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Where there are mountains, there are chestnuts: A summary of the controversy surrounding the biotechnology-forward restoration of the cradle-to-grave king of the forest (5,656 WORDS)

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Introduction

The American chestnut tree, *castanea dentata*, once defined the canopies of the wooded Appalachian region, where generations of Indigenous people and poor farmers depended on it for its food and lumber. A century ago, it was one of the most important and numerous hardwood trees — its abundance spreading from Georgia to Maine due to a combination of rapid growth, its general fire resistance and a large, repeating annual nut crop that allowed it to take over the region. The pre-blight distribution of trees — called by those who revered them "the redwood of the east"[1] — was generally contained in the geographic area where well-drained, steep slopes still provided enough moisture to acid-loam soils.

Growing upwards of 100 feet with trunk diameters of more than 10 feet, a matured American chestnut tree was recognizable by its dark red bark and elongated oval, dull leaves with jagged edges. Appalachian old guard families wanted their babies to sleep in cribs made of chestnut wood and wanted their grandfathers to be buried in chestnut stumps.[2] Used in teas, roasted during the winter holidays and eaten by a variety of animals, three of the tree's nuts are enclosed by a spiny, green burr that begins producing about a decade into the tree's lifespan. But matured American chestnuts have been virtually extinct for decades, the only existing chestnut trees being small stump sprouts originating from old root systems that die before they even have a chance to reproduce.

Ink disease, *phytophthora cinnamomi*, a soil-borne water mold that creates root rot, narrowed the population in the southern regions where chestnuts were especially populous in the early 1800s. The trees were again later devastated in a more wide scope by a fungal disease with origins in Asia where it was relatively harmless to Chinese chestnut trees growing close to sea

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[1] Hale, D. (2021). The American Chestnut Tree. *Appalachian Trail Conservancy*. Accessed online.
[2] Baxter, B.N. (2009). An Oral History of the American Chestnut in Southern Appalachia. *A Thesis Presented for the Master of Environmental Science Degree at the University of Tennessee at Chattanooga*. Accessed online.

level. Known as chestnut blight, *cryphonectria parasitica*, the wind-borne fungus was accidentally discovered in New York City in 1904 when Chinese chestnut trees were finally imported and propagated. The fungus enters and eats away at tree bark through incisions and other kinds of lesions until the tissue layer that facilitates secondary growth of stems and roots, called the cambium, is destroyed.[3] Just as "Americans were just starting to recognize that the country's natural bounty had limits,"[4] somewhere between three and four million trees were wiped out by the blight in the first half of the 20th century.

Early efforts to contain the blight fungus included the passage of the first Plant Quarantine Act of 1912, which authorized the United States Department of Agriculture to inspect and even quarantine agricultural goods upon their entry into the country. When alternative paths needed to be taken, especially in the case of the chestnut, whose population and livelihood had already been heavily altered by the fungus, hybrid trees and trees born from backcross breeding[5] were created with the hopes that they could replace the susceptible ones. These efforts were largely unsuccessful,[6] though not all hope was lost for the tree.

Disappearance of the tree was just the beginning of an abject change to the structure and composition of eastern forests and the Appalachian way of life. The loss of the tree as a vital and stable resource "no doubt gave additional advantage to the forces of industrialization that were

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[3] Anagnostakis, S.L. (1997). Chestnuts and the Introduction of Chestnut Blight. The Department of Plant Pathology and Ecology at The Connecticut Agricultural Experiment Station. Accessed online.
[4] Freinkel, S. (2007). Introduction. *American Chestnut: The Life, Death, and Rebirth of a Perfect Tree* (pp. 1-6). University of California Press.
[5] Jacobs, D.F. (2007). Toward development of silvical strategies for forest restoration of American chestnut (*Castanea dentata*) using blight-resistant hybrids. *Biological Conservation, 137* (pp. 497-506). Hardwood Tree Improvement and Regeneration Center at the Department of Forestry and Natural Resources housed at Purdue University. Accessed online.
[6] Newhouse, A.E. & Powell, W.A. (2020). Intentional introgression of a blight tolerance transgene to rescue the remnant population of American chestnut. *Conservation Science and Practice, 3(4)*. Society for Conservation Biology. Accessed online.

gaining a stronger and stronger foothold on the regional and local economy."[7] It should be noted that this change was not necessarily a bad thing, only that the subsistence culture was irreversibly damaged in the area and wildlife that made up the ecosystem either disappeared or relocated. The biome where the trees once dominated has adapted without its presence, Appalachian and Indigenous people embracing other resources, plants and animals doing the same.

Today, researchers, who are part of well-funded groups like the American Chestnut Research and Restoration Program at the State University of New York's College of Environmental Science and Forestry, the American Chestnut Foundation, the United States Department of Agriculture and others, are making attempts at restoration. By learning from traditional breeding and biotechnology, researchers are beginning to facilitate the intentional introgression of a blight tolerant transgene. A genetically modified American chestnut would retain all of its original genes with the addition of a single gene from wheat that would make it stronger against blight. This biotechnology-forward approach to restoring an entire species has been years in the making and is closing in on a completed timeline of studies and testing before the genetically modified tree has full approval to be reintegrated into the wild. Federal regulatory groups like the United States Department of Agriculture, the United States Food and Drug Administration and the United States Environmental Protection Agency are encouraging and helpful as laws are tricky and the tree's very existence crosses into unprecedented territory.

Reintroducing a blight-resistant American chestnut has the potential to increase biodiversity, once again creating a superior food for all types of wildlife that once relied on it, namely black bears and dozens of moth species. Its installation would restore a centuries-long legacy, allowing the generations of today to experience and take in the very thing the region was

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[7] Davis, D.E. (2006). Historical significance of American chestnut to Appalachian culture and ecology. *Restoration of American Chestnut to Forest Lands — Proceedings of a Conference and Workshop at The North Carolina Arboretum* (pp. 53-60). Natural Resources Report for the National Park Service. Accessed online.

built on. Adding the American chestnut back into the forest fold would similarly serve as an important rehabilitation tool for complex and numerous ecosystems, returning degraded landscapes of Appalachia, like those left ravaged by surface mining, to healthy ones. Most importantly, and a topic of focus for this paper, is the modified American chestnut's role as a template for the restoration of other species that are near and closing in on complete and total extinction.

With that in mind, the following subsection will outline additional background information and all of the context necessary to establish a complete and holistic understanding of the biotechnology-forward restoration of the American chestnut. Using that context that will reveal the regulatory process and concerns of a number of stakeholders, a summary of sides will present information as to how the tree's reintroduction could help or hurt existing ecosystems. Next, this paper will delve into a discussion of how the American chestnut is ground zero for all kinds of restoration that could take place to increase biodiversity, recover a lost legacy and return degraded landscapes to healthy ones.

Additional background and context on genetic modification

When Herbert Darling heard a hunter had discovered an American chestnut on his property in 1989, he hiked through New York's Zoar Valley, a scenic gorge just south of Buffalo, to find it. When he spied it through the woods and had finished marveling at its height and width, Darling noticed the tree was dying, battered by the same fungus that had wiped out so many of its kind. He knew of its significance and knew the signs of dying meant he couldn't save the whole tree. But Darling couldn't save its seeds either; the tree wasn't growing any because there were no similar trees nearby to help in proper pollination. When another chestnut he knew about just a few miles north was blooming, he filled shotgun shells with the yellow pollen and fired rounds at his own tree, hoping the explosion would distribute more than just metal casings from his bullets.[8] Unsuccessful the first time, Darling wasn't going to give up easily. Rather than shooting pollen into the tree the following summer, Darling was intentional about the process, using an 80-foot-tall platform to brush his tree's blossoms with flowers from the other. A few months later, Darling's tree was producing spiny, green burrs that resulted in a small bounty of about 100 nuts.

Darling, who gave some of his chestnut crop to tree geneticists at the State University of New York College of Environmental Science and Forestry, is the namesake of the school's genetically engineered American chestnut tree. Created by the State University of New York College of Environmental Science and Forestry's American Chestnut Research and Restoration Program, Darling 58 has all of the same genetic makeup of the once mighty chestnut, plus a single wheat gene. By inserting an oxalate oxidase gene from wheat into the genome of an American chestnut, the tree became resistant to the fungus that once destroyed it. The chestnut blight fungus "thrives by secreting a chemical called oxalic acid, which kills cells and allows the pathogen to feast on the dead tissue. But many other plants, including bananas, strawberries and wheat, avoid that fate by providing an enzyme called oxalate oxidase that breaks down the toxin."[9] In 2014, the wheat gene was successfully added to chestnuts scientists hoped would be blight resistant. When biologists part of the restoration project intentionally infected chestnuts with the fungus to check their work, chestnuts with the blight-resistant wheat gene swelled at the site of infection, but not to a point where the tree could no longer survive. In trees without the

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[8] Popkin, G. (2020). Can Genetic Engineering Bring Back the American Chestnut? *The New York Times Magazine*. Accessed online.
[9] Grandoni, D. (2022). Gene editing could revive a nearly lost tree. Not everyone is on board. *The Washington Post*. Accessed online.

wheat gene, a dark orange infection spread across the trunk, suffocating the cambium and effectively killing the tree.

Before people even began to consider biotechnology like breeding and transgenic mutation, the United States Department of Agriculture tried to intentionally introduce the Chinese chestnut into the ecosystem. The trees however, were non-native plants meant to take the place of an ecological giant and their growth was dwarfed by larger oaks and maples that stunted the Chinese chestnut's outward rather than upward growth. Turning to breeding next, scientists attempted to put positive traits of the American and Chinese chestnuts together to make a hybrid that would last. These attempts to revive the American chestnut began picking up in the early 1980s when the American Chestnut Foundation began its own breeding program. Earlier trials in breeding the chestnut for blight resistance in the 1930s were given up well into the 1960s when scientists were unable to successfully find a reliable source for the blight resistant genes they knew they needed.

It was Charles Burnham who first thought the blight resistant attributes of the Chinese chestnut that was left unphased by the fungal disease could be backcrossed into the American chestnut. Attempts at a backcrossing process, "the method of choice for introgressing a simply inherited trait into an otherwise acceptable cultivar,"[10] were largely ineffective. At the same time, breeding for blight resistance was being pursued similarly unsuccessfully by the American Chestnut Cooperators' Foundation, which was intercrossing American chestnuts by grafting surviving genes that made it through the first blight into new plots of trees. When it comes to traditional plant breeding like these attempts, farmers and scientists cross varieties of their crops

[10] Hebard, F.V. (2012). The American Chestnut Breeding Program. *Proceedings of the 4th International Workshop on the Genetics of Host-Parasite Interactions in Forestry: Disease and Insect Resistance in Forest Trees* (pp. 221-234). Pacific Southwest Research Station for the U.S. Department of Agriculture Forest Service. Accessed online.

or specimens with desired traits. The process can be slow and arduous, the timeline for success sometimes taking generations before yielding a commercially viable product. Genetic engineering on the other hand means farmers and scientists have more control over the genes they select for particular purposes, even if those genes come from unrelated species.

This is where we circle back to Darling 58. If the American chestnut could produce its own oxalate oxidase, a specialized protein that breaks down and detoxifies oxalic acid while allowing the fungus to still live,[11] it might be able to defend itself against something like chestnut blight. Using a technique to fire wheat's oxalate oxidase gene into chestnut embryos, scientists and students at the State University of New York College of Environmental Science and Forestry's American Chestnut Research and Restoration Program hoped it would slot itself into the embryonic DNA. The wheat gene lodged only temporarily before vanishing. After abandoning the approach, replacing the firing technique with a naturally occurring bacterium that could carry genes that make the host produce bacterial food, the scientists were able to insert the wheat gene into the chestnut. Interpolated alongside protein markers, the wheat gene illuminated green under a microscope when tested, indicating that it had been well added to the tree's genetic material. To turn modified chestnut embryos into chestnut trees, root growth hormones were added periodically as it was transferred carefully from a Petri dish to larger plastic containers resembling ice cube trays nestled together under fluorescent lights and then finally into pots with soil kept in closely monitored, temperature-controlled indoor greenhouses.

To show the tree is safe, the team at the State University of New York College of Environmental Science and Forestry has already conducted a number of tests in addition to filing petitions with federal regulatory agencies to speed up the process of allowing Darling 58 to be

[11] Newhouse, A. (2018). Transgenic American chestnuts for potential forest restoration: Scientific successes, regulatory challenges. *Presented to the State University of New York College of Environmental Science and Forestry*. Accessed online.

reintroduced slowly en masse. The research team part of the American Chestnut Research and Restoration Program fed oxalate oxidase pollen to bees, left leaves from the modified Darling 58 in water to see how tadpoles would fare and even sent a crop of harvested chestnuts that dropped from the modified trees to an independent lab for analysis. No adverse effects were observed in any of the studies.

Three-tiered ongoing regulatory process and other considerations

The request to release the genetically modified Darling 58 American chestnut is different from approval processes the United States, and other countries like Brazil and China, have plowed through to get transgenic trees in orchards and biofuel plantations.[12] As opposed to hybridized trees, which are genetically different from traditional American chestnuts because they have DNA from Chinese chestnuts, and other transgenic trees before it, this transgenic tree only has a few new genes. Likewise, the transgenic trees are not a genetically modified organism being grown on cropland for profit; rather, they are being produced for restoration without end goals of monetary gain.

While the genetic engineering done to American chestnuts will not impact the speed and breadth of its spread, its approval would allow the tree to outcross beyond its own species and grow freely, making it different from other genetically engineered plants. The tree has “the potential for transgenic material to move across sovereign borders of federally recognized tribal territories (...). The GEAC (genetically engineered American chestnut) has the potential to fundamentally reshape the shared environment, and thus calls for deliberative and inclusive

[12] Popkin, G. (2018). To save iconic American chestnut, researchers plan introduction of genetically engineered tree into wild. *Science*. Accessed online.

decision-making in shared environments."[13] Environmental justice scholarship has centered on official tribal recognition as "a necessary precondition for *participating* in environmental decisions (...), and as the necessary precondition for effective inclusive GEAC (genetically engineered American chestnut) governance."

Genetic engineering on its face generally creates space for interrogating tribal sovereignty, allowing consideration of Indigenous relationships with land as foundational to their existence. With a tree that would outcross freely into a shared environment with no foreseeable opt-out option, Indigenous people who still have not had their tribes recognized deserve a seat at the table in discussions over regulation. As discussed, the historic chestnut range covers much of the Appalachian region, the eastern band of Cherokee Indians having much of the stake in the tree's release if and when it happens in the area. Trial fields belonging to the State University of New York College of Environmental Science and Forestry in Syracuse, New York and proposed release sites in the area are located within territories of the Haudenosaunee Confederacy, made up of Seneca, Cayuga, Onondaga, Oneida and Tuscarora Nations.

So far, attitudes about the American chestnut's restoration has been cast as an uncontested public good surrounded by familiar debates about the ethics and morality of use of genetically modified organisms in any context. The chestnut blight arrived just as the United States was implementing another one of its forced resettlement, assimilation and reeducation programs targeting Indigenous people. Their societal upheaval coincided with the ecological disturbance and like so much else, Native chestnut culture was lost. When non-Native researchers partner with Indigenous communities, it is important to recognize differing worldviews and encourage free, prior and informed consent from marginalized people.

[13] Barnhill-Dilling, S.K.; Delborne, J.A. & Rivers, L. (2019). Rooted in Recognition: Indigineous Environmental Justice and the Genetically Engineered American Chestnut Tree. *Society & Natural Resources: An International Journal*. Accessed online.

What's especially interesting and tricky about the regulatory process to get Darling 58 distributed and incorporated into the wild is the layered decisions that have to come from three different federal regulatory agencies. Just like other agricultural projects that have been through genetic modification, the newly blight-resistant chestnut tree will need to be reviewed and approved by the United States Department of Agriculture, the United States Food and Drug Administration and the United States Environmental Protection Agency. This regulatory process began in 2020, the United States Environmental Protection Agency reviewing how the transgenic enzyme of Darling 58 would interact with people and the already present environment in Appalachia. The United States Environmental Protection Agency generally grants seed companies the licenses it needs to sell transgenic seeds, but in the case of the American chestnut, there isn't necessarily a company to hold the license and there is nothing to sell. At the same time, the United States Food and Drug Administration began assessing the nuts' nutritional safety while the United States Department of Agriculture surveyed how the genetically modified tree would impact other insects and plants throughout its integration.

During a 30-day public comment period conducted in 2021 by the United States Department of Agriculture's Animal and Plant Health Inspection Service, the same concerns were frequently cited in the almost 4,000 responses:

A. "Potential for gene flow to wild relatives;
B. "Potential to spread and become invasive;
C. "Potential non-target impacts, specifically to beneficial fungi, the microbiome, mycorrhizal networks, and the forest ecosystem;
D. "Potential impacts to wildlife, including pollinators, and threatened and endangered species; and

E. "Potential human health impacts from consuming nuts as well as potential allergies from pollen."[14]

These concerns are some of the same held by the regulatory agencies, the United States Department of Agriculture's Animal and Plant Health Inspection Service setting the bar so that "When a developer has collected enough evidence that a GE (genetically engineered) organism poses no more of a plant pest risk than an equivalent non-GE organism, the developer may petition APHIS (Animal and Plant Health Inspection Service) to determine non-regulated status for the GE organism."[15]

The regulatory process Darling 58 is actively going through and as described here is the same process other plants produced from biotechnology must go through. It is a costly and time consuming procedure for almost all genetically engineered product developers and researchers no matter where they come from. As mentioned, it seems on the surface regulators are responsive and helpful in the process, but are bound by regulatory, bureaucratic red tape that in and of itself is convoluted. Head researchers and scientists at the State University of New York College of Environmental Science and Forestry's American Chestnut Research and Restoration Program have said they "do not believe that government regulations are necessarily a insurmountable obstacle to restoration, but they could be improved by better reflecting relative risks amon plant breeding methods."[16]

Aside from hoping that familiarity with the safe future use of biotechnology (which seems true of a number of topics from vaccines and other health products to tomatoes and animal

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[14] Shea, A. (2022). State University of New York College of Environmental Science and Forestry; Availability of a Draft Environmental Impact Statement and Draft Plant Pest Risk Assessment for Determination of Nonregulated Status for Blight-Tolerant Darling 58 American Chestnut (Castanea dentata) Developed Using Genetic Engineering. *A Notice by the United States Department of Agriculture Animal and Plant Health Inspection Service*. Accessed online.

[15] Permits, Notifications, and Petitions. *United States Department of Agriculture Animal and Plant Health Inspection Service*. Accessed online.

[16] See Newhouse, A.E. & Powell, W.A. (2020).

products that are commercially mass produced and consumed by millions) will streamline processes so realistic risks from non regulated alternatives can be studied, there is more to note. Both the organism itself and its new trait determine regulatory oversight in the United States. Ash and hemlock trees, those that are not producing food products but that have recently been genetically modified in their own way, would not be regulated by the United States Food and Drug Administration. Any modifications to trees that are not associated with pests, like changes made for climatic adaptability or even disease resistance, would likely not be regulated as pesticides by the United States Environmental Protection Agency. This kind of pesticide regulation is what has scientists and researchers stopped in their tracks as the blight-resistant gene doesn't traditionally fall into the agency's regulatory purview, primarily given the non-pesticidal mechanisms of the science-based part of the new trait.

The only intended consequences of Darling 58 is to introgress blight resistance into the remaining American chestnut tree population using methods that will allow the species to keep much of its original genetic material, allowing for natural adaptation and ecosystems to be once again customers of the tree's services. If the tree gets the government's blessing, it can flower openly. The yellow pollen, toughened with its blight resistant gene and all, would blow or be carried onto trees-in-waiting and transgenic restoration of the American chestnut tree would unravel independently of controlled experimental settings. Scientists know the gene holds up in the lab, but monitoring its evolution as the species spreads outwardly into eastern forests will be the true mark of a point of no return that researchers have longed for and that activists seem to dread.

A summary of sides

When the American Chestnut Foundation, just one of the many nonprofits dedicated to breeding blight-resistant chestnut trees for reintroduction into eastern United States forests, announced it would support the biotechnology-forward research that would lead to the tree's restoration, it had to move forward after several high-profile resignations. The couple that led the Massachusetts/Rhode Island chapter of the foundation left in 2019, calling the investments a potentially disastrous "Trojan horse" that would clear the way for other deregulation of modified trees for commercial use that could harm people and the environment. Genetic modification offers modern solutions to modern ecological challenges, but at the same time, some worry the technology may post ecological threats and open doors for unsound and unchecked science.

Preserving and/or restoring an entire species using biotechnology and genetic engineering is relatively equal parts a public relations battle as it is a scientific and a regulatory one. The most rampant concern seems to come from the potential complication in gene flow from transgenic trees, like the American chestnut, to other potentially sexually compatible wild trees. While it is the intended goal of genetically modified trees like Darling 58 to only reproduce with the wild American chestnut to increase biodiversity, "if a transgenic poplar tree modified for increased insect resistance pollinated a compatible wild poplar tree, the transgene may be present in the resulting progeny."[17] It is possible the tree in its pollination process could find other organisms not like itself to breed with, though the genes inserted into the American chestnut are not produced in a lab and themselves have the possibility to enter into any changing ecosystem. Researchers who created and continue to monitor and alter Darling 58 have repeatedly said publicly and in the course of the regulatory process that the blight-resistant gene inserted into the American chestnut from wheat only enhances blight tolerance.

[17] Pinchot, L. (2014). American Chestnut: A Test Case for Genetic Engineering? *Forest Wisdom for the Forest Guild* (pp. 8-15). Accessed online.

An intense circle of anti-biotechnology activists organizing themselves as “The Campaign to STOP GE Trees” oppose the petition submitted by the American Chestnut Foundation and the State University of New York College of Environmental Science and Forestry to the United States Department of Agriculture to give Darling 58 non regulated status. Using a precautionary approach, the activists “measure only risks and not benefits of new technologies and amounts to arguing that we should ‘never do anything for the first time.’”[18] These particular activists continuously assert that because there has been no study on long-term impacts or the consequences of transferring what has been a tree confined to laboratories and controlled conditions to the wild, there is too much left to the unknown. This argument could be used for a number of things, including natural adaptation processes that are almost trivial to try to predict but happen to every organism every day naturally.

While restoration is a respectable experiment, some believe “the process should be done as carefully as possible, without harming the genomic heritage of this iconic tree.” Donald Edward Davis, author and editor of seven books, including one on the environmental history of the American chestnut, and founding member of the Georgia chapter of the American Chestnut Foundation, knows the best option forward is to have the chestnut thriving again, how we achieve that is where Davis has concerns. Writing in an opinion column for *The Hill*, Davis says “The supposition that genetically modified chestnut trees will behave in a specific and predictable way, based only on a decade of research, is premature, if not bad science.”[19] In a letter writing in favor of the genetically engineered, blight-resistant American chestnut,[20] the Sierra Club said the benefits of this particular organism outweigh the risks. Introducing a

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[18] Bailey, R. (2020). The USDA Should Let People Plant Blight-Resistant American Chestnut Trees. *Reason*. Accessed online.
[19] Davis, D.E. (2022). That new chestnut? USDA plans to allow the release of GE trees into wild forests. *The Hill*. Accessed online.
[20] Pufalt, C. (2020). Comment from Caroline Pufalt. Posted by the Animal and Plant Health Inspection Service. Accessed online.

genetically engineered and modified chestnut into an already complex ecosystem should not be the go-to response to a perceived problem when that problem is "tied to our desire for greater, faster growth or adaptation, or the addition of organisms which can increase a bottom line. (...) the particular case (...) does not fully meet the dangerous circumstance just described." The environmental organization goes on to write that the tree provides opportunity and with the proper monitoring and full and informed consent of Indigenous Nations should be released.

Some in the opposition still believe that impact should have more weight than intention because good intentions do have bad outcomes that often come with negative consequences.[21] Disregarding intention and profit as the main motive, other genetically modified organisms that fit into the category where their benefits outweigh their risks is largely subjective. Take for example the genetically engineered rainbow papaya — developed in the 1990s to be resistant to a deadly plantation virus in Hawaii, the papaya was meant to conserve an agricultural species. In contrast, the American chestnut that has been genetically modified to be resistant to a fungus, fulfills the want and need to conserve a wild species. The narrow definition of conservation that potentially excludes agriculture leaves out important strategies and opportunities. Ultimately, these people believe that genetically modified organisms should be present in ecosystems, but that they should only be introduced if they have a deeper meaning and purpose. They encourage "a broader conversation about which GMOs are acceptable and why, rather than blanket opposition based on the technology."

Aside from the beloved chestnut at the focal point of this paper, environmental groups have long warned about the unintended consequences of the process of moving genes between two distantly related, or even sometimes completely unrelated, species. Based on conspiracy

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[21] Kovak, E. (2021). GMO Chestnuts Splinter Anti-biotech Environmentalists. *The Breakthrough Institute*. Accessed online.

theories and other fear mongering propaganda, these same groups also worry giant, agriculture-focused companies like Monsanto could be using genetic engineering to patent and control more living things. Other factors relatively untouched by the research presented in this paper that environmental groups opposed to the integration of Darling 58 include a worry that general rising temperature around the globe, other diseases and the original chestnut blight's evolutions could complicate things for the chestnut's restoration.

The bigger picture

If federal regulatory agencies approve requests to breed trees and plant transgenic mutated ones without restriction, it would be a precedent-setting move, making Darling 58 the first genetically modified tree to go from just a possibility to noncommercial, widespread implementation in the wild. The three-tiered regulation of the genetically modified American chestnut posits an interesting case study for other genetically modified organisms and their creators. In the case of transgenic mutation, one of the easier biotechnology methods used to manipulate a species to respond to variables in ways it should, the American chestnut's journey stands out. Humans have been modifying plant genomes for thousands of years but the research and development surrounding Darling 58 allowed for more focused results that maintains the integrity of the species. Retaining the purity of the chestnut genome is beyond important when creating a tree with the intention to reintegrate it and have it adapt to a natural forest ecosystem.

It's clear to those who study it closely that genetic engineering more often than not mirrors natural adaptation and other natural phenomena that occur regularly. But genetic engineering in the eyes of the public is a scary thing, with limitless potential for disaster and with unproven modes or paths to long-term success. People are initially skeptical about allowing biotechnology to cross over into the wild, but when given clear information about the realistic alternatives biotechnology provides, they are swayed. Seeing a tree reintegrated into the wild could mean so much more for acceptance of biotechnologies.

Conclusion

As we continue through the Anthropocene, a geological era that "requires that we make management decisions today that may or may not reflect the ecological conditions of the future,"[22] it almost seems as though the American chestnut's disappearance at the hands of humans could only be fixed with human intervention.[23]

The case of the American chestnut is particularly alluring because of the storied attempts at restoring it. Leaving the blight fungus to run rampant, replacing native chestnuts with non-native ones, using mutagenesis and backcross breeding all ended in dead ends. Genetic engineering that allows for change while minimizing any negative impacts to other parts of the plant's genome seems advantageous. But to conclude generally, it is unfair to determine what could or could not happen as a result of or in the process of regulating how we interact with and how the American chestnut interacts with us — its approval to grow freely would make the tree the first to do so. The controversy does however beg the question, who even needs the American chestnut anymore? Timber companies aren't asking for it to reenter the market. The subsistence farming culture of Indigenous and Appalachian people that built itself up around the chestnut is almost entirely gone. Almost no one has experience extracting the nut from its spiny casing and most people don't know anything is even missing from the forest. Restoring a legacy only matters if the relationship between the people and the American chestnut tree can similarly be

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[22] See Pinchot, L. (2014).
[23] Powell, W. (2014). The American Chestnut's Genetic Rebirth. *Scientific American, 310(3),* (pp. 68-73). Accessed online.

restored. If American chestnuts were still standing tall today, covering the Appalachian mountains as they once did, they would be dropping enough chestnuts to make train cars overflow. Families would be buying them by the dozen, roasting them just in time for the holidays —

> "Now is the time for chestnuts. A stone cast against the trees shakes them down in showers upon one's head and shoulders. (...) It is worse than boorish, it is criminal, to inflict an unnecessary injury on the tree that feeds or shadows us. Old trees are our parents, and our parents' parents, perchance. If you would learn the secrets of Nature, you must practice more humanity than others."[24]

[24] Thoreau, H.D. (1855). The Journal of Henry David Thoreau. Accessed online.