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The politics of genetic technoscience for conservation: The case of blight-resistant American chestnut

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Abstract

Innovations in genetics and genomics have been heavily critiqued as technologies that have widely supported the privatization and commodification of natural resources. However, emerging applications of these tools to ecological restoration challenge narratives that cast genetic technoscience as inevitably enrolled in the enactment and extension of neoliberal capitalism. In this paper, we draw on Langdon Winner's theory of technological politics to suggest that the context in which genetic technologies are developed and deployed matters for their political outcomes. We describe how genetic approaches to the restoration of functionally extinct American chestnut trees—by non-profit organizations, for the restoration of a wild, heritage forest species, and with unconventional intellectual property protections—are challenging precedents in the political economy of plant biotechnology. Through participant observation, interviews with scientists, and historical analysis, we employ the theoretical lens provided by Karl Polanyi's double movement to describe how the anticipations and agency of the developers of blight-resistant American chestnut trees, combined with chestnut biology and the context of restoration, have thus far resisted key forms of the genetic privatization and commodification of chestnut germplasm. Still, the politics of blight-resistant American chestnut remain incomplete and undetermined; we thus call upon scholars to use the uneven and socially constructed character of both technologies and neoliberalism to help shape this and other applications of genetic technoscience for conservation.

Keywords

Genetic engineering, neoliberalism, double movement, forest biotechnology, ecological restoration

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Introduction

Early in 2020, a transgenic American chestnut tree became the first genetically engineered organism developed for ecological restoration—with no presumption of containment—to be considered for federal deregulation in the United States (Powell, 2020). Clones of this tree contain a gene from wheat plants that allows them to tolerate infection with *Cryphonectria parasitica*, or chestnut blight, a fungal pathogen that was introduced to the U.S. on imported plant products in the late 1800s (Powell, 2020). Within decades, the fatal cankers of chestnut blight had reduced American chestnut—previously abundant across the eastern U.S.—to functional extinction (Russell, 1987). Named "Darling 58," this blight-resistant line of trees was developed by the American Chestnut Research and Restoration Project at the State University of New York, College of Environmental Science and Forestry (SUNY-ESF) to enable the genetic rescue of surviving American chestnut populations (Powell, 2020). To that end, Dr William Powell, the project's Co-Director, and his colleagues expect that after federal regulatory approval, their transgenic trees and pollen will be integrated into the restoration program of the non-profit American Chestnut Foundation (TACF) (Westbrook et al., 2020a) and made available for widespread planting and sharing by the public (Newhouse, 2018; Steiner et al., 2017). Although trees produced by the program may eventually be sold to offset production costs, their genetic material will not be patented (Newhouse, 2018; Powell, 2014). Darling 58 trees and their pollen are intended for unrestricted and open release for the restoration of American chestnut to forests across the species' historical range (SUNY-ESF, 2018).

This paper explores the ways in which this and other uses of genetic technoscience in American chestnut restoration—by non-profit organizations, for the restoration of a wild, heritage forest species, and with unconventional intellectual property (IP) protections—are challenging precedents in the political economy of plant biotechnology. Scholars across the social sciences have drawn attention to relationships between innovations in genetics and genomics and the enactment and extension of neoliberal capitalism (Barben, 1998; Birch, 2006; Cooper, 2008). The neoliberal privatization and commodification that generally characterize agricultural biotechnology have been linked to scientific and political processes that privilege corporations (Busch, 2010; Kloppenburg, 2005; Schurman and Munro, 2010), threaten small-scale and subsistence production and associated livelihoods (McMichael, 2006; Otero and Pechlaner, 2008; Pechlaner and Otero, 2008), and irrevocably alter ecological systems by ignoring their complexity (Fitting, 2006; McAfee, 2003). These analyses have provided essential perspectives on the potential consequences of biotechnological innovation for social and environmental systems. However, applications of genetic and genomic science to ecological restoration have challenged narratives that cast genetic technoscience as inevitably enrolled in the neoliberalization of natural resources (Rossi, 2014).

This paper draws on the theory of technological politics (Winner, 1980) to explore how and why genetic approaches to the restoration of American chestnut trees have been contrary to the key neoliberal processes of privatization and commodification. Even for technologies that are consistently accompanied by particular political or economic structures,

> [t]he important question is: Does this state of affairs derive from an unavoidable social response to intractable properties in the things themselves, or is it instead a pattern imposed independently by a governing body, ruling class, or some other social or cultural institution to further its own purposes? (Winner, 1980: 131)

Drawing from a set of diverse case studies, Winner (1980) ultimately demonstrates that technologies can be political in at least two different ways: (1) because they are necessarily or strongly aligned with certain political structures; in other words, they are inherently political, or (2) because they are *used* politically; they are not inherently political, but may have political consequences that outlast initial motivations for the technology. We adopt the latter frame provided by Winner's analysis to suggest that, while biopolitics are evident in genetic technoscience (Cooper, 2008), biodiversity conservation generally (Biermann and Anderson, 2017; Biermann and Mansfield, 2014), and American chestnut restoration, in particular (Biermann, 2014, 2016), the context in which technologies are developed and deployed matters for their particular political outcomes.

We draw on three years of in-depth, qualitative research, and multiple methods. This work began with document analysis, followed by participant observation at three annual meetings of TACF and an annual U.S. EPA- Region 2 Indian Nation Leaders Meeting, at which the transgenic American chestnut was discussed by Powell and others. We also visited American chestnut breeding orchards and restoration locations in Meadowview, Virginia and Portland, Maine and laboratories and transgenic field sites in Syracuse, New York. Additionally, we conducted 10 semi-structured interviews in-person and by phone in 2017 with a purposive sample of scientists involved in American chestnut restoration among the small staff and Board of TACF and scientists affiliated with the American Chestnut Research and Restoration Project at SUNY-ESF. Interviews explored scientists' perspectives on the history and future of American chestnut restoration, including the timelines and baselines that shape their work and their anticipations about future regulatory, public perception, and technological conditions. All research activities were approved by and conducted in accordance with the North Carolina State University Institutional Review Board (Protocols #6403 and #6372).

In what follows, we first briefly review the concept of neoliberalism and associated critiques of genetic science and technologies. We then relate a broad history of American chestnut restoration, followed by an analysis of the ways in which the application of genetic technologies in this restoration effort diverges in key, but complicated, ways from the neoliberal patterns described for the genetic manipulation of plants in agriculture. Next, we employ Polanyi's (1944) theory of the double movement, which describes the push-and-pull of market expansion and resistance to markets, to explain why species restoration, especially given the particular qualities of American chestnut, may be a context that allows reimagining the political potential of genetic technologies. We conclude by calling upon social scientists to capitalize on the uneven and socially constructed character of both technologies and neoliberalism to help shape genetic technologies for ends that are ecologically and socially just.

The critiques: Technologies of neoliberal governance

As a *new (neo) liberalism*, neoliberalism broadly refers to an approach to governance that resurrects and reshapes earlier liberal economic policies. Committed to the notion that market competition is the most efficient, rational, and fair way to distribute goods, services, and information—and key to political freedom (Friedman, 2009) —neoliberalism reimagines the role of the state as establishing the conditions required for free markets to persist and expand into new realms, including through market-oriented regulation (Harvey, 2007). Like its liberal predecessor, neoliberalism results in the creation of what Polanyi (1944) called "fictitious commodities"—human, financial, and natural resources that have been marketized but are not intrinsically amenable to being bought and sold (Block, 2001).

Busch (2010) has suggested that neoliberalism might be best understood as a combination of social technologies (including organizations, institutions, and strategies) and artifacts (various physical and digital technologies) that have been particularly influential in and compatible with the extension of markets into new arenas. Genetic and genomic technologies are implicated among these "technologies of neoliberal governance" principally because they have enabled the privatization and commodification of nature (Busch, 2010). In general, privatization broadly entails the application of ownership rights to resources that were once public or unowned. Throughout the 20th century, IP protections, particularly patents, were fundamental to this process. Patent laws have explicitly excluded the products of nature, but what counts as a natural product has been unclear and contested for over a century, especially in light of genetic technoscience, which has been used to expand patent protection to both organisms and genetic sequences (Beauchamp, 2013). Genetic technologies have also aided the commodification of nature or its transformation into mere tradable goods with market value (Rossi, 2013). This process prioritizes precision, efficiency, uniformity, and profit and severs organisms from their social and ecological contexts (Parry, 2006). In agriculture, genetic engineering dramatically reduced the time and space required for moving genetic material between organisms and thus increased the rate at which new plant varieties could be moved to market (Busch, 2010). Commodification and privatization have both benefited from the notion that genes are discrete, transferrable, and deterministic in their influence on the phenotypes of living organisms—what McAfee (2003) refers to as "molecular-genetic reductionism." This reductionism has unfortunately drawn attention away from the root causes of agricultural problems and solutions that are situated at levels other than the molecular (Busch, 2010; McAfee, 2003).

Genetic technologies entail knowledge production as well as the production of artifacts, and science itself has also been a location for critical analysis of the influence of neoliberalism. Lave et al. (2010) suggest that, across academic fields, neoliberalism has generally resulted in the adoption of market logics within university science through a number of processes. These include the expansion of IP protections and the commodification of knowledge, a reduction in public funding for science that requires universities to act like corporations, reliance on market forces to decide intellectual disputes, and an increasing focus in public research on the development of knowledge and products with profit potential. As one example in agriculture, this shift has resulted in the disproportionate production of hybrid and genetically engineered crops that benefit industrial farming systems typical in the global North but are incongruous with subsistence systems common in the global South (Brooks, 2015; Glover, 2010).

While these trends have been consistently described for plant biotechnology, in line with the theory of technological politics (Winner, 1980), Busch (2010: 345) leaves room for genetics and genomics to realize other political possibilities by noting that technologies of neoliberal governance should not be, by default, unacceptable to the critics of neoliberalism. Similarly, while a handful of processes have been consistently ascribed to neoliberalism, scholars have demonstrated that "neoliberalism is not monolithic" (Mansfield, 2004: 580). Just as the politics of genetic technoscience can be constructed anew in different contexts, neoliberalism is shaped by the political, cultural, and ecological realities of the settings in which it is enacted (Barnett, 2005; Larner, 2003; O'Neill and Argent, 2005; Peck, 2004). The process of neoliberalization thus unfolds differently in different places and times, and the neoliberal ideal often diverges from what have been referred to as "actually existing neoliberalisms" (Brenner and Theodore, 2002). In what follows, we hold these two theoretical lenses—one on the uneven nature of neoliberalism and the other on the uneven politics of technologies—together, to explore why the use of genetic technologies in efforts to develop blight-resistant American chestnut trees has been inconsistent with some of the neoliberal patterns described for genetic technoscience in other contexts.

The case: Genetic approaches to American chestnut conservation

The history of American chestnut conservation closely follows the historical arc of genetics as a scientific field and the application of this emerging science in the development of improved crop varieties. Below, we chronicle efforts to rescue, and later, to restore, populations of American chestnut, in order to situate our discussion about contemporary, genetics-based approaches to restoration within this 120-year history.

Chestnut blight was first detected on American chestnut trees growing in what is now the Bronx Zoo in 1904 (Anagnostakis, 2012). In the following years, heated debates would take place over both the identity of the pathogen and the appropriate approach to its control. The earliest attempts to treat chestnut blight infection were chemical and physical, focused on the use of fungicides, tree surgery to remove infected limbs, and the removal of infected trees from cultivated and forest stands (Curry, 2014; Freinkel, 2007). Quarantine measures were also implemented, eventually supported by the passage of the Plant Quarantine Act, which aimed to limit the importation of additional potential plant pathogens in light of the destruction wrought by chestnut blight (Waterworth and White, 1982). These measures were largely unsuccessful. Human interaction with American chestnut over centuries had created nearly pure stands of the tree in some regions of its expansive range; this host density and distribution allowed chestnut blight to spread rapidly, while a lack of native tolerance or resistance to the blight resulted in infection and die-off in nearly every American chestnut tree in its wake (Freinkel, 2007).

Failure to kill or limit the spread of chestnut blight quickly turned attention and effort to the possibility of inducing blight resistance in American chestnut trees (Curry, 2014). In 1914, a botanist named Arthur Graves suggested that the only way to save the species might be to "outwit" the blight fungus by breeding American chestnut with its blight-resistant Asian cousins, a strategy that was used widely in corn breeding (Freinkel, 2007). Scientists at the United States Department of Agriculture (USDA) subsequently began an intensive effort to cross American chestnut with *Castanea mollissima*, the Chinese chestnut, with the hope of producing trees with the blight resistance of the Chinese species and the form and function of the American species (Curry, 2014; Jacobs et al., 2013). When the USDA's hybridization effort ended in 1960, an estimated 10,000 distinct crosses had been made, but both Graves' and the USDA's programs ended without a great deal of success; hybrid trees rarely maintained what were considered the essential characteristics of American chestnut, principally its height and growth form (Curry, 2014).

The breeding efforts at USDA began just after Gregor Mendel's experiments in heredity were rediscovered, and the relationships between plant genotypes and phenotypes were still being worked out (Freinkel, 2007). Building on genetic knowledge established in the intervening years, in the 1980s, Charles Burnham, a retired corn geneticist, hypothesized that the backcross breeding approach that worked in agriculture could also work for American chestnut (Burnham, 1988). The non-profit TACF was established to make such an attempt, initiating a restoration program that continues today, guided by a mission to return American chestnut to its native range (TACF, 2018a). Following Burnham's prescription, for almost four decades, TACF has been crossing surviving American chestnut trees and blight-resistant Chinese chestnut trees; the hybrid progeny are then crossed back to the American parent in an attempt to transfer the blight resistance of the Chinese species while maintaining or recovering the characteristics of the American species (Hebard, 2005). Hybrid trees in later generations of this program display levels of blight resistance that are intermediate between American and Chinese resistance (Steiner et al., 2017). Members of state chapters of TACF are now crossing these trees, which are bred in Meadowview, Virginia, with surviving, wild-type American chestnut trees located in their respective regions in order to improve the local adaptation of the backcross population (Steiner et al., 2017). Meanwhile, the national organization continues to cull their breeding orchard in Meadowview, currently aiming to reduce 10,000 trees from the last backcross generation down to the 500 most resistant ones (Westbrook et al., 2020b). To aid in this process, scientists affiliated and collaborating with TACF produced a draft reference map of the American chestnut genome and markers for genomic selection, an efficient, DNA-based method for detecting blight resistance among their hybrid trees (Westbrook et al., 2020b).

In 1989, members of the New York Chapter of TACF approached William Powell and a colleague, Charles Maynard, at SUNY-ESF to explore the use of the emerging science of genetic engineering to produce blight-resistant trees; thus began the American Chestnut Research and Restoration Project (Powell, 2014). After failed attempts to use antimicrobial peptides to combat *C. parasitica*, struggling for years to grow American chestnut embryos under laboratory conditions, and then trying to design appropriate genetic constructs, in 2012, Powell's laboratory successfully developed transgenic American chestnut trees that tolerate blight infection (Powell, 2014; Zhang et al., 2013). Although a number of genes have been tested, an oxalate oxidase gene from wheat plants has been by far the most promising; this gene, which codes for an enzyme that neutralizes the destructive acid produced by *C. parasitica*, confers levels of blight resistance that are equal to or higher than that of Asian chestnut species (Zhang et al., 2013). One transgenic line carrying this gene—Darling 58—is currently under federal review for deregulation in the United States (Westbrook et al., 2020a), and an application for release in Canada is expected to follow (William Powell, personal communication, 7 October 2017).[1] For many years, TACF's national leadership maintained some distance from and ambiguity toward a biotechnological approach to blight resistance (Popkin, 2020); however, SUNY-ESF's transgenic trees were officially incorporated into TACF's latest Strategic Plan for restoration (TACF, 2017) and are now expected to be used in conjunction with germplasm developed in the backcross breeding program (Westbrook, 2018).

One additional program has been integral to the development of genetic and genomic tools for American chestnut restoration. In 2009, with financial support from the U.S. Endowment for Forests and Communities, the USDA Forest Service, and Duke Energy, the Institute of Forest Biotechnology (later renamed the Institute of Forest Biosciences (IFB)) established the Forest Health Initiative (FHI), a collaborative program that aimed to demonstrate the potential of emerging biotechnologies for addressing pressing problems in forest health (FHI, 2018). The FHI adopted American chestnut as its "test case" (FHI, 2018) and, in the interest of making rapid progress in the development and field testing of disease-resistant American chestnut trees, enrolled experts already working on American chestnut, including the team at SUNY-ESF and researchers affiliated with TACF. FHI projects have now ended, but they funded a number of developments that have dramatically increased the integration of genetic technologies into chestnut restoration, including assays for earlier detection of blight resistance in transgenic plants (Newhouse et al., 2014), improved somatic embryogenesis techniques for generating whole plants from transformed cells (Holtz et al., 2016), a reference genome for Chinese chestnut (Fang et al., 2013; Kubisiak et al., 2013), and the transformation of American chestnut embryos with candidate blight resistance genes from Chinese chestnut (FHI, 2018). FHI aimed to be groundbreaking in both its commitment to public interests and its "braided process" that considered regulatory, environmental, and social dimensions of the use of genetic technologies for forest health, concurrent with the development of scientific knowledge and protocols (FHI, 2018).

This historical perspective begins to illustrate how scientists concerned with halting and reversing the decline of American chestnut have learned from the biological and social experimentation that accompanied the use of genetic science and technologies in agriculture. This reflexivity has facilitated their adoption of genetic approaches and, as we describe in the following sections, has also shaped their decisions about privatizing and commodifying American chestnut genetic material.

The contradictions: Unevenness in the marketization of blight-resistant chestnut

Many of the genetic technologies that have been adopted by groups involved in American chestnut restoration—including hybridization, genetic mapping, genomic selection, and cis- and transgenic engineering—were first used in agriculture and, in that context, scholars have discussed them as having fundamental properties that enroll them in the realization of neoliberal goals (Busch, 2010; McAfee, 2003). Below, we consider the ways in which American chestnut resists and reifies two interrelated neoliberal patterns consistently discussed by scholars: (1) the enclosure and privatization of genetic resources and knowledge and (2) the transformation of nature into a tradable commodity.

Privatization

One of the most glaring inconsistencies between neoliberal patterns of privatization in agricultural biotechnology and the application of genetic engineering to American chestnut restoration is the lack of IP protection sought for the transgenic trees being developed by the American Chestnut Research and Restoration Project at SUNY-ESF. Powell explained that the decision to forgo a patent on their transgenic lines was motivated primarily by early realization that doing so would be an impediment to chestnut restoration (personal communication, 7 October 2017). In direct opposition to Powell's goals, a patent would constrain the spread of the oxalate oxidase transgene into American chestnut populations by limiting the ability of conservationists and members of the public to freely plant transgenic trees and cross them with surviving American chestnut trees or hybrids produced through TACF's backcross program. A number of scientists affiliated with TACF, who consider Powell's lack of proprietary interest to be "noble," suggested in interviews that his decision might also be linked to the collaborative nature of American chestnut restoration (S05, personal communication, 16 March 2017; S09, personal communication, 15 May 2017). The research conducted at SUNY-ESF and the transgenic trees that have resulted from that research have been enabled by a wide variety of funding sources; in particular, the financial backing and political clout of TACF members, especially those of the New York Chapter, have been paramount to the success of the project. Although Powell originally received some pressure from SUNY-ESF to patent his trees (personal communication, 7 October 2017), his refusal to do so may thus also reflect resistance to the prospect of the university singularly benefiting from what has been a collaborative effort.

Although patent protection has not been sought for the transgenic events that define blight-resistant American chestnut trees, patents are not the only tool for privatizing access to plant germplasm. Lave et al. (2010: 666) insist that a focus on patents has distracted critical attention away from other locations of IP fortification, especially material transfer agreements. These contracts, which specify the conditions of ownership and use of research materials transferred between parties and any developments resulting from the materials, have “become the instrument of choice to control the commercial implications of cutting-edge research,” especially when the marketability of future developments made with those materials remain uncertain. TACF maintains IP protection on germplasm generated in their breeding program through a Germplasm Agreement, which is signed by all collaborators who receive plant materials from the organization (TACF, 2018c), including Powell (personal communication, 7 October 2017). However, just as Rossi (2014: 71) has described for the exchange of plant genetic resources for the reintroduction of a rare sand prairie flower, American chestnut materials “are exchanged not as commodities with monetary value, but as entities with the potential to reverse the decline of a rare species.”

TACF relies on volunteers working in locations across the native range of American chestnut to test the fitness of backcross populations for varied environmental conditions, develop locally adapted germplasm, and investigate the silvicultural practices required for reintroducing American chestnut in forests and other landscapes, such as mined lands. To this end, the organization distributes plant materials produced through the backcross program in Meadowview, aware that these materials have inconsistent blight resistance and other traits. The Germplasm Agreement prohibits the propagation of materials from early backcross generations and the sale or transfer of any American chestnut germplasm received from TACF without the organization’s approval because:

> (1) the Recipient and TACF wish to preserve TACF’s rights to such genetic material; and (2) the Recipient and TACF most emphatically do not want any person to take such material and market it, or to market any progeny from it; the material may not have the characteristics desired or have characteristics that are not consistent with the goal of TACF, namely “the Restoration of the American Chestnut,” and not a Chinese or other type of tree; and (3) the Recipient and TACF do not want to be identified with the distribution, increase or marketing of material that has the potential of diluting the resident American chestnut population in the Appalachian mountains. (TACF, 2018c)

While Powell sees foregoing patent protection as important for facilitating restoration, TACF “most emphatically” (TACF, 2018c) views maintaining IP as necessary for successful restoration. In pursuit of its goal to restore populations of *American* chestnut to the species’ native range, the organization is interested in keeping germplasm that retains too many characteristics of Chinese chestnut or is otherwise unfit for forest restoration out of open circulation. However, this agreement also clearly maintains TACF’s options for commercialization. Over 10 years ago, Jacobs (2007: 504) reported that TACF “expects to develop cultivar names with trademark protections for deployment of blight-resistant germplasm,” but our more recent interviews with TACF staff and Board members indicated continuing uncertainty within the Foundation about the future ownership, large-scale production, and distribution of blight-resistant, backcross trees (S02, personal communication, 22 February 2017; S10, personal communication, 11 May 2017).

In addition to protections on TACF’s technological artifacts—its hybrid germplasm—the organization’s Germplasm Agreement also protects the knowledge generated from research on its plant materials: the agreement “conveys only a right to carry out research, evaluations and/or field testing on the germplasm *on behalf of and in consultation with TACF*” (TACF, 2018c; italics added). However, contrary to what Evans (2010) found to be true for public–private partnerships in plant breeding, this language does not appear to limit the ability of university researchers to present on or publish research findings related to the molecular characterization or ecological performance of TACF's backcross trees. As a non-profit organization with a small staff, TACF relies on these collaborations for technical expertise and experimental resources, and university scientists publish their findings independently (e.g., Clark et al., 2019; Kane et al., 2019).

The structure and guiding principles of the FHI's work on American chestnut are also inconsistent with the privatization of knowledge. The research conducted by the FHI committees—the Science Advisory Committee, the Social and Environmental Committee, and the Policy and Regulatory Committee—was explicitly imagined as a public good and "predicated on the core operating values of the FHI including that the public owns the intellectual property created by FHI-sponsored research" (FHI, 2018). All knowledge produced through research funded by FHI was thus made publicly available online. This lack of privatization may be at least partially attributable to FHI's financial structure, reliant as it was on funds from the USDA Forest Service, which requires science produced by its staff and beneficiaries to be open-access and in the public domain.

Commodification

The American chestnut project is also complicating patterns of commodification described for genetic science and technologies in the context of agriculture. In the early 20th century, American chestnut products, especially timber, tannins, and nuts, comprised a substantial portion of national commodity markets (Freinkel, 2007). Facing the imminent demise of a species that featured prominently in multiple markets, in addition to its widespread subsistence use by homesteaders throughout the Appalachians, foresters recommended harvesting remaining chestnut in an attempt to both limit the spread of *C. parasitica* and maximize short-term profit if it could not be stopped (Freinkel, 2007). Although initial interest in preventing the decline of American chestnut may have been principally related to its market value, its loss was concurrent with a number of other changes in Appalachia that undermined industry investment in its restoration: the forestry industry turned to new tree species, nut vendors started importing and growing European chestnuts, and the leather tanning industry adopted synthetic chemicals (Freinkel, 2007). Consequently, in the long history of efforts to resurrect American chestnut populations, industry interest and involvement have been minimal. While the historical importance of markets for chestnut is often invoked as a prelude to contemporary restoration efforts, today, restoration is primarily justified on the basis of its potential to restore lost aspects of Appalachian culture and ecology. As described previously, the initial impetus for a transgenic approach to American chestnut restoration came from the non-profit sector—the New York chapter of TACF—not from industry, and the project continues to be oriented by motives that are more environmental than economic. As Powell (2014: 73) has written:

> We are not growing a genetically modified organism on cropland for profit rather we are producing trees for restoration without monetary gain. Like researchers working on golden rice enriched with a precursor of vitamin A, we are motivated by the public good—and the health of the forest.

In fact, although Powell has said that their transgenic trees may eventually be sold to compensate for the cost of production (personal communication, 9 May 2017), no American chestnut materials are currently offered for sale by SUNY-ESF. Additionally, while TACF has offered a limited number of wild-type American chestnut seeds for sale in the past to raise funds and promote public interaction with the species (TACF, 2018b), the organization does not sell any materials from their breeding program (TACF, 2020).

Consistent with the use of genetic technologies to further the commodification of plants, however, ongoing efforts to use genetic engineering and genomic sequencing in American chestnut restoration were initiated in the interest of producing more blight-resistant trees in less time with less labor (FHI, 2018; Powell, 2014; TACF, 2017). As Busch et al. (1991) describe for genetic technoscience in agriculture, in chestnut restoration, the turn to emerging genetic and genomic technologies has been framed—most notably by Powell—as an approach that could supplant slower, more cumbersome breeding approaches:

> In addition to being rather imprecise. . .backcross breeding requires many generations and thousand[s] of trees to produce individuals suitable for restoration. For those reasons, my many collaborators and I are focusing on a second approach, which relies on altering the chestnut tree's DNA in a much more exact way than traditional breeding and which has the potential to produce more fungus-resistant trees more quickly. (Powell, 2014: 71)

The projects funded by the FHI were also motivated by an interest in expediting the production of disease-resistant lines with "rapid and responsible innovation" (FHI, 2018). The results of that project include new leaf assays which enable the detection of blight resistance in transgenic plants after one year, rather than five; new transformation techniques that carve a year off of the time it takes to develop potted plants from transformed embryos; and new somatic embryogenesis techniques that have "the potential to condense 50 years of breeding into 15 years" (FHI, 2018: 11). Of course, these innovations and the trails being blazed by their application to American chestnut are also valuable for industry actors interested in the quick expansion of markets for the products of forest biotechnology.

However, the thrust for precision and efficiency in the chestnut case principally emerges, not from an interest in cycling more capital, as has been argued in agriculture (Busch, 2010) and would likely apply to commercial forestry, but from the sense of crisis and urgency that have always characterized biodiversity conservation (Soulé, 1985). In the case of American chestnut restoration, this urgency may be both biological and social. Powell and TACF staff have argued that the re-establishment of independent and evolving American chestnut populations requires returning the genetic diversity housed in remaining stump sprouts to the reproductive gene pool of the species by crossing them with blight-resistant backcross or transgenic trees. Most chestnut sprouts in contemporary forests regenerated from root systems that were already established in the late 1800s or early 1900s (Paillet, 2002); over time, stumps lose this regenerative capacity, meaning scientists are working against the clock to develop restoration approaches that can rescue this genetic diversity. Reflecting on the work done by the FHI, Carlton Owen, President and CEO of the U.S. Endowment for Forests and Communities, said, "Forests are being lost at an alarming rate due to devastating insect and disease infestations, and we don't have the luxury of time that affords using only 20th century tools to deal with 21st century challenges" (U.S. Endowment for Forests and Communities, 2018). Additionally, the project arguably becomes less tractable socially as time passes, since remaining relationships to and memories of American chestnut are lost with each human generation.

Although genetic technologies have expedited the production of blight-resistant American chestnut germplasm, in our interviews, scientists involved in both the backcross and transgenic programs expressed concern over the imminent bottleneck in the production of blight-resistant material for restoration and uncertainty about how it might be resolved. The goal of restoring the species across its native range, which covered some 180 million acres, will require large-scale production of seeds and trees, and TACF's seed orchards are not likely sufficient to keep up with demand, either for restoration or to satisfy public interest (Jacobs, 2007). Some of the scientists we interviewed suggested that commercial nurseries may play an important role. One scientist said,

> We're mostly molecular biologists, so we can produce a tree, and we can describe a tree, and we can produce a few trees, but we're not a tree production facility, and we never will be. We can talk about trees in the thousands, but meaningful restoration will be trees in the millions. Realistically, producing that kind of number would mean contracting with really large-scale nurseries and a really different set of expertise than we have. (S08, personal communication, 9 May 2017)

Like this scientist, others we interviewed discussed nurseries primarily as a source of expertise in the cultivation and large-scale production of trees. However, nurseries are also businesses, and collaborations forged between TACF or SUNY-ESF and commercial nurseries may involve the establishment of new relationships to American chestnut as a commodity. A TACF scientist explained that there has been some reluctance to involve nurseries in the restoration project thus far, perhaps due to mistrust of commercial motives (S06, personal communication, 30 March 2017). Thanks to a large and committed volunteer network, the project may avoid engaging with nurseries into the future; scientists leading the project recently indicated that propagation of an American chestnut population of adequate size and genetic diversity for restoration will continue to rely on volunteer citizen scientists (Westbrook et al., 2020a).

An additional dimension of marketization described by scholars has been the adoption of practices in public science that reveal commercial logics and have typically been characteristic of businesses. As the team at SUNY-ESF prepared for the regulatory process, with hopes of large-scale distribution of their transgenic trees to follow, they initiated a crowdfunding campaign called the "10,000 Chestnut Challenge" to raise funds for the production of 10,000 transgenic seeds. The appeal of crowdfunding in science may be partially driven by the neoliberal constriction of public funding for research (Hui and Gerber, 2015), and crowdfunding appears to both embody neoliberal faith in the wisdom of crowds and reinforce consumer-based activism. Consistent with the expectations of Lave et al. (2010), who suggest that neoliberal science is marked by deference to market mechanisms to decide intellectual disputes, unexpected levels of financial support in the 10,000 Chestnut Challenge and associated positive commentary in social media forums have been interpreted as evidence for broad public support of a transgenic approach to blight resistance (Harrison et al., 2017). However, this crowdfunding effort also aimed to establish an infrastructure for the future distribution and diversification of transgenic American chestnut trees. Campaign donors received a wild-type American chestnut seed and the promise of a transgenic seed, pending their federal deregulation. American chestnut is self-sterile and requires another, genetically distinct tree nearby in order to reproduce. Donors were thus instructed to plant their native American chestnut seed now, in order to grow a large number of "mother trees" which might be receptive to the pollen of transgenic trees, once available. If successful, this process would generate large numbers of American chestnut seeds, half of which would be expected to carry the oxalate oxidase gene and be blight-resistant.

On the whole, the use of genetic technologies in American chestnut restoration demonstrates important—though certainly incomplete—discontinuities with the use of these technologies in agriculture. While hybrid and engineered crop varieties have been subject to intense IP fortification driven by profit, in the American chestnut case, patents have been forgone, a collaborative germplasm agreement has been established, and knowledge has been kept in the public domain in order to facilitate successful restoration. And, rather than turning to partnerships with commercial nurseries, the project has thus far relied on a vast volunteer network to propagate and distribute both wild-type and blight-resistant American chestnut materials suited for local environmental conditions. Next, we explore and explain how genetic technologies, which have been described as "neoliberalism on the molecular scale" (McAfee, 2003: 203) in agriculture, are able to eschew some of the defining characteristics of this economic and political project in the context of American chestnut restoration.

The context: A double movement in American chestnut restoration

Although the American chestnut case does not demonstrate all components of neoliberalism, we cannot simply conclude that it is not a technology of neoliberal governance or free of the neoliberal logics that have defined biotechnologies in agriculture. As Mansfield (2004: 580) has written

> The particular forms that neoliberalism takes should not be taken as aberrant from an ideal, or as not really neoliberal. Instead, our understanding of neoliberalism needs to acknowledge that it is something created in practice, and that through practice, it becomes varied, fractured, and even contradictory.

Polanyi (1944) similarly insisted that the perfectly free markets of classical liberalism were a utopian ideal that could never be fully realized in practice. This is because efforts to completely disembed the economy from social controls as a self-regulating market and to transform human labor and the environment into commodities would inevitably be resisted by both society and nature (Block, 2001). Polanyi (1944) described this phenomenon as a *double movement*; the first movement toward the marketization of everything is countered by a second movement that resists marketization. In response to this resistance, the liberal state establishes protective policies, for example, labor laws and tariffs, that insulate society and natural resources from the ills of unchecked capitalism.

Scholars have shown that this double movement also characterizes neoliberalism, which has been "beaten back in places by virulent resistance" against the removal of the state from environmental governance and its replacement with a free market (McCarthy and Prudham, 2004: 275). Castree (2010b: 1744) has explained that a double movement occurs when "a market economy rubs up against various pre-existing moral economies and 'unruly' biophysical systems." These moral economies, embodied in concerns about nature and related political resistance, have supported some of the strongest opposition to neoliberalism and unveiled its contradictions (McCarthy and Prudham, 2004), while the ecologies and evolutionary processes of biophysical systems have challenged marketization and illustrated its limits (Castree, 2010a). These two origins of the double movement—social and biological resistance—provide a useful heuristic for considering the reasons that genetic technoscience has evaded some neoliberal patterns in the context of American chestnut restoration. In this case, social and biological resistance have imposed limits on the ability of genetic technologies to expand the reach of neoliberalism or make nature—the complex, ecological systems that include the American chestnut—less "fictitious" (Polanyi, 1944) and amenable to further privatization and commodification. Importantly, while the double movement in classical liberalism resulted in social protections provided by the state, under neoliberalism, in which the role of the state is diminished, resistance is increasingly responded to by non-governmental actors, civil society groups, and, perhaps, individual scientists, which act as "flanking mechanisms" (Castree, 2010b), providing balm for the externalities of capitalism.

Social resistance

Polanyi (1944) held that the subjection of human labor and nature to the market under liberal capitalism violates long-held beliefs about the exceptionality of human and non-human life, and that this violation provides a major impetus for resistance to marketization. Much of the opposition to the use of genetic and genomic technoscience in agriculture has been in response to the privatization, through patents, of plant materials that have been stewarded and improved by indigenous and subsistence communities for centuries (Delborne and Kinchy, 2008; McAfee, 2003). Indigenous groups throughout the world have been particularly active in promoting the notion of the "genetic commons" in an effort to resist the privatization and commodification of agricultural germplasm (Scharper and Cunningham, 2006). Efforts to protect the genetic commons have now been formalized in treaties including the Treaty to Share the Genetic Commons and the International Treaty on Plant Genetic Resources for Food and Agriculture, supported by the international authority of the Food and Agricultural Organization. Genetic approaches to American chestnut restoration have been pursued with this legacy of the fraught history of genetic technologies in agriculture. Powell's decision not to seek a patent on his Darling trees, the FHI's commitment to transparent and publicly available science, and TACF's resistance to collaboration with commercial nurseries might all be understood as responses to the moral arguments that have been powerful in restraining the adoption of agricultural biotechnologies.

It is important to note, however, that Powell has never indicated an explicit rejection of the privatization of American chestnut or other plant genetic resources. In fact, he and other scientists involved in American chestnut restoration have defended the right of corporations to patent the products of forest biotechnology; they simply see patented germplasm as inconsistent with a restoration program premised on the open and uncontrolled release of blight-resistant American chestnut into wild ecosystems (S09, personal communication, 11 May 2017; S07, personal communication, 7 October 2017). For that and the reasons described above, Powell's decision to forego patent protection appears to be more practical than philosophical. However, in his presentation at an annual U.S. EPA- Region 2 Indian Nation Leaders Meeting, Powell indicated sensitivity to another "pre-existing moral economy" (Castree, 2010b: 1744) by invoking the notion of reciprocity. In that meeting, and in others since, Powell discussed a transgenic American chestnut as a way to give back to nature by quoting Robin Kimmerer, Professor of Environmental and Forest Biology and founding Director of the Center for Native Peoples and the Environment at SUNY-ESF. Speaking before the United Nations, Kimmerer (2016) stated, "We humans are more than consumers; we have gifts of our own to give to the Earth. We are scientists and artists and farmers and storytellers. We can join in the covenant of reciprocity..." Powell's use of this talk to frame his work as an act of reciprocity is echoed in the motivations espoused by TACF and collaborators for returning the species to its former niche, which are restorative in nature, rather than extractive. Although early efforts to protect American chestnut populations were undoubtedly motivated by economies based on chestnut, today, TACF focuses on the re-establishment of American chestnut as a mechanism for restoring forest ecosystems, lost biodiversity, cultural heritage, and even degraded minelands (TACF, 2018a). Whether or not arguments against privatizing the commons and for acts of reciprocity toward nature have been internalized by those involved in American chestnut restoration at SUNY-ESF, TACF, and FHI, their awareness of these moral imperatives and their power in thwarting the use of genetic technoscience in agriculture appear to be shaping the political economy of the technology in species restoration.

Biophysical resistance

Like social norms and values, biophysical systems can impose limits on the ability of technological innovation to extend markets to nature. In the history of various efforts to protect and restore populations of American chestnut, the biology of the species has consistently complicated human attempts to save it (Curry, 2014; Jacobs et al., 2013; Powell, 2014). Once attention turned to developing blight-resistant American chestnut trees using genetic approaches, scientists encountered a long lifespan and delayed reproductive maturity, sectorial mutation, and self-sterility. Blight-resistant backcross trees expected to be developed in a few generations (Burnham, 1981) are still blighted 40 years later due to genetic recombination near the locus of blight resistance (Wheeler and Sederoff, 2009) and the difficulty of controlling the prolific, wind-dispersed pollen of both American and Chinese trees in breeding orchards. The application of genetic technoscience to American chestnut restoration was initiated to overcome many of these constraints, but those innovations continue to work with and against the biophysical nature of the species. Although researchers at SUNY-ESF thought the production of blight-resistant trees using genetic engineering would take five years, it ultimately took 27 (Zhang et al., 2013). Powell said, “It was much more difficult than we thought it would be” (personal communication, 9 May 2017). Transgenic American chestnut seedlings raised from tissue culture still do not always develop neatly into tall, straight trees because this process generates whole seedlings from individual plant cells that were otherwise destined to form a leaf, branch, or root. American chestnut cannot be simply privatized and commodified with the application of genetic technoscience because it remains “[a] tree that was never tamed, a wild forest king whose dominion sprawled over more than two hundred million miles” (Freinkel, 2007: 15).

Still, the difficulties posed to the privatization and commodification of American chestnut by the biology of the species might be overcome in time; indeed, similar kinds of biological resistance have been subdued in agriculture (Kloppenburg, 2005) and forestry (Prudham, 2005) by scientific and political innovation. In this case, however, the primary incompatibility between neoliberalization and the “unruly biophysical systems” that contain American chestnut emerges from the very goal of the project, which is to return blight-resistant American chestnut populations to the species’ expansive historical range. The restoration of the chestnut is thus not envisioned in neat rows but across wild landscapes where ecological realities resist marketization. Although one scientist we interviewed described TACF’s interest in being “more involved, more heavy-handed, in distributing the trees in a large-scale way, in an intelligent way” (S02, personal communication, 22 February 2017), achieving restoration is, in many ways, fundamentally inconsistent with the “detailed control of people and things” characteristic of neoliberalism (Busch, 2010: 343). It will instead require diversity and local adaptation in American chestnut germplasm, not to mention the maintenance or re-establishment of complex ecological relationships, particularly with pollinators, dispersers, and microbial communities. Thus, even where reductionism and standardization are visible in this project, they are necessarily temporary, eventually followed by mechanisms for diversifying and “rewilding” the germplasm developed in breeding orchards and laboratories.

The ultimate release of blight-resistant American chestnut to natural ecological and evolutionary processes eliminates the feasibility of human and market control over the conditions of reproduction for the species. This is a key difference between the open release of a genetically manipulated organism for conservation of a wild species and the use of biotechnologies in presumably contained agricultural systems. While IP and proposed genetic technologies such as "terminator" genes, which prevent second generation seeds from producing viable plants, could be used to prevent the proliferation of the products of genetic technoscience in agriculture (Biermann and Anderson, 2017), these same controls would critically undermine the goal of re-establishing independent and evolving American chestnut populations in Appalachian forests.

The catch: Resisting markets for chestnut, opening markets for forest biotechnology?

For Polanyi (1944), the double movement that characterizes liberal capitalism—the resistance and ultimately, social protections, precipitated by the ills of marketization—is as much about making the market work as it is about challenging it. The flanking mechanisms that resist some of the patterns and consequences of marketization simultaneously facilitate them. Mansfield (2004) has demonstrated this in fisheries, where regulatory intervention—theoretically, the anathema to free markets—has been used to ensure the continuation of the market for Alaskan Pollock by protecting the biological sustainability of fishing stocks and the economic viability of local communities. Because the double movement phenomenon has been useful in explaining the ability of genetic technoscience to resist neoliberal logics in the context of American chestnut restoration, we must also consider the ways in which this resistance might be enabling the persistence and growth of markets for forest biotechnology, intentionally, or not.

Although commercial actors were largely uninterested in American chestnut for some time, various portions of this restoration effort have now been supported by key industry players. While the initial thrust for a transgenic American chestnut originated with TACF, as described previously, in 2009, the project was taken up as a "test case" by the FHI. Even though "all funding for the FHI came from partners outside of any for-profit biotechnology companies to ensure the program's objectives of transparency, independence, and maximizing societal benefit" (FHI, 2018), the initiative was run by the IFB, which worked with its partners, including ArborGen, one of the largest global providers of both conventional and engineered tree seedlings for commercial forestry, and Weyerhaeuser, one of the largest forest products companies in the world, to "accelerate the responsible use of forest biotechnologies" (IFB, 2018). Additionally, FHI was supported by Duke Energy, which has a growing interest in and commitment to the use of biofuels for energy production (Duke Energy, 2018); conveniently, ArborGen has engineered a cold-tolerant eucalyptus tree that could be used for that purpose, pending regulatory and public approval (Voosen, 2010).

Research at SUNY-ESF has also been directly funded by many donors over the life of the project, including ArborGen, Weyerhaeuser, and Monsanto (SUNY-ESF, 2018). Notably, though, none of these investments were accompanied by strings that would provide ownership claims to the scientific insights or products of biotechnology resulting from the research (William Powell, personal communication, 9 May 2017; Popkin, 2020). In recent years, Powell's work on American chestnut has been supported primarily by philanthropy, including from the Templeton World Charity Foundation, which funds scientific innovation and break-through in order "to fuel the human search for meaning, purpose, and truth"

(Dunn, 2020). A new US$3.2 million award from the Templeton Foundation in 2020 will be critical for the project to complete regulatory review, engage with the public through demonstration plantings and outreach, and scale up production, and eventually, distribution, of transgenic trees for restoration (Dunn, 2020).

Still, for industry groups, American chestnut restoration provides a valuable example of the benevolent potential of forest biotechnology to rescue heritage tree species from threats associated with invasive pests and pathogens (National Academies of Sciences, Engineering, and Medicine (NASEM), 2019). Multiple scientists involved in American chestnut restoration expressed concerns about the co-optation of the transgenic approach to blight resistance by those interested in the commercialization of other genetically engineered trees. One scientist said:

> I knew we were being used . . . I knew the only reason [they] got interested in chestnut was to sell [genetic engineering] in trees. Companies are not interested in chestnut, but once they get that through regulation, it's going to be easier to get loblolly pine and eucalyptus and Douglas fir through. To me, it's kind of a Trojan horse that's supposed to grease the wheels. (S06, personal communication, 30 March 2017)

While not directly interested in American chestnut, commercial actors are invested in the technical and regulatory insights and achievements emerging from the American chestnut project, and the potential exists for this non-profit application of genetic technoscience to be used to smooth acceptance of applications that are commercially motivated (NASEM, 2019). Scholars (Harrison et al., 2017) and activists (Smolker and Petermann, 2019) alike have thus questioned whether the choices about privatization and commodification made by scientists involved in American chestnut restoration represent genuine divergence from patterns set by biotechnology in agriculture. They have suggested that the project may instead be a Trojan horse, using the guise of forest health to overcome regulatory and public acceptance challenges in order to usher in broader—and more profitable—uses of forest biotechnology.

Although the entire forest biotechnology community undoubtedly stands to benefit from the work being done with American chestnut, the Trojan horse metaphor breaks down to some extent in this case. In literary accounts, the Trojan horse was constructed by and then concealed Greek soldiers determined to breach the walls of Troy. Who are the Greeks in the American chestnut saga, and what exactly is being smuggled into where? Activists and others concerned with the modification and marketization of nature have cast scientists as the Greeks, smuggling forest biotechnology into an unwitting governance system of regulations and public opinion under a banner of ecological justice (Smolker and Petermann, 2019). But the metaphor could be applied differently to describe a mixture of actors hijacking the strong scientific, economic, and political forces of genetic technoscience to achieve a heretofore unrealized goal of restoring American chestnut populations for ecological and cultural benefit. TACF has a stated, singular interest in the restoration of American chestnut (TACF, 2020), and as Powell understands it, his role is to use his expertise in genetics to develop blight-resistant chestnut trees and "light the spark of restoration" by providing them to restorationists and "the people," who must decide whether and how to use them (William Powell, personal communication, 9 May 2017).[2]

Ultimately, whether or not the scientists leading American chestnut restoration are acting as the Greeks or a flanking mechanism for neoliberalism, surreptitiously supporting the further marketization of forest trees through biotechnology, comes down to what we make of the double movement itself. If we interpret both the processes of privatization and commodification *and* resistance to those same processes as inherently neoliberal, we are at an impasse; it becomes difficult, if not impossible, to recommend steps for change, to imagine how we might work with our current world to build political and technological systems that support social and ecological justice (Castree, 2011). If this is the case, Margaret Thatcher may have been correct: truly, “there is no alternative” to the marketization of everything. Instead, we align with Barben (1998), seeing both neoliberalism *and* technologies as socially constructed and therefore malleable. We thus adopt an optimistic reading of the power of the double movement, not to overturn neoliberal structures entirely, but to make real changes to the constitution of neoliberalism in specific contexts. This perspective leaves critical space for reflexivity and response by scientists engaged in technological innovation, allowing them to make changes—if small ones—to shape the trajectory and impact of their work. It is in this vein that we have reported the stated motives of the scientists we studied and drawn attention to points where they, often in response to concerns raised about the neoliberal nature of genetic technologies in agriculture, have successfully resisted some market logics, even while embedded in neoliberal structures.

Conclusion

The ongoing application of genetic and genomic technologies to the restoration of American chestnut to its former niche and native range in the eastern United States is incongruent with the neoliberal patterns of privatization and commodification that have been described for the use of these technologies in agricultural systems. The theory of technological politics reminds us that this is not necessarily unexpected; while some technologies are inevitably linked to certain political and economic arrangements, many others can be involved in the production of a variety of political orders. This distinction matters, for, as Winner (1980: 134) has suggested, “[t]o know which variety of interpretation is applicable in a given case is often what is at stake in disputes, some of them passionate ones, about the meaning of technology for how we live.” At stake in current debates is whether genetic technologies will be spurned outright as inevitably complicit in the neoliberalization of nature, or considered, even if cautiously, as tools that could be used in new ways with decidedly different politics.

Genetic technoscience has been embraced for American chestnut restoration and thus far with outcomes that are largely inconsistent with neoliberalization. But American chestnut restoration is still unfolding, and key decisions remain open about the privatization of hybrid germplasm and commercialization of blight-resistant trees. The impact of this project on the political and economic future of forest biotechnology, more broadly, also remains to be seen. Those involved in chestnut restoration, by forgoing IP protections on transgenic American chestnut lines and framing chestnut restoration as an act of reciprocity, may merely be acting as flanking mechanisms positioned to mitigate resistance to both global capitalism, which brought chestnut blight to American shores in the 19th century, and the continued expansion of forest biotechnology. Polanyi’s (1944) double movement holds, however, that it is quite possible to be embedded in neoliberalism while challenging it, as conditions internal to the neoliberal project—principally, the creation of “free, self-actualizing subjects” (Bondi and Laurie, 2005) —leave room for meaningful resistance to the extension of markets to nature. Even in its nascent stage, the American chestnut project demonstrates the ways in which “pre-existing moral economies” and “unruly biophysical systems” (Castree, 2010b: 1744) can provide substantial challenge to the neoliberalization of nature. Historical social resistance to the commodification of plant germplasm and biological resistance posed by the very nature of species restoration have precipitated political and economic decisions by actors in American chestnut restoration that are at odds with the neoliberal patterns described in agriculture.

As calls continue to increase for the use of emerging genetic and genomic technologies for addressing global problems in human health, biodiversity conservation, and even food security, social scientists must remain committed to nuanced analyses and avoid approaching biotechnologies as inherently neoliberal and neoliberalism as inherently destructive. Rather, scholars should use their understanding of both technologies and political structures as uneven and socially constructed to contribute to the co-production of new applications of genetic technoscience (Barben, 1998; Jasanoff, 2004). Being invited to these co-productive tables will require social scientists to communicate their theory and observations in a way that does not alienate geneticists, biologists, and ecologists nor their more traditional NGO and activist allies, and for natural scientists to see the social, political, and ecological futures shaped by their work as within their purview. This kind of integration can perhaps best be achieved through institutions and frameworks that normalize engagement between natural scientists, social scientists, and the public (NASEM, 2019), such as anticipatory governance (Guston, 2014) and responsible research and innovation (Stilgoe et al., 2013). The scientists using genetic technologies to resurrect American chestnut populations in Appalachian forests—and those working on genetic approaches to the conservation of an array of other species in ecosystems across the globe—are making decisions each day that determine the politics of their technoscience. Scholars of science, technology, and society should be engaged in shaping these evolving projects in ways that revive degraded ecosystems while acknowledging biological complexity, respecting the genetic commons, and empowering human communities.

Highlights

- Genetic approaches to American chestnut restoration are inconsistent with the neoliberal processes of privatization and commodification described for agricultural biotechnology.
- Social and biological resistance have limited the ability of genetic technologies to extend neoliberal logics to American chestnut restoration.
- The unevenness of both technological politics and neoliberalism create critical space for shaping the trajectory of biotechnologies for conservation.

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Notes

1. We refer to all interview subjects anonymously, with the exception of Dr. William Powell, due to his central role in developing a transgenic approach to American chestnut restoration. Powell gave informed consent to be referenced by name in manuscripts resulting from this research.
2. In our analysis, we have chosen to take seriously the sentiments and statements of the actors involved in American chestnut restoration, rather than assuming intent, particularly malicious intent. Other scholars have similarly challenged interpretations that require either claiming conspiracy and deceit or ignoring the agency and concern of those involved (Hoeyer, 2007a, 2007b). Like Hoeyer (2007a), we have instead focused on how social concerns about the commodification of natural materials—human blood and tissues in Hoeyer's case, American chestnut germplasm in ours—have effectively shaped the governance of science and innovation in these contexts.

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