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Meet the new mammoth, same as the old? Resurrecting the *Mammuthus primigenius*

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Abstract Media reporters often announce that we are on the verge of bringing back the woolly mammoth, even while there is growing consensus among scientists that resurrecting the mammoth is unlikely. In fact, current "de-extinction" efforts are not designed to bring back a mammoth, but rather adaptations of the mammoth using close relatives. For example, Harvard scientists are working on creating an Asian elephant with the thick coat of a mammoth by merging mammoth and elephant DNA. But how should such creatures be classified? Are they elephants, mammoths, or both? Answering these questions requires getting clear about the concept of reproduction. What I hope to show is that with an appropriate notion of reproduction—one for which I will argue—resurrecting a member of *Mammuthus primigenius* is a genuine possibility.

Keywords De-extinction · Reproduction · Spatiotemporal continuity · Species

Introduction

Media reporters often announce that we are on the verge of bringing back the woolly mammoth (cf. Kaplan 2015; Knapton 2017; Shultz 2016), even while there is growing consensus among scientists that resurrecting the mammoth is unlikely. In fact, current "de-extinction" efforts are not designed to bring back a mammoth, but rather adaptations of the mammoth using close relatives. Harvard scientists, for example, are working on creating an Asian elephant with the thick coat of a mammoth by merging mammoth and elephant DNA (Knapton 2017). Such a creature will look

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mammoth like, but it will remain an elephant according to the scientific consensus. But is that right? How should such creations be classified? Are they elephants, mammoths, or both? As Ross MacPhee points out, "[R]e-establishing viable populations of the un-extinct raises knotty questions that traditional taxonomic approaches are ill designed to answer. Can such creations be regarded as members of the same species as the ones that supplied the genetic information?" (2015, 11) Or, in contrast, is it more appropriate to classify the organism by appealing to its immediate progenitor?

To answer these questions requires getting clear about the concept of reproduction. Only if the long-dead mammoth (or its parts) can be used to produce another mammoth will we potentially resurrect a member of the extinct species. Using the notion of reproduction to approach questions of de-extinction is an alternative to dominant trends in the area, which tend to approach such questions using similarity relations. But relying on similarity to answer questions about de-extinction is a mistake.[1] Since Darwin, we've known that membership in a species doesn't depend on similarity or resemblance relations between members. My alternative provides the framework for thinking about the only widely conceded[2] necessary requirement for species membership, viz, spatiotemporal continuity.[3] What I hope to show is that with an appropriate notion of reproduction (one for which I will argue), creating a member of *M. primigenius* is a genuine possibility.

The paper unfolds as follows. I begin with our problem, explaining why bringing back something that looks and acts like a mammoth is unlikely, and also why, even if we could produce something that looks and acts like a mammoth, that new organism wouldn't necessarily be a member of the species *M. primigenius*. Second, I defend the view that membership in a species requires spatiotemporal continuity between members of a separately evolving lineage and argue that whether we can create an animal that is spatiotemporally continuous with an extinct species depends on how we understand 'reproduction.' With the paper's set-up complete, I propose an account of reproduction—which I call the "Overlap, Development and Persistence" (ODP) account—and apply it to our problem. I do this by reviewing the methods available for bringing back the woolly mammoth. If any of these methods meet the conditions of my ODP account, it will be possible to satisfy a necessary

[1] Unless, of course, one is not interested in bringing back a member of *M. primigenius*. Recreating members of lost species is just one aim of de-extinction (albeit one that is the focus of this paper), but there are numerous others. For example, Shapiro (2015) has argued that the aim should be the restoration of lost ecological interactions. If we embrace Shapiro's aim, the question of whether a mammoth-like creature is really a woolly mammoth is only relevant if a creature must be a member of *M. primigenius* in order to provide those interactions.

[2] Of course, even widely conceded requirements occasionally face opposition. See Kitcher (1984) for an argument against the spatiotemporal continuity condition.

[3] Focusing on this condition of species membership means I needn't resolve sticky questions about what it means for a species to no longer be extinct. Whether members of a species must be viable in the wild or merely in confinement, whether they must survive to adulthood or not, or whether they must meet some further condition in order to qualify as "de-extinct" can be ignored for my purposes. Before any of those further, knotty questions can be resolved, we must first determine whether an organism meets the only widely conceded necessary condition of species membership, viz, is it spatiotemporally continuous with other members of the species?

condition of species membership and possibly resurrect the extinct species. I conclude that creating an animal that is spatiotemporally continuous with a species that went extinct 3600 years ago is possible. Resurrecting the woolly mammoth is theoretically possible.[4]

Before I begin, a brief comment about the scope of the paper is in order. I'm interested in the question of what properties an organism must have in order to be classified as *M. primigenius* (as opposed to, say, *Mammuthus columbi*). This has been referred to, by Siipi and Finkelman (2016), as a "species taxon" question. Even more narrowly, the paper focuses only on necessary conditions, leaving aside conditions sufficient for an organism to be a member of an extinct species. This focus means that I am not explicitly addressing what Siipi and Finkelman refer to as the "species category" question: Are species the kind of entities that can be resurrected? Whether or not a new member of *M. primigenius* can resurrect *the species* depends on whether species are sets, real classes, nominal classes or super-organisms. What I say in the paper has implications for how we ought to answer that question, but I don't take up those implications here.

Skepticism about methods

Shapiro (2015) has recently argued that if the goal of de-extinction is to bring back something that looks and acts like a mammoth, de-extinction has no place in our scientific future. "Extinct species are gone forever. We will never bring something back that is 100 percent identical—physiologically, genetically, and behaviorally identical—to a species that is no longer alive" (Shapiro 2015, 10).[5] This is an odd claim. What could it mean for an individual organism to be 100 percent identical to a species, one whose individual members are not identical to each other? It seems Shapiro is making a sort of category mistake, comparing one class of things (members of a species) with the thing (a species) of which they are members. Presumably, then, Shapiro doesn't mean what she says here. Rather, she means that we will never bring back members of *M. primigenius*, because we can't create something that adequately resembles the range of traits typical of the species. But why is Shapiro pessimistic about that possibility?

[4] My focus on *M. primigenius* is not essential to my argument. The woolly mammoth is merely a conceptual test case. I'm asking whether it's possible to satisfy the only widely conceded essential condition of species membership: Are there methods for ensuring spatiotemporal continuity with members of extinct species? *M. primigenius* is merely a captivating test case for engaging this question. Some of the practical barriers that may stand in the way of actually resurrecting a member of *M. primigenius* (e.g., raising adequate capital, housing and feeding host animals, implanting a mammoth/elephant fetus in a host, etc.) may not be barriers for other extinct species. If we can see our way through certain practical barriers (but not others) in the case of *M. primigenius*, that will help us to understand the conceptual and theoretical constraints facing de-extinction efforts.

[5] Following Shapiro, I take 'extinction' to mean final extinction. Final extinction occurs when a species stops existing because no organism survives and reproduces. For other types of extinction in an evolutionary context, see Delord (2007, 2014).

First, to resurrect a member of an extinct species, one must have a method for doing so, and it's not clear what method could be used to resurrect a member of *M. primigenius*. Of course, if a species has *recently* gone extinct, there is a chance to resurrect a member by cloning, using somatic cell nuclear transfer (SCNT). However, this would require some scientific foresight. Researchers would need to collect and freeze cells from one of a species' living members before it vanished. Such foresight is not unheard of: after the extinction of the Pyrenean Ibex in 2000, scientists removed the genome from frozen cells and inserted it into enucleated eggs of domestic goats (Folch et al. 2009). The embryos were then implanted into a subspecies of Spanish ibex, which served as gestational surrogates. A single bucardo made it to term, thereby proving that SCNT might be an effective method for resurrecting members of extinct species.

But could a species that went extinct 3600 years ago—like the woolly mammoth—have its members resurrected in this way? Only if its genome has remained intact, which is highly unlikely. Animal cells contain enzymes called nucleases that start breaking down DNA immediately after death. To make matters worse, the bacteria and fungi that colonize decaying bodies of animals also make nucleases. That's not to say that it is impossible for DNA to survive for many hundreds of thousands of years. It could if the sample containing the DNA is de-fleshed, frozen, and preserved immediately after death. But such accidental preservation will likely consist exclusively of DNA fragments, not an entire genome. As Ross Barnett puts it:

> [E]ven with the best permafrost preservation, DNA is often broken into segments of only 500–1,000 base pairs (the ACGT 'letters' of DNA). When you consider that a single chromosome may have 250 million base pairs, complete without a single gap, and that the working of the chromosome depends critically on the uninterrupted order of the base pairs contained within it, you see the problem. (2016, 68)

No environment on earth is cold enough to freeze a large animal like the mammoth quickly enough to prevent DNA decay altogether. And since the process of DNA decay involves not only the fragmentation of DNA but also spontaneous mutations, Barnett concludes, "No one is ever going to clone a mammoth by using frozen cells from the permafrost" (2016, 68). If all this is right, Shapiro's initial skepticism seems on target: resurrecting a mammoth with the behavioral, genetic, and physiological traits of the original may be impossible.

A second reason for Shapiro's pessimism is that even if we could clone a mammoth, there are other factors that might prevent the creature produced using such techniques from looking and acting like a typical *M. primigenius*. Cloning a member of an extinct species, using SCNT, requires inserting its genome into the enucleated egg of a close living relative, which in the case of the mammoth would be the Asian elephant. One problem, however, is that the mitochondrial genome of the Asian elephant might be incompatible with the nuclear genome of the mammoth, which is to say that hosting mammoth DNA in the enucleated egg of an elephant might lead to metabolic or neurologic diseases or even death (Shapiro 2015, 148). Assuming these potential problems could be overcome, there are still others. The environmental differences that determine gene expression, e.g., when and for how long a gene is turned on during development, must be compatible between the Asian elephant and the mammoth, for example. To resurrect a member of *M. primigenius*, then, we would have to hope that the surrogate mother's genetic makeup, diet, hormones, and stress level wouldn't alter the expression of the nuclear genome. Still further, when the baby is born, there are additional environmental differences that are likely to influence development. One such difference is that "Baby mammoths, like baby elephants, ate their mother's feces to establish a microbial community capable of breaking down the food they consumed" (Shapiro 2015, 13). If we're unable to reconstruct mammoth gut microbes, what effect will this have on the baby? And what about not having a mammoth community to teach the infant how to live or the absence of the environment that was present when mammoths roamed the earth? In summary, not having anything close to an intact mammoth genome, having to use an egg donor and gestational surrogate of a different species, and all the environmental differences that the infant would face after birth make it very unlikely that we could ever create a mammoth whose physiological and behavioral traits would fall within the range of what was typical of *M. primigenius*. Again, Shapiro's pessimism seems on target.

The spatiotemporal continuity of species

Having shown that there are genuine methodological obstacles to resurrecting members of extinct species, I want to set those problems to the side for a moment. I'll return to them later in the essay. In the meantime, and before we can further address the methodological barriers de-extinction efforts face, we must clarify the concepts used to think about these issues. After all, Shapiro's pessimism is only warranted if the goal of de-extinction is to create a creature that closely resembles (physiologically and behaviorally) the woolly mammoth. If, however, the goal is to create a member of the species *M. primigenius*, her pessimism may be too quick. For starters, if the aim is to continue the species, the newly created individual need not resemble other mammoths. This follows from the fact that species are themselves individuals (Ghiselin 1974; Hull 1976). Species are, as it were, one thing composed of indefinitely many members persisting through space and time. Species are not delimited by resemblance but by the fact that an organism stands in a particular relation to other members of the same species. Michael Ghiselin initially compared species to corporate firms to make the idea clear. Firms are individuals composed of diverse members and they persist despite the coming and going of diverse members. Like firms, species are also individuals that persist through time despite the death and replacement of individual members. Another common comparison, that between species and organisms, is similarly apt. Karim Jebari writes:

> [A species is] a spatiotemporally restricted entity, in which members of the species are to be understood as parts of that entity. In other words, an animal relates to the species in the same way as a [body] part relates to a [body]. Just as my hand is part of my [body] by virtue of physical connectedness,

> only organisms with the right spatiotemporal relation to the collective are properly considered to be members (or parts) of the species. (2016, 217)

As Scholl (2007) explains, "for two objects encountered at different locations to be subsequent stages of the same individual [species], there must be a spatiotemporally continuous path between them" (566). In the same way that body parts are spatiotemporally connected to form an organism, so too, mammoths must be spatiotemporally connected to form the species *M. primigenius*. Resemblance between members of a species, then, is accidental and not an essential feature of species membership. It follows that determining whether we can resurrect members of an extinct species will not turn on whether the new individuals resemble their progenitors. Instead, the question will turn on whether the new mammoth is spatiotemporally continuous with other mammoths.

Is it possible to satisfy that condition, given that the mammoth went extinct 3600 years ago? Julien Delord is skeptical. He argues that if species are individuals in the same way that organisms are individuals, you can't resurrect an extinct species. The death of a species, just like the death of an organism, is final. He writes:

> [W]hen a species goes phyletically extinct…one can make a straightforward analogy with the death of an organism. It ceases to exist both functionally, as there are no more vital relations (reproductive, ecological and so on), and even materially, as no spatio-temporal entity that was part of the species exists anymore. This is comparable to a dead organism which does not exhibit any vital physiological relation among its internal parts (such as organs or cells) and whose organs fall increasingly apart with time. All attempts to resurrect it from a cell or from the genetic information taken from the dead organism is doomed to failure, as this would create a new organism, that is a new spatio-temporally delimited individual, although one very similar in many respects to the dead organism. (Delord 2014, 28)

According to Delord, using cellular or genetic material from a dead organism to create a new one fails to preserve the spatiotemporal continuity necessary for the two creatures to be members of the same species. The new organism would not be a living extension of the old. Instead, the new organism would be a "new spatiotemporally delimited individual" and, thus, lose contact with an essential condition of species membership.

Delord is not alone in claiming that the death of a species is final. Charles Darwin made a similar claim in *The Origin*, "When a group has once wholly disappeared, it does not reappear; for the link of generation has been broken" (1882, 314). Darwin, however, lived at a time when the technology required to resurrect an extinct species, like the Pyrenean ibex, did not exist. Given this fact, it's not clear whether Darwin thought de-extinction was impossible in theory or merely in practice. Delord, on the other hand, clearly believes that de-extinction is impossible in both theory and practice. Accordingly, even something as seemingly straightforward as creating an offspring from the frozen egg and sperm cells of a member of an extinct species does not qualify as resurrecting an extinct species for Delord. Once spatiotemporal continuity is broken, there is no sense to be made of the idea that the new organism is a member of the old species.

Although the intuition behind Delord's view is compelling in the case of individual organisms, I don't believe his view is right in the case of species. Indeed, when it comes to species, it's clear that offspring of the same species can be born even after all the living members have died—that is, the same species may persist during a time with no living members.[6] Consider, for example, species of annual plants. During winter, when the plants die, there are no living members of the species. Yet, when spring rolls around, the seeds that froze over winter give rise to new members of the same species. The point is made by Alastair Gunn when he writes:

> Certainly we are in no doubt about the continued existence of species such as annual plants, whose entire population dies off each year. The seeds, which are all that survive the winter, are genes, not plants. Similarly, it is possible to imagine a species which survives the winter only in the form of unfertilized ova and sperm, relying on vector organisms or other environmental factors to arrange fertilization. In such a case, even though no individual member of the species exists, not even in embryonic form, we would surely not want to say that a new species evolved each spring. (Gunn 1991, 300–301)

If a plant species can survive the winter even though its living members do not, why resist the idea that a new mammoth could belong to the species *M. primigenius* even though there was a time when there were no living members? I don't believe there is good reason for such resistance. Plausibly, then, it seems theoretically possible that the spatiotemporal continuity of extinct species can be preserved or maintained even when all living members are no more.

But is it practically possible to revive members of a species that has been extinct for thousands of years while maintaining the spatiotemporal continuity necessary for species membership? This is a question best answered by thinking about what it would mean to reproduce a new member of an extinct species. In the case of the mammoth, since neither sexual nor asexual reproduction is available for bringing back one of its members, the practical possibility depends on alternative forms of reproduction. Are unusual modes of reproduction legitimate ways of producing members of dead or dying species? The following quote from Marc Ereshefsky suggests the answer should be yes.

> The intrinsic reproductive mechanisms within the organisms of a species can be changed, but being part of the same lineage or gene pool cannot be changed. To make this more concrete, consider the case of ring species. A ring species consists of a geographic ring of populations such that organisms in contiguous populations can successfully mate, but organisms in populations at distant links in the ring cannot successfully mate. Interestingly, the organisms in distant populations of a ring species have different reproductive mechanisms. (The same is true of different generations of a single species: contemporary

[6] Perhaps this possibility reveals a weakness in the analogy between species and individual organisms.

> organisms within a species may have different reproductive mechanisms than those of organisms in earlier generations.) Suppose Joe is a member of a ring species. Joe could have had a different intrinsic reproductive mechanism than the one he has. Imagine counterfactually that he is a member of a different population of his ring species, namely, one with different reproductive mechanisms than those found in his actual population. In this counterfactual situation, Joe is still a member of his species so long as we do not remove him from the lineage and gene pool of that ring species. Generally, an organism in a ring species can have a different reproductive mechanism and still be a part of that species. But an organism cannot be removed from his original lineage and be put in another lineage and remain part of the original species. Relations, I submit, are more fundamental for species (and taxon) membership than intrinsic properties are. (Ereshefsky 2010, 681-2, references omitted)

According to Ereshefsky, the relations fundamental to species membership can be realized in ways independent of a species' characteristic reproductive mechanisms. Reproductive mechanisms can change over time without changing the identity of the species. As far as we are concerned, this means that members of a species may be revived using forms of reproduction atypical of the members of that species. But what alternative forms of reproduction are available for reviving *M. primigenius*?

One option is to create an elephant with mammoth parts. By inserting parts of the mammoth genome into an elephant genome,[7] we can resurrect extinct traits. But we've already seen reasons to be skeptical of this mode of resurrection: reviving traits in an elephant that resemble those of the mammoth isn't the same as reviving members of the species. Even so, if inserting parts of the mammoth genome into an elephant genome counts as reproduction—that is, if splicing bits of mammoth DNA into elephant DNA preserves spatiotemporal continuity with extinct mammoths—it may be possible to resurrect a member of the species. As Jebari explains, whether methods other than sexual and asexual reproduction can create spatiotemporal continuity characteristic of a lineage, "depend[s] on what constraints we place on the term "reproduction"" (2016, 218).

Reproduction as overlap, development, and persistence

So, what constraints should we place on the notion of reproduction? Presumably, we want a minimal account, one that can capture the sense of 'reproduction' in the biological sciences without being overly permissive or restrictive. Given this broad principle we can follow James Griesemer's view, which takes reproduction to be a process necessary for evolution by natural selection. What, then, is required for evolution by natural selection? What further constraints are thereby imposed on 'reproduction'? For natural selection to act on organisms such that

[7] Mammoth DNA can be inserted into an elephant genome using targeted genome editing technologies, e.g., CRISPR-Cas9.

they evolve adaptations, there must be both resemblance and variation between generations. Offspring must resemble their parents but they cannot be identical to them—there must be a source of variation for populations of organisms to change in ways suitable to changing environments. What must reproduction be like for successive generations to resemble each other in non-random ways, while, at the same time, maintaining the phenotypic variation necessary for natural selection? According to Griesemer, resemblance is the product of material overlap. He writes, "similarities *result from* descent and descent relations are not merely cause-effect relations" (2005, 88). Instead, the descent relation is grounded in the fact that some of the parts of the offspring were once parts of the parent. This material overlap requirement, which is present in both sexual and asexual reproduction, permits a degree of resemblance between successive generations, since shared parts give rise to offspring with features resembling their parents to a degree greater than randomly selected individuals.

However, sharing material parts across generations (and the resulting resemblance) is not sufficient for reproduction. If it were, getting a haircut or donating a kidney may count as reproduction. In addition to material overlap, an account of reproduction tied to evolution by natural selection demands a source of variation. On Griesemer's account, this demand is satisfied by the fact that reproduction is a process that requires the parent to confer on the offspring the capacity to develop into something capable of reproduction. According to Griesemer, "What avoids trivializing reproduction as just any change of parts is that reproduction involves the conveyance or conferral of developmental capacities. Not every mereological change achieves that" (2016, 809). The idea is that materially transferred parts must *develop* in the recipient of those parts (i.e., offspring) the capacity to restart the process of material transfer. Again, from Griesemer: "the capacity to reproduce must be *acquired* or built-up; things are not born with it" (2000b, 246). Given that the capacity to reproduce is not simply copied from parent to offspring, but must develop, variations are likely to arise in the process of development. As Griesemer explains:

> If heredity were exact, then evolution would come to a halt…heredity is likely to be exact whenever development is null. Variation "emerges" in the developmental process of acquiring the capacity to reproduce. Null developers need not acquire reproductive capacity, so the opportunity for variation which nevertheless leads to reproductive capacity is absent. (2000a, 74)

In summary, the process of acquiring the capacity to reproduce, through the development of materially transferred parts, gives rise to the novelty and resemblance we expect to find between parents and offspring.

These two requirements of Griesemer's account adequately capture the concept of reproduction in a context free of human-invented ways of creating organisms. In such a context, it's fair to assume that a new organism, along with its own capacity to reproduce, develops from parts it has inherited from its parent(s). Since the new being is made from the physical parts of its parent, its own parts will inevitably get passed down to make the next generation, and that future generation will contain parts of its parent (or descendants of the parts of its parent). After all, the third generation is also made from those parts (or their descendants). It is this overlap of parts between generations that creates the spatiotemporal continuity characteristic of a lineage.

However, in the context of human-invented ways of creating new organisms, a context where it's possible to merge a variety of parts from a variety of individuals, it's not clear that Griesemer's two requirements are adequate. Consider, for example, a stem cell transplant aimed at reconstructing a uterus in a recipient organism. Such a transplant would seem to meet Griesemer's requirements—through material overlap, the transferred parts confer on the recipient the capacity to develop its own reproductive capacity. If that's right, the stem cell donor would according to Griesemer's view qualify as the parent of the recipient. This fact suggests that Griesemer's account is overly permissive: too many modes of material transfer end up counting as instances of reproduction.

To keep the virtues of Griesemer's account in the context of human-invented methods of reproduction, we need a third requirement. Notice that in the case of a stem cell transplant, the spatiotemporal continuity preserved through the transfer of parts from donor to recipient is broken in future generations. The transferred stem cells (and their descendants) die with the recipient in just the same way that cells comprising a transplanted kidney die with the recipient. The genetic information encoded in the transplanted cells fails to be passed to successive generations. This observation grounds a distinction between material transfers that are mere transplants and material transfers that are instances of reproduction. This distinction, between parts transferred as transplants and parts transferred as instance of reproduction, can be used to formulate an addendum to Griesemer's account.

Let me explain. Griesemer's first requirement is that there be material overlap between parent and offspring; the second is that the inherited parts contribute to the development of the offspring's own reproductive capacities. We can meet these two requirements, however, through stem cell transplants. To avoid this overly permissive consequence of Griesemer's view, we can add the requirement that material parts, or their descendants, be passed to at least one subsequent generation. Since transplanted parts are not passed to subsequent generations, even transplants that help the recipient develop a capacity to reproduce will not count as instances of reproduction. Only when all three conditions are met will a material transfer count as an instance of reproduction. If we label Griesemer's requirements "overlap" and "development" and add my third requirement, "persistence," we end up with my proposed account: Overlap, Development, and Persistence (ODP).

One common worry about the ODP view is that it seems to carry the implication that individuals with offspring who don't have children have failed to reproduce. Let me say two things in response. First, the worry is allayed in cases of offspring who *choose* not to have children if my third requirement is understood counterfactually: it's not necessary that the parts contributed by a parent, which play a role in the development of the offspring's ability to reproduce, actually persist to the next generation. Instead, it's enough that those parts be of a type that *would* persist if, contrary to fact, the offspring *were* to make an alternative choice.

Construing my third requirement counterfactually, however, doesn't avoid another potential worry. Indeed, a further implication of my position seems to be that parents with infertile offspring have failed to reproduce. Is that right? Is producing sterile offspring failed reproduction? In answer, consider two examples of organisms that never develop the capacity to reproduce: worker bees and mules. In each case, the parents produce offspring that never develop the capacity to reproduce. Are these instances of failed reproduction? It seems so. A queen bee does not produce another of what she is when she produces a worker bee. Similarly, a horse and donkey do not produce more of what they are when they produce a mule. The extension of the worry to human beings may be more troubling, but the consequence of my view is one I can accept. And, anyway, the conclusion is entailed by Griesemer's account, too. As he notes, "The production of offspring that do not have the capacity to reproduce is not reproduction" (2000b, 246). A potentially controversial conclusion, perhaps, but it's one consistent with the recursive nature of reproduction: offspring inherit material parts from their parents that allow them to develop their own reproductive capacities. A process that fails to meet that condition is not reproduction.

Creating a mammoth that's spatiotemporally continuous with the species *M. primigenius*

With an account of reproduction in hand, let's return to the question of de-extinction. Is it possible to reproduce another member of the species *M. primigenius*? To arrive at an answer, we needn't worry about resemblance relations and whether a newly created "mammoth" looks as past mammoths did. Instead, our concern should be on the continuity of spatiotemporal relations. If we can't create a mammoth to meet the requirements built into an account of reproduction, the spatiotemporal relations necessary for species membership will be broken and the created organism (whatever it looks like) will not be a member of *M. primigenius*. Is there a way, then, to create an organism that is spatiotemporally continuous with a species whose members have been extinct for 3600 years?

To answer that question, I want to look at possible methods for resurrecting the extinct mammoth. I begin with the method least likely to fulfill the requirements of my ODP account, and, consequently, the method least likely to succeed in creating a member of the extinct species. In this scenario, scientists use a chemical reaction to link nucleotides that match recovered mammoth DNA. The matching DNA is made from scratch; there is no material overlap between any part of the mammoth donor and the elephant recipient. Consequently, this method clearly fails to meet the "overlap" requirement of our account of reproduction. Sure, there is transmission of information—that is, the information contained in the mammoth DNA is replicated with synthetic DNA—but merely transmitting information is not sufficient for reproduction, since the spatiotemporal continuity required for species membership is broken. Creating synthetic DNA that matches mammoth DNA and inserting it into an elephant's genome may sound promising, but it will (at best) create an organism that looks like a woolly mammoth while failing to meet the conditions necessary for membership in the species *M. primigenius*.

One reaction to this argument might be to resist building material overlap into an account of reproduction.[8] Why wouldn't the transmission of genetic information that leads to the production of an organism that looks just like a mammoth be enough for the new creature to qualify as a member of the extinct species? Consider an analogous question in the case of annual plants. When an annual returns in the spring, "Does any physical DNA need to exist [through the winter]? Does it make any difference whether the genetic information of a species is stored in DNA or on a floppy disk" (Gunn 1991, 301)? Suppose the DNA is stored on a floppy disk and that information is used to bring back the plant. Such a process wouldn't involve any material overlap, so would that plant, which may look just like the one from which the information was copied, belong to a different species? Well, of course the answer to that question depends on an account of reproduction and what it means for plants to be spatiotemporally continuous.

Gunn, however, rejects the idea that the mere transmission of information could be sufficient for reproduction. He writes, "there is something odd about the idea that the extinction of a species could occur at the moment the disk file is erased" (1991, 301). Griesemer (2005) arrives at a similar conclusion by comparing synthetic replicas in biology to art replicas, neither of which involve material overlap. In cases of artistic 'reproduction,' an artist sits before an original Mona Lisa, for example, and paints another painting that reproduces the original. It's tempting to say that the original Mona Lisa gave rise to the replica, or that the original is the replica's ancestor, but Griesemer asks: Is that an accurate description of the relation between them? Isn't it the artist, not the original Mona Lisa that is the efficient cause of the replica? An analogous point applies to synthetic replicas in biology. If there is no material overlap between two genomes, but one is a synthetic copy of another, we might be tempted to say that the original gave rise to the other. But that is a mistake. The efficient cause of a synthetic replica is the lab technician and not the original genome. In contrast, in cases of biological reproduction, the parent's genome is the efficient cause of the offspring, since the offspring is created from the material parts of the parent. Without material overlap, then, synthetic reproduction of DNA breaks the spatiotemporal relation required for biological reproduction and species membership. A method that relies on it will not be in a position to resurrect members of *M. primigenius.*

Methods of synthetically replicating DNA, however, are not all the same. In contrast to methods that aim to produce DNA without using material from a parental genome, an alternative method of synthetic reproduction, known as Polymerase Chain Reaction (PCR), does make use of parental genomic material. The method is both quicker and less expensive than methods that aim to synthesize DNA from scratch. Elizabeth van Pelt-Verkuil et al. describe the basic principle behind the method as follows:

[8] Godfrey-Smith (2009) has criticized Griesemer's account precisely on this point, arguing that an account of reproduction does not require material overlap.

> The leading principle of PCR lies in the fact that extremely small amounts of target DNA can be specifically amplified to large amounts of synthetic DNA in vitro. Essentially, the continuous, exponential, *semi-conservative replication* of a well-defined DNA region present in the template DNA leads to the accumulation of large quantities of newly synthesized but specific target DNA product. (2008, 5, emphasis mine)

In contrast to fully conservative methods of replication, semi-conservative methods, like PCR, mimic nature's way of replicating DNA. In nature, one strand of the parent double helix is conserved in each new DNA molecule, creating material overlap. The same semi-conservative method is used when DNA is amplified using PCR.

As it happens, scientists are already using PCR to resurrect the phenotypic traits of extinct species (cf., Callaway 2015; Campbell et al. 2010). This raises the question: if PCR is semi-conservative and meets the material overlap requirement of my account of reproduction, can it meet the other requirements? Can PCR produce a mammoth that also develops a means of reproduction that persists through generations? Will replacing elephant DNA with portions of mammoth DNA using a semi-conservative method like PCR, fulfill the requirements of an acceptable account of reproduction?

It could. To see why, consider the following scenario. Suppose a scientist recovers a sequence of mammoth DNA and uses a semi-conservative method of replication like PCR to amplify the sequence. Suppose further that she takes the DNA product and inserts it into the genome of an elephant embryo, creating material overlap between the extinct mammoth and the embryo. This process would mean meeting the first requirement of my ODP account of reproduction. Since the DNA merger would happen at a very early stage of embryonic development, the mammoth DNA would likely contribute to the full development of the offspring, including its reproductive organs. If so, the second requirement of my ODP account would also be met. Further, and maintaining these assumptions, if the mammoth DNA were passed to further generations, all three requirements of my ODP account would be met. In such a case, then, amplifying and inserting mammoth DNA into an elephant egg would preserve the spatiotemporal continuity required of species membership and the newly created organism would meet the only widely conceded essential condition for qualifying as a member of the species *M. primigenius*.[9]

[9] It's worth emphasizing the weight of these assumptions. As one anonymous reviewer points out: the cost of acquiring, nurturing, transporting, anesthetizing, and generally funding an experiment with (possibly generations of) elephant hosts is tremendous. Further, even if it were possible to overcome such barriers, the idea that an elephant's mammoth offspring would be born alive, that it would survive long enough to develop reproductive organs, or that its DNA would be passed to further generations is extraordinarily unlikely. Such practical improbabilities, however, seem to be the type of barrier we can see our way through when thinking about resurrecting members of extinct species. Mega-fauna may present a range of problems too difficult to overcome, but many of those problems seem to disappear when thinking about species that do not demand such extraordinary resources. Furthermore, those practical barriers do nothing to undermine my central point, which is that there seems to be methods available for establishing the spatiotemporal continuity required of species membership.

I can imagine an opponent resisting this conclusion by saying, “Surely, it’s absurd to believe that an organism born of an Asian elephant, created using an elephant’s egg, and containing only a small fraction of mammoth DNA is a member of *M. primigenius*.” What pieces of mammoth DNA and how many must be transferred in order to create a member of the extinct species using the Asian elephant as host? According to Barnett, “This [question] becomes somewhat like the ship of Theseus: at what point does a modified elephant become a mammoth, if ever?” (2016, 69) As I’ve already argued, there’s no point in thinking about this question in terms of resemblance relations between extinct members of *M. primigenius* and a newly created “mammoth.” Instead, the question should be understood in terms of the only widely conceded necessary condition for species membership. It’s not clear, however, that it makes sense to ask what degree of spatiotemporal continuity is required for a modified elephant to become a mammoth. Indeed, spatiotemporal continuity doesn’t seem to be a relation that comes in degrees. No matter how small the fraction of mammoth DNA used to produce a new “mammoth” using an elephant as host, as long as there is overlap, development, and persistence, the spatiotemporal requirement of species membership is fulfilled.

Be that as it may, I’m sympathetic to the idea that there is something peculiar about classifying an organism created in such a way as a member of *M. primigenius.* It is a mistake, however, to ground that sentiment in either the quantity of modification done to an elephant’s genome or the quantity of similarity relations between organisms. That is to say, the odd feeling associated with classifying this animal as a woolly mammoth doesn’t arise after the manner of problems associated with the ship of Theseus. Degree of similarity or number of parts is not what is at issue. A process doesn’t stop being one of reproduction—that is, one preserving the spatiotemporal continuity necessary for species membership—merely because the *amount* of material that’s been transmitted fails to meet some quantifiable standard or because the offspring aren’t similar enough to their parents. To see why, consider the difference in the amount of DNA transmitted in two standard forms of reproduction: sexual and asexual. In asexual reproduction, the offspring inherits 100% of the DNA of its parent, but in sexual reproduction, that amount drops by half. The offspring of sexually reproducing parents inherits only half of a parent’s DNA, yet the process is still considered reproduction. If the amount of DNA passed from parent to offspring can vary this dramatically and still count as reproduction, what prevents even smaller amounts of DNA transmission from being considered cases of reproduction? Nothing. Whether a process qualifies as reproduction doesn’t depend on the amount of material that’s been transmitted, but rather on what happens to that material once it is transmitted. Does it serve to produce more of the same kind of thing by developing an organism’s capacity to reproduce and persist to the next generation? If so, the material overlap, no matter how small, has created the spatiotemporal continuity characteristic of a lineage. If that’s right, then PCR and the direct insertion of mammoth DNA into the genome of an Asian elephant are both methods by which the condition necessary for species membership is satisfied.

Of course, this point doesn’t allay (or explain) the peculiarity of classifying an organism born of an Asian elephant, created using an elephant’s egg, and containing only a small fraction of mammoth DNA a member of *M. primigenius*. What does? In answer, it is worth pointing out that spatiotemporal continuity is a necessary and not a sufficient condition for species membership. There may be other conditions needed for determining when an organism belongs to a particular species. What those conditions are continues to be a matter of controversy (cf. Ereshefsky 2016; Wilkins 2009). As Kevin De Queiroz explains, "each of several contemporary species concepts adopts a different property…as its cutoff for considering a separately evolving lineage to have become a species" (2007, 881). For example, on the biological species concept, members of a species must be capable of interbreeding; on the ecological species concept, they must share the same niche; and so on. If an organism fails to meet one or another of these further conditions of species membership, we may be inclined to resist including it as a member of a species, even if it is spatiotemporally continuous with the relevant species. That is to say, failure to meet conditions of species membership over and above spatiotemporal continuity may justify excluding some particular organism from a species. And I suspect this is what explains the oddity of classifying an organism born and bred using an elephant host as a member of the species *M. primigenius*. It's not that such an organism fails to have the right number of parts, or fails to be relevantly similar to its extinct ancestors. Rather, it's that it fails to meet some further condition of species membership, even if we can't say definitively what that further condition is or ought to be.

It follows from this that an organism created with mammoth DNA—although a direct descendant of *M. primigenius*—may fail to meet the conditions required for species membership. And this seems right. For an organism resurrected from an extinct species, fulfilling further conditions of species membership may simply not be an option. If there are no other woolly mammoths around, it will be impossible to fulfill the interbreeding criterion; if today's ecological niche is too different, it's not clear how a resurrected mammoth could occupy the same niche as its extinct relatives; and so on. In such cases, we might be inclined to say that an organism resurrected from an extinct species is a direct descendent of that species but one that stands at the head of a new lineage. That is, maybe the best we'll be able to say is that we've created a new species of organism.

But even that may be too fast. After all, lack of opportunity is not the same as inability. Just because there are no living mammoths around doesn't mean that the new mammoth is *unable* to breed with past members of the species. Rather, the new mammoth lacks the *opportunity* to do so.[10] In short, it's not obvious that an organism resurrected using PCR would necessarily fail further conditions of species membership (whatever they may be). If that's right, then resurrecting a member of the extinct *M. primigenius* species is a genuine possibility. An organism meeting some further condition of species membership and fulfilling the requirement of spatiotemporal continuity—which is determined using my ODP account of reproduction—would be a living member of *M. primigenius*.

[10] Whether the interbreeding criterion must be testable in practice or in theory, i.e., as potential to interbreed, is a matter of controversy. For a discussion of the interbreeding criterion in the context of de-extinction, see Siipi and Finkelman (2016).

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