

7. ***Does the species have a suitable habitat that will remain suitable into the future?***

   Yes.

   It is believed that, although the climate is warmer now than during the Pleistocene, the present climate of Siberia may be acceptable or even optimal for mammoth survival. The mammoth steppe ecosystem created and required by mammoths is no longer present, however it can be resurrected along with the mammoth as the grazing of herbivores has been shown to recreate this habitat within Pleistocene Park[24]. The goal of the mammoth de-extinction project is to prevent the acceleration of climate change so, if mammoths can indeed fulfil this goal, their own actions in engineering their ecosystem will mean that the habitat will remain suitable into the future.

8. ***Have past/future extinction threats been identified/removed/controlled?***

   Yes.

   It is generally believed that the extinction of the mammoths was due to a combination of human hunting and climate change which changed the mammoth steppe grassland into an inhospitable tundra[17]. The mammoths persisted during warmer inter-glacial periods and survived alongside humans during the late Pleistocene/ early Holocene so, individually these extinction threats are unlikely to have been the cause of mammoth extinction[2]. Although the current climate is warmer than when mammoths were at their most abundant, it is likely that they will survive well today. Additionally, human hunting for survival is no longer necessary so this extinction threat has been removed. A possible new extinction threat is human hunting for sport or trade as approximately 55 tonnes of mammoth ivory is sold every year[3]. Protections similar to those in place to protect elephants and rhinoceroses would be required to prevent re-extinction due to hunting.

9. ***Will it be possible to produce enough individuals with adequate genetic diversity?***

No.

Although the remains of mammoths are described as 'abundant'[2], suggesting that genetically diverse DNA can be retrieved, the surrogate species, likely the Asian elephant, is endangered so the diversity within the living population may be low. Furthermore, as elephants are highly social creatures that require large herds in the wild[2], it must be possible to produce high numbers of de-extinct mammoths which may be difficult as female elephants only birth one baby approximately every 5 years[25] causing the average generation length to be 22 years[6].

10. ***Is the biological knowledge of the species sufficient?***

No.

It is generally believed that biological knowledge learnt from elephants can be used for mammoths, especially since the finding that baby mammoths, like elephants, ate the faeces of their mother to take in necessary microbes[2]. However, the fact that elephants fare so poorly in captivity may be due to a lack of information regarding their survival requirements. More research is therefore required before biological knowledge can be classed as sufficient.

11. ***Is there a low risk of the species having negative impacts on the environment and other species?***

Yes.

Although the environmental benefits of mammoth reintroduction into Siberia include the apparent destruction of the current landscape, it is for the long-term restoration of a more productive and biodiverse ecosystem so the initial disturbance to forests and the few species that live there is unlikely to be seen as negative. One theory suggests that removing the insulating snow, as mammoth grazing would do, may cause the permafrost to increase, instead of decrease, in temperature if the winters are too warm. This is a genuine risk but, as the Pleistocene Park experiment has shown a decrease in permafrost temperature due to grazing, the current winter temperatures are not too high to reverse the effect[17]. This is something to be monitored and, if temperatures do surpass a threshold that would lead to a warming effect, the experiment should be terminated.

12. ***Is there a low risk of the species posing or receiving negative health effects?***

    Unknown.

    Although there may be some indirect evidence to suggest that woolly mammoths may be susceptible to tuberculosis[26], there does not appear to be enough research on the topic of health effects to form an opinion.

13. ***Is there a low risk of the species, or other species involved in its de-extinction, incurring negative welfare effects?***

    No.

    During the cloning process, the surrogate elephant may be harmed by the development of ovarian tumours and the pressure on the body of an interspecies pregnancy. The mammoth offspring may also be harmed due to the inefficient cloning process which leads to most experiments ending in miscarriage, development abnormalities, or premature death. Surrogate harm may be avoided by use of an artificial uterus and offspring harm may be minimised by the development of cloning procedures, but both solutions are unlikely to occur in the near future[27].

    During the captive rearing process, welfare issues such as psychological distress, poor health, and difficulty reproducing are common in elephants so it is likely that they will also be seen for mammoths[2].

    During the reintroduction process, as parental care and social groups may be necessary for mammoth learning and survival, the fact that these cannot currently be adequately provided in a captive environment means that welfare issues may occur when mammoths are reintroduced into the wild[2].

14. ***Can the species be removed if necessary?***

    Yes.

    As the mammoth was very large it could be seen easily. The top speed of the mammoth is estimated to be 20 miles per hour which means that it can be caught quite easily by a vehicle[16]. A key feature of the mammoth was its ability to travel long distances which may become an issue, but the species should be easy enough to monitor and control[9]. Finally, if mammoth reproduction is anything like elephant reproduction, rapid, unexpected, and uncontrollable expansion of the population is unlikely to occur, making removal easier.

15. ***Will the public be accepting of the species?***
    Uncertain.
    There are certainly some reasons why the public may be accepting of the woolly mammoth. A feeling of justice towards a species that humans rendered extinct as well as the wonder and economic benefits that may be provided by 'mammoth tourism' are strong indicators that woolly mammoth de-extinction will be accepted[27]. The facts that the mammoth was a herbivore and will be reintroduced into a relatively unpopulated habitat are also appealing. However, the possibility for conflicts between humans and mammoths cannot be ignored, especially if additional protections enforced to prevent the re-extinction of the mammoth stops the highly lucrative ivory trade out of Siberia. Additionally, some communities and cultures, especially those with a history of living side by side with mammoths, see mammoths as an ill omen and representative of the underworld[2], possibly reducing acceptance of mammoth reintroduction in the communities most affected.

Conclusion:

With a total score of 8 out of 15 (53%), I am uncertain about the woolly mammoth's suitability for de-extinction. There are certainly benefits, most notably environmental and public related, but significant problems arise when considering the prospective health and survival of any individual mammoth. Whether de-extinction is necessary to achieve the goals of the project is not clear. Ultimately, although de-extinction of the woolly mammoth is being actively pursued, large developments and research are required to make mammoth de-extinction and reintroduction ethical and effective.

3.2. Passenger Pigeon:

The passenger pigeon (*Ectopistes migratorius*) was an ecosystem engineer native to the United States that went extinct in 1914[7]. The passenger pigeon is considered an important species for de-extinction and a project led by Revive & Restore is actively trying to resurrect the species[28].

1. ***Are there environmental/ conservation reasons for de-extinction?***
    Yes.
    The disruptive nature of the passenger pigeon meant that the forests that they nested in were subjected to cycles of destruction and regeneration which supported many different

animal and plant species[28]. Since its extinction, these successional forests have become rare[7] which has led to declines in the species that traditionally lived there. The reintroduction of the passenger pigeon has the potential to restore these cyclical forests and increase species diversity and richness[28].

2. ***Is de-extinction the only way to fulfil the objective of a project?***

   Yes.

   The passenger pigeon was a unique species as it formed flocks of approximately 1 billion birds[29] that would fly across the eastern United States without any fixed route[2]. The sheer size of these flocks meant that the forests that they nested in were disrupted through the breaking of branches and the excreta the birds left behind. Seeds were distributed great distances and animal behaviour were affected[9]. Over the century since its extinction, humans have attempted to mimic the behaviour of the passenger pigeon flock but to little success[7]. Ultimately, the behaviour of the passenger pigeon was so unique and influential to the life of the forest that de-extinction appears to be the only way to restore it.

3. ***Can usable DNA be obtained?***

   Yes.

   As only 110 years have passed since the extinction of the passenger pigeon and it was already an established practice to preserve animals in museums by the beginning of the 20th century, there is a large store of passenger pigeon DNA that could be used for de-extinction[2]. Chemicals that were used to preserve the birds are likely to have degraded the DNA somewhat[3] but there should be enough samples to make de-extinction feasible.

4. ***Has the candidate species, and any other species required for de-extinction, had its genome sequenced?***

   Yes.

   Although genomes for both the band-tailed pigeon (*Patagioenas fasciata monilis*)[30] and rock pigeon (*Columba livia*)[31] have been sequenced, only the mitochondrial genome of the passenger pigeon[32] has been deposited in the NCBI genome database. Passenger pigeon nuclear genomes have been sequenced, however[28].

5. ***Are appropriate surrogate and donor species available?***

   Yes.

   The closest living relative of the passenger pigeon is the band-tailed pigeon which is classified by the IUCN as a species of Least Concern[33]. This species will be used as a donor species whose genome will be edited to include passenger pigeon DNA[28]. The rock pigeon will be used as the surrogate species[28] and is also classified as a species of Least Concern[34]. There are therefore no ethical concerns regarding the use of surrogate or donor species, and both appear to be appropriate for the project.

6. ***Will it be possible to breed and raise the species in captivity?***
   Uncertain.
   Although there is a quite comprehensive method for the raising and teaching of passenger pigeons using other bird species[3, 28, 35], the feasibility of this method is unknown. The generation length is approximately 7 years[6] but it is possible to obtain new eggs from mature birds every 8-10 days[28] so large numbers of pigeons can be produced rapidly, although it will take some time to produce flocks of differently aged pigeons. However, the 1-billion-strong flocks of the past may be too large to create. It is thought that 100 000 birds will be enough to have an impact on the environment[3], but this is still likely to be challenging. The non-migratory nature of the passenger pigeon[2] means that they will be easier to raise in captivity but behaviours, including random flight patterns, need to be taught. Ultimately, there are reasons to be both optimistic and sceptical about the passenger pigeon's ability to be raised in captivity and a conclusion will only be reached once experiments are underway.

7. ***Does the species have a suitable habitat that will remain suitable into the future?***
   Yes.
   There have been clear changes in the environment since the extinction of the passenger pigeon 110 years ago with their forest homes being taken over by humans[2]. However, climatically, there are areas that are and will remain suitable for passenger pigeons breeding and survival[14].

8. ***Have past/future extinction threats been identified/removed/controlled?***
   Uncertain.
   Human hunting and habitat destruction caused the passenger pigeon to go from the most abundant bird species in the world to extinct in just 50 years[3]. Unfortunately, although these extinction threats have been identified, it is unknown whether it will be possible to control the hunting of the passenger pigeon, especially when they inevitably become a disturbance to humans.

9. ***Will it be possible to produce enough individuals with adequate genetic diversity?***
   Yes.
   As there are many passenger pigeons stored in museums[2] and the donor band-tailed pigeon is not endangered, it is likely that adequate genetic diversity can be obtained. Furthermore, the rapid production of eggs from mature individuals shows that it may be possible to produce large numbers of passenger pigeons in a short time[28]. Whether it will be possible to produce large enough flocks remains to be seen but there is certainly reason to be optimistic.

10. ***Is the biological knowledge of the species sufficient?***
    Yes.
    The relatively recent extinction of the passenger pigeon means that their behaviour and requirements have been studied well. There are still unknowns such as how much of their behaviour was learnt from parents and how much was genetically encoded[9], but requirements for habitat, diet, and impact are relatively well known.

11. ***Is there a low risk of the species having negative impacts on the environment and other species?***
    No.
    As suitable habitat extends beyond native ranges, colonisation and invasion of these new spaces is likely and therefore interactions with the environment and other species will be unknown and possibly negative[14].

12. ***Is there a low risk of the species posing or receiving negative health effects?***[5]
    Uncertain.
    Pigeons are known to carry diseases which they can spread to humans through their droppings[36]. If passenger pigeons are vectors for the same or different diseases as other species, their large flocks which create large amounts of droppings may be a health risk to humans. However, it is unknown whether this is the case. Furthermore, it is not known how the passenger pigeon will be affected by new diseases within their environment.

13. ***Is there a low risk of the species, or other species involved in its de-extinction, incurring negative welfare effects?***

    Uncertain.

    The use of non-endangered species as surrogate and donor species and the use of the more efficient PGC cloning method means that welfare issues at the cloning stage are, although not non-existent, certainly minimised[2].

    During the captive rearing stage, the hypersocial nature of the passenger pigeon could cause welfare issues as there is a limit to how many pigeons can be raised in captivity at once[9].

    During the reintroduction stage, possible welfare issues could be produced if flocks of an appropriate size cannot be produced or if species confusion occurs which causes clashes between the individuals genetically and environmentally encoded behaviours[2].

14. ***Can the species be removed if necessary?***[5]

    Yes.

    The large flocks make it easier to locate the pigeons and it is likely that, once the flock dips below a population threshold, the remaining individuals will be less fit and will die without further intervention[2].

15. ***Will the public be accepting of the species?***

    No.

    Although some of the foremost proponents of passenger pigeon de-extinction believe that the wonder that will come from seeing large flocks of passenger pigeons will counteract the disruption that they will cause, I disagree. The destruction that passenger pigeons cause is unlikely to stop with the forests in which they nest. It is possible, for example, that the mass-movement of up to a billion birds will cause disruption to the infrastructure of cities which, although short lived, could be greatly disruptive to the people living there. The mess and noise caused by the birds will also likely be a source of annoyance[2].

Conclusion:

With a score of 11/15 (73%), I believe that the passenger pigeon is generally suitable for de-extinction although work is needed to reduce the risk of negative impacts on the environment and to make the public more accepting of the species.

3.3. Thylacine

The thylacine (*Thylacinus cynocephalus*), or Tasmanian tiger, was an apex predator[37] that went extinct in Tasmania, Australia in 1936[6]. A cloning experiment starting in 1999 failed to resurrect the species[38], but Colossal Laboratories is actively pursuing genetic engineering to reintroduce the thylacine to the world[37].

1. ***Are there environmental/ conservation reasons for de-extinction?***

   Yes.

   The reintroduction of the thylacine has the potential to control the population of small mammals, especially rabbits, that rapidly increased after the extinction of their predator. These small mammals damage the environment through foraging and eating crops which is thought to be a reason for the increased number of wildfires in the country. If a predator such as the thylacine was reintroduced into the environment, they may act as a 'trophic biocontrol' to restore the environment to a healthier state. Additionally, development of scientific knowledge and techniques could be of use for the conservation of endangered marsupials more generally[37].

2. ***Is de-extinction the only way to fulfil the objective of a project?***

   Uncertain.

   Even though only 17 generations are estimated to have occurred since its extinction[6], the apex predator niche has been filled by the dingo which has controlled kangaroo and emu populations and increased the health of the environment, as the thylacine would do. Due to some slight differences in the behaviour of the two species, however, it is possible that they may fill slightly different niches and so can work alongside each other to control other species[37]. Furthermore, the thylacine is evolutionarily unique[39] which increases the likelihood that it is also functionally unique and therefore necessary for the project.

3. ***Can usable DNA be obtained?***

   Yes.

   Although the previous failed cloning experiment suggests that obtained thylacine DNA is too damaged for cloning, it should be preserved well enough for genetic engineering due to recent extinction and preservation in museums[40].

4. **Has the candidate species, and any other species required for de-extinction, had its genome sequenced?**

   Yes.

   The thylacine has a contaminated sequence in the NCBI genome database[41] and the fat-tailed dunnart (*Sminthopsis crassicaudata*) has a partial sequence[42]. The Tasmanian Devil (*Sarcophilus harrisii*) has a full reference sequence[43].

5. ***Are appropriate surrogate and donor species available?***

   Uncertain.

   As the thylacine was the last member of the Thylacinidae family, it does not have any living close relatives. The closest living relative is the fat-tailed dunnart of the Dasyuridae family, which diverged from the thylacine 70 million years ago. Projects using the fat-tailed dunnart[37] and the related Tasmanian Devil[40] have been suggested but whether these will succeed or not is unknown. As the fat-tailed dunnart is classified as a species of Least Concern[44] and the Tasmanian Devil is classified as endangered[45], the fat-tailed dunnart project currently overseen by Colossal is the most ethical thylacine de-extinction project.

6. ***Will it be possible to breed and raise the species in captivity?***

   No.

   The thylacine did not fare well when kept in captivity in the past. Specifically, illness and death due to not eating, and an inability to breed were common[46, 47].

7. ***Does the species have a suitable habitat that will remain suitable into the future?***

   Yes.

   The range of habitats previously occupied by the thylacine is quite varied and unchanged[37] so most experts believe that the species can be reintroduced into its former ranges without much problem[5, 11, 40]. However, an expert disputes this assumption and believes that, due to habitat destruction and climate change, adequate thylacine habitat no longer exists[48]. The original population is thought to have declined partly due to climate change[40] so future climatic suitability should be assessed.

8. ***Have past/future extinction threats been identified/removed/controlled?***

   Yes.

   The original thylacine population declined due to climate change and dingo protection and the eventual extinction was due to government endorsed hunting[5, 40]. Protections were provided in 1936, too late to prevent the extinction but possibly signalling a change in public opinion that would lead to the hunting pressure being lifted. Competition with other predators such as the dingo and the Tasmanian devil may pose an extinction risk[37]. To control this risk, it may be sensible to release the thylacine in habitats that do not currently contain other predators.

9. ***Will it be possible to produce enough individuals with adequate genetic diversity?***
   Uncertain.
   Although there are many preserved thylacines in museum collections and the prospective surrogate species is not endangered, there is some debate over whether it will be possible to produce a thylacine population with enough genetic diversity for survival[48]. With a generation length of under 5 years[6], and litter sizes of up to 4 joeys[37] it may be possible to produce a considerable number of individuals in a short amount of time.

10. ***Is the biological knowledge of the species sufficient?***
    Uncertain.
    Information regarding the diet, habitat, and life cycle of the thylacine are known[47] but as their ability to survive and breed in captivity was compromised, this knowledge may be incorrect or insufficient.

11. ***Is there a low risk of the species having negative impacts on the environment and other species?***
    Yes.
    The carnivorous nature of the thylacine means that negative impacts on other species, specifically the predation of livestock, are possible[47]. That being said, the relatively recent extinction combined with the probable continued existence of native habitat suggests that the thylacine will fill its original ecological role and not become invasive, hence have minimal negative impact on the environment and other species.

12. ***Is there a low risk of the species posing or receiving negative health effects?***
    Unknown.
    It is not known whether the thylacine will pose or receive health risks. The invasive cane toad may pose a risk to thylacine health, but work is being done to reduce this risk[49]. Additionally, roundworms, tapeworms, and fleas have all been recorded on thylacines but the effect of them on other species is not known[5].

13. ***Is there a low risk of the species, or other species involved in its de-extinction, incurring negative welfare effects?***

    No.

    During the cloning stage, a small surrogate (fat-tailed dunnart) will be used to gestate the considerably larger thylacine. Ordinarily this would be a major welfare issue but due to the specific biology of marsupials, newborn joeys are very small and grow to their full size outside of the host, meaning that there should be no issues during gestation or birth, except for those linked to the cloning procedure itself[37]. An artificial uterus is in development to avoid the use of a surrogate altogether, but this is not currently available[49].

    During the captive rearing stage, negative welfare effects may occur if the correct way of raising the thylacine is not found. Research has taken place since the extinction so it is likely that individuals will survive better in captivity now than in the past, but there is still risk and uncertainty in this stage.

    During the reintroduction stage, negative welfare effects may occur if competition exists between the thylacine and other predators such as the dingo, if sufficient habitat is not present, or if previous hunting practices cannot be controlled[37].

14. ***Can the species be removed if necessary?***[5]

    Yes.

    As the thylacine is relatively slow[37] and live in small groups and small areas[5] it is likely that they will be easily removable.

15. ***Will the public be accepting of the species?***

    Uncertain.

    In the years since the extinction of the thylacine, it has become a cultural symbol of Tasmania so it is likely that many individuals will be accepting of its reintroduction on to the island. The support for the reintroduction of the Tasmanian Devil is indicative of increased acceptance and interest in bringing back native species. Additionally, a great amount of tourism may be created through the project which is likely to increase acceptance more. However, it is likely that landowners and especially livestock owners will be apprehensive or outright hostile towards the concept of reintroducing predators into the environment[5]. Generally, carnivores are unlikely to be accepted by the public[50]. Ultimately, the question of public acceptance is incredibly complicated for the thylacine and will require public engagement and debate.

Conclusion:

With a score of 9.5/15 (63%), I am uncertain of the suitability of the thylacine for de-extinction. There is a great amount of uncertainty regarding the biological feasibility, justification, and the likelihood of success of the project and not enough is known about the negative impacts to make a definite decision. More work is needed to make sure that the welfare of de-extinct individuals is not compromised and that the public will be accepting of the species if it were to be released.

3.4. Dodo:

The dodo (*Raphus cucullatus*) was a large pigeon native to the island of Mauritius[2] that went extinct in 1662[6]. The dodo has long been seen as a symbol of human-induced extinction[2] and as such great interest has been generated by the possibility of its resurrection. Colossal Laboratories is actively pursuing this project[51].

1. ***Are there environmental/ conservation reasons for de-extinction?***

   Yes.

   Unlike other species discussed, the dodo appears to be a 'flagship species' whose de-extinction, instead of having a direct impact on the environment, will increase interest in the creation of a suitable habitat which will allow for the protection of other endangered species native to Mauritius[2, 51].

2. ***Is de-extinction the only way to fulfil the objective of a project?***

   No.

   As the most impactful aspect of dodo de-extinction would be its diversion of resources and attention to the Mauritius habitat, the dodo itself is not necessary for the conservation project to succeed. Alternatives would be campaigns to protect endangered species currently living in Mauritius. However, the interest generated by dodo de-extinction would be effective in producing necessary funds and attention and possibly may not be replicated by traditional conservation projects.

3. ***Can usable DNA be obtained?***

Yes.

Although extinction occurred 362 years ago and the tropical native habitat of the dodo is not conducive to DNA preservation, the remains of dodos are stored in museums so it is possible that damaged but usable DNA will be available for de-extinction[2].

4. ***Has the candidate species, and any other species required for de-extinction, had its genome sequenced?***

Yes.

The dodo[51] and its closest living relative, the Nicobar pigeon (C*aloenas nicobarica*), have had their genome sequenced[52].

5. ***Are appropriate surrogate and donor species available?***

Yes.

The Nicobar pigeon is classified as Near Threatened by the IUCN[53] so it could be generally deemed as ethical to use as a surrogate, and it is in the same family as the dodo so should be a close enough relative for effective de-extinction.

6. ***Will it be possible to breed and raise the species in captivity?***

Uncertain.

Although little is known about how the dodo will respond to captivity, there is cause for optimism as it appears that the Nicobar pigeon fares very well[54]. Similarities in diet and behaviour suggest that the dodo will also react well but there is great uncertainty.

7. ***Does the species have a suitable habitat that will remain suitable into the future?***[5]

No.

There is currently no appropriate habitat for the dodo to be reintroduced to on the island of Mauritius due to deforestation and invasive species. If the dodo were to be reintroduced, suitable habitat would need to be created by humans[2].

8. ***Have past/future extinction threats been identified/removed/controlled?***

No.

It is generally believed that dodo extinction was due to a combination of human hunting, deforestation due to human settlement, and invasion by cats, rats, pigs, and other species which destroyed the ground-level nests and ate the eggs of the dodo[2, 51, 56]. Although human hunting can be controlled, the habitat destruction caused by deforestation is harder to recover, and the removal of invasive species that would pose a continued extinction risk is harder still. Furthermore, future extinction threats remain unknown.

9. ***Will it be possible to produce enough individuals with adequate genetic diversity?***
   Unknown.
   It is not known how many individuals will be required to create a sustainable population, nor how much genetic diversity exists in the dodo remains preserved in museums. As the dodo only produced one egg per year[51] it is likely that a large population will not be feasible to produce.

10. ***Is the biological knowledge of the species sufficient?***
    Uncertain.
    Information regarding diet and habitat are known[51] but whether this knowledge is sufficient for appropriate raising and teaching of behaviours is uncertain.

11. ***Is there a low risk of the species having negative impacts on the environment and other species?***
    Yes.
    Although its native habitat is no longer suitable, if the dodo were reintroduced into a 'clean' Mauritius (i.e. if invasive species were removed leaving only native species) it is likely that there would be minimal risk of negative environmental impacts.

12. ***Is there a low risk of the species posing or receiving negative health effects?***
    Unknown.
    There currently appears to be little information regarding the possible health impacts of dodo de-extinction for the dodo and other species. Even if only native species that co-evolved with the dodo were left in Mauritius after the environmental 'clean-up', it is likely that there will be some mismatch in the parasites and disease defences evolved in the dodo and other species due to the 362 years that evolution has continued to occur without the dodo. Whether these mismatches will prove dangerous is yet to be fully researched.

13. ***Is there a low risk of the species, or other species involved in its de-extinction, incurring negative welfare effects?***
    Uncertain.
    Welfare issues for the Nicobar pigeon surrogate are possible during the cloning stage, however these are reduced using the more effective PGC transfer method of cloning.

During the captive rearing stage, it is unknown whether there will be significant welfare issues as, although the Nicobar pigeon has been shown to respond well to captivity, the same may not be so for the dodo. If the needs of the dodo are not met, then welfare problems may present themselves. There is reason to be optimistic, however, as the dodo had a reasonably varied diet, limited habitat requirements, and could not fly[51] so their needs may be accommodated within a captive setting.

There is the potential for welfare issues during the reintroduction stage if extinction threats are not removed from the environment and if the captive rearing process does not adequately prepare the species for life in the wild. It has been shown that Nicobar pigeons are more friendly towards humans in captivity[57] which could pose welfare issues if the dodo reacts to humans similarly.

14. ***Can the species be removed if necessary?***

    Yes.

    As the dodo is flightless, large and lives on the forest floor[51] they should be relatively easy to capture and remove the environment.

15. ***Will the public be accepting of the species?***

    Yes.

    The symbolic nature of the dodo and its potential to increase tourism to Mauritius are factors that may increase the acceptance of de-extinction[2]. Additionally, the requirement for an environmental 'clean-up' to safely reintroduce the dodo will be an additional incentive as this will be beneficial both for native species and indigenous communities. Nevertheless, in depth public discussions should take place before any reintroductions are made to be sure of public acceptance and support.

Conclusion:

With a score of 8.5/15 (57%), I am uncertain of the dodo's suitability as a de-extinction candidate species. The environmental and conservation benefits are exciting but as the dodo itself will not be responsible for enacting these benefits the justification for the project is uncertain. Additionally, there are several unknowns regarding how successful the project will be and the ability for the project to avoid negative impacts. Ultimately, much more research is needed to answer important questions more fully.

3.5. Aurochs:

The aurochs (*Bos taurus primigenius*) was a wild species of cattle which was domesticated to produce the various lineages of domestic cattle we see today[10]. The species officially went extinct in 1627 and since the 1920s various projects have attempted to resurrect the species through backbreeding[7], including the Heck project, the Uruz project, and the Tauros programme. The latter project will form the basis of this section.

1. ***Are there environmental/ conservation reasons for de-extinction?***

   Yes.

   Like the woolly mammoth, the aurochs was an ecosystem engineer that grazed and therefore maintained the grassland ecosystems of Europe[7]. Resurrecting this species and their ecological role could lead to the restoration of the steppe-like environment that supported a greater number of species than can currently be housed in the present ecosystems[2, 3].

2. ***Is de-extinction the only way to fulfil the objective of a project?***

   Uncertain.

   Although the aurochs, as a megaherbivore, had a very important and influential role in the shaping of European landscape, it is possible that other species such as bison, ibex, horses, and deer may also fill this ecological role. The aurochs was heavier than these other species[58] so the effect of aurochs grazing and living in the ecosystem may be greater than for other species, so aurochs' de-extinction may be necessary for project success or at least success in a timely manner, but this is uncertain.

3. ***Can usable DNA be obtained?***

   Yes.

   Unlike genetic engineering methods of de-extinction, backbreeding doesn't require the direct manipulation of DNA so physically obtaining DNA is not necessary. However, as all modern cattle breeds are descended from the aurochs, the genome of the ancient species should be still present, although likely distributed across many lineages. It may, therefore, be possible to selectively breed different species to reconstitute the aurochs' genome in one lineage[2].

4. ***Has the candidate species, and any other species required for de-extinction, had its genome sequenced?***

   Yes.

   Again, genome sequencing is not a requirement for the backbreeding approach to de-extinction, but it could be helpful in guiding breeding experiments. Domestic cattle (*bos taurus)* has had its genome sequenced[59] as has the aurochs[60]. Genetic studies have been conducted on the various breeds of domestic cattle chosen for the project[58].

5. ***Are appropriate surrogate and donor species available?***

   Yes.

   Six main breeds of domestic cattle have been chosen by the Tauros programme[57] and as they are domestic animals, they are unlikely to be endangered. The successive and gradual nature of backbreeding means that any differences between a mother and offspring are likely to be small so there is limited risk of incompatibility-induced problems in gestation or birth.

6. ***Will it be possible to breed and raise the species in captivity?***

   Yes.

   As the breeds involved in the project are already domesticated, a lot of knowledge has already been obtained regarding how to breed and raise individuals in a non-wild setting. The Tauros programme outlines a four-stage programme going from domestic to feral to wild aurochs[58] which suggests that they have a comprehensive plan of how to achieve the goal of produce wild aurochs.

7. ***Does the species have a suitable habitat that will remain suitable into the future?***

   Yes.

   Appropriate habitat has been sourced in six countries across Europe[58] and aurochs have already been released in Portugal[61] and Spain[62].

8. ***Have past/future extinction threats been identified/removed/controlled?***

   Yes.

   The main cause of aurochs decline would have been increased domestication and the final extinction threat is likely to have been human pressures such as hunting and habitat loss[63]. These threats can be removed by ensuring that protections are in place for the aurochs and their habitat. Releasing aurochs exclusively into managed nature reserve allows for protections to be enforced and prevents human-aurochs conflicts from occurring.

9. ***Will it be possible to produce enough individuals with adequate genetic diversity?***

   Yes.

   As female cattle can birth their first calf at just 18 months old, breeding can occur rapidly which is good as backbreeding requires many generations to produce the desired product[2]. The use of several different breeds of cattle in the backbreeding experiments means that the genetic diversity within the final aurochs' population will be relatively high. Additionally, genome sequencing can be used to guide experiments to maximise genetic diversity.

10. ***Is the biological knowledge of the species sufficient?***

    Yes.

    The phenotype of the aurochs is generally well described in ancient artefacts such as art and fossils[64] and the genome of the aurochs has been sequenced so the end-goal of backbreeding experiments is generally well understood. Additionally, the diet, habitat and general survival requirements are known[65] and much can be inferred from more primitive domestic breeds of cattle.

11. ***Is there a low risk of the species having negative impacts on the environment and other species?***

    Yes.

    For the majority of Europe, it has been 2000 years since the aurochs has roamed[10] meaning that it is possible that the reintroduction of such a disruptive species will negatively impact the environment and other species through invasion. However, most of the ecosystems targeted for aurochs release are species-poor and recovering from recent agricultural use. It is therefore more likely that any impact the aurochs will have on an ecosystem will be positive. An important negative impact could be the potential for hybridisation of the aurochs with domestic cattle causing so-called genetic-based extinction[65], but this can be controlled by judicious selection of release sites away from domestic herds and monitoring of aurochs herds.

12. ***Is there a low risk of the species posing or receiving negative health effects?***

    Uncertain.

    As there is no cloning involved, there is no risk of resurrecting ancient pathogens in the de-extinction process. However, the aurochs may be susceptible to new pathogens in the environment, including diseases from domesticated cattle which was a potential cause of original aurochs decline[65], and may be in poorer health than their extinct relatives due to the lack of symbiotic parasites that may be important for aurochs health and behaviour.

13. ***Is there a low risk of the species, or other species involved in its de-extinction, incurring negative welfare effects?***

    Yes.

    During the backbreeding stage, mating different breeds of cattle together may cause incompatibilities and welfare issues in mating, gestation, and birth, but these issues can be minimised through using artificial insemination, artificial uteri, or simply using the wealth of knowledge of breeding domestic cattle to appropriately select mating pairs.

    During the captive rearing stage, there is unlikely to be considerable welfare issues due to the gradual nature of backbreeding which will minimise the species confusion experienced by offspring. Differences between the current generation and the next one are likely to be small which means that survival requirements will also tend to be minimally different so handlers should be able to accommodate these requirements without much difficulty.

    During the reintroduction stage, there is possibility for welfare issues if the habitat is not suitable for the species or if parasites, or lack thereof, alter the behaviour or health of the species. As the backbreeding process is gradual, however, these problems are likely to be noticed and solved prior to reintroduction.

14. ***Can the species be removed if necessary?***

    Yes.

    The aurochs' size and their residence within a nature reserve makes them relatively easy to catch and remove if necessary. This may become more difficult if aurochs are released more widely but this stage should come only after all necessary research regarding their behaviour has taken place so removal should become less necessary. Additionally, as they can live in herds up to 30 individuals[65], they will be easier to remove, even in the wild, than solitary species.

15. ***Will the public be accepting of the species?***

    Yes.

    The large, aggressive nature of the aurochs may at first appear frightening, but it is likely that communities will be accepting of this ancient species reintroduction. Before the Tauros programme released their aurochs into Portugal, the team reached out to local communities to understand their opinions. Public outreach was generally positive with benefits such as increased tourism and attention, and ecological consequences such as a reduction in wildfires being noted[61]. Every community is different, however, so such outreach should be conducted before every reintroduction.

Conclusion:

With a score of 14/15 (93%), I believe that the aurochs is a suitable candidate species for de-extinction. The Tauros programme in particular has clear goals and plans to reach those goals and has already been successful in reintroducing their aurochs into the European landscape. Although this is highly positive, the results of these reintroductions are yet to be seen, and it is likely that community and governmental acceptance will be an important factor regarding where reintroductions take place.

3.6. Summary:

Question Category	Question Number	Woolly Mammoth	Passenger Pigeon	Thylacine	Dodo	Aurochs
J	1	✓	✓	✓	✓	✓
	2	✗	✓	!	✗	!
BF	3	✓	✓	✓	✓	✓
	4	✓	✓	✓	✓	✓
	5	!	✓	!	✓	✓
LoS	6	✗	!	✗	!	✓
	7	✓	✓	✓	✗	✓
	8	✓	!	✓	✗	✓
	9	✗	✓	!	-	✓
	10	✗	✓	!	!	✓
LoNI	11	✓	✗	✓	✓	✓
	12	-	!	-	-	!
	13	✗	!	✗	!	✓
	14	✓	✓	✓	✓	✓
PA	15	!	✗	!	✓	✓
Conclusion		!	✓	!	!	✓

Summary table of de-extinction candidate species suitability using green ticks (yes), red crosses (no), yellow exclamation marks (uncertain), and black dashes (unknown) to represent answers to questions 1-15 (Categories: Justification (J), Biological Feasibility (BF), Likelihood of Success (LoS), Likelihood of Negative Impacts (LoNI) and Public Acceptance (PA)) and conclusion.

4. Conclusion:

When five active de-extinction projects were evaluated according to selection criteria, the passenger pigeon and aurochs were considered generally suitable for de-extinction while there was uncertainty over the suitability of the woolly mammoth, thylacine, and dodo. The most pervasive issue that appeared throughout the evaluation was a lack of research regarding the likelihood of success and negative impacts. While the de-extinction of all five species may cause environmental and conservation benefits, only the passenger pigeon is necessary for those benefits to be seen. Ultimately, this analysis has shown that each de-extinction project must be evaluated individually and that the majority of de-extinction projects require more research before resurrected species are released.

This essay series has covered the science of de-extinction, the various arguments both for and against the practice, and an analysis of the suitability of de-extinction candidate species. This topic is highly controversial with some people optimistic about the environmental and community-based benefits of resurrecting extinct species, and others showing hostility towards the practice due to the potential for environmental and moral harm. This series has shown how complicated the topic is and how the potential benefits may be undercut by the potential harms. It is my opinion that de-extinction as a practice is exciting and has the potential to revolutionise conservation science. However, this potential can only be fulfilled with more research and development of the technology which will minimise the harm caused to the environment and to the species involved. Furthermore, candidate species should be subjected to rigorous suitability analysis, even more stringent than the one presented here, and not simply picked for their charismatic nature and possible impact on the environment. To conclude this series, I believe that, although admirable in its intentions, de-extinction has a long way to go in terms of making sure that the technology is safe and effective and in the selection of candidate species that will produce the most benefit whilst producing the least risk.

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