Not the Same Old Chestnut: Rewilding Forests with Biotechnology

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We argue that the wild release of genetically modified organisms (GMOs) can be justified as a way of preserving species and ecosystems. We look at the case of a genetically modified American chestnut (*Castanea dentata*) that is currently undergoing regulatory review. Because American chestnuts are functionally extinct, a genetically modified replacement has significant conservation value. In addition, many of the arguments used against GMOs, especially GMO crops, do not hold for American chestnut trees. Finally, we show how GMOs such as the American chestnut support a reorientation of conservation values away from restoration as it has historically been interpreted, and toward an alternative framework known as rewilding.

Globally, society has come to realize that the climate crisis threatens the well-being of current and future generations[1] and that the threat of habitat loss is as big a danger as climate change.[2] The aim of this article is to examine whether, in this context of rapid environmental change and urgent need, the wild release of genetically modified organisms (GMOs) for the sake of preserving species and ecosystems can be justified. A genetically modified variety of the American chestnut tree (*Castanea dentata*) is undergoing regulatory review in the US, and we evaluate it as a test case. Even if a GM chestnut receives government permission for wild release, an initiative to restore American chestnuts will fail unless there is support from the public, and especially from environmentalists. Currently, some major environmental organizations in the US are expressly opposed to GMOs, and relatively few actively express support for biotechnology. Traditionally, environmental restoration aims

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[1] Matthew Taylor, "Climate Crisis Seen as 'Most Important Issue' by Public, Poll Shows," *The Guardian* (September 18, 2019), https://www.theguardian.com/environment/2019/sep/18/climate-crisis-seen-as-most-important-issue-by-public-poll-shows.

[2] Jonathan Watts, "Habitat Loss Threatens All Our Futures, World Leaders Warned," *The Guardian* (November 17, 2018), https://www.theguardian.com/world/2018/nov/17/habitat-loss-biodiversity-wildlife-climate-change.

to restore past environmental conditions and to avoid, when possible, novel and untested solutions to environmental degradation and species loss. We argue that, given the scale and urgency of the threat to forest health, a reflective consideration of the values that motivate conservation should generate support for reintroducing a genetically modified variety of the American chestnut to eastern US forests. Moreover, support for similar genetic interventions should be extended based on a consideration of the merits of individual cases.

Our emphasis in the following argument is how the ethical evaluation of this and other proposed interventions turns on details of the interlocking facts and values of the case. Ecological relationships vary from one place to another, conservation priorities change through time and from one society to another, the suitability of technical interventions such as the use of genetic modification or the introduction of biocontrols depends on the suitability of particular species—and all of these dynamic, interacting conditions require evaluating the distinct risks and benefits present in particular cases. Blanket rules opposing all uses of GMOs or, conversely, endorsing every restoration or reintroduction attempt are unlikely to be sufficiently sensitive and agile during a period of rapid anthropogenic ecological change.

After presenting a picture of the opportunity to reintroduce a genetically modified American chestnut, we examine arguments for supporting the reintroduction and for opposing it. Many of the reasons that environmentalists have given for blanket opposition to GMOs are derived from the specific context of GM crops, which has been the only context of regulatory evaluation until now. We argue that these reasons to oppose GMOs fail to hold in this new case—a case that may be the first of many future opportunities to deploy GM technologies to preserve species and ecosystems. For environmentalists, the value of preserving this species should take precedence over wariness about GM technologies. We also analyze ethical arguments related to structural changes to wild entities. In the course of that analysis, we present *rewilding*, a contested successor to ecological restoration, as an appropriate way to describe how conservation practices may shift to utilize more GM technologies. We conclude that while transgenics fail to meet some traditional expectations for restoration, they are more suitable when goals and expectations for practice are revised under a rewilding framework.

I. AMERICAN CHESTNUTS: A TEST CASE FOR CONSERVATION GMOS

Conservation genetics is a field that studies population genetics in order to aid in managing populations of threatened species so that they can avoid extinction. Applications of conservation genetics include breeding programs for captive populations (e.g., in zoos), reintroductions designed to support genetic diversity, and tracking the origin of illegally traded endangered organisms. Genetic modification is not currently an application of conservation genetics because no genetically modified organism has yet been approved specifically for conservation purposes.[3]

[3] Two cases that are similar in certain respects to conservation GMOs are a GM salmon and a GM mosquito. The AquAdvantage salmon was approved by the US FDA in 2015. The salmon is grown

However, genetic modification could be used for conservation purposes in the future. Organisms—including plants, animals, insects, fungi, and bacteria—could be genetically modified to confer resistance to a pathogen, to better adapt a population to changing habitat conditions, or to drive the decline of invasive or pathogenic populations of species. For instance, genetic modification of pikas or corals could confer greater tolerance to warmer temperatures,[4] and related technologies called gene drives might be used to control populations of invasive mammals such as rats or feral dogs without euthanasia or the use of poison.[5]

The particular case of a conservation-focused transgenic organism we will examine is the American chestnut tree being developed by researchers at the State University of New York College of Environmental Science and Forestry (ESF). American chestnuts were once a dominant species in eastern US forests, but in the early twentieth century an imported fungal blight wiped out nearly all of them: about 4 billion trees died as a result. A relatively small number of isolated legacy trees remain today. While some long-lived stumps still sprout even a century later, few of these sprouts survive the blight long enough to reach reproductive maturity, and so the species is considered functionally extinct.[6]

The chestnut has economic, cultural, and ecological value; public agencies and a private foundation have been working toward reintroduction for decades. Two strategies are currently being pursued, and both are reaping success. One attempt uses traditional breeding techniques to backcross a disease-tolerant Chinese chestnut species (*Castanea mollissima*) with the American chestnut. While 50–50 hybrids have moderate disease tolerance, this initiative is aiming for a hybrid variety that is roughly 94 percent genetically American chestnut with sufficient disease tolerance to allow survival in the face of blight. The other attempt is a transgenic variety that inserts one new functional gene—from wheat—into the American chestnut genome. The inserted gene gives the chestnut the ability to create an enzyme that breaks down a toxin produced by the fungus, allowing the tree to survive the infection.

commercially for human consumption, and precautions have been taken to prevent wild release because of the possibility that GM salmon would mate with wild salmon. As of 2020, commercial development of this salmon in the US has been legislatively blocked. A GM mosquito has been intentionally released in Brazil, and approval was recently granted in the US for test releases of a similar mosquito. The goal of that project is to protect human health by reducing the viability of mosquito populations that carry malaria, Zika, and other dangerous pathogens. In neither case is the point of the GM intervention to protect biodiversity or to preserve the GM species or a species that interacts with it.

[4] Clare Palmer, "Saving Species but Losing Wildness: Should We Genetically Adapt Wild Animal Species to Help Them Respond to Climate Change?," *Midwest Studies in Philosophy* 40(1) (2016): 234–251; Ken Anthony, Line K. Bay, Robert Costanza, et al., "New Interventions Are Needed to Save Coral Reefs," *Nature Ecology & Evolution* 1 (2017): 1420–1422.

[5] Antoinette Piaggio, Gernot Segelbacher, Philip J. Seddon, et al., "Is It Time for Synthetic Biodiversity Conservation?," *Trends in Ecology & Evolution* 32(2) (2017): 97–107.

[6] American chestnuts are not currently at risk of complete extinction because individuals remain in places where they can be protected from the blight, e.g., in botanical gardens elsewhere in North America and on other continents. But because the fungus is fully established in eastern US forests, where it is also hosted by other tree species, an unaltered American chestnut tree cannot be reintroduced to its native range and be expected to survive or spread.

The enzyme that is produced is common in the vegetable kingdom and is found in grains, strawberries, bananas, and other plants. Since the transgenic chestnut is tolerant of the fungal infection and in other ways maintains the characteristics of an American chestnut, it may be a good candidate for wild reintroduction, providing objections to its transgenic origin can be answered.[7]

This transgenic variety of American chestnut is far enough along in its development and testing to be undergoing regulatory evaluation in the US, and its potential approval for non-profit distribution in the near future pressures environmentalists and philosophers to consider the reasons for and against a wild release into eastern US forests.[8] After all, even if the tree is deregulated, the goal of effectively returning the American chestnut to its native range likely requires millions of seedlings to be propagated, planted, and maintained; so, this ambitious goal could not be fulfilled without strong support from volunteers, NGOs, patrons, and government agencies. The question that ethicists and environmentalists must now consider is whether the nature of this biotech intervention should block support, since planting viable tree species like the American chestnut is otherwise a high priority for forest restoration projects.

II. ENVIRONMENTALISM AND THE DEBATE OVER GM CROPS

Could biotechnology have a place among our tools for restoring ecosystems and promoting forest health? Biotechnology has been in use since the early 1990s but has not been used for the sake of promoting conservation. The case for conservation biotech must respond to environmentalist criticisms of genetic engineering and, in addition, demonstrate that biotech conveys advantages that would make its development as a new conservation practice worthwhile. Currently, there is significant opposition to transgenics among some environmentalists, and so the arguments in favor of conservation uses of transgenics must be more compelling than merely a demonstration of plausibility. To be compelling, the arguments in favor of conservation biotech must show that GMOs can achieve goals significantly faster, cheaper, or to a degree that conventional species introductions could not. We argue that in the case of the transgenic chestnut, such a high standard can be met.

Though half of Americans have no particular view on GM crops, and GM foods are in fact ubiquitous in US supermarkets, the minority of Americans who do have a strong opinion about biotech food tend to have a strongly negative one.[9] Environmentalists have strongly opposed transgenic crops, and the Sierra Club, the oldest and largest environmental organization in the US, adopted a policy statement in

[7] Andrew Newhouse, L. D. McGuigan., K. A. Baier, et al., "Transgenic American Chestnuts Show Enhanced Blight Resistance and Transmit the Trait to T1 Progeny," *Plant Science* 228 (2014): 88–97.

[8] An application for deregulation is being reviewed by the USDA-APHIS, and documentation will soon be submitted to the FDA (because chestnuts are edible) and the EPA. These agencies are interested in confirming that foreseeable nutritional or ecological harms have been evaluated by appropriate lab and field tests.

[9] Pew Research Center, "The New Food Fights: U.S. Public Divides Over Food Science," 2016, https://www.pewresearch.org/science/2016/12/01/the-new-food-fights/.

2001 that calls "for a ban on the planting of all genetically engineered crops and the release of all GMOs into the environment, including those now approved, pending improved regulatory procedures and safety testing."[10] However, the opposition of environmentalists to GM crops may not translate to opposition when it comes to conservation purposes. That opposition was made manifest in the early 1990s, at a time when the technology was still unfamiliar to the public and when almost all proposed uses of biotech displaced agricultural practices that were perceived as more environmentally friendly and socially sustainable.

Public attitudes toward GM foods do not track political party, education, income, or geography, but they do strongly track attitudes toward food and the food system, and in particular, they track the view that individual and societal wellbeing are strongly tied to the foods we eat and how those foods are grown.[11] Since uses of biotech for conservation are not embedded in agricultural systems, environmentalists—and the public more generally—may be more open to their use than they are to GM crops. Indeed, there is wide public support for biomedical uses of transgenics, which demonstrates that some uses of biotech are viewed as more acceptable than crop biotech.[12] For instance, the Sierra Club policy that advocates a ban on biotech does not apply to biomedical uses. Some environmentalist opposition to biotech trees has focused on anticipating a slide along a slippery slope from conservation uses of biotechnology to industrial and timber uses that would profit corporations, perhaps without environmental value.[13] However, how the public, regulatory agencies, and prominent environmental organizations will judge the political and ethical acceptability of conservation uses of biotechnology might instead derive from their function in preserving health—in this case, forest and ecosystem health rather than human health.[14]

Opposition to biotech crops among environmentalists is primarily linked to aspects of biotechnology that would not be problematic for conservation biotech. The reasons that environmentalists give for opposing GM crops include two concerns that conservation GMOs such as the American chestnut should be able to avoid. The first concern is about the consequences of privately owned and controlled biotech for the socioeconomic stability of the agricultural system, and the second is the concern about environmental harms that result from particular GM species and varieties. The first concern centers on the nature of the intellectual property rights granted to biotech patent holders. Some GM crops have been economically

[10] Sierra Club, "Biotechnology Policy" (2001), https://www.sierraclub.org/policy/biotechnology.

[11] Pew Research Center, "Food Fights," 2016.

[12] Melanie Connor and Michael Siegrist, "Factors Influencing People's Acceptance of Gene Technology: The Role of Knowledge, Health Expectations, Naturalness, and Social Trust," *Science Communication* 32(4) (2010): 514–538.

[13] Rachel Smolker, "Biotechnology and Forest Health," Webinar presentation to the National Academies of Sciences, Engineering, and Medicine Committee on the Potential for Biotechnology to Address Forest Health (March 27, 2018); http://nas-sites.org/dels/studies/forest-biotech/webinar-risk/.

[14] Michael Aucott and Rex A. Parker, "Medical Biotechnology as a Paradigm for Forest Restoration and Introduction of the Transgenic American Chestnut," *Conservation Biology* (2020), published online ahead of print; https://doi.org/10.1111/cobi.13566.

linked to agricultural practices that are at odds with environmental values, including monocultures and the loss of crop varieties. Biotech seed companies such as Monsanto (acquired by Bayer in 2018) have been criticized for imperialistic practices, legal intimidation of farmers who resist planting biotech crops, consolidating control of the global seed market, and integrating the seed business with widespread pesticide use. To take just one example, activist Vandana Shiva argued in the 1990s that agrobusiness' destructive commercialization of science and commodification of nature were facilitated by the intellectual property ownership framework that gives biotech companies exclusive control of seeds and, through seeds, the agricultural system.[15] Since that time, there has been an increased desire to include evaluations of socio-economic impacts in regulatory assessments of GM crops, but knowledge about socio-economic impacts has been slow to develop, and the focus has been on a narrow set of monetary economic parameters.[16]

The legal ownership framework that generates vulnerabilities for food systems is of serious ethical concern to environmentalists and to environmental philosophers,[17] but it is not especially relevant to considering whether to support introducing a GM chestnut variety. This tree is being developed by a non-profit university research team for the purpose of wild release, and insofar as it is used for human food, it could revive a wild-gathering activity that is familiar from cultural lore ("chestnuts roasting on an open fire") but not part of contemporary experience. Indeed, only one biotech crop developed through university research has been brought to market in the US—a biotech papaya was developed by researchers at the University of Hawaii and Cornell University in the 1990s. The resulting public-private partnership was responsible for saving the Hawaiian papaya industry after a severe plant viral infection became endemic. Since then, financial barriers in the regulatory process have made it formidably difficult for publicly-funded biotech products to reach market stage. Thus, public support for the development of biotech in the public interest might even yield future socioeconomic benefits, and a distinction should be made between the role of biotech in the agricultural industry in recent decades and its potential future roles in conservation and other public interest applications.

A second argument against the planting of biotech crops is also peripheral to the question of whether to introduce a transgenic chestnut to the wild: namely, the relationship between biotech crops and pesticide use. The most common GM crops permit heavy use of glyphosate herbicides, which many fear are harmful to human and ecosystem health. In addition, some organic farmers have expressed a fear that transgenic *Bt*-producing crops could pose a threat to organic farming because they may induce resistance to pest control agents used by organic farmers.

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[15] Vandana Shiva, *Biopiracy* (Berkeley, CA: North Atlantic Books, 1998).

[16] Georgina Catacora-Vargas, Rosa Binimelas, Anne I. Myhr, and Brian Wynne, "Socio-economic Research on Genetically Modified Crops: A Study of the Literature," *Agriculture and Human Values* 35 (2018): 489–513.

[17] Fern Wickson, Christopher Preston, Rosa Binimelas, et al., "Addressing Socio-Economic and Ethical Considerations in Biotechnology Governance: The Potential of a New Politics of Care," *Food Ethics* 1 (2017): 193–199.

There is considerable controversy over the degree to which these fears are warranted, whether GM crops may also provide some ecological benefits, and whether US regulatory strategies optimally balance the risks and benefits.[18] However, such concerns about health and ecological risks related to pesticide use and production do not translate to analogous concerns about a biotech chestnut.

More broadly, introduced plant varieties have in the past altered ecosystems, and some might have a legitimate concern that new and introduced plant varieties, whether selectively bred, genetically engineered, or translocated, pose a potential risk. However, prior and ongoing investigation of ecosystem interactions can help practitioners understand which varieties or treatments are most likely to involve substantial risks. In the case of the chestnut, it is imperative for both researchers and regulators that possible ecological effects are investigated, and so far experiments have failed to find significant ecological differences between transgenic and wild type chestnuts. As a part of applying for USDA and EPA regulatory approval, ESF researchers and collaborators have run tests and failed to find potentially detrimental ecological effects such as differences between mycorrhizal colonization of transgenic and wild type tree roots,[19] harm to native frogs,[20] altered insect herbivory of chestnut leaves,[21] or inhibition of the germination of other species' seeds in chestnut leaf litter.[22] In addition, independent compositional tests that will be especially relevant to FDA regulators have also failed to find nutritional differences that could have harmful effects on wildlife or humans.[23]

On the other hand, returning the chestnut to its native range could have positive ecological effects for pollinators,[24] stream invertebrates,[25] and the wildlife that feed on nuts.[26] It could also have add-on effects for forest health. For example, the oaks

[18] National Academies of Sciences, Engineering, and Medicine, *Genetically Engineered Crops: Experiences and Prospects* (Washington, DC: The National Academies Press, 2016).

[19] K. M. D'Amico, T. R. Horton, C. A. Maynard, et al., "Comparisons of Ectomycorrhizal Colonization of Transgenic American Chestnut with Those of the Wild Type, a Conventionally Bred Hybrid, and Related *Fagaceae* Species," *Applied and Environmental Microbiology* 81(1) (2015): 100–108.

[20] H. B. Goldspiel, A. E. Newhouse, W. A. Powell, et al., " Effects of Transgenic American Chestnut Leaf Litter on Growth and Survival of Wood Frog Larvae," *Restoration Ecology* 27 (2018): 371–378.

[21] Aaron J. Brown, Andrew E. Newhouse, William A. Powell, and Dylan Parry, "Comparative Efficacy of Gypsy Moth (Lepidoptera: Erebidae) Entomopathogens on Transgenic Blight-Tolerant and Wild-Type American, Chinese, and Hybrid Chestnuts (Fagales: Fagaceae)," *Insect Science* (2019); https://doi.org/10.1111/1744-7917.12713.

[22] A. E. Newhouse, A. D. Oakes, H. C. Pilkey, et al., "Transgenic American Chestnuts Do Not Inhibit Germination of Native Seeds or Colonization of Mycorrhizal Fungi," *Frontiers in Plant Science* 9 (2018): 1046.

[23] Andrew E. Newhouse, "Safety Tests on Transgenic American Chestnut Part 1: Nutrition," *Chestnut: The Journal of the American Chestnut Foundation* 34(1) (2020): 26–27.

[24] Joel-Noel Tasei and Pierrick Aupinel, "Nutritive Value of 15 Single Pollens and Pollen Mixes Tested on Larvae Produced by Bumblebee Workers (*Bombus terrestris*, Hymenoptera: Apidae)," *Apidologie* 39(4) (2008): 397–409.

[25] Leonard A. Smock and Christina M. MacGregor, "Impact of the American Chestnut Blight on Aquatic Shredding Macroinvertebrates," *Freshwater Science* 9(3) (1988): 212–221.

[26] Harmony J. Dalgleish and Robert K. Swihart, "American Chestnut Past and Future: Implications of Restoration for Resource Pulses and Consumer Populations of Eastern U.S. Forests," *Restoration*

that largely replaced chestnuts may have increased the prevalence of destructive gypsy moths both directly, because they are more susceptible to gypsy moth invasions,[27] and indirectly, by depriving small mammal populations that feed on gypsy moth larvae of reliable chestnut mast and thus depressing their populations.[28] In addition to the overall likelihood of chestnut reintroduction increasing the resilience and stability of eastern US forests[29] and the possibility of decreasing undesirable forest pests, chestnut reintroduction might increase soil carbon storage[30] and may particularly benefit the rehabilitation of degraded sites such as mined lands and abandoned farms, facilitating greater carbon storage due to the chestnut's suitability to return forest cover to such sites.[31] Thus, there are many reasons the potential for benefit exceeds the known risks. Though the possibility of unknown risks cannot be ruled out, considerable effort has been made to seek out and study possible risks, and extended evaluation of ecological relationships will continue throughout the process of reintroduction—a process which would be much more gradual than the American chestnut's initial loss to blight.

The ecological potential for restoring the GM American chestnut should be compared with two alternatives: allowing the American chestnut to effectively go extinct from its native range, and limiting restoration efforts to the backcrossed variety. Regional extinction presents opportunity costs in terms of losses to biodiversity, and it should be considered in the larger context of a rapid decline in forest health due to introduced pests and climate change. Although forests have been expanding in much of the chestnut's native range, their health is at risk from biological invasions, such as the chestnut blight, and this poses a long-term threat to ecosystem stability, productivity, and resilience.[32] As a result, the loss of the American chestnut needs to be understood in relation to more recent threats to dominant tree species, including elm, beech, hemlock, ash, butternut, and oak.[33] Returning a lost tree species is one step toward addressing the decline in health of US forests.

Ecology 20(4) (2011): 490–497.

[27] Steve Oak, "Forest Health Impacts of the Loss of American Chetsnut," in *Proceedings of Conference on Restoration of American Chestnut to Forest Lands*, ed. K. C. Steiner and J. E. Carlson, Natural Resources Report NPS/NCR/CUE/NRR - 2006/001 (Washington, DC: National Park Service, 2006).

[28] Dalgleish and Swihart, "American Chestnut Past and Future."

[29] Aaron M. Ellison, Michael S. Bank, Barton D. Clinton, et al., "Loss of Foundation Species: Consequences for the Structure and Dynamics of Forested Ecosystems," *Frontiers in Ecology and the Environment* 3(9) (2005): 479–486.

[30] Geoffrey W. Schwaner and Charlene N. Kelly, "American Chestnut Soil Carbon and Nitrogen Dynamics: Implications for Ecosystem Response following Restoration," *Pedobiologia: Journal of Soil Ecology* 75 (2019): 24–33.

[31] Jenise M. Bauman, Carolyn Howes Keiffer, and Brian C. McCarthy, "Growth Performance and Chestnut Blight Incidence (*Cryphonectria Parasitica*) of Backcrossed Chestnut Seedlings in Surface Mine Restoration," *New Forests* 45(6) (2014): 813–828.

[32] A. M. Liebhold, E.G. Brockerhoff, S. Kalisz, et al., "Biological Invasions in Forest Ecosystems," *Biological Invasions* 19(11) (2017): 3437–3458.

[33] F. J. Krist, J. R. Ellenwood, M. E. Woods, et al., *2013–2027 National Insect and Disease Forest Risk Assessment* (Fort Collins, CO: US Forest Service, 2014).

And how does the potential for restoration success for a GM American chestnut compare with a backcross hybrid between American and Chinese chestnuts? The majority of backcross varieties have not yet been able to achieve as high a level of disease tolerance as the biotech tree. The blight tolerance of most backcross varieties still appears to be close to 50–50 hybrids, and the most blight-resistant backcross trees have less than 94 percent American chestnut genome (and therefore have more characteristics of the Chinese parent trees). Chestnut blight tolerance seems to require that numerous genetic alleles be present,[34] rather than the two or three that were assumed when the program was started, and so it has been difficult to establish lines that reliably transmit the disease tolerance trait from parent to child. It has also been difficult to establish lines with meaningful blight tolerance that achieve the height and form of American chestnuts. Chinese chestnuts have a shorter, more branching nature, and hybrid lines that retain these traits are less likely to successfully compete for light in eastern US forests. For these reasons, the backcross variety is less likely to be suitable for restoration activities in as short a timeframe as a biotech variety could be. However, these two initiatives are not in competition with each other: they may be seen as complementary approaches that could each have a role to play, and efforts to produce a suitable backcross variety might provide genetic resources to increase any restoration project's success.

The details of the case of the transgenic American chestnut force a new consideration of environmentalists' blanket proscriptions against the use of biotech. In the early days of transgenic crops, the process seemed new and untested, but by now the technology is robust and has become familiar. In fact, recent reports even suggest that transgenesis typically results in smaller genomic changes than traditional techniques like hybrid breeding[35] and that many plants have been naturally genetically engineered by the same bacterium that is used for laboratory transformations.[36] ESF's transgenic chestnut project is in its twenty-ninth year, and some formerly skeptical individuals and groups have become enthusiastic supporters. Many of the unknowns that once seemed to demand a prudent application of the precautionary principle have now been answered. Thus, it is now possible to show that in at least certain cases, the arguments against conservation biotech that appeal to the potential for empirically measurable harmful consequences have been adequately addressed, especially when measured against the possible benefit of increasing the resilience and diversity of forests at a time when they are under severe stress.

Nonetheless, there are objections to biotech that are more philosophical than empirical, and these concerns require additional evaluation.

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[34] Jared W. Westbrook, Qian Zhang, Mihir K. Mandal, et al., "Optimizing Genomic Selection for Blight Resistance in American Chestnut Backcross Populations: A Tradeoff with American Chestnut Ancestry Implies Resistance Is Polygenic," *Evolutionary Applications* 13(1) (2020): 31–47.

[35] Justin E. Anderson, Jean-Michel Michno, Thomas J. Y. Kono, et al., "Genomic Variation and DNA Repair Associated with Soybean Transgenesis: A Comparison to Cultivars and Mutagenized Plants," *BMC Biotechnology* 16(1) (2016): 41.

[36] Tatiana V. Matveeva and Leon Otten, "Widespread Occurrence of Natural Genetic Transformation of Plants by Agrobacterium," *Plant Molecular Biology* 101(4) (2019): 415–437.

III. BIOTECHNOLOGY AND CONSERVATION VALUES

Even though at least some potential conservation uses of biotech do not threaten the predictable ecological and socioeconomic harm that have led environmentalists to be opposed to biotech crops, there are several hard questions about conservation biotech that should be investigated. These concerns arise from the difference between conservation biotech and agricultural applications: namely, conservation biotech concerns the intentional wild release of novel genetic material. Crops typically require active human cultivation, and even when it is possible for genetic material to be released into the wild (as with the AquAdvantage salmon, see note 3), steps are taken to prevent this from happening (such as by containment in enclosed land-based facilities and by generating an all-female population). In the case of conservation biotech, however, the point of the introduction is for the transgene to spread throughout a population.

Wild release of a transgenic organism raises two worries: 1) that it could cause unexpected ecological harm and could not be retrieved; and 2) that it would be wrong to alter the gene pool of wild species, permanently changing something essential about the species. We will treat these issues as operating at two levels—a practical level versus a more philosophical level. At a practical level, we would want to know whether scientists have gathered enough empirical evidence to show a minimal risk of ecological harm. Of course, many common, everyday actions carry some risks, but is the risk of ecological harm less than the risk of species loss and also less than the costs and risks of alternatives, such as sticking with traditional breeding methods to attain disease tolerance? Moreover, if an unanticipated harm should appear, what would the response be?

In the case of the transgenic American chestnut, we have the means to address these practical concerns. The difference between crop biotech and conservation biotech is key. In the production of biotech crops, there is the possibility of a conflict of interest between the aims of the developer to sell a profitable product and the aims of environmentalists to preserve sustainable agricultural systems. However, in the case of conservation biotech, the aims of the research scientists and environmentalists are aligned: both are interested in reintroducing a species that could contribute significant ecological value to eastern US forests. An introduced variety that impairs the well-being of pollinators, amphibians, beneficial fungi, or other native plant species would not achieve the conservation aim. The convergence of aims among the Forest Service, the American Chestnut Foundation, and research scientists has supported collaboration between researchers working on the biotech American chestnut and researchers working on the backcrossed variety. At present, the biotech version seems to have attained greater disease tolerance while retaining the native traits for growth pattern and height that will benefit its survival in the wild. But the native genetic diversity that has been gathered by the traditional breeding program will play a crucial role in the future to add resilience to the biotech variety and to adapt it to local growing conditions up and down the east coast.[37] An assay has been developed which allows transgenic trees to be easily identified, and, in this way, its spread can be tracked. It takes several years for American chestnuts to reach reproductive maturity, and several decades before they produce prolific seeds. These trees don't move far or fast, so it would be much easier to "recall" or limit the spread of transgenic chestnut trees than a mobile organism like a salmon, or even a fast-spreading plant.

While scientific understanding can help to clarify the practical risks and benefits of introducing transgenic organisms, the more philosophical concern is the question of whether intentional genetic engineering changes something essential about the species that traditional breeding does not, especially given that similar changes can also occur through natural processes. By extension, another philosophical question is whether introducing genetic changes using certain techniques has a negative effect on the relationship between human society and nature. These are ultimately judgments about human values and aims. This second concern leads to an evaluation of whether conservation applications of transgenic biotech are aligned with principles of ecological restoration or rewilding. Specifically, in the next section, we examine whether the possibility of intentionally and permanently altering a species' genome is related both to the value that ecological restoration places on historical fidelity and to the attitude restoration produces toward human intervention in ecosystems.

Modern backcrossing (using traditional breeding methods) and biotech are both sophisticated modern techniques. Both kinds of techniques were developed or optimized in the late twentieth century and require expert knowledge and sophisticated lab equipment. In modern agricultural production, lab techniques for producing and analyzing GE vs. non-GE crops look similar. Which is more natural? Which is more respectful of genetic integrity and natural processes? Which process is better understood? The answers to these questions are not straightforward. On the one hand, the backcrossed variety differs from the native species by a couple thousand genes, the mechanisms of its blight resistance are complex and still not well understood, and the trait for blight tolerance is not consistently passed down from one generation to the next. The GM chestnut, on the other hand, possesses a single functional transgene that has well-known effects in other plants, can be identified and tracked in the wild by an assay, and is reliably passed to progeny. Additionally, while approximately 50 percent of the offspring from a transgenic parent will inherit the transgene, the other half are entirely non-transgenic and indistinguishable from wild relatives. This means wild-type chestnuts will always be available and retrievable, which is not the case with hybrid breeding. Thus, the transgenic tree's disease tolerance is, so far, better suited for returning American chestnuts to native forests.

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[37] Jared W. Westbrook, Jason A. Holliday, Andrew E. Newhouse, and William A. Powell, "A Plan to Diversify a Transgenic Blight-Tolerant American Chestnut Population Using Citizen Science," *Plants, People, Planet* 2(1) (2020): 84–95.

Lurking in the background of skepticism about genetic engineering, there is sometimes the idea that a species possesses genetic integrity, or an essence linked to the purity or unchanging nature of its genome, and that any human intervention—even a small one—destroys genetic integrity. But species naturally change through time as a result of genetic mutation, sexual reproduction, and horizontal gene transfer between unrelated species through bacterial activity. There is genetic diversity within species, and identifying essential genetic components is not required in order to delineate species. If preservation of genetic integrity were a moral requirement, it would proscribe artificial selection, or traditional breeding, as much as it would genetic engineering.[38] In the American chestnut's case, there is no viable genotype for tolerance of chestnut blight that has not been altered by human activity. Native relatives of the American chestnut have been decimated by the blight, and even familiar Asian chestnut varieties with partial defenses against blight are largely domesticated. The most widely grown chestnut lines in the US have been subject to thousands of years of artificial selection, most of which occurred on a different continent. Moreover, even the natural range of the American chestnut (which more easily fits the conception of *wild* than the common hybrid varieties) has likely been affected by human activity: there is evidence that Native American trade aided its establishment in the northern part of its pre-blight range,[39] and repeated forest clearing by European settlers likely increased prominence of chestnuts in the northern part of their range.[40] This puts into question whether hybrid chestnut varieties are any more *wild* than a biotech variety.

Thus, neither a biotech American chestnut nor the back-crossed variety is *natural* in the sense that it could have been generated in the necessary timeframe without human involvement. That is, even though nature allows the Chinese and American chestnut species to interbreed when they come into contact, their native habitats are separated by thousands of miles of ocean, and the process of artificial selection for the back-crossed variety has been carefully guided for several decades. Likewise, the enzyme that makes the transgenic tree disease resistant has evolved naturally multiple times elsewhere in the plant kingdom, but there are not sufficient numbers of breeding stock remaining such that natural evolutionary processes would have time to save the American chestnut by spontaneously generating disease-tolerance.

At a different scale, we might initially be drawn to the intuition that a forest containing a transgenic tree is less natural or less wild than a forest without it. But consider that our current forest, the one where chestnuts only grow for a few years

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[38] We even induce genetic change, or mutagenesis, in agriculture by exposing seeds to high levels of radiation in order to induce helpful mutations, a practice which is not regulated. For more discussion of genetic integrity and environmental ethics, see Yasha Rohwer and Emma Marris, "Is There a *Prima Facie* Duty to Preserve Genetic Integrity in Conservation Biology?" *Ethics, Policy & Environment* 18(3) (2015): 233–247.

[39] Emily W. B. Russell, "Pre-Blight Distribution of *Castanea Dentata* (Marsh.) Borkh," *Bulletin of the Torrey Botanical Club* 114(2) (1987): 183–190.

[40] David M. Smith, "Changes in Eastern Forests Since 1600 and Possible Effects," in *Perspectives in Forest Entomology*, ed. John F. Anderson and Harry K. Kaya (New York: Academic Press, 1976), 1–20.

as stump sprouts before dying back, is missing the chestnut precisely because of human actions. Global trade has brought pests from all over the world into forests where plants are not equipped to fend them off. Forests that lose dominant tree species have lost not only some component trees and the wildlife that depend on them; they also lose resilience and their full range of function. (Keep in mind that besides the American chestnut, other species under threat include elm, hemlock, ash, beech, butternut, and oak—and those are just examples found within the American chestnut's range!) In sum, from the perspective of simplicity and effectiveness, the transgenic intervention does not seem less natural than the backcrossed variety, and a forest with a transgenic chestnut is not obviously less natural than a forest depleted of a dominant species due to human activity. Thus, it seems that the value placed on conserving entities and processes that are *natural* and forests that are *wild* could lead to favoring a transgenic American chestnut as much (or more) as it could to favoring a backcrossed chestnut variety or to allowing the chestnut to remain functionally extinct.

IV. RESTORATION PRINCIPLES AND REWILDING AS AN ALTERNATIVE

The set of land management practices that aims to restore lost species, ecological processes, and natural value to landscapes has been termed ecological restoration. We will now consider the charge that the core principles of ecological restoration are at odds with using a transgenic variety to restore American chestnuts to their historical range. We will examine how biotechnology challenges restoration—but also how this challenge traces existing lines of criticism against restoration principles. In the next section, we will draw the conclusion that the use of genetic technologies to promote conservation should lead to a reorientation of conservation values and techniques along the lines of what has been termed *rewilding*, a set of practices that can be seen as a successor to restoration.

Ecological restoration is a science-based approach to land management that draws on historical baseline data and ecological understanding for the sake of repairing human-caused damage to ecosystems. Within this broad category, there is much diversity. Restoration has been applied to different ecosystems, from marine to montane and from rainforest to desert; on different scales, from abandoned city blocks to the Everglades; and by different actors, from government agencies to private companies, by amateurs and by professionals. Ecological restoration was consolidated as a professional practice in the late 1980s, and in a little over thirty years, the field's knowledge base, theory, and best practices have shifted to accommodate new scientific understanding as well as to respond to criticism.[41]

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[41] Ecological restoration is not a clearly-defined and uniform approach, and we describe it according to recent commonly accepted versions. There are scientists and conservation practitioners who, like us, call the approach we advocate rewilding and others who would see these conceptual changes as an evolution of restoration rather than the development of a successor practice. See David Nogués-Bravo, Daniel Simberloff, Carsten Rahbek, and Nathan James Sanders, "Rewilding Is the New Pandora's Box in Conservation," *Current Biology* 26(3) (2016): R87–R91. We are sympathetic with both views, being

Two common criticisms of restoration approaches have been 1) that restoration is too dependent on historical baselines and the value of historical fidelity, and 2) that restoration often fails to cultivate an appropriate relationship with nature—namely, that it derives from an arrogant attitude of control rather than from a stance of humility and respect. We will consider each of these in turn.

Ecological restoration is used to reverse environmental degradation caused by human activities, and its success can be measured by a variety of criteria such as the provision of biodiversity and ecosystem services, functional stability, or approximating a return to pre-disturbance historical baselines, termed historical fidelity.[42] Frequently, restoration places greater value on historical fidelity than on functional stability or provision of ecosystem services. Ecological restoration typically identifies historical reference conditions and uses these as a tool to identify and characterize appropriate targets for restoration efforts. However, there are problems with picking historical conditions against which to benchmark the success of restoration efforts. One is a conceptual problem with picking conditions that are natural, in the sense that they arose in the absence of human intervention in an area's ecology. In areas where humans were present at the time of the baseline conditions, there was, in fact, frequently a human influence on ecological conditions. This has become more recognized recently than it was when ecological restoration was first conceived. In the US, restorationists often pick the period of European settlement to establish a baseline; in Europe, they often pick a time period before Roman settlement or before the Iron Age. In both cases, however, humans had significant impacts on landscapes even before these periods of settlement and technological innovation. These choices therefore cannot be justified on the grounds that a historical reference condition is free of human influence. Moreover, attempts to provide other justifications have been criticized as post hoc and relativist. A similar criticism of historical fidelity can be made on the basis that ecosystems are dynamic and are constantly changing in unexpected ways. For instance, North American flora (including American chestnuts, until blight) have been migrating northward following the last Ice Age. In response to this criticism, restorationists have (necessarily and appropriately) become more flexible about which benchmarks are chosen and how closely their targets hew to historical fidelity.[43] In the absence of a replacement criterion for judging success, this loosening has led some restorationists to be charged with relativism.

The strong emphasis that restorationists place on historical fidelity is also undermined by the pressures of anthropogenic ecological change—both by the influx

more focused on the principles and practices at stake than the question of whether these changes are revolutionary or evolutionary.

[42] Susan Baker and Katarina Eckerberg, "Ecological Restoration Success: A Policy Analysis Understanding," *Restoration Ecology* 24(3) (2016): 284–290.

[43] Eric Higgs, Donald A. Falk, Anita Guerrini, et al., "The Changing Role of History in Restoration Ecology," *Frontiers in Ecology and the Environment* 12(9) (2014): 499–506.

of invasive species and by uncertainties introduced by rapid climate change.[44] The label *restoration* seems to indicate that it is both possible and desirable to undo human damage to ecosystems by returning them to a past condition. However, in many cases, a return to earlier conditions requires costly long-term upkeep, either because natural processes like wildfire cannot be restored or because introduced diseases, pests, and competitors pose a constant threat. As climatic conditions also change, a return may be impossible on the timescale of human generations. Past species assemblages for a place may no longer be viable just a few decades in the future. One response has been to pick reference conditions for species restoration from other places based on abiotic conditions (soil and climate) rather than on a place's own ecological history. This strategy accepts that it may be necessary to steer emerging novel ecosystems for the sake of maintaining ecosystem goods and services. In doing so, it does seem to avoid the criticism that restoration relies over much on historical fidelity, but at the same time, it leans toward the instrumental values of natural resource conservation that ecological restoration initially intended to avoid.

A second criticism of restoration is that it assumes that nature engineered is nature improved and that a *natural* product—an ecosystem that looks familiar or is pleasing according to human aesthetic criteria—is more valuable than natural processes.[45] The simple version of this criticism is most often directed at commercial restorations where the intent is to achieve rapid results on a scale of months or years rather than decades, and where insufficient attention is given to restoring natural processes. However, a more sophisticated version of this criticism can be directed even at apparently careful and successful restorations on the grounds that they cultivate an attitude of arrogance rather than humility.[46] In fact, restorations that most closely achieve historical fidelity often require an intensive, long-term management approach.

Shifts in rhetoric and practice have led to rewilding as an alternative to restoration. The uses of the term rewilding are more divergent from each other and therefore present a less cohesive category than restoration, and the meaning of rewilding varies significantly between scientific and environmentalist discourse and between Europe and North America. As Andrea Gammon demonstrates through a careful typology and analysis, overlapping characteristics in these disparate arenas of discourse justify treating rewilding as a forward-looking ethos that may prove useful in guiding ecosystem management in a way that is responsive to environmental values.[47]

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[44] Stephen T. Jackson and Richard J. Hobbs, "Ecological Restoration in the Light of Ecological History," *Science* 325 (2009): 567–569.

[45] Eric Katz, "The Big Lie: Human Restoration of Nature," *Research in Philosophy and Technology* 12 (1992): 231–241.

[46] William M. Throop, "Environmental Virtues and the Aims of Restoration," in *Ethical Adaptation to Climate Change*, ed. Allen Thompson and Jeremy Bendik-Keymer, 47–62 (Cambridge, MA: MIT Press, 2012).

[47] Andrea Gammon, "The Many Meanings of Rewilding: An Introduction and the Case for a Broad Conceptualisation," *Environmental Values* 27(4) (2018): 331–350.

In scientific contexts, rewilding most commonly refers to species reintroduction (typically vertebrate animal species) to places where a species, taxon, or class of animals has become rare or extinct due to human activity.[48] The term *rewilding* has been applied to plans to reintroduce large predators in North America, beaver in Scotland, and tortoises to the Mauritius Islands. It also sometimes refers to a passive approach to managing abandoned agricultural lands—i.e., allowing them to become wild on their own rather than restoring them under an active management plan.[49]

Environmental activists have picked up on the theme of reintroducing extinct or missing species, but, compared with scientists, environmental activists have split more strongly from the use of historic reference conditions that guide restoration. They are more likely to call an attachment to history a form of nostalgia and to aim for increasing the extent of wildlands by, for example, creating wildlife corridors and by tracking and supporting a combination of private and public initiatives under various forms of management in pursuit of long-term conservation goals.[50] Thus, a prominent goal of rewilding, especially in North America, is to preserve and consolidate large swathes of wilderness to preserve migration paths and facilitate passive reintroductions. A related sense that *rewilding* has in Europe is the transformation of abandoned agricultural and industrial lands to a more natural state, especially under passive management, and often with the use of surrogates for species that have become extinct.[51] An additional sense of rewilding that is forming in environmentalist communities is the development of strategies to increase biodiversity, and especially more animal species, in urban, suburban, agricultural, and industrial places. These prioritize long-term maintenance strategies over emergency rescues.[52]

From these diverse approaches, some key themes emerge. Rewilding is developing as an alternative to restoration in a few key ways: 1) it is more forward-looking than backward-looking, 2) it aims to depend on or restore natural processes to permit passive management strategies, 3) it prioritizes a landscape-scale perspective, and 4) it is satisfied with the use of surrogate species to achieve regeneration of ecosystem function. Rewilding generally rejects historical fidelity as the primary criterion for success without rejecting the relevance of historical conditions as informative. Instead, rewilding accepts current social and environmental conditions—that the climate is changing, that there is pressure on habitats, that both ecosystems and social needs are dynamic, and that there are limited resources for conservation.

[48] Jens-Christian Svenning, Pil Pedersen, C. Josh Donlan, et al., "Science for a Wilder Anthropocene: Synthesis and Future Directions for Trophic Rewilding Research," *PNAS* 113(4) (2016): 898–906.

[49] Koen Arts, Anke Fischer, and René van der Wal, "Boundaries of the Wolf and the Wild: A Conceptual Examination of the Relationship between Rewilding and Animal Reintroduction," *Restoration Ecology* 24(1) (2016): 27–34; Dolly Jorgensen, "Rethinking Rewilding," *Geoforum* 65 (2015): 482–488.

[50] Jozef Keulartz, "Future Directions for Conservation," *Environmental Values* 25 (2016): 385–407.

[51] Holly Deary, "Restoring Wildness to the Scottish Highlands: A Landscape of Legacies," in *Restoring Layered Landscapes: History, Ecology, and Culture*, ed. Marion Hourdequin and David G. Havlick (New York: Oxford Univeresity Press, 2017).

[52] Richard T. Corlett, "Restoration, Reintroduction, and Rewilding in a Changing World," *Trends in Ecology & Evolution* 31(6) (2016): 453–462.

From those conditions, rewilding attempts to preserve species and their interactions with an eye toward developing systems that will sustain themselves.

V. BIOTECHNOLOGY'S COMPATIBILITY WITH REWILDING

The principles of ecological restoration support the preservation of native tree species, and restorationists have been strong supporters of reintroducing chestnuts. However, the possibility of reintroducing a transgenic version of the American chestnut requires closer examination from a restorationist perspective. At first glance, the use of biotechnology may seem to stray from the guideline of historical fidelity and perhaps also from an attitude of humility and cooperation with natural processes. If the adoption of biotechnologies were endorsed due to the release of ecosystem management from historical guidelines, then it might appear that biotechnology will be used as a quick technological fix for any number of serious or not-so-serious ecological disturbances. We will argue that examining the philosophical assumptions at the root of skepticism toward biotechnology may lead to new ways of thinking about its role in conservation without acceding to the "anything goes" approach that may appear to follow from the release of historicity conditions.[53] In the case of the chestnut, no return to a historical condition is possible; it is, however, possible to select surrogates and proxies that best achieve management goals.

Several hidden assumptions are behind a rejection of conservation biotechnology, and we will open up these assumptions to question in light of the above critiques of restoration. These assumptions are: 1) that the transgenic is less natural than any alternative, 2) that producing a transgenic tree for wild release expresses an attitude of arrogance, and 3) that nature will rewild itself. Under examination, revisions to these assumptions point to the transgenic chestnut qualifying as at least one case of a transgenic organism which is compatible with the goals and values of rewilding.

The first assumption that is ripe for revision is the idea that a transgenic American chestnut tree would reduce what we think of as the *wildness* or the *naturalness* of eastern forests. Although we are sure that the Amazon river basin is more wild than Amazon.com and that the Yukon territory is more natural than a GMC Yukon, there is no clear and shared science-based standard for how to quantify wildness or naturalness. From a forward-looking rewilding perspective, the transgenic tree is a timely solution to a human-caused problem. The introduction of pests from the other side of the globe interrupts the evolutionary process; this intervention could put the tree on a level playing field again, allowing evolutionary processes to continue. As a specifically targeted intervention, the outcomes can be relatively well anticipated, while a hybrid tree could introduce uncertainties with regard to how well the tree would be able to compete with other canopy trees and what its ecological interactions would look like. There is no strict historical fidelity available here: the tree will continue to decline, or else it will be replaced by an altered variety. Strict historical fidelity is unattainable in either case. In the end,

[53] Eric Desjardins, Justin Donhauser, and Gillian Barker, "Ecological Historicity, Functional Goals, and Novelty in the Anthropocene," *Environmental Values* 28(3) (2018): 275–303.

the human-caused extinction of a recently-dominant species is not more natural or more wild than a forest that includes a close copy. Thus, a value for historical fidelity requires considering additional values in order to make reasoned distinctions between management options.[54] The chestnut can be seen as a case at the leading edge of possible interventions aimed at benefiting multiple conservation aims, as we are increasingly likely to see applications of biotechnology that could modify an organism to be more similar to its historical relatives, not less.

The second assumption worth questioning is the idea that genetic engineering is arrogant while allowing nature to take its course is a virtuous form of humility. Yasha Rohwer and Emma Marris argue that the future of restoration requires "a restoration of moral value," one form of which is "community connection."[55] Arrogance, humility, and moral intention are as vague and contextual as *nature* and *wildness*, but one interpretation of the opportunity presented by the transgenic chestnut is as a chance to regain a sense of ethical responsibility for the state of our forests. We have known for more than a century that international trade in plant materials leads to introduced pests, and chestnut blight made it clear that some of those will have malignant effects. Often these introductions are considered unintentional, but they are no more the result of ignorance than our continuing addition of greenhouse gases to the atmosphere. There continue to be introductions of harmful forest pests—we've lost a hundred million ash trees in the last decade—and these occur not unknowingly but because cheap wood pallets from China facilitate international trade (to take one example), and that is worth more to our society than reducing risks from introduced insects. If the costs were low or the fix were easy, such introductions could have been halted long ago. Refusing to address the rapidly increasing threat to forest health is itself a form of arrogance coupled with apathy. In contrast, reintroducing a nearly extinct tree—something that will require many volunteers across the eastern US to become involved in planting and nurturing—is a way of re-establishing an earlier sense of connectedness to forests that has been lost with increasingly urban lifestyles. It presents an opportunity for engaging in the satisfying labor of moral repair.[56] Rewilding prioritizes taking such actions for the sake of ecosystem health and resilience and doing so in ways that build community connection and a sense of responsibility for the uniqueness of place.

The third and final assumption that should be examined is that nature will rewild itself. By focusing on appearance and on product rather than process, restorationists have often opted for an intensive land management approach. The assumption that if historical conditions (in forests, for example) are put into place they will be able to maintain themselves stems from failing to recognize the degree of our current forest health crisis and the role of climate change and other forces affecting species

[54] Eric Desjardins, "Historicity and Ecological Restoration," *Biology and Philosophy* 30 (2015): 77–98.

[55] Yasha Rohwer and Emma Marris, "Renaming Restoration: Conceptualizing and Justifying the Activity as a Restoration of Lost Moral Value Rather Than a Return to a Previous State," *Restoration Ecology* 24(5) (2016): 674–679, 678.

[56] Benjamin Almassi, "Ecological Restorations as Practices of Moral Repair," *Ethics & the Environment* 22(1) (2017): 19–40.

survival.[57] Forest biotech can be an appropriate management strategy because it offers a chance for threatened species to re-establish themselves in a long future filled with uncertainty and change. It can also be implemented on a landscape scale where a hands-on restoration approach would be unwieldy.

Once we question and overturn the assumptions that transgenic trees are less wild or natural than the alternatives, that biotechnology necessarily expresses arrogance and irresponsibility, and that forest health can be preserved against contemporary threats without deliberate efforts, the case for environmentalist support for a transgenic chestnut tree is compelling. Though it may be at odds with a strict adherence to historical fidelity, there are other reasons to revise past interpretations of what historical fidelity required of restorations. Indeed, at least this one case of conservation biotechnology—and possibly others—is compatible with the goals of rewilding. According to the key principles used to support rewilding efforts, a transgenic chestnut offers environmentalists an opportunity to revive a dominant forest species at the brink of extinction using a forward-looking approach to land management. Among the benefits of rewilding chestnut trees are that they could be reintroduced on a landscape scale and, once reintroduced, natural processes (and, therefore, passive management strategies, such as monitoring spread) are likely to be sufficient. Rewilding has previously embraced the reintroduction of surrogate species, and in this case a transgenic variety is an appropriate surrogate given the magnitude of the loss of this species in the context of urgent threats to a large number of forest tree species.

This is an important issue for environmental philosophers for two reasons. It challenges a habitual rejection of techno-scientific solutions by demonstrating that whether environmentalists should support a particular solution depends on details about the nature of both the problem and proposed solution. And it changes the frame within which we consider the nature of environmental responsibility for an era when problems develop at a pace faster than natural processes can address them—an era of environmental urgency and crisis.

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[57] National Academies of Sciences, Engineering, and Medicine, *Forest Health and Biotechnology: Possibilities and Considerations* (Washington, DC: The National Academies Press, 2019).