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The Extinction and De-Extinction of Species

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I. Introduction

When death came for Celia, it took the form of a tree. Heedless of the danger posed by branches overladen with snow, Celia wandered through the landscape of Spain's Ordesa national park in January 2000. A branch fell on her skull and crushed it. So death came and took her, leaving a body to be found by park rangers and a legacy to be mourned by conservationists around the world.

The conservationists mourned not only the death of the organism, but also an attendant decrease in biodiversity. Celia was the last member of the subspecies *Capra pyrenaica pyrenaica,* better known as the Pyrenean ibex; when she died, so too did the taxon become extinct.

Where most stories would end, Celia's story—or at least the story of her DNA—had just begun. Biologists had collected tissue samples from her body shortly before her passing. Using cells cultured from those samples, scientists working for the company Advanced Cell Technology set about cloning Celia. The fruit of their labor was born in 2009 and survived for seven minutes before succumbing to lung problems. Celia's clone did represent a material triumph of resurrection biology, more popularly known as de-extinction (Folch *et al* 2009; Pina-Aguilar *et al* 2009).

At the moment, numerous research groups around the world are working towards de-extinction of different species. Efforts are under way, for example, to engineer a passenger pigeon (*Ectopistes migratorius*) from the genome of the related band-tailed pigeon (*Patagioenas fasciata*) (Zimmer 2013; O'Connor 2015). Woolly mammoths might be cloned from the tissues preserved in the permafrost of the Siberian tundra (Loi *et al* 2011). Alternatively, an Indian elephant (*Elephas maximus*) genome might serve as a template (Salsberg 2000). Several groups are working towards cloning Tasmanian tigers (Greer 2009).

Worries regarding anthropogenic extinction have this far, at least partly, been based on a view about irreversibility of extinction. As Johan-Wolfgang Wägele (2014) puts it, "[...] the political support for actions that can mitigate biodiversity losses is half-hearted and inadequate. This is extremely dangerous, because loss of species is *irreversible*. [...] life forms, once lost, cannot regenerate." The developments in resurrection biology question this vary basic tenet of conservation. Resurrection biology is taken to imply that "the revival of an extinct species is no longer a fantasy" (Zimmer 2013) or that "extinction might not be forever [...]" (Redford et al. 2013). Consequently, developments in resurrection biology are often met with enthusiasm.

Yet, the possibility of future success in resurrection biology raises many questions. Some are empirical: can resurrected species be reintroduced into the wild? What are the environmental costs and benefits of species resurrection? Other questions are philosophical. In this essay we address some of these philosophical questions. In particular, we consider whether the goals of resurrection biology are conceptually coherent. Our inquiry analyses two related concepts relevant to the resurrection: the concept of extinction and the concept of species. Through the analyses of them we demonstrate, first, the implications that resurrection biology may have for the conceptual foundations of life sciences, and second, implications that different species concepts and understandings of extinction may have on the status of animals produced by de-extinction technologies.

Before engaging our inquiry, we will first briefly describe “de-extinction” techniques and technologies in Part II below. In Part III we present four different species concepts and three different ways of understanding extinction. We also raise the challenge of seeing extinction as something necessarily final. In Part IV we apply the presented concepts to resurrection biology and discuss the possible ways of fitting resurrection biology together with the idea of finality of extinction. In part V we discuss the species and extinction concepts that are compatible with resurrection biology if extinction is not seen as necessarily final. Finally, we conclude in Part VI with thoughts on further implications of our analysis.

II. De-extinction

The goal of resurrection biology is deceptively simple in its articulation: it is to make extinct species extant once more. As we will see, however, this simple formulation begs a number of theoretical questions. Phrased more neutrally, resurrection biology aims to produce animals that are (to a high degree) similar to members of extinct species. These kinds of animals can be created either through selective breeding or through different applications of cloning technologies.

Resurrection biology’s earliest attempts took the form of “back-breeding”(Oksanen & Siipi 2014). Through well-practiced methods of husbandry, skilled breeders may cross extant lineages towards the end of replicating phenotypes, and perhaps even genotypes, of closely-related extinct lineages. This method is structurally identical to other forms of artificial selection, with one key difference: instead of producing new organisms in existing breeds or new types of breeds, the goal is to produce animals that are similar to members of extinct breeds. More recently, conservationists have considered the possibility that this technique, also known as “lineage fusion,” could resurrect extinct subspecies of Galápagos tortoises (Poulakakis *et al* 2008; Garrick *et al* 2014).

The more publicized versions of resurrection biology are based on applying the cloning technologies (Zimmer 2013). In fact, there are two methods by which the goal of resurrection can be achieved: through somatic cell nuclear transfer or through genetic engineering (Sherkow & Greely 2013; Oksanen & Siipi 2014).

Resurrection by somatic cell nuclear transfer (abbreviated to SCNT) is quite similar to “ordinary” cloning exemplified in the famed sheep Dolly. SCNT’s use in resurrection biology is popularized by works such as *Jurassic Park* and it is sometimes called *cross-species cloning*. (Wilmut *et al* 1999; Zimmer 2013.) The resurrection process begins with the cultivation of a somatic cell’s nucleus from the tissue of the extinct species. That nucleus, including its full complement of genetic material, is then inserted into an enucleated egg of another species. A member of that species works as a surrogate mother. When carried to term, the procedure produces nearly-identical twins to the members of the extinct species; the only genetic differences would be in the organisms’ mitochondrial and immune cell DNA (Hiendleder *et al* 2004).

SCNT is the means by which Celia was cloned. This method is also studied as a means of resurrecting species such as gastric brooding frogs (*Rheobatrachus silus*) (Archer 2013), woolly mammoths (*Mammuthus primigenius*) (Loi *et al* 2011), and Tasmanian tigers (*Thylacinus cynocephalus*) (Greer 2009).

As a method of resurrection biology, genetic engineering is similar to SCNT in that an organism is produced from the implantation of a modified embryo into a surrogate mother; the difference between the methods lies in the origin of the embryo’s genetic material. De-extinction through genetic engineering begins with the cultivation of genetic material from a member of a sister taxon to the target extinct species, rather than from a tissue of the extinct species itself. When genomic differences between the extinct species and its sister taxon can be identified, the genetic material from the donor organism can be modified to match the extinct species’ genome. The modified genetic material is placed into the donor nucleus, which is then inserted into an enucleated egg, which is in turn implanted into the surrogate mother. This method has the advantage of potentially increasing the genetic similarity between clone and donor organism: engineers might reconstitute the donor’s mitochrondrial DNA, thereby offsetting potential problems in the SCNT process such as those outlined by Hiendleder *et al* (2004).

A passenger pigeon (*Ectopistes migratorius*) might be resurrected this way from the genome of the related band-tailed pigeon (*Patagioenas fasciata*) (Zimmer 2013; O’Connor 2015). Horner & Gorman (2009) go as far as suggesting that non-avian dinosaurs might be engineered from the genome of a domestic chicken; Bhullar *et al* (2015) have made progress in deriving a dinosaur phenotype from the chicken’s genotype[1].

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[1] The reproduction of nonavian dinosaur traits differs from the resurrection of the passenger pigeon in one important respect: the latter would be the result of replicating an organism’s entire genome whereas the former would be the result of replicating an organism’s gene sequences. Nevertheless, this is a difference of degree rather than of kind; certainly, if a sufficient number of nonavian dinosaur traits were to be replicated then the entirety of a nonavian dinosaur phenotype

Each of these methods of resurrection biology faces practical obstacles and limitations. To wit: back-breeding can only resurrect extinct taxa below the species category; SCNT and genetic engineering are viable only for extinct taxa whose developmental environments were sufficiently similar to those of surrogates; genetic engineering assumes antecedent knowledge of the extinct taxon's genome. Nevertheless, many of the obstacles are contingent on the state of our technological art. The success of resurrection biology may not be inevitable, but it may be likelier than not (Stone 2003; Zimmer 2013).

In addition to these practical obstacles, however, there are significant conceptual challenges to be met. In this paper we question the common views regarding the success of resurrection biology. It is not self-evident that animals created by above described methods are members of the extinct species (e.g. Pyrenean ibex, woolly mammoth, passenger pigeon, or gastric brooding frog). One need not take it for granted that the irreversibility of extinction can (or will) be changed by the technological developments described above.

III. Concepts of species and extinction

III.1. Species concepts

One of the most intractable issues in the philosophy of biology is the species problem. We do not expect to resolve here the question of how to conceive and delineate species, but we do believe that the foregoing discussion carries implications that should direct future debates. A theorist's view of resurrection biology should be compatible with the theorist's choice of species concept.

One reason that debate over the species problem remains so vigorous is that disputants cannot agree on what exactly is at stake. The number of species concepts currently under consideration may range anywhere between one (Wilkins 2009) and more than two dozen (Mayden 1997). We will not enumerate the variety of species concepts here. Instead, we follow Okasha (2002) in distinguishing four basic categories of species concepts. This schema should be broad enough to accommodate any reader's chosen concept; it should also remain informative enough to demonstrate how one's views regarding the success and possibility of resurrection biology and the choice of species concept are necessarily closely connected to each other.

Okasha argues that species concepts may be fundamentally categorized as phenetic, biological, ecological, or phylogenetic. Phenetic concepts define species membership in terms of overall trait similarity. Concepts falling under this category, including Boyd's homeostatic property cluster theory (1999) or Devitt's new biological

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would follow. Whether or not scientists can know when they have succeeded in replicating a dinosaur phenotype is a separate epistemological question.

essentialism (2008), tend to treat species as natural kinds or at least as sets of organisms (Kitcher 1984). Biological concepts, tracing most explicitly back to Dobzhansky (1937), define species membership in terms of intrinsic reproductive isolating mechanisms. Organisms are then seen to belong to a same species if it is actually possible for them to interbreed.[2] Ecological concepts, by contrast, define species membership in terms of extrinsic reproductive isolating mechanisms. Species as conceived biologically or ecologically are counted as units in the biological ontology, either as individuals (Ghiselin 1987) or as sets (Kitcher 1984; see also Ereshefsky 2010). Phylogenetic concepts define species membership in terms of genealogical history, as in the lineage concepts endorsed by Simpson (1961) and De Quieroz (1998).

The description of species concepts rarely, if ever, includes conditions for a species' extinction. Ghiselin (1987) argues that the extinction of a species is analogous with the death of an organism, but this is not an especially informative claim given the vagueness of organismal death (Zandt *et al* 2011). To wit: one may endorse Dobzhansky's biological species concept—as Ghiselin does and college-level texts often do—and therefore conceive species as units, but this commitment offers little help in classifying poor Celia at the time of her death. On the one hand, the last *C. pyrenaica pyrenaica* was obviously not part of any population capable of producing viable offspring through natural means of reproduction[3]; on the other hand, it seems *prima facie* absurd to assert that the last *C. pyrenaica pyrenaica* was not, in fact, a member of the taxon *C. pyrenaica pyrenaica*. At a minimum, the choice of a species concept is ambiguous with respect to the definition of "extinction."

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[2] Biological species concepts may be operational, i.e. testable in practice, or theoretical (Mayden 1997). Ernst Mayr, the most vocal proponent of biological concepts, distinguished between these senses of his biological species concept by reference either to actual interbreeding between organisms (in the operational sense) or to potential interbreeding between organisms (in the theoretical sense) (Stamos 2003). In order to recognize organisms' potential to interbreed, a concept must specify some salient trait similarity between those organisms, such as Paterson's specific mate recognition system (1985) or overall genetic similarity (see Mayden 1997). In this sense, the theoretical sense of biological species concepts is functionally indistinguishable from phenetic species concepts. When we refer to biological concepts, then, we mean specifically the operational sense of those concepts.

[3] One might argue that Celia bore traits that demonstrated her reproductive compatibility with other members of the subspecies, and that we could therefore recognize her as a member of that taxon; but doing so would entail rejecting an operational view of the biological species concept (see note 2). Given Celia's separation in time from members of the taxon *C. pyrenaica pyrenaica,* she could not actually interbreed with any organism in that taxon; it is for this reason that Simpson (1961) and Mayr argue that the biological species concept is not operational across the temporal dimension (see Stamos 2003).

While species concept choice does not imply any particular definition of extinction, the converse does not hold. How one defines extinction does carry implications for which species concept one may choose. The debate over de-extinction may therefore contribute information that advances the species problem.

III.2. Extinction concepts and the challenge of finality

The term 'extinction' can refer to four different kinds of disappearance of a species. A species can vanish by hybridization with another interfertile species. It can also give birth to two (or more) new daughter species through allopatric speciation. Sometimes a species slowly transforms itself into a new species. However, what is under interest in resurrection biology is a type of extinction in which species vanish from the ontological ledger without evolving into or merging with some other taxon. (Delord 2007; Delord 2014.) Extinction is then said to come through termination of a lineage (Raup and Stanley 1971). According to our knowledge, ongoing resurrection projects concern animals that are extinct in this last mentioned sense.[4] As Julien Delord (2014) puts it, "people get excited by the possibility of recreation of a totally extinct species, and not on species that were only submitted to a process of anaphyletic change of specification". The type of extinction under interest in resurrection biology has in literature also been called "final extinction" (Delord 2007; Delord 2014) and "true extinction" (Raup 1991).

The enthusiasm for resurrection biology is often based on conviction that finality of 'final extinction' or 'true extinction' can be changed by the technologies described above. Resurrection biology is commonly presented as similar to advances in medicine: just as we may cure diseases that were formerly terminal, resurrection biology may change extinction from a terminal state to a temporary one. The idea then is that extinction has this far been irreversible merely because scientists have lacked practical tools for revising it. This might be called practical irreversibility.

Some theorists dispute this view. Alistair Gunn is among the opponents. He argues that

> *extinct* also says something about future of the class – that once it becomes a null class, it can never come to have members again. It may even be claimed that this is what *extinct* means. If so, then the question, "Can extinct species be recreated?" is answered negatively by a resort to what is sometimes called "definitional stop".
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> Wildlife preservationist are always telling us, as warning, that "Extinction is forever!". Perhaps this warning tells us no more about the world than "Bachelors are unmarried!" […] An extinct species is one that has come to an

[4] The projects also seem to concern charismatic animals and animals that have gone extinct because of human activities.

> end, has died out, is permanently a null class. As we use the word *extinct,* it seems, the recreation of an extinct species is a logical impossibility. (1991)

According to Gunn, finality of extinction is a conceptual necessity: for him extinction is irreversible not just in practice but also in principle. Can Gunn's view be accepted? If extinction is necessarily final, how should the animals born from de-extinction procedures be understood? Ideas about resurrection biology making extinction non-final rests on certain views regarding species and extinction, but also Gunn's view has strong ties to certain (other) species and extinction concepts. We will next present three ways of fitting Gunn's view together with current technological developments in resurrection science. Of each of the three alternatives we present its implications regarding concepts of species and extinction. In order to demonstrate these implications, we will employ the example of Celia and her clone—let's call the latter Delia.[5]

IV. Finality of extinction and implications of the concepts

IV.1. First alternative: replication

According to the first alternative, animals created by resurrection biology do not belong to the original species (such as the Pyrenean ibex, woolly mammoth, and passenger pigeon.)[6]**.** Even when morphological, genetic and behavioral properties of the animals produced by resurrection biology are to a great extent similar to members of the extinct species in question they cannot and should not be considered as members of that species.

This alternative requires that classification of an organism does not depend (at least solely or mainly) on its features and properties. Two animals can belong to a different species even though they are to a very high extent similar with respect to their (genetic) properties. By this standard, it is possible for Delia to be classified outside the taxon *C. pyrenaica pyrenaica* even if Celia—the organism from which Delia's genome was derived—is a member of that taxon.

To accept this view requires rejection of phenetic species concepts. If species are defined by similarities between organisms then two fully developed organisms sharing the same genome ought to be members of the same species; given the

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[5] The case of Celia and Delia concerns extinction and de-extinction of a subspecies. Yet, in the paper the interest is in the extinction of species and in the species concept. For the sake of the argument and in order to include a real life case of Celia and Delia, we presuppose that extinction of sub-species is an instance of real extinction. As a result, we also presuppose that questions presented about de-extinction in this paper can and should be answered similarly regarding species and sub-species. These presuppositions, however, are not detrimental to our general argument regarding species concept and species extinction.

[6] For discussion of this suggestion see Siipi 2014; Garvey 2007; Delord 2014.

assumption that Celia and Delia are members of different species, we would have to conclude that species are not defined by similarities between organisms. According to Gunn this is a desirable outcome: “classification [of species] is supposed to exhibit evolutionary relationships, not mere morphological similarities: to provide explanations and not merely descriptions” (1991).

The central problem of the first alternative is that it does not seem consistent with views generally held regarding clones. Dolly, the cloned sheep, is generally accepted to be a sheep (Siipi 2014). Gunn (1991) and Delord (2014) are certainly right in claiming that a clone of any individual is not identical to that individual. A hypothetical clone of Charles Darwin, for example, is not Charles Darwin, but a numerically distinct individual genetically identical to him. Nevertheless, even though Darwin’s clone is not Darwin, his clone is quite generally accepted to be a human being (Garvey 2007; Siipi 2014). Thus, the supporters of this first alternative have several questions to answer. What is that crucial difference between “ordinary” cloning and resurrection biology because of which outcomes of the latter fail to be members of the target species? If Delia is not a *C. pyrenaica pyrenaica,* what is she?

There are at least four possibilities. First, an animal produced by de-extinction procedures might be considered as a hybrid organism – for example, a hybrid between a mammoth and an elephant. A second possibility is to see the organisms produced as chimeras. (Delord 2014.) However, these alternatives considerably stretch the current meanings of the terms ‘hybrid’ and ‘chimera’. Thus, adoption of a new term denoting merely to mixes of species produced by cross-species cloning might be a third, and better, alternative. Seen in these ways, de-extinction procedures might still be seen as partly successful. Even though these procedures cannot bring extinct species back to life, they are able to create some kind of mixes between the extinct species and other (closely related) species. By this logic, the extinct species remains extinct.

Fourth, the animals produced by de-extinction procedures might be seen to belong to new human created species that may be understood as a copy of (and thus distinct from the) the original species (Garvey 2007; Delord 2014; Siipi 2014). We call this third possibility *replication.* Can it be accepted and what are its implications?

One might, following Gunn (1991) and Delord (2014) argue for *replication* by noting that the environment and ecological roles of the members of the extinct species and of the animals created by resurrection biology are likely to differ a lot. For example, a woolly mammoth created by resurrection biology would have to live with elephants (or alone or, at best, in a small group with other similarly produced animals) and in an environment widely different from the one of the original woolly mammoths. According to this line of thought, species may well, as noted by Robert Elliot (1994) have members that are artificially created. Yet, the living conditions of members of the original species and the animals born through de-extinction procedures differ dramatically. Moreover, despite their genetic similarity, the animals created by resurrection biology differ from the extinct species with respect to their cellular machinery (mitochondria, ribosomes etc) (Zimmer 2013). These two issues do not hold with respect to (ordinary) clones. They and their surrogate mothers belong to same species and they live in communities of the species from which they are cloned. Yet, these differences may not be sufficient for justifying the alternative of *replication***.** Epigenetic variations *per se* are insufficient for distinguishing species (Bentley *et al* 2004; *cf* Delord 2014). Neither are even great differences to so-called 'normal' behavior usually considered as threats to species status.

One might claim that even if it were possible to create organisms that are not just genetically but also morphologically and behaviorally totally similar to members of the original species, these animals still may fail to members of the original species. The reason is that the created animals lack the necessary connection with the original species. What is crucial for species membership is a continuity and lineage between its members. According to this line of thought, "a species went definitely extinct at the end of the reproductive or living process, and so there is no resurrection at all: we only witness the results of human modification on the living process of the bearing species, which is another stream of life than the extinct one" (Delord 2014).

This way of classifying Delia as a member of a species distinct from *C. pyrenaica pyrenaica* is consistent with biological and ecological species concepts. Since biological concepts are intended to be operational—that is, testable in actual practice—then it follows that Celia and Delia should be classified in different species, since their spatio-temporal separation would make it impossible to test the compatibility of any relevant intrinsic mechanisms for reproductive isolation[7]**.** Ecological concepts allow that spatial distance may be sufficient for species distinctions by ecological standards (Van Valen 1976); temporal distance is an even more effective extrinsic mechanism for reproductive isolation.

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[7] Proponents of biological species concepts often deny that their concepts are operational across the temporal dimension (see *supra* note 3). It is for this reason that Simpson (1961) argued for supplementing biological species concepts with his "successional species concept" for the purposes of phylogenetic reconstruction. One may argue that Celia and Delia have traits that give them the potential to interact within the same reproductively isolated population; however, Hull argues that '*unrealized* potentialities don't count' in diagnosing species membership by biological standards (1965). Even laboratory tests performed using Celia's preserved genetic information would therefore be insufficient to demonstrate the conspecificity of Celia with clones: if two organisms do not actually bear the appropriate relation prescribed by biological concepts then they are in fact not members of the same species. Whether this should be considered a virtue or a vice of biological concepts is left to the reader to decide.

Phylogenetic species concepts may or may not be consistent with classification of Celia and Delia in different species. The key point is how one defines a biological lineage. Ghiselin, for example, conceives lineages as concrete entities delimited in space and time by a particular kind of connectedness between species members (1987). Lineages of this kind preclude the classification of Delia with Celia, given their spatio-temporal separation. However, one might alternatively conceive of lineages in terms of the transmission of genetic information, in which case the identification of Delia's genetic information with Celia's would entail their classification in the same species (Garvey 2007; Delord 2014).

IV.2. Second alternative: re-creation

The second alternative for fitting resurrection science together with finality of extinction is to claim that animals created are members of the species (e.g. Pyrenean Ibex , woolly mammoth, Passenger Pigeon, etc) that once went extinct. Yet, despite their existence, the species remains extinct. This alternative is called *re-creation*. By this standard, *C. pyrenaica pyrenaica* would be an extinct sub-species even following the creation of its new member, Delia. The alternative of re-creation may sound surprising for it requires a possibility of a species being extinct even though it has living members. Could such statement be intellectually acceptable?

Non-existence is certainly conceptually central to extinction. It might even be suggested that it follows from the definition of extinction that if a species is extinct, then there are no living organisms that belong to it. But has the non-existence have to permanent? As noted by David M. Raup, the word 'extinct' is an adjective (1991). Animals are said to *go extinct* or to *become extinct*. The alternative of re-creation is based on understanding *going* or *becoming extinct* as a *process*. It is a process in which a species becomes a null class through the death of the last member of the species. When that process is complete the species is extinct and, crucially to the alternative of re-creation, remains extinct whatever happens later. Resurrection biology is unable to change species status from extinct to non-extinct because the process of extinction has already been completed. Once a species becomes a null class it remains extinct, even though it may be caused to have new members later (and consequently is no longer a null class). If resurrection biology becomes successful we will have two kinds of extinct species in the future: ones that have been and others that have not been re-created.

This second alternative, of course, to a great extent relies on certain views regarding extinction. First and foremost, it requires seeing extinction as a process: a species *becoming* a null class by the death of the only members of the species. The alternative is not compatible with seeing extinction as a property of a species *being* a null class. The alternative may seem odd, but it is also possible that this oddity is only apparent and follows from the fact that until now the process of extinction has always led to a permanent non-existence of members of the species in question. What the success of resurrection biology may change is this contingent connection between *becoming* and *being* a null class. However, the term 'final' is usually taken to refer to states of affairs of enumerated objects, not to processes. Thus, if the goal is to save finality of extinction, and if it is senseless to claim processes to be final, then claiming that extinction is a process is not a solution at all.

The more serious problem of the alternative of re-creation is that it does not seem to be consistent with any species concept presented. Phenetic species concepts would demand that Delia be classified with Celia, but phenetic concepts—wherein species membership is defined by the instantiation of individually necessary or jointly sufficient properties—treat species as natural kinds (Devitt 2008; Ereshefsky 2010). If a kind has members, then it most certainly exists; if Delia is a member of *C. pyrenaica pyrenaica,* and if *C. pyrenaica pyrenaica* is a natural kind, then that sub-species must be extant.

The alternative of re-creation is also inconsistent with biological and ecological species concepts. Since both of these species concepts treat species as concrete populations, and since all members of *C. pyrenaica pyrenaica* had died at some point in the past, it would follow that the species was extinct (Hull 1965; Ghiselin 1987). Moreover, Delia cannot be classified as a member of *C. pyrenaica pyrenaica* by these concepts since she cannot be considered a member of now-vanished populations.

Similarly, this suggestion is inconsistent with phylogenetic species concepts. By these concepts, a species is extinct if the lineage has ended and an organism is a member of a species if it is part of the species' lineage. To say that *C. pyrenaica pyrenaica* is extinct would therefore imply that there can be no future members of the lineage, but this would be contradicted by Delia's classification as a member of the sub-species.

Thus, either alternative of re-creation would have to rely on some new kind of view of species, or its incompatibility with species concepts can be taken to imply the alternative to be inconsistent and, thus, not successful.

IV.3. Third alternative: non-extinction

The third alternative for fitting Gunn's view together with resurrection biology is to claim that in successful cases of cross-species cloning extinction actually never took place. According to this line of thought, animals produced by cross-species cloning belong to the target species. Delia, for example, is a member of *C. pyrenaica pyrenaica.* However, exactly because it is possible to create these animals, extinction did not happen when all members of the species population died. We call this alternative *non-extinction*.

The *non-extinction* alternative is based on the view that extinction can be conceptualized and understood in several different ways that differ with respect to the point in which extinction is seen to take place. Most commonly, extinction is seen to take place when all members of a species have died. As noted above, sometimes extinction is associated with end of reproductive possibilities – that is, with the disappearance of the reproductive population. By this understanding, a species might be considered extinct even though there remain living organisms classified within the species. This may be the case if all living members belong to the same sex, or if they are all sterile, or if the population is too small to maintain the requisite genetic diversity (Tilman *et al* 1994). This kind of extinction is sometimes called *functional extinction***.** Finally, and relevantly to resurrection biology, it may also be possible to associate extinction with a loss of information sufficient for producing an individual with characteristics of the species. (Delord 2007.) According to this line of thought, extinction is not a question about whether a species has living members; rather, it is a function of propagating genetic (or other relevant) information. In the case of successful resurrection biology, then, extinction could never have actually taken place: information necessary for producing individuals was not lost and it was possible to bring them into existence by cloning methods.

The third alternative implies that resurrection biology is not, strictly speaking, de-extinction or resurrection. Since extinction did not take place, neither can de-extinction happen. One oddity of the alternative is that it requires that a species may fail to be extinct even when no animal belonging to it is alive. However, this may not, be as strange as it first sounds. The plant species *Silene stenophylla,* for example, persisted for 30,000 years in well-preserved seeds before being cultivated again in the modern day (Yeshina *et al* 2012).

The non-extinction alternative is consistent with phenetic species concepts because those concepts treat species as natural kinds. Hull (1980) argues that natural kinds may have gaps in time and space between members while the kind itself persists. In his example, an atomic element such as gold would continue to exist even if every individual gold atom in the universe were to disappear, because new atoms with the appropriate atomic number may yet be created. The atomic element itself is a class that may persist despite a temporary absence of members. Such would be the case with species subject to de-extinction. *C. pyreneica pyreneica* might have seemed to be extinct following Celia's death, but the later creation of Delia, a new member of Celia's species, demonstrates that the species was not in fact extinct.

Phylogenetic species concepts may be likewise consistent with non-extinction, provided that lineages are defined appropriately. If we take a lineage to be a sequence of individuals who propagate some information about the species—be it genetic or phenotypic—regardless of the means of propagation (as suggested in De Queiroz 1998), then a lineage of living organisms may have gaps in space or time so long as the important information is preserved. Delia propagates information that originated in Celia about *C. pyreneica pyreneica*; Delia and Celia are members of the same species for this reason, and the preservation of relevant information between the death of the latter and the birth of the former would allow for the persistence of the species in that timeframe. So long as the lineage is a lineage of some kind of information, rather than a lineage of individual organisms, then phylogenetic species concepts may accommodate the non-extinction view.

By contrast, neither biological nor ecological concepts can be consistent with this suggestion. Both treat species as populations whose boundaries in time and space are delimited by particular relations, either between members of the populations with each other or between members of the populations and their environments. In our chosen example, Delia simply does not stand in those relations to any population that would have included Celia, nor could she: those populations are too distant in space and time for Delia to enter into the appropriate relations with any members of those populations.

V. Non-final extinction: literal resurrection

What if Gunn's view about finality of extinction is not accepted? We call *literal resurrection* the view that resurrection biology actually can be successful in reversing extinction through the creation of new members of species that once went extinct. According to this line of thought, resurrection biology accomplishes two goals: first, the production of animals that belong to a species that is (or more precisely, has thus far been) extinct; second, a change of extinction from final to non-final state. The organisms produced by resurrection biology are then classified as the members of the extinct species, and their existence changes the species' status from extinct to extant. Following this logic, Delia is a member of *C. pyrenaica pyrenaica* and when she was born the sub-species was (for a moment) resurrected from the species category's equivalent of death.

Literal resurrection is most obviously compatible with phenetic species concepts, but this consistency must be qualified. The relevant question here is not about the species taxon: as repeatedly noted above, phenetic concepts would hold that Celia and Delia must both be members of *C. pyreneica pyreneica* given their near-complete genetic and phenotypic similarity. Instead, the relevant question is about the species category: are species classes or sets? If the former, then a species may persist even if all of its members are dead; if the latter, then a species' existence depends on the existence of its constituent members (Stamos 2003).

In the previous section we discussed the possibility that species are natural kind classes: in that case, *C. pyreneica pyreneica* would not have really been extinct between Celia's death and Delia's birth. If species are natural kind sets, however, the implications are different. Sets only exist given the existence of the set's members (see Kitcher 1984); since the set associated with *C. pyreneica pyreneica* had no members between Celia's death and Delia's birth, it would follow that the species was extinct. Since Celia and Delia must be members of the same species, however, the relevant set would have to reappear upon Delia's birth.

The alternative of literal resurrection is certainly inconsistent with biological species concepts and probably inconsistent with ecological ones. Biological concepts define species in terms of relations intrinsic to the species, and as we have already discussed a clone such as Delia cannot enter into the requisite intraspecific relations with members of an extinct species, by definition[8]. Ecological species concepts, which define species in terms of relations between members of a species and some extrinsic factor, could allow for literal resurrection in principle – assuming that the relevant extrinsic (i.e., ecological) factors remain constant. In practice, this is exceedingly unlikely. The constancy of ecological factors associated with a species is contingent on the absence of ecological cascade effects following the species' extinction, but research shows that such effects may be rapid across a variety of different ecosystems (Pace *et al* 1999). Delia might be a member of *C. pyreneica pyreneica* if the ecology of Ordesa national park had remained unchanged following Celia's death; however, extinction of *C. pyreneica pyreneica* itself likely ensured some ecological change.

Phylogenetic concepts also seem inconsistent with true resurrection. If a lineage is defined both by historical endpoints and connectedness between those points, then species cannot return from extinction *ex hypothesi,* as Gunn argued. By this standard, one of the necessary conditions of being a member of *C. pyrenaica pyrenaica* would be inclusion within an historical lineage that ended with the death of Celia; since Delia was born after Celia's death, it follows that Delia cannot be a member of *C. pyrenaica pyrenaica* and that sub-species must remain extinct. Even though phylogenetic concepts maybe consistent with Celia and Delia belonging to the same species, as shown above in the alternative of non-extinction, this is possible only provided that no extinction has taken place between the genetic donor's death and the clone's birth.

VI. Conclusion

Literal resurrection seems to be the view of resurrection biology closest to popular conceptions (cf. Zimmer 2013). Assuming that extinction is a result of the disappearance of a species population, and that extinction is not necessarily a final state (as literal resurrection presupposes), it follows (for reasons stated above) that one must adopt a phenetic species concept to maintain logical consistency.

However, the technological developments of resurrection biology do not imply that we must accept the phenetic species concept or the assumptions behind literal resurrection. As shown above, one may adopt a view of resurrection biology that rejects the literal resurrection view that extinction is not a terminal state. One may accommodate a view of extinction as final if one is willing either (a) to give up the view that Celia and Delia belong to the same species, as would be the case in species

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[8] The inconsistency of literal resurrection with biological species concepts rests on the assumption that biological concepts are operational rather than theoretical (see footnote 2). If a biological concept is taken to be theoretical—that is, if it defines species in terms of counterfactual relations in addition to real ones—then Delia might be a member of *C. pyreneica pyreneica*. However, this possibility can only be accepted by reference to phenetic similarity, and so the relevant species concept underwriting the argument would be phenetic rather than biological.

replication or (b) to give up the view of extinction as disappearance of a species population, as would be the case with the non-extinction alternative.

It is notable that no species concept is consistent with all possible views of resurrection biology, nor is any view of resurrection biology consistent with all species concepts. Phenetic concepts are incompatible with replication and re-creation; biological concepts are incompatible with re-creation, non-extinction, and literal resurrection; ecological concepts are incompatible with re-creation and literal resurrection in principle, and with non-extinction in practice; phylogenetic concepts are incompatible with re-creation and literal resurrection.

What, then, does the progress of resurrection biology imply for biological theory? It may be significant that biological and ecological concepts are least compatible with views of de-extinction. Phylogenetic concepts may be more easily compatible with views of de-extinction, but their inconsistency with literal resurrection requires significant change to received concepts of extinction. It is for these and similar reasons that Delord (2014) argues that phenetic concepts are most consistent with species resurrection. We agree.

Achievements in resurrection biology may soon influence the intellectual bases of life sciences and especially the concepts of species and extinction. At the same time, views regarding those very same bases should effect on how one sees and understands the outcomes of resurrection biology. This would mark a useful cognitive shift among conservationists and biologists, but progress in resurrection biology could also produce an even rarer jewel: conceptual change among philosophers. We may cling to old views and devalue this developing technology and research or we may embrace the science and revise how its important concepts are defined. That choice is left to the reader.

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