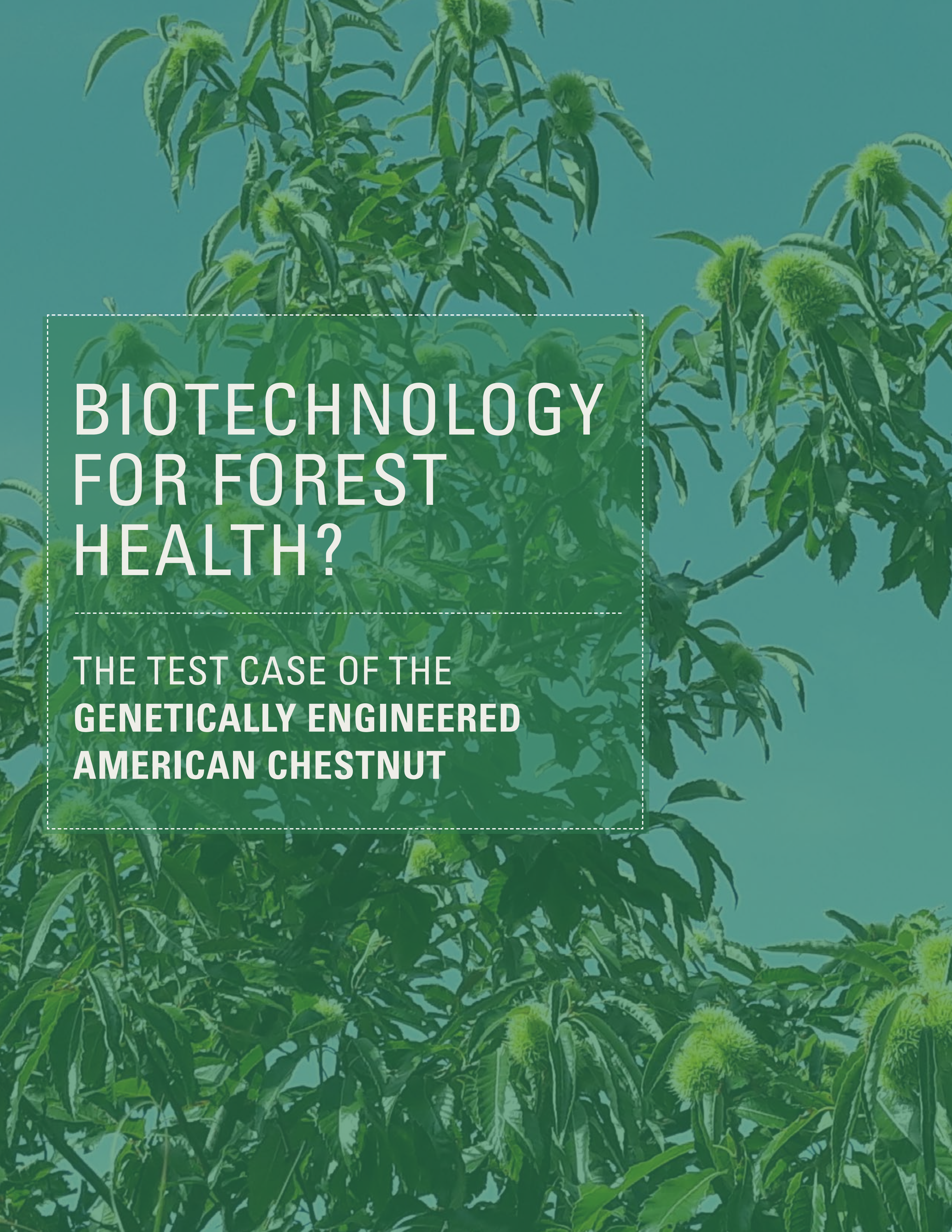


BIOTECHNOLOGY FOR FOREST HEALTH?

THE TEST CASE OF THE **GENETICALLY ENGINEERED AMERICAN CHESTNUT**

Biotechnology for Forest Health?

The Test Case of the Genetically Engineered American Chestnut

Produced by: The Campaign to STOP GE Trees, Biofuelwatch and Global Justice Ecology Project.

Lead authors: Rachel Smolker, Biofuelwatch, and Anne Petermann, Global Justice Ecology Project.

Research support: Steve Horn, Lance Olsen

Graphic design: jwalker design

Acknowledgements: We are grateful to the Ceres Trust for its generous support of this publication and associated program work. We are also grateful to Marti Crouch for engaging in several useful conversations during the course of preparing this report. Thank you to Taarini Chopra and Lucy Sharratt of the Canadian Biotechnology Action Network for review and editing assistance.

We thank the following for their help with reviewing the content of this report: A.L. Anderson-Lazo, Ph.D, Rural Coalition; John Johnson, assistant research forester, University of Tennessee, Dept of Forestry, Wildlife and Fisheries* (for identification purposes only); BJ McManama, Save Our Roots Campaigner, Indigenous Environmental Network; Lois Breault-Melican and Denis Melican, American chestnut enthusiasts, Helena Paul & Ricarda Steinbrecher, Co-Directors EcoNexus; Ruddy Turnstone, Global Justice Ecology Project.

April 2019

The Campaign to STOP GE Trees is an international alliance of organizations that united in 2004 to stop the release of genetically engineered trees in order to prevent the anticipated ecologically and socially devastating impacts. Global Justice Ecology Project coordinates, administrates and fundraises for the campaign. World Rainforest Movement, based in Uruguay, is the Southern contact for the Campaign and publishes materials and research in English, Spanish and Portuguese.
www.stopgetrees.org/

Global Justice Ecology Project is a non-governmental environmental organization founded in the US in 2003. It explores and exposes the intertwined root causes of social injustice, ecological destruction, and economic domination. GJEP envisions a world in which all societies are justly and equitably governed with full participation by an engaged and informed populace living in harmony with the natural world and one another. We accomplish our mission by prioritizing campaigns that are key leverage points for advancing systemic change, and linking struggles and strengthening diverse movements with strategic action, information, and analysis.
www.globaljusticeecology.org

Biofuelwatch is a non-governmental environmental organization based in the United Kingdom and the United States that provides information, advocacy and campaigning in relation to the climate, environmental, human rights and public health impacts of large-scale industrial bioenergy. **www.biofuelwatch.org.uk/**

"Will the blight end the chestnut?
The farmers rather guess not.
It keeps smouldering at the roots
And sending up new shoots
Till another parasite
Shall come and end the blight."

—Robert Frost (1936)

Table of Contents

Acronyms and abbreviations

AC	American chestnut
APHIS	Animal and Plant Health Inspection Service
CRISPR	Clustered regularly interspaced short palindromic repeats
EPA	Environmental Protection Agency
FDA	Food and Drug Administration
FHI	Forest Health Initiative
GE	Genetically engineered
GE AC	Genetically engineered American chestnut
GMO	Genetically modified organism
IEN	Indigenous Environmental Network
IFB	Institute of Forest Biosciences
IUCN	International Union for Conservation of Nature
NARA	Northwest Advanced Renewables Alliance
NAS	National Academies of Science, Engineering and Medicine
OxO	Oxalate oxidase enzyme
PR	Public relations
SUNY-ESF	State University of New York College of Environmental Science and Forestry
TACF	The American Chestnut Foundation
UN	United Nations
USDA	United States Department of Agriculture

EXECUTIVE SUMMARY

The American chestnut, once a dominant species in eastern North American forests, was decimated in the first half of the 20th century by a fungal blight (*Cryphonectria parasitica*, also referred to as chestnut blight) and logging. Researchers at the State University of New York College of Environmental Science and Forestry are developing a genetically engineered (GE) blight-resistant American chestnut (AC), and hope to win government approval for its unregulated release into the environment. If they are successful, the GE AC will be the first GE forest tree species planted specifically to spread freely through forests. Once the GE AC is released, there will be little potential to track or reverse its spread.

The GE AC is promoted as a test case to sway public opinion toward supporting the use of biotechnology for forest conservation, and to pave the way for the introduction of other GE trees. However, most other GE trees in development would be grown in industrial monoculture plantations, for the commercial production of timber, pulp and biofuels. A close look at who is promoting the GE AC reveals direct and indirect financial and other links between the nonprofit The American Chestnut Foundation, the researchers developing the GE AC, tree biotechnology company ArborGen, biotechnology company Monsanto (now Bayer), Duke Energy, government agencies, and other entities including the Forest Health Initiative and the Institute of Forest Biosciences that are deeply invested in advancing the use of biotechnology for forest restoration as a public relations tool.

If they are successful, the GE AC will be the first GE forest tree species planted specifically to spread freely through forests. Once the GE AC is released, there will be little potential to track or reverse its spread.

The GE AC tree has been engineered with an oxalate oxidase enzyme, or OxO, derived from wheat, along with other marker and promoter genes. The OxO trait does not eliminate the pathogen, but inhibits it from spreading on the tree, making it less lethal. While tests on a small number of young GE AC trees have shown some resistance to *Cryphonectria*, extrapolation from these results is unreliable, given the long lifespan of AC (potentially over 200 years) and the variable conditions it encounters in nature. Efforts to genetically engineer pathogen resistance, even in common agricultural crops, have been unsuccessful because pathogens evolve to overcome plant defenses, and increasing resistance to one pathogen may lead to higher susceptibility to others. In addition, the existence of other pathogens lethal to AC, such as *Phytophthera cinnamomi*, as well as a variety of stresses including climate change, contribute further to the challenge of chestnut restoration, with or without genetic engineering.

The GE AC is specifically intended to be released into forests, and to spread its GE pollen and seeds. Locating and monitoring all GE AC trees and their progeny will be nearly impossible, especially over a long period of time. GE AC pollen and nuts could contaminate hybrid chestnut orchards, and spread across borders and jurisdictions. Researchers claim that a robust regulatory process will be sufficient to address risks. However, the U.S. regulatory system has no specific regulations to deal with the release of GE trees into forests. In addition, our minimal knowledge about highly complex forest ecosystems and the potential impacts of climate change make adequate risk assessments impossible. Other concerns include the safety of eating GE AC nuts or inhaling GE AC pollen, and impacts on wildlife, pollinators, other plants, soils and waterways.

The release of GE AC into forests would be a massive and irreversible experiment

The development of GE trees has been met with strong and ongoing public opposition including from scientists, foresters, and ecologists. Indigenous Peoples whose traditional lands fall in the range of AC have expressed concern about the impacts on their territorial sovereignty and right to keep GMOs off their lands.

The release of GE AC into forests would be a massive and irreversible experiment. The introduction of GE AC could not only fail, but also create new problems and exacerbate existing pressures on forest ecosystems. Forests are already threatened by unsustainable logging practices, invasive species and introduced pests and pathogens, urban sprawl, and the escalating impacts of climate change. Without solving these underlying causes of forest demise, the restoration of the American chestnut through any technology is highly improbable.

Decisions about the introduction of the GE AC will set a regulatory precedent and set the stage for the future of forest genetics. **The GE AC should not be permitted for distribution**. The UN Convention on Biological Diversity and forest certification regimes including the Forest Stewardship Council and Sustainable Forestry Initiative call for application of the precautionary principle to GE trees, with the FSC and SFI banning their use. The precautionary principle, which was formulated to avert harm by delaying action until safety can be proven, is the appropriate framework to apply to decision-making related to the GE AC.

INTRODUCTION

Forests around the world face several grave and compounding risks: legal and illegal logging; deforestation driven by industrial exploitation, the expansion of industrial agriculture and monoculture timber plantations; the introduction of pests and pathogens as a result of global trade; and the escalating impacts of climate change.

In this troubling context, the biotechnology, energy and forest products industries and their associates in academia are promoting genetic engineering as a tool to protect forests and tree species at risk, and restore species faced with extinction. In response to this rising emphasis on genetic engineering to solve forest health crises, the National Academies of Science, Engineering and Medicine in the U.S., in 2018, convened a study group to explore "The Potential for Biotechnology to Address Forest Health."[1]

The American chestnut (*Castanea dentata*) has risen to prominence as the poster species for this new biotechnology-focused "forest health" strategy

The American chestnut (*Castanea dentata*) has risen to prominence as the poster species for this new biotechnology-focused "forest health" strategy. Once the dominant tree of the eastern U.S. forest, the American chestnut (AC) was decimated in the first half of the 20th century by a deadly blight introduced from Asia, combined with unsustainable logging and well-intentioned but somewhat overzealous actions to try to stop the spread of the blight. However, the AC did not die off completely. Millions of stumps continue to send up sprouts that occasionally grow into trees large enough to produce nuts. Most are then re-infected with the blight and die back, starting the cycle again. Whether any naturally blight-resistant American chestnuts will emerge in the future is unknown.

The American chestnut was highly valued for its beautiful and rot-resistant wood, and abundant nuts that sustained both wildlife and rural economies. Species that relied on chestnuts as a food source were affected by its loss. Human communities, particularly in Appalachia, which used the chestnut for food, livestock feed, and timber, were also impacted. However, forest ecosystems adapted, with nut-bearing species such as oak, hickory and beech filling much of the void that was left by the disappearance of the American chestnut.

Some people have a strong desire to see the American chestnut restored to forests. The nonprofit group The American Chestnut Foundation was established with the goal of breeding disease-resistant chestnuts in hope of achieving restoration. Recently, the foundation has included the use of genetic engineering as a tool in this effort, partnering with the American Chestnut Research and Restoration Project[2] at the SUNY College of Environmental Science and Forestry,[3] which is undertaking the research and development of genetically engineered American chestnut (GE AC) trees. The researchers say they hope to win U.S. government approval to deregulate the GE AC by 2020.

The American chestnut is the first plant to be genetically engineered with the express intent to spread freely in wild ecosystems. Once it is released into the wild, there will be no way to recall it.

If deregulated, the GE AC will be freely available for planting, without government oversight or monitoring for potential impacts. The American chestnut is the first plant to be genetically engineered with the express intent to spread freely in wild ecosystems. Once it is released into the wild, there will be no way to recall it.

It is critically important, therefore, to carefully evaluate this proposed use of genetic engineering and assess the concerns it presents. This includes acknowledging and addressing the fact that **there are many unknown and unknowable risks**, and recognizing the limitations of our regulatory agencies. Any evaluation must not only examine the ecological risks, but also consider the social and economic context of introducing GE AC to forests. Further, it is necessary to distinguish fact from hype, which in turn requires assessing the commercial or other interests of the institutions behind the project, some of which may not be driven by broader societal interests.

Public opposition to genetically engineered trees has been strong and steadily growing. Commercial and academic advocates of tree biotechnology believe that they can win over a wary public by promoting biotechnology research on a charismatic species such as the American chestnut, under the guise of enhancing forest health. However, **tree biotechnology research and development is overwhelmingly oriented toward commercial and industrial plantation forestry**, primarily for pulp and biofuel production, not fostering the health of natural forests for the public good.

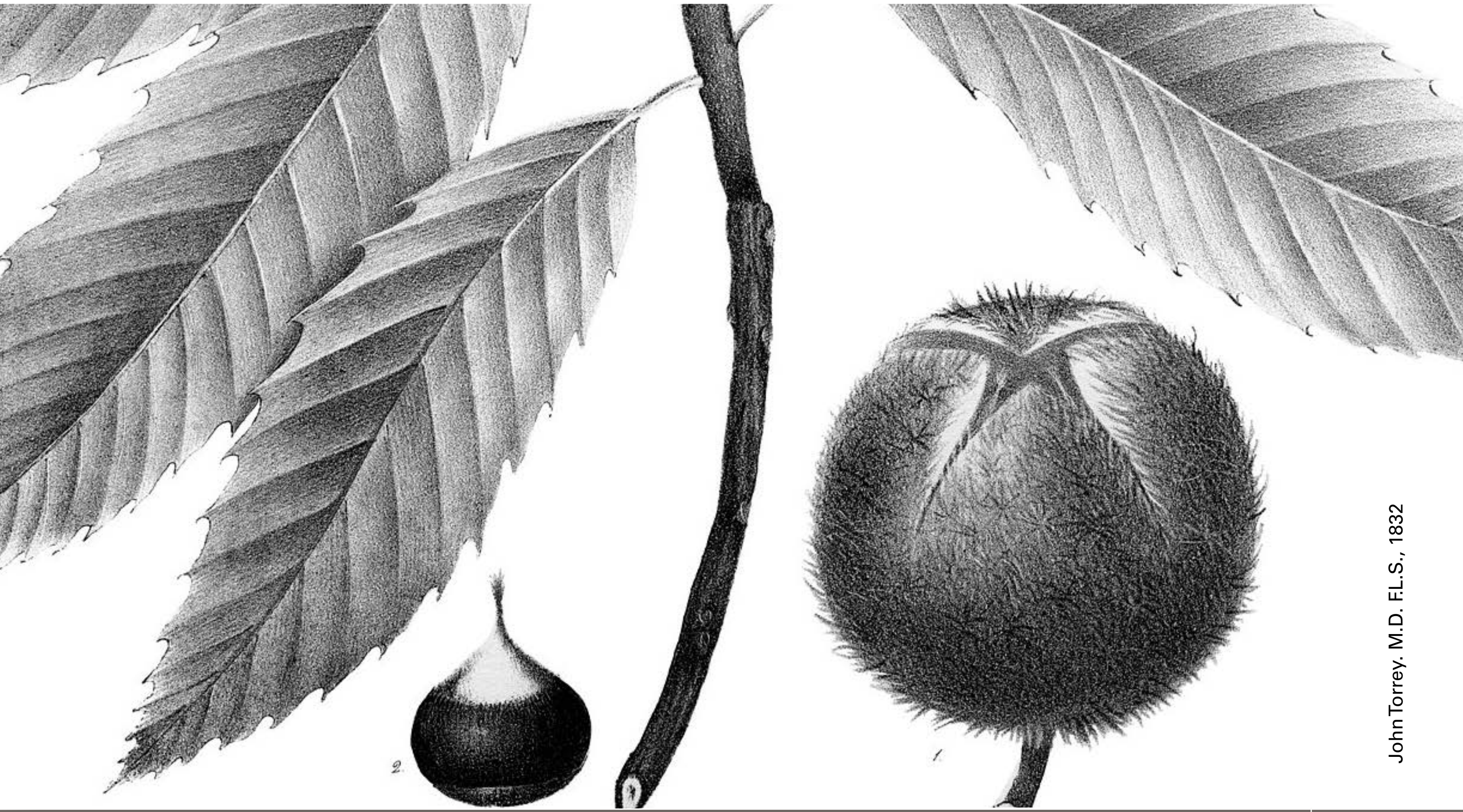
Proponents of GE trees, and the GE AC in particular, commonly dismiss the concerns of opponents and question their motives. However, opposition to genetically engineered trees, and to the GE AC specifically, comes from a diverse public that includes scientists, foresters, ecologists, chestnut growers, and Indigenous Peoples. Their concerns are informed by over twenty years of experience with GE crops and their impacts, decades of dealing with the fallout from broken promises made by government regulatory agencies, and an acute awareness that we know far too little about trees and forest ecosystems to adequately assess the risks of releasing GE trees into the wild.

Concerns about the GE AC include the potential health impacts for humans and wildlife from eating GE chestnuts or inhaling GE pollen, and the impacts on chestnut growers' livelihoods if their orchards are contaminated. Indigenous Peoples have raised concerns that they will be unable to keep unwanted GE AC trees off their lands, violating their sovereignty. Others point out that these GE trees, which have never before existed in nature, do not fit into their traditional worldviews. Concerns are also grounded in ancestral traditions of considering long-term impacts when intervening in the natural world. In the case of the GE AC, these impacts are unknown.

Critics of the GE AC also point to decades of efforts to breed blight-resistant American chestnut trees through hybridization and backcrossing with naturally resistant Asian chestnuts. They fear the push to promote GE AC as a "fast fix" is undermining those ongoing efforts and diverting funds.

Our forests face serious threats. Ultimately, biotechnology cannot fix the many problems created by poorly regulated trade and transport of plant materials, the reckless degradation of forest ecosystems, or the unknown future of a changing climate. It is essential to focus on the entirety of the forest health crisis to develop ecologically and socially appropriate strategies to protect and restore forests.

It is essential to focus on the entirety of the forest health crisis to develop ecologically and socially appropriate strategies to protect and restore forests.



John Torrey. M.D. F.L.S., 1832

WHAT HAS BEEN ENGINEERED AND WILL IT WORK?

THE OXO CODING SEQUENCE

The GE AC was developed by researchers at the State University of New York College of Environmental Science and Forestry (SUNY-ESF), under the leadership of professors William Powell and Charles Maynard. They began the work in the 1980s, collaborating with Scott Merkle at the University of Georgia and others. Research initially focused on methods to introduce DNA and propagate plants from cell culture, neither of which had been done previously with American chestnut trees.

In their work to engineer blight resistance into the AC, Powell and his colleagues experimented with a variety of genes and gene constructs over the years. In 2010, they were granted major financial support from the Forest Health Initiative to test a wider variety of genes, markers and promoters, and move their tests from the laboratory to the field.

In a review of American chestnut biotechnology research, the researchers reported that they tested six different transgenes containing sequences from wheat, grape, pepper, the mustard-family plant *Arabidopsis*, and an orchid, as well as 26 cisgenes largely derived from Chinese chestnut (Nelson et al. 2014).[4]

The research team tested various promoters to aid gene expression. Initial experiments used a promoter from cauliflower mosaic virus and subsequent ones used tissue-specific promoters from plants. They also used a herbicide-resistance gene from a bacterium (glufosinate resistance with a viral promoter) to select transformed cells, and a green fluorescent protein (with viral promoter) from a jellyfish as markers.

Powell and his colleagues also experimented with emerging synthetic biology techniques, introducing a synthetic antimicrobial protein derived from the skin of the African clawed frog, which they patented[5] and tested on elms.[6]

After years of trial and error, Powell's team settled on using a gene derived from wheat, which encodes for the oxalate oxidase enzyme (OxO). DNA was inserted into American chestnut using *Agrobacterium* mediated transformation. OxO was chosen because it is known to play a role in plant defenses in a variety of species, and had already been studied in some detail. It had been shown to be effective in conferring resistance to various pathogens, such as in peanut (Livingstone et al. 2005),[7] soybean (Donaldson et al. 2001),[8] canola (Dong et al. 2008)[9] and poplar trees (Liang et al. 2001).[10] In spite of this considerable research, there are no commercially available OxO-engineered, pathogen-resistant crops on the market yet.

OxO inhibits the chestnut blight (*Cryphonectria parasitica*) by detoxifying the oxalate secreted by the fungus. Oxalate breaks down cell walls in the tree tissue at the edge of the infected area (canker), making it easier for the fungus to spread. OxO converts this toxic oxalate into hydrogen peroxide (H2O2) and water, making it harder for the fungus to spread into adjacent tissue (Williams et al 2011,[11] Welch et al 2007,[12] Zhang et al 2013[13]). It does not destroy the fungus, but limits its spread, and therefore makes it less lethal to the tree.

The process to genetically engineer OxO into AC is not as simple as introducing a single wheat OxO coding sequence. It also requires the introduction of regulatory sequences such as promoters derived from other organisms, and marker genes that select and identify cells that have taken up the foreign DNA. What will finally be submitted for government review is a GE "event" – in this case, trees derived from a particular cell line in which the introduced OxO gene and associated genetic markers have been uniquely integrated into the chestnut genome.

The process to genetically engineer OxO into AC is not as simple as introducing a single wheat OxO coding sequence

The GE AC event submitted for regulatory review will most likely be "Darling 58" and perhaps also "Darling 54."[14] Both have been transformed with OxO, but the details, for instance about which promoters and markers are used, have not been published yet, to our knowledge.

In a 2017 paper, Steiner et al. point out: *"The Darling 54 and Darling 58 events occurred in ramets of the same clone of C. dentata ('Ellis 1'), so they should be identical in all respects other than the transformation event itself. During the review process, the transgenes from these two events will be bred into one or more seedling populations of C. dentata within the restrictions imposed by the review process. The reason for this is that chestnuts typically do not grow well when propagated from tissue culture or other clonal means, but seedling populations carrying the transgenes can be created in a single generation by selecting for the 50% of the offspring that are transgenic. Trees carrying the OxO transgene can be rapidly identified using an enzyme assay. Additional breeding could be pursued without further review if non-regulated status is approved by USDA-APHIS and a registration granted by the EPA. A second generation of breeding would fix the transgene in the homozygous state in about one-fourth of the intercrossed progeny."*[15]

Introducing the wheat OxO gene into American chestnut has been reasonably demonstrated to confer at least partial resistance to blight. Newhouse and colleagues (2014) tested blight resistance in trees up to four years old, and found that OxO-transformed trees exhibited resistance at levels intermediate between unmodified AC and the resistant Chinese chestnut.[16] However, those tests were done on earlier OxO transformation events (Darling 4 and 5, Hinchee 1 and 2), not on the Darling 58 or 54 events. Results of blight resistance testing on Darling 58 were presented at the American Chestnut Foundation meeting in Huntsville, Alabama, in 2018, via a PowerPoint presentation. Though highly preliminary, they indicate that Darling 58 trees may have greater blight resistance than the OxO trees tested previously.

Public communications about the project to genetically engineer American chestnut have theatrically oversimplified the science and certainty involved. In a video for an online fundraiser to support GE AC research, Powell and a young girl sit at a kitchen table happily munching on slices of toast as he explains that OxO is an enzyme common in many cereal grains, is perfectly safe, and will enable the restoration of the magnificent American chestnut tree. Similarly, in a presentation on public attitudes towards GE trees, titled "Transgenic American chestnuts for potential forest restoration: scientific successes, regulatory challenges, Andy Newhouse, a researcher in Powell's lab, shows a cartoon image of "Buster Blight" attacking "Charlie Chestnut." Charlie whips out his OxO shield and the cartoon concludes that "they live in harmony forever after."[17]

Public communications about the project to genetically engineer American chestnut have theatrically oversimplified the science and certainty involved.

THE DIFFICULTY OF ENGINEERING PATHOGEN RESISTANCE

The research on GE AC has occurred against a backdrop of efforts by many other researchers to genetically engineer agricultural crop plants to be resistant to viral, bacterial and fungal pathogens. However, successful engineering of pathogen resistance has been remarkably elusive. Collinge et al. (2010) discuss some of the reasons. One frequent problem is that engineering resistance to one pathogen often leaves plants more susceptible to other pathogens or stresses, or reduces plant growth significantly.[18]

Another problem is the loss of pathogen resistance over time. Plants and pathogens are engaged in an ongoing evolutionary arms race.[19] Fungal (and other) pathogens are notoriously capable of rapidly adapting to find ways around plant defenses. A modification that may initially be effective can be rendered ineffective as the pathogen adapts. A recent example comes from a Chinese GE papaya (Huanong No.1) that was engineered to be resistant to ringspot virus. Wu et al (2018) report that a new virus lineage has now evolved and overcome resistance.[20]

In 2010, when Collinge et al. published their review on engineering pathogen resistance in crops, 853 of the 15,850 field test applications submitted to the U.S Department of Agriculture involved traits for resistance to fungal pathogens (the remainder involved viral and bacterial pathogen resistance).[21] Yet, only one GE crop with resistance to a fungal pathogen has been commercialized at this point: a late-blight-resistant-potato (from the company JR Simplot).[22] Given such limited success with commonly cultivated and short-lived domestic crop plants, the prospects for successful and durable engineering of fungal pathogen resistance into a long-lived wild forest tree species appear remote.

While researchers publicly describe use of a single wheat gene to confer blight tolerance, these simplistic representations conceal the complexity of the task at hand. A single gene construct – the OxO transformation – is unlikely to be effective on its own in conferring durable blight resistance. Blight resistance in Chinese chestnut, for example, is known to be quantitative (varying along a continuum, involving combined activity from multiple genes and environmental factors).[23]

The researchers working on the GE AC acknowledge (though not always in public communications) that in order to have any chance of successful restoration using GE AC, it will be necessary to use a suite of genes to confer stable and long-term resistance to the blight. William Powell says: *"Eventually we hope to fortify American chestnuts with many different genes that confer resistance in distinct ways. Then, even if the fungus evolves new weapons against one of the engineered defenses, the trees will not be helpless."*[24]

Given such limited success with commonly cultivated and short-lived domestic crop plants, the prospects for successful and durable engineering of fungal pathogen resistance into a long-lived wild forest tree species appear remote

EXTRAPOLATION FROM LAB AND FIELD TESTS OF YOUNG TREES IS UNRELIABLE

Existing studies of blight resistance in American chestnut have all been on young trees in lab or field trial conditions. Experimental AC trees engineered with wheat OxO were first field tested in 2006, and are therefore less than 15 years old. Younger trees are known to be more resistant to the blight; however, chestnut trees can live for well over 200 years and face many environmental conditions over their lifespans: drought, flood, heat, pests and the basic changes associated with aging. All these factors could influence how genes are expressed over time and whether or not the trees will retain blight resistance and withstand other challenges. We cannot rely on extrapolation from test results from young trees to assume that blight resistance will be functional over a longer period and under the variable conditions of natural forests.

GE crop plants that grow for a single season (or at most a few seasons, as in the case of GE alfalfa) experience less variation in environmental conditions over time. For longer-living trees grown in orchards, such as GE apple or plum, there may be more variation, but the trees are also under cultivation, observation and some degree of human control. For a forest tree growing wild in a forest ecosystem, changes in gene expression over the long term cannot be predicted or managed.

In a report published in 2019, the National Academies of Science, Engineering and Medicine (NAS) questions the long-term stability of genetically engineered resistance to pests and pathogens in trees: *"Exposure of trees to pest species over many generations has resulted in development of resistance to impacts of both specific and generalized pests. The distribution of this resistance may not be consistent across the range of a tree species…, and resistance may involve trade-offs with other traits such as growth, drought resistance, seed production, tissue palatability, and nutrient dynamics that have implications for ecosystem function (Reid et al., 2016; Lovett, 2018). Additionally, the longevity of trees relative to their pests means that the latter have the potential to evolve more rapidly than their hosts."*[25]

Given the long lifespan of trees and varying environmental conditions they face, we cannot extrapolate from tests done on very young trees under controlled lab and field conditions. How GE trees might behave in the diverse and changing context of natural forests over long periods of time is unknown and likely to remain unknown even after they are released.

Given the long lifespan of trees and varying environmental conditions they face, we cannot extrapolate from tests done on very young trees under controlled lab and field conditions

The stark difference between controlled lab and field trial results, and those involving older trees grown in natural forest conditions, can be seen in a recent study (Clark et al. 2018) that compared blight resistance in the hybrid backcross "BC3F3" to earlier back-cross generations, resistant Chinese chestnut and susceptible American chestnut. This was one of the first studies of backcrossed hybrid trees grown out in forest settings, rather than in orchards. The authors state: *"Interactions between planting location and breeding generation affected resistance ranking, suggesting that longer term testing is need to determine resistance of a particular breeding line across a variety of sites."*[26] They also point out that trees up to eight years old are *"too young to determine durable resistance"* and emphasize that *"Additional orchard selections, progeny tests, and field testing are required before restoration efforts that involve substantial resources and infrastructure should begin (Steiner et al., 2017; Clark et al., 2014b). A transgenic chestnut is currently being developed, and will require similar rigorous testing as hybrid seedlings prior to investment of restoration activities (Newhouse et al., 2014)."* The authors also point out concerns about the long-term stability of resistance: *"Expression of resistance in hybrid seedlings can also change over time, but this is not well understood. Studies of pure American chestnut indicate disease incidence and tolerance were affected by weather conditions, canopy conditions, and blight strains, all of which are dynamic (Griffin et al., 2006)."*[27]

Trait stability could theoretically be evaluated through empirical research, but those tests would need to be conducted over the lifespan of the trees, on a wide range of genetically diverse representatives, and under varying conditions comparable to wild forest ecosystems. Such testing would be tremendously time-consuming and complex, and the study design would need to anticipate conditions trees might face in a climate-changing future.

BIOTECHNOLOGY IS BASED ON INVALID AND REDUCTIONIST ASSUMPTIONS ABOUT GENETICS

Our understanding of how genetics work has evolved significantly away from the reductionist view of the "one-gene-one-trait" model. In "Bound To Fail: The flawed scientific foundations of agricultural genetic engineering" (2018) Michael Antoniou argues, *"…attempts to engineer complex traits (e.g. higher yield, drought tolerance, or disease resistance) into crops using transgenic and gene editing is destined to fail. This is because no gene and/or its RNA or protein product works in isolation. These molecular components of life work as part of an integrated whole… It's possible that a set of "core" genes may be at the basis of complex traits, but omnigenics reveals that their function is augmented by all the other genes that are expressed in a given cell or tissue. Crucially, omnigenics suggests that genes in a cell should be viewed as a network… in-depth molecular profiling analysis of transgenic plants shows that transgenic procedures invariably result in a spectrum of unpredicted alterations, not only in the function of the inserted foreign transgene but also of the plant's host genes. This in turn results in unintended changes in the plant's biochemistry."*[28]

Trait expression is also dependent on a wide array of environmental conditions which can change over time

In presentations, William Powell and colleagues argue that the OxO modified trees are "more pure AC" than those hybridized with Asian chestnuts and backcrossed with pure American chestnuts, because there are fewer foreign genes involved. However, the quantity of introduced DNA or transgenes is not the basis for risk concerns, but rather there are a host of other factors that contribute to the impact of an introduced gene construct, including how the new gene construct interacts with other genes, construct placement in the genome, and mutations and epigenetic changes induced during tissue culture. Trait expression is also dependent on a wide array of environmental conditions which can change over time.

In sum, engineering chestnut for reliable long-term resistance to the blight is complex, slow, and painstaking work. The results to date are based on limited testing of young trees in controlled conditions and should be considered preliminary. Extrapolation about the stability and viability of GE AC over the many decades of a tree's lifespan, and under the many diverse conditions encountered in nature is simply not possible at this time. Releasing GE AC into forests would therefore be highly premature.

WHAT ARE THE RISKS OF THE GE AC AND CAN WE EVEN ASSESS THEM?

"We're still at the very beginning of understanding what we're doing. The rush to apply these [genetic engineering] ideas is absolutely dangerous, because we don't have a clue what the long-term impacts of our manipulations are going to be."

— Geneticist Dr. David Suzuki[29]

The NAS report states: *"A unique aspect of a biotech tree developed to address forest health is that it will result in an unconfined release into the environment that is meant to propagate, spread, and persist without human oversight and control; this is significantly different from previously developed biotech trees, which are meant to be grown in orchards or plantations, and biotech crops, which are grown on managed farms."*[30]

If it is allowed by government regulatory agencies, the introduction of genetically engineered American chestnut into eastern U.S. forests will be a giant and irreversible experiment.

Locating and monitoring the progress of all the GE AC trees and their progeny will be near impossible, especially over a long period of time. There has been some discussion of planting the GE trees slowly, in stages, to improve the potential for monitoring. However, common sense and past experience with genetically engineered crops suggests that monitoring is not feasible.

If it is allowed by government regulatory agencies, the introduction of genetically engineered American chestnut into eastern U.S. forests will be a giant and irreversible experiment.

A release of GE AC trees into natural forests raises some important questions and concerns about potential risks. For example: Will the nuts from GE AC be safe to eat? Will GE AC be safe for soils, waterways, fungi, pollinators, and other animal and plant species in the forest ecosystems where they grow? Will inhaling pollen from GE chestnut be harmful? Will introducing GE AC present risks to the few remaining native AC trees, or those in hybrid backcross breeding program orchards?

Bees, butterflies, squirrels, birds and humans can carry away tree nuts and pollen, and pollen can also be blown on the wind. Once the engineered trees are released into forests, the GE AC "experiment" will be irreversible. There is no way to prevent the trees from spreading, including across cultural or jurisdictional boundaries.

Before we can evaluate the risks, we must first ask: do we have the tools, information, time and wisdom to conduct adequate risk assessments? Only then can we determine whether the risks are worth taking.

CONTAMINATION RISKS

"We have no control over the movement of insects, birds and mammals, wind and rain that carry pollen. GM trees, with the potential to transfer pollen for hundreds of miles carrying genes for traits including insect resistance, herbicide tolerance, sterility and reduced lignin, thus have the potential to wreak havoc throughout the world's native forests."

— Geneticist Dr. David Suzuki[31]

Genetic contamination from GE trees, which can spread pollen up to hundreds of miles, has long been one of the most serious concerns of their introduction to forests. Almost half of the GE tree researchers surveyed in the 2006 UN report "Preliminary Review of Biotechnology in Forestry, Including Genetic Modification" reported GE plant or gene escape or impacts on non-target species as "anticipated environmental risks." More than one-quarter of respondents reported "anticipated human health risks." The unknown risks from GE tree release has led a wide array of organizations – including the Federation of German Scientists,[32] the UN Convention on Biological Diversity,[33] and the Forest Stewardship Council[34] – to call for the application of the precautionary principle when considering their release.

Genetic contamination from GE trees, which can spread pollen up to hundreds of miles, has long been one of the most serious concerns of their introduction to forests

The precautionary principle *"provides guidance for governance and management in responding to uncertainty. It provides for action to avert risks of serious or irreversible harm to the environment or human health in the absence of scientific certainty about that harm. It is* *now widely and increasingly accepted in sustainable development and environmental policy at multilateral and national levels. The principle represents a formalization of the intuitively attractive idea that delaying action until harm is certain will often mean delaying until it is too late or too costly to avert it."*[35]

The NAS also highlights concerns about contamination for any GE forest tree: *"Additionally, interspecies gene flow, via horizontal gene transfer or hybridization, could occur…In the case of an introduced GE tree, if hybridization with other species occurs, constraining such hybridization would be impossible unless hybrids had significantly reduced fitness (e.g., Ellstrand, 1992; Feurtey et al., 2017). Given that the tree species under experimentation for genetic engineering are native species and that the introduced gene will likely spread, or is designed to spread, within the native community, potential impacts both to the species involved and to the associated ecological and human communities need careful analysis."*[36]

An additional risk of the release of GE AC is the contamination of orchards of chestnut trees bearing edible chestnuts. Such contamination would threaten commercial chestnut growers selling into a non-GMO market, and have serious impacts on their livelihoods in the face of a public increasingly wary of GM foods.

A U.S. release of GE AC would be of international concern, as the trees range into Canada. In fact, Jessica Barnes predicts that climate change will result in a northward shift in the range of the American chestnut, into the Canadian Maritime provinces.[37] *"The Canadian government regulates hybrid and transgenic organisms differently than the US. The large sale release of AC trees carrying novel, blight resistant traits may trigger regulatory processes in Canada…The potential for AC to become a primarily Canadian species in the future suggests that public and governmental actors in Canada should be involved in decisions being made about chestnut restoration."*

REGULATIONS ARE WOEFULLY INADEQUATE

Under current regulations, before unrestricted release into the environment occurs, GE AC will undergo assessments by the U.S. Department of Agriculture (USDA), Environmental Protection Agency (EPA), and Food and Drug Administration (FDA).

U.S. regulations governing GE organisms are grossly outdated, and ill-suited to deal with the unique concerns from releasing GE trees into forests. Under USDA Animal and Plant Health Inspection Service (APHIS) guidelines, a GE tree is only regulated if it was engineered using materials that could be categorized as a plant pest, such as Agrobacterium vectors or sequences derived from plant viruses. GE AC used such methods and has been grown in USDA-regulated field trials, so must be officially assessed for risks

U.S. regulations governing GE organisms are grossly outdated, and ill-suited to deal with the unique concerns from releasing GE trees into forests

before it can be grown freely. However, USDA only takes into account impacts related to plant pests in the final deregulation decision, not animal health or ecological concerns. (If non-pest-related techniques were used, the GE tree would not be regulated at any stage and thus never be assessed for risks at all). EPA regulates GE trees only if their engineered properties are considered a "plant incorporated protectant" (i.e. pesticide). Although the fungal-resistance trait in GE AC may qualify as a plant incorporated protectant, the developers plan to seek an exemption from EPA registration of GE AC. Finally, FDA considers the potential for edible GE chestnuts to impact human health. Though this FDA consultation is voluntary, Powell's team has indicated that it will go through the process.[38]

It is broadly agreed by experts, including the NAS research team that studied the use of biotechnology for forest health, that the U.S. regulatory system is not equipped to deal with the release of GE trees into forests. The NAS report's conclusions and recommendations regarding regulation raise serious flags: *"Forest health is not accounted for in the regulations for the use of biotechnology or for other approaches to mitigating forest tree insect pests or pathogens.... There are no specific regulations or policies that those agencies apply to biotech trees."*[39]

Despite this, GE AC researchers continue to argue that transgenic trees will be subject to stringent regulatory review by the USDA, EPA and FDA, *"with the broad goal of ensuring the transgenic product is not significantly riskier than similar products produced with traditional breeding."*[40] Such arguments do not consider the fact that it is impossible for regulators to assess the risks that the GE AC will have 25, 50, 100 or even 200 years from now.

USDA FORGOES REVIEW OF GE PINE

In 2015, the USDA determined that a genetically engineered loblolly pine developed by ArborGen, was outside of their mandate for review. That decision was based on a narrow interpretation that regulation is only necessary when "plant pests" are utilized in the process of introducing genetic material, which was not the case with this GE pine. This arcane rule means that ArborGen is, by default, free to commercially distribute the trees without regulatory review (though the company said it had no immediate plans to sell the GE trees).[41]

FOREST ECOSYSTEMS ARE HIGHLY COMPLEX AND POORLY UNDERSTOOD

Forest trees are intricately embedded within their ecosystems in ways that are both highly complex and poorly understood, making it very challenging to even imagine what risks might arise with the introduction of GE AC, much less undertake holistic risk assessments. For example, the complex functions of mycorrhizal fungal symbiosis with trees and their role in forest ecosystems is only recently coming to light. Along with facilitating the exchange of water and nutrients and providing protection from drought and pathogens, these filamentous fungal networks also essentially serve as a medium for communication among trees (referred to as "the wood wide web"), permitting the transport of chemical signals among and between even distant trees in a forest.

> Forest trees are intricately embedded within their ecosystems in ways that are both highly complex and poorly understood

Trees can therefore effectively communicate to neighboring trees the presence of pests, triggering defense responses, including in trees that have not yet been attacked. Trees have even been found to share carbon with one another via the fungal networks, contributing to the maintenance and growth of their neighbors. Much as we have recently begun to understand the role of gut microbial communities in human health, there is advancing recognition of the important interplay between soil and plant tissue microbial communities and tree and forest health. In a 2016 article, Beckers et al state: *"The interactions between a plant and its microbiome are highly complex and dynamic, involving multiple reciprocal signaling mechanisms and an intricate interplay between the bacteria and the plant's innate immune system. Therefore, even small changes in the host genome (ecotypes, cultivars, genetically modified genotypes, etc.) may influence the plant microbiome and may even feed back to modulate the behavior and the productivity of the host plant."*[42] Very little is known about the impact of genetic engineering on tree microbiomes, nor has it been a focus of environmental impact studies. However, one study of genetically engineered poplars did report changes in endosphere microbiome as a result of altered lignin biosynthesis.[43]

Such intricate interactions and symbiotic networking among trees confirms the worldview of "interconnectedness" that has been a foundation of Indigenous Peoples' cultures for millennia. It also exposes the inadequacy of a piecemeal and trait-specific risk assessment.

To assess how the GE AC will affect other trees, understory plants, insects, soils, fungi, and wildlife over time, we would need to have a far better understanding of both American chestnut and overall forest ecology. Powell and colleagues have conducted some limited tests in anticipation of issues that may come up during environmental impact assessment processes during regulatory evaluation (presented on the website of the SUNY-ESF chestnut project).[44] These tests, however, are far too limited in duration and scope, and at best begin to address only a tiny fraction of the issues that could arise given the complex ecology of chestnut trees and forest ecosystems.

The Federation of German Scientists, in considering the issues that would need to be part of a GE tree risk assessment, states: *"A review of the scientific literature shows that due to the complexity of trees as organisms with large habitats and numerous interactions, currently no meaningful and sufficient risk assessment of GE trees is possible, and that especially a trait-specific risk assessment is not appropriate."*[45]

The many known and unknown impacts of climate change further complicate the risk assessment of GE AC. Shifting ranges of trees and plants, spreading pests and pathogens, and increasing heat, droughts, fires, floods, strong winds and other weather extremes are likely to affect American chestnut trees in unpredictable ways.

We do not know how forests in such a state of flux will respond to the reintroduction of a species that has been functionally absent for nearly a century. Will the GE AC compete with other forest species and contribute to the stressors that those species are already experiencing?

To assess how the GE AC will affect other trees, understory plants, insects, soils, fungi, and wildlife over time, we would need to have a far better understanding of both American chestnut and overall forest ecology

ARE THE RISKS WORTH TAKING?

The logistics of the restoration effort, either with GE or non-GE blight-resistant AC, will require enormous time and energy, and face many diverse challenges. For example, raising seedlings in nurseries, and transporting and planting them out into forests will be expensive. Once planted, they may require ongoing care until established. All of these steps are costly and labor-intensive.

A large number of trees will likely succumb to a variety of other known pest and pathogen threats including the oak weevil, gall wasp, and deer herbivory. Especially concerning is the fungal pathogen *Phytophthera cinnamomi* (also known as root rot or ink disease). This pathogen is lethal to AC, especially in the southern part of its range where it had already decimated AC even prior to the arrival of blight. Currently there is no "cure." OxO-engineered blight resistance does not protect AC from *Phytophthera*. It is not known whether engineering for blight resistance will impact the trees' vulnerability to this (or other) pathogens.

Stacking resistance traits to both the blight and Phytophthera is considered essential to any successful restoration of AC to forests. Nelson et al (2014) states: *"For sustainable blight and Phytophthora resistance, it will be necessary to pyramid both types of genes.*

As with most tree species, producing durable resistance is a key to forest health. Perhaps durable resistance will be achieved by stacking genes that enhance resistance by different mechanisms. Identification of multiple genes will facilitate such stacking."[46]

While researchers have worked to understand the genetics of Phytophthera resistance in Chinese and Japanese chestnuts,[47] hybrid backcrossing programs to breed resistance into lines of AC have so far met with only limited success.[48]

It is also anticipated that *Phytophthera* will spread further north within the chestnut range under a warming climate.[49] Hence there is potential that even if OxO confers effective and stable resistance to blight, restoration may be severely hindered by *Phytophthera*.

Even if OxO confers effective and stable resistance to blight, restoration may be severely hindered by Phytophthera

If OxO-engineered chestnuts are introduced into forests, and become established over the short term, but then fail over the longer term, due either to failure of blight resistance, or because they succumb to other stresses such as *Phythopthera* and climate change induced weather extremes, the massive amount of labor and funding involved in the effort will be wasted. Worse yet, the introduction of GE AC will only have further contributed to disruption of forest ecosystems.

CHAPTER 3

IS THE GE AC BEING USED AS A PUBLIC RELATIONS TOOL?

"We like to support projects that we think might not have commercial value but have huge value to society, like rescuing the chestnut. It allows the public to see the use of the technology and understand the benefits and risks in something they care about. Chestnuts are a noble cause."

— Maud Hinchee, former Chief Science Officer, ArborGen (2012)[50]

THE GE AC AS A TEST CASE FOR GE TREES

Concern has been raised (including in a presentation to the NAS by the authors of this paper), that the GE AC is being used as a PR tool to win over support for GE trees and the use of biotechnology more generally. The National Academy report recorded this concern: *"...the use of biotechnology for forest health could have the effect of making the adoption of biotechnology seem more routine, thus serving as a perceived portal or "Trojan horse" for future biotech modifications in forests or other environments for very different—and less altruistic—purposes."*[51]

While this has been denied by some proponents of GE AC, it is explicitly stated in multiple locations that the GE AC is considered and supported as a "test tree." Proponents anticipate that a GE tree developed for species restoration will be more acceptable to those who otherwise do not favor the genetic engineering of forest trees. U.S. Forest Service researcher Leila Pinchot, for example, writes, *"The basic inclination of most Forest Guild stewards is to reject GE trees as violating our principle to imitate nature, but are there cases where GE trees should be used? The American chestnut (Castanea dentata) may be the most compelling case thus far for the use of genetic engineering."*[52]

The public relations potential of the American chestnut was raised as early as 2005 by forest industry veteran Scott Wallinger, who worked at paper company MeadWestvaco (now Westrock): ***"This pathway [promoting GE chestnut as forest restoration] can begin to provide the public with a much more personal sense of the value of forest biotechnology and receptivity to other aspects of genetic engineering."***[53] [emphasis added]

This pathway to public acceptance of GE trees was also made explicit in a 2007 assessment of forest biotechnology: *"There is opposition to commercial application of trees engineered specifically for fast growth and increased yields, by those whose stance is that the value accrues only to 'big companies'. It will remain for traits that have broad societal benefits, such as conservation of threatened and endangered species and biofuels, for acceptance to be gained. Even then some countries will benefit before others, not because of the science, which is universal, but because of organized resistance… conservation of threatened and endangered species and bioenergy [are] the two disciplines that will most rapidly get public support…Following acceptance of specialty crops for the good of the whole will set the stage for acceptance of value-added products such as trees engineered for fast growth, tolerance to adverse sites, and exotic plantations."*[54]

The role of GE AC as a public relations tool for tree biotechnology is also made quite explicit by the Forest Health Initiative (FHI), a major funder of GE AC development. The FHI hosts an initiative called "Exploring Biotechnology to Protect Forest Health," which aims to *"advance the country's understanding and the role of biotechnology to address some of today's most pressing forest health challenges. The initiative will initially focus on a "test species" and an icon of Eastern U.S. forests – the American Chestnut – whose numbers were virtually wiped out during the past century by chestnut blight. While working with the American Chestnut as the test tree, the program will explore new approaches to enhance the health and vitality of other trees, forests and forest ecosystems."*[55] [emphasis added]

The initiative will initially focus on a "test species" and an icon of Eastern U.S. forests – the American Chestnut

The importance of GE AC to the broader promotion of GE trees was also echoed by the American Chestnut Foundation at a Science Cabinet meeting, *"… the Forest Health Initiative by the U.S. Endowment for Forestry and Communities, proposes to use the American chestnut as a "poster child" for use of genetic modification. The Forest Service has invested $3,000,000 into the project, and other entities (including Duke Energy) have put another $2,500,000, for a total of $5,500,000."*[56] *In a fact sheet on GE AC, The American Chestnut Foundation (TACF) asks, "Is TACF paving the way for wide-scale use of transgenic trees in the landscape?" and answers: "If SUNY-ESF is successful in obtaining regulatory approval for its transgenic blight-resistant American chestnut trees, then that would pave the way for broader use of transgenic trees in the landscape."*[57]

Powell also reports interest in studying the potential commercial applications of the GE AC. His 2016-2017 annual report lists a research proposal to the **U.S. Department of Energy Bioenergy Research Center**: "Title: Triangle REnewable Energy Science – Center (TREES-C) based at North Carolina State University. This was a collaboration between 10 universities and research centers. Total budget was to fall between $15 and $20 million. **ESF's portion covered the American chestnut and was calculated to be $1,010,000.** I had to withdraw after working for 3 months on the project…"[58] [emphasis added]

WHAT OTHER GE TREES ARE BEING DEVELOPED?

The majority of GE tree research underway is not oriented towards addressing threats to forest health as a public good or preservation and restoration of nature. Rather it is focused on the interests of commercial forest products industries, biofuels, biochemicals, bioplastics, and the emerging "bioeconomy."[59] Researchers are engineering trees that are tolerant to stresses associated with industrial plantation forestry monoculture planting practices, including pest and pathogen outbreaks that threaten commercial species. They are also genetically engineering trees to enhance the commercially valued characteristics of wood, such as modification of growth pattern, fiber structure and lignin content, for the purposes of pulp and paper production, timber, and bioenergy and biochemical production.

The majority of GE tree research underway is not oriented towards addressing threats to forest health as a public good or preservation and restoration of nature

A 2018 review of GE trees sums up the commercial focus of current research: *"Genetic engineering of trees to improve productivity, wood quality, and resistance to biotic and abiotic stresses has been the primary goal of the forest biotechnology community for decades. … Examples include novel methods for lignin modification, solutions for long-standing problems related to pathogen resistance, modifications to flowering onset and fertility, and drought and freeze tolerance."*[60]

A 2017 review titled "Biotechnology for bioenergy dedicated trees: meeting future energy demands" points to eucalyptus, poplar, willow and pine as the species of most tree biotechnology research, and a focus on efforts to engineer enhanced growth and yield, wood properties, site adaptability and stress tolerance, and alteration of lignin/cellulose/hemicellulose ratio and composition, towards effective conversion in biorefineries for cellulosic biofuels.[61]

Efforts to produce cellulosic biofuels have received massive supports and are mandated under the Renewable Fuel Standard, in spite of ongoing failure of commercial production.[62] The primary barrier has been the "recalcitrance" of plant cell walls – which makes it difficult to access the sugars embedded in woody plant material. The recalcitrance barrier is largely due to the lignin component, which, among other purposes, provides plant cells with rigid structure.[63] Altering lignin composition has been a particular focus of tree biotechnology research, both for pulp and biofuels.[64]

To date, only a few GE tree research efforts have moved from laboratory into regulatory review and potential commercial release. One prominent example is ArborGen's freeze-tolerant GE eucalyptus. Eucalypts are highly valued plantation trees in many parts of the world for pulp production, though most species are native to Australia. ArborGen engineered a hybrid eucalyptus to tolerate colder climates, with the goal of extending the potential for plantations from South Carolina to Texas, for pulp and paper and potentially for bioenergy. Eucalyptus species are not native to the U.S., deplete waterways, and pose a serious fire risk. The proposed field trials of this GE eucalyptus were met with resistance, including a lawsuit.[65] ArborGen submitted a petition to the USDA requesting deregulation of this GE eucalyptus in 2011. This decision is still pending.

Another example is the research of Steve Strauss at Oregon State University which is focused on commercially valuable poplar and eucalyptus.[66] Strauss states: *"we use modern plant biotechnologies – both genomics and genetic engineering – to help create environmentally sustainable biotechnologies to aid in the production of tree crops, including for renewable energy, wood, paper, ornamentals and fruit."*[67]

The U.S. Department of Energy, (which houses the Joint Genome Institute where the genome of Poplar trichocarpa was sequenced) along with USDA and other agencies, have invested huge sums into a multitude of initiatives, research centers and academic departments engaged in biotechnology development of crops, microbes and trees for bioenergy. One of many such initiatives is the "Northwest Advanced Renewables Alliance" (NARA) which engages several academic institutions in developing biofuels, including in "Wood to Wing" production of aviation biofuels from wood.[68] Funding through the "Plant Feedstock Genomics for Bioenergy" program, housed in the Department of Energy (among other agencies and agency branches), provides supports for research on GE trees. Multiple grants have been provided for research on GE poplar and other tree species, such as the 2018 grant to University of Florida researchers for "enhanced resistance pines for improved renewable biofuel and chemical production."[69]

GE AC AND THE BIOECONOMY

The GE AC "test case" comes at a time when forests are increasingly valued for their role in climate regulation and the carbon cycle. Forests are recognized as an effective means of storing carbon on the one hand, while on the other hand they are viewed as a source of biomass, subsidized as renewable energy and falsely considered "carbon neutral" or "low carbon." The use of wood pellets to generate industrial scale heat and electricity – in stand-alone facilities or as a replacement for coal – is already accelerating deforestation and new international trade in wood (and the pests and pathogens that are transported with it).[70] According to the U.S. International Trade Administration, market demand for pellet exports is anticipated to average 21 billion kilograms annually, primarily exported to the UK.[71] That figure does not include domestic use, which is also expanding. Research and development to produce liquid transportation biofuels as well as bioplastics, biochemical and various biomaterials from wood is also underway but has thus far been stymied by technical challenges despite decades of significant funding supports. Researchers continue to genetically engineer both trees and microbes in hope of overcoming the challenges. If that comes to pass, demand for wood will further threaten forests globally.

These new demands for wood are additional to the already expanding demands for wood for construction and for pulp and paper production. With this growing demand, there are huge profits to be made from engineering "purpose grown" trees for faster plantation growth, insect resistance, herbicide tolerance, and a suite of other characteristics. Although the GE AC is being held up as a solution to forest health crises, in reality it may pave the way toward a future where plantations of GE trees designed for industrial uses replace wild forests, displace Indigenous and forest dependent communities, and exacerbate the climate crisis, a trend already clearly documented by existing industrial tree plantations.[72]

GE AC AND BIOTECHNOLOGY AS A TOOL FOR NATURE CONSERVATION

The GE AC is also a valuable PR tool to win public approval for the use of biotechnology in general as a "public good" to achieve broader conservation goals. At the 2016 International Union for Conservation of Nature (IUCN) World Conservation Congress, for example, the new and unproven technology of gene drives was promoted by the "de-extinction" group *Revive and Restore*, among others, for the eradication of various pests and pathogens responsible for endangering other species.[a] These proposals were strongly opposed by a global network of civil society groups who demanded "Conservation with a Conscience." They argue that gene drives are risky, unproven, and could potentially backfire.[73]

Brad Stanback, one of the lead funders and supporters of GE AC research and development, sits on both the Board of The American Chestnut Foundation and the Board of Revive and Restore,[74] which has, among other projects, a plan to "de-extinct" the woolly mammoth.[75]

The concept of de-extinction is fraught with ethical issues and technical hurdles. Do we really know what we are doing? Who is making the decisions and which worldviews weigh into decision making? At what point has human intervention and manipulation of nature and the "code of life" gone too far? Where do we draw the line?

When the IUCN released their draft report *"Genes for Nature: An Assessment of Synthetic Biology for Biodiversity Conservation"* they highlighted the GE American chestnut as a case study for the use of biotechnology in nature conservation (even though transformation of the chestnut was achieved using earlier genetic engineering technology, not "synthetic biology").[76]

---

a Gene drives are genetic manipulations that effect heredity of a trait, making it possible to "drive" a trait into a population rapidly. Gene drives can be utilized to force a population into extinction (by, for example, driving genes for sexual sterility through a population.)

This demonstrates the danger of the promotion of the GE AC for "conservation" being used to open the door to the application of controversial gene editing technologies, such as the technique called CRISPR, which is already being applied to trees.[77,78] These tools allow us to rapidly and dramatically alter the genomes of many organisms, and outpace our ability to evaluate their impacts and make well-considered and ethical decisions about their use. There are no regulations on many uses of these new, unproven technologies, with the exception of cases considered to increase (narrowly defined) plant pest risks, and the USDA has stated that they have no plans to regulate most applications in the future.[79]

Decisions we make now will set precedent for the future of biotechnology regulation, and for the application of biotechnology to forests and conservation. Our evaluation of the GE AC must therefore be done with the "big picture" in full view, and must include a careful assessment of the interests of those funding, promoting or potentially benefitting commercially, either directly or indirectly, from the GE AC.

Decisions we make now will set precedent for the future of biotechnology regulation, and for the application of biotechnology to forests and conservation

Orin Langelle/ photolangelle.org

WHO IS PROMOTING THE GE AC AND WHY?

There are a number of key players who are involved in the development and promotion of the GE AC in some capacity. They include university researchers, corporate interests, and government agencies, many of whom are working closely together, directly or by providing funding and other support.

SUNY-ESF

The State University of New York College of Environmental Science and Forestry's (SUNY-ESF) American Chestnut Research and Restoration Center (also called the American Chestnut Project), which is leading the research on GE AC, has been deeply connected to timber, energy and biotechnology companies through funding, institutional ties and shared research. The project, headed up by William Powell, receives funding from companies with financial interests in advancing public acceptance of GE trees as well as biotechnology generally. Funders have included Monsanto (now Bayer),[80] Duke Energy (through the Forest Health Initiative) and GE tree company ArborGen, which donated half a million dollars between 2002-2012.[81]

UNIVERSITY OF GEORGIA

ArborGen has also funded research by Scott Merkle, professor of forestry and natural resources at the University of Georgia, for "American Chestnut restoration through biotechnology"[82] Merkle has spoken out about the commercial potential of the GE AC: *"You think maybe you'd get a lot more trees planted if landowners said, 'I'd like to plant 10,000 chestnut trees on my property.' **Well, that's not just restoration anymore, that is commercialization**. Because eventually people are going to want to plant chestnut trees for timber and for nuts."*[83]

Both Merkle and Powell also serve as Science Team Leaders for the Forest Health Initiative.[84]

THE AMERICAN CHESTNUT FOUNDATION (TACF)

TACF gave Powell's American Chestnut Project grants of $200,000,[85] $250,000[86] and $247,500[87] in fiscal years 2015, 2016 and 2017 respectively, dwarfing their contributions to any other chapters or research efforts.[88] The New York Chapter of TACF has also provided substantial support to Powell's research, for example giving $400,000 in 2008-2009.[89] TACF also receives funding from Monsanto, and has dozens of other corporate funders, sponsors, and partners including ArborGen, MeadWestvaco, Georgia Pacific, American Electric and Power, Dupont, ExxonMobil and Duke Energy.[91]

TACF also receives funding from Monsanto, and has dozens of other corporate funders, sponsors, and partners including ArborGen, MeadWestvaco, Georgia Pacific, American Electric and Power, Dupont, ExxonMobil and Duke Energy

ARBORGEN AND MONSANTO

ArborGen, a key backer of GE AC research and development, was founded in 1999 as a "forestry biotechnology joint venture" by Monsanto and timber multinationals International Paper, Westvaco, and Fletcher Challenge Forests.[92] While Monsanto quickly dropped out of the collaboration, ArborGen has continued to play a leading role in developing genetically engineered forest trees for industrial plantations and has a deep financial interest in advancing the public acceptance of GE trees. In addition to providing financial support to the SUNY American Chestnut Project, ArborGen's former Chief Science Officer Maud Hinchee worked closely with Powell's research team to offer technical support. In fact, one of Powell's lines of GE American chestnuts is called the Hinchee 1.[93] Prior to joining ArborGen, Hinchee spent eighteen years at Monsanto.

Although Monsanto is not directly involved with ArborGen, there are deep ties between the two companies and both are invested in the success of the GE AC. In addition to providing "in kind and monetary donations" to GE AC research, Monsanto assisted William Powell in preparing for the U.S. federal review process to deregulate the GE AC.[94]

A number of ArborGen's top executive staff have come from Monsanto. In addition to Maud Hinchee, other ArborGen staff from Monsanto include Barbara Wells, who was ArborGen's CEO until 2012; Andrew Baum, who is the current CEO and President; and David Nothmann, who was Vice President of Business and Product Development until 2012.

THE FOREST HEALTH INITIATIVE AND DUKE ENERGY

A collaborative effort between Duke Energy, the U.S. Endowment for Forestry and Communities[95] and the USDA Forest Service,[96] the Forest Health Initiative (FHI) views its role as supporting research on GE trees and working with regulatory agencies to remove the barriers to their environmental release. The FHI promotes the claim that GE trees will not pose a threat, and that effective GE tree research requires their release into natural environments. FHI's policy document says, *"Genes that are similar in function, have been well studied and have a strong basis to assume they will cause limited perturbations, could be allowed to be tested in GM trees in natural environments. This is because the tree's efficacy and ecological effects can only be confidently observed in the field."*[97]

The FHI supports research into the GE AC as a "test tree" for the regulatory system in the U.S.,[98] and over 2009-2010 provided grants of more than $1-million to Powell's research,[99] as part of a multi-institutional grant totaling $5.2-million.[100] In their press release announcing the funding, Duke Energy stated they were, *"...supporting this project for a variety of reasons, especially the early focus on the American chestnut."*[101]

The deep involvement of Duke Energy and other companies in the FHI raises troubling questions about the initiative's purpose. Duke Energy is a founder and member organization of the FHI Steering Committee; GE tree company ArborGen sits on the FHI Social and Environmental Committee; and the corporate-backed Institute for Forest Biosciences sits on the FHI Policy Committee. The U.S. Endowment for Forestry and Communities, USDA Forest Service, and Duke Energy are listed as "primary financial sponsors" of the Forest Health Initiative.

The involvement of corporations with financial interests in commercial GE trees flags a connection of GE AC to a corporate agenda spelled out in the FHI document "The Legal Barriers and Potential Benefits of Biotech Trees,"[102] which concludes, *"Biotech trees will find their place in this world, providing fiber, fuel and even sustainable comfort food (e.g., biotech American chestnuts roasting on an open fire). This is an industry to watch, as it evolves toward 'responsible use' and takes its place in the pipeline of sustainable biotech products."*

In 2012, Duke Energy confirmed their interest in the GE AC, which they view as a tool for 'greening' their ecologically devastated mountaintop removal coal mines sites. *"Duke Energy is financing the production and planting of 'transgenic' (genome-altered) seedlings recently developed by the Forest Health Initiative, and working with landowners, coal suppliers and academic experts to find the most suitable sites for testing. The tree is expected to thrive on former surface-mine sites in Central Appalachia, which has been a major coal-supply region for electric generation…In addition to its voracious appetite for carbon, the American chestnut can one day provide high-quality lumber, biomass fuel for electric generation, and a food source for people and wildlife — all potentially contributing to the region's economic growth."*[103]

…the American chestnut can one day provide high-quality lumber, biomass fuel for electric generation

THE INSTITUTE OF FOREST BIOSCIENCES

Formerly the Institute for Forest Biotechnology, the Institute of Forest Biosciences (IFB) is another major promoter of the GE AC, and genetic engineering in trees more broadly. **It staffs and manages the Forest Health Initiative**.[104]

IFB partners include the U.S. Forest Service, and the U.S. Endowment for Forestry and Communities, SUNY-ESF, as well as a raft of other universities and corporations.[105]

Until October 2018, the President of the IFB was Adam Costanza, formerly of International Paper, the largest pulp and paper company in the world. International Paper is one of the IFB partners, along with ArborGen, GE tree company FuturaGene (a subsidiary of Brazil timber company Suzano), and timber multinationals Weyerhaeuser, Fibria and MeadWestvaco (now Westrock).

In his role as President, Costanza regularly made the case for more lenient regulation of GE trees. In a 2018 presentation to the NAS during their study on using biotechnology for forest health, Costanza promoted regulatory changes, including voluntary industry self-regulation and the oft-repeated argument that GE regulation should ignore the genetic engineering process itself and focus instead on the end product.[106] This argument has been repeatedly debunked with extensive documentation of the damage genetic engineering causes to an organism's genome, and the inability to predict what consequences this damage may ultimately cause.[107] Costanza's presentation to the NAS recommended agencies:

> *"1. Balance risk of using GE tree w/ risk of not using it or moving too slowly to combat disaster*
>
> *2. Incorporate voluntary and adaptive management measures.*
>
> *3. Stop regulating based on process or categories of technologies. Focus only on what really matters: the end product."*[108]

The researchers and backers of transgenic American chestnuts portray themselves as working in the public interest. However, large sums of corporate money have poured into this project, which begs the question, who will ultimately benefit from the genetically engineered American chestnut trees? The answer goes far beyond whether or not its developers will profit from commercialization of GE AC trees. Rather, there are many players who stand to benefit from the PR value of the GE AC – including tree biotechnology interests and the broader biotechnology community, and timber, pulp and paper, and forest products industries who seek to be able to grow "purpose grown" GE trees like poplar and eucalyptus in vast industrial plantations for various commercial applications.

CHAPTER 5

WILL THE PUBLIC ACCEPT A GENETICALLY ENGINEERED AMERICAN CHESTNUT TREE?

A HISTORY OF OPPOSITION TO GE TREES

The first documented action against GE trees occurred in the United Kingdom in 1999, when activists destroyed more than a hundred GE trees at agrochemical company Zeneca's research site. The communique sent out about the action read, *"those who are manipulating the DNA of trees, using a very powerful but dimly understood technology, show contempt for our planet and the life it supports, including human life."*[109] Following the action, *The Daily Telegraph* printed an article warning that GE trees could lead to " a silent spring in the forests of the future."[110]

In the years since, other direct actions aimed at sabotaging GE tree research or GE tree facilities have taken place in New Zealand, Belgium, Brazil, Canada and the United States.

The first official campaign to oppose GE trees was launched in the summer of 2000 in Boston, outside the Biotechnology Industry Organization's annual convention. The press conference announcing the campaign was covered on the front page of *The Washington Post*.[111] This initial campaign was succeeded by an international campaign launched in 2004, which was re-launched in 2014 as the Campaign to STOP GE Trees.[112]

This initial opposition has continued to grow over the past two decades, in the form of dozens of protests on six continents involving many thousands of people; declarations demanding an end to GE tree research from citizens and groups in North America, Europe, Africa, Latin America, Australia and New Zealand; and several petitions demanding a ban on GE trees signed by more than half a million people.

This opposition has been accompanied by a ban on the use of GE trees and their products by the three major forest certification bodies: the Forest Stewardship Council, the Programme for the Endorsement of Forest Certification and the Sustainable Forestry Initiative (See box on page 31).

CERTIFICATION PROGRAMS EXCLUDING GE TREES

FOREST STEWARDSHIP COUNCIL

"[The] use and commercial introduction of GE Trees or 'Genetically Modified Organisms' (GMOs) is strictly excluded by FSC policies and standards, not only within FSC certified forests but for any part of an organization that is associated with FSC through certification or membership."[113]

FSC Criterion 6.8: Use of Genetically modified organisms shall be prohibited.[114]

PROGRAMME FOR THE ENDORSEMENT OF FOREST CERTIFICATION AND SUSTAINABLE FORESTRY INITIATIVE

"The restriction on the usage of genetically-modified trees has been adopted based on the Precautionary Principle. Until enough scientific data on genetically-modified trees indicates that impacts on human and animal health and the environment are equivalent to, or more positive than, those presented by trees genetically improved by traditional methods, no genetically-modified trees will be used."[115,116]

Additionally, the 2008 Conference of the Parties of the UN Convention on Biological Diversity in Bonn, Germany, was the site of a large international mobilization calling for a global ban on the environmental release of GE trees, including in field trials. There was near unanimous support for this demand from all non-governmental organizations and Indigenous Peoples' organizations present, as well as from all African government delegations and many delegations from Asian and South America governments. Ultimately, the UN meeting approved language warning of the potential dangers of GE trees and calling for the application of a precautionary approach.

UNITED NATIONS CONVENTION ON BIOLOGICAL DIVERSITY, CONFERENCE OF THE PARTIES, MAY 2008

"The Conference of the Parties, … Recognizing the uncertainties related to the potential environmental and socio-economic impacts, including long-term and transboundary impacts, of genetically modified trees on global forest biological diversity, as well as on the livelihoods of indigenous and local communities, and given the absence of reliable data and of capacity in some countries to undertake risk assessments and to evaluate those potential impacts,… recommends parties to take a precautionary approach when addressing the issue of genetically modified trees."[117]

In 2010, the USDA approved an ArborGen field trial involving more than a quarter of a million GE eucalyptus trees. In response, the Sierra Club, Center for Food Safety, International Center for Technology Assessment, Center for Biological Diversity, Global Justice Ecology Project, and Dogwood Alliance filed suit against the USDA to stop the GE tree field trials. While the field trials went ahead, *Biomass Power and Thermal Magazine* wrote that the lawsuit was scaring away investors.[118] Two weeks after the publication of that article, ArborGen abandoned its plans for its Initial Public Offering on the NASDAQ, and later fired its executive staff.

> …a FuturaGene greenhouse growing GE eucalyptus seedlings was destroyed by more than 1,000 women from Brazilian social movements

ArborGen submitted a petition to the USDA requesting deregulation of their GE freeze-tolerant eucalyptus tree in 2011, and after years of delays, the agency released their draft Environmental Impact Statement recommending approval in 2017. The GE eucalyptus tree was, however, opposed by 284,000 people who signed on to comments or sent individual comments to the USDA. The USDA has yet to issue a final Environmental Impact Statement.[119]

In 2016, more than 150,000 people signed onto letters and petitions to the Brazilian Biosafety Commission calling on them to reject a GE eucalyptus tree developed by the company FuturaGene. Demonstrations against GE trees were organized at Brazilian consulates and embassies on five continents. On the day the Commission was to decide, their meeting was taken over by women of La Via Campesina, the global peasant farmers' movement. That same day, a FuturaGene greenhouse growing GE eucalyptus seedlings was destroyed by more than 1,000 women from Brazilian social movements who denounced the devastating impacts of eucalyptus plantations on their communities.[120]

Much of the opposition to GE trees is in response to the unpredictable, uncontrollable and irreversible nature of their impacts, the knowledge that GE tree pollen and seeds cannot be contained, and the understanding that use of GE trees in plantations would exacerbate the already severe social and ecological impacts of tree monocultures.

INDUSTRY AND RESEARCHERS' RESPONSE TO PUBLIC OPPOSITION

Some GE AC researchers and proponents have dismissed GE tree opponents as ill-informed or as being "anti-science." Researchers, and even the NAS in their recent report, point to a 2015 survey of public opinion on GE trees, conducted by Mark Needham at Oregon State University,[121] as proof that people generally support the GE AC, especially when "factual scientific information" is provided. The NAS report cites the survey more than twenty times in its discussions about public opinion.

However, in his evaluation of Needham's survey, retired City University of New York Mathematician Adam Koranyi summarizes his concerns, *"...in the technical analysis of the data there are indications of serious flaws and there is a lack of information about the methods used. The sample sizes are definitely too small. Most importantly, the design of the study, as well as the presentation of its results, show a built-in bias favoring intervention using genetic technology in forestry."*[122]

Fueling concerns is the attitude of some GE AC researchers who have stated that after the trees are developed and deregulated, they are no longer responsible for what happens. They claim that the process of distributing and planting the trees, and any consequent impacts on ecosystems, wildlife or communities is not their concern. In a presentation about the GE AC at North Carolina State University in April 2018, SUNY-ESF researcher Andrew Newhouse explained this view. When asked, "In looking at ecological long-term risks, is the potential for GE ACs to transform eastern forests being considered?" his reply was, "restoration is not the responsibility of the researchers." Similarly, when asked, "What are the ecological benefits of restoring the American chestnut, or are we restoring it just because we like the tree?" Newhouse replied, "ESF is not looking at that."[123] The lack of concern about the ecological and social impacts of the GE AC articulated by those researching it adds to public unease about its impacts.

INDIGENOUS PEOPLES' CONCERNS

The NAS has taken seriously some of the concerns raised by Indigenous Peoples:

"Indigenous populations who have spiritual relationships with, and value for, particular forests and tree species are likely to be significantly affected by the use of biotechnology in noncommercial forests (Nilausen et al., 2016; see also Box 4-1). For example, black ash (Fraxinus nigra) has special significance for indigenous peoples in the Great Lakes region, especially for basket making (Poland et al., 2017). Although black ash is seriously threatened by the emerald ash borer, the use of biotechnology to increase resistance in black ash trees might significantly change the relationship indigenous peoples have to this species. Relatedly, recent research on the potential restoration of the American chestnut tree draws on interviews with Haudenosaunee community members and participant observation of tribal meetings. Barnhill-Dilling (2018) acknowledged great diversity in perspectives among the indigenous people with whom she interacted, but reports several themes relevant to this discussion; the committee heard similar information in one of its webinars (Dockry, 2018; McManama, 2018; Patterson, 2018). First, traditions of nonintervention in natural processes (Nelson, 2008) question the wisdom of attempting to counteract the effects of the chestnut blight altogether. Second, cultural and medicinal practices that used to involve the American chestnut tree are viewed as unlikely to be restored with a transgenic or hybrid tree. Third, disrespect and abuse of native peoples by Western scientists (Sikes, 2006; Smith, 2013) has created a culture of mistrust that fosters

Orin Langelle/ photolangelle.org

skepticism of scientific innovations even when they are presented as beneficial. Fourth, in a period of increased attention to indigenous cultural restoration, a narrow focus on the restoration of a single tree species is experienced by some tribal members as marginal, if not irrelevant (also see Higgs, 2005; Kimmerer, 2011). Fifth, and most broadly, in some indigenous communities, genetic engineering has come to be viewed as violating tribal sovereignty, self-determination, and the natural order (also see Harry, 2001; Roberts, 2005; Antoine, 2014; Francis, 2015; IEN, 2016) and, as noted in Box 4-1, might be interpreted as violating indigenous peoples' rights."[124]

The GE AC raises particular concerns in relation to Indigenous Peoples' territorial sovereignty, and the application of the UN's Free, Prior and Informed Consent requirement when dealing with issues impacting Indigenous Peoples or their territories. Indigenous Peoples in the regions of proposed GE AC releases have expressed concern that unregulated distribution of a GE tree would violate their sovereign right to keep their territories GMO-free. If released, GE American chestnuts will spread uncontrolled and will not respect territorial borders.

These and other concerns led the Indigenous Environmental Network (IEN) to organize the Indigenous Peoples' GE Trees Action Camp in Cherokee, North Carolina, in 2014, to discuss strategies to keep GE trees off of Indigenous Peoples' territories.[125] The IEN established the Save Our Roots Campaign following this event, due to the consensus of concern.

CHAPTER 6

CAN THE AC BE RESTORED TO FORESTS WITHOUT ADDRESSING THE UNDERLYING CAUSES OF FOREST HEALTH DEMISE?

"It's the pest of the month club. We've lost chestnut and lost elm. Now, it's almost a new species or pest is being identified and a new tree or forest is being threatened almost on a monthly basis."[126]

— Carlton Owen, Forest Health Initiative

To protect forest health, we must address the underlying causes of forest demise. Doing so is essential – including to any successful restoration of American chestnut. Forests are threatened by unsustainable logging practices, invasive species, introduced pests and pathogens, urban sprawl, and the escalating impacts of climate change. A piecemeal approach to reintroducing a single tree species, without addressing these underlying drivers of forest demise, makes little sense and will be unlikely to succeed.

To protect forest health, we must address the underlying causes of forest demise

The introduction of GE AC could not only fail, but also has the potential to exacerbate existing pressures on forest ecosystems, with potentially irreversible consequences.

PATHOGENS AND PESTS SPREAD BY GLOBAL TRADE

Pathogens and pests are one of several major challenges to forests. The evolving history of forest infection and infestation is difficult to predict. Pathogens and pests are powerful evolutionary forces that shape forest ecosystems as well as the internal genetic landscapes of organisms. The poorly regulated global movement of people and goods has created unprecedented opportunities for pathogens and pests to spread outside their native ranges. Forest trees are exposed to pathogens and pests they may have no evolutionary history of contact with and hence no, or limited, evolved mechanisms for resistance.

Susceptibility to pathogens and pests is heightened when forests are stressed and weakened by compounding pressures such as those from climate change, droughts, flooding, extreme heat, excessive logging, and invasive species competition.[127,128]

The chestnut blight was introduced to U.S. forests with the importation of nursery stock from Asia. Trade and transport of plant materials is responsible for a vast array of pest, pathogen and invasive species introductions that have had dire ecological and economic consequences in the U.S. and globally. Indeed, there are several other recently introduced pathogens and pests that also pose serious threats to the American chestnut, including *Phytophthora cinnamoni* (ink disease or root rot) and the oriental chestnut gall wasp *Dryocosmus kuriphilus*.[129]

Fungal pathogens are particularly difficult to control, contain and detect, because fungal spores are minute and can easily become airborne or be transported via water over very long distances. With people and goods moving across continents on a regular basis, fungi are easily delivered into new environments where they can rapidly adapt to and infect new hosts with which they have no coevolutionary history.

In a 2016 special issue of *Proceedings of The Royal Society* on emerging fungal threats to ecosystem health and food security, Fisher et al. point to human activity, including disruption of natural systems and long-distance dispersal via global trade, as having *"opened a Pandora's box of emerging fungal infections that are now causing a tsunami of biodiversity loss in frogs, bats, snakes and other wildlife species."* Only about five percent of an estimated 1-5 million species of fungi have been identified, and our basic knowledge of the ecology and genetics of those species that have been identified is minimal.[130]

Liebhold and colleagues (2012) estimate that about 70% of damaging forest insects and pathogens established in the U.S. between 1860 and 2006 most likely entered on imported live plants facilitated by outdated regulations.[131] And Roy et al (2014) point out that, *"Because invasions often originate from taxa that are scientifically described only after their introduction, current phytosanitary regulations – which target specific already named organisms – are ineffective."*[132]

Trade and transport will continue to introduce new threats to forests, and action to curtail these introductions is urgently required. Given the track record of pest and pathogen introductions through trade, the insufficiency of phytosanitary regulation and practice, and our inability to successfully control damage after introduction, it is essential to limit trade in the first place. As the NAS report explains: *"Many tools are available to mitigate the effects of insect and disease outbreaks. For introduced species, the most cost-effective measures are those that prevent the arrival of the invasive species in the first place."*[133]

INDUSTRIAL MONOCULTURES AND MACHINES

The widespread adoption of industrial forestry practices contributes to the spread of pests and fungal and other pathogens that weaken ecosystems. Monoculture plantations, often of non-native species, lack biodiversity and genetic diversity. Plantations are managed for the purposes of food and fiber production and, though they are often misrepresented as "forests", they are not healthy, diverse or resilient ecosystems. Repeated soil disturbance and compaction from harvesting and logging activities have long-lasting negative impacts on soil microbiomes and soil function,[134] as do the applications of fertilizers, herbicides and other agrichemicals.

SALVAGE LOGGING

Logging threatened or diseased trees to salvage timber appears to have played a role in the demise of the chestnut. Frienkel (2007) reports, *"One day, deep in the University of Minnesota library stacks, [Phil] Rutter stumbled across a 1920 U.S. Forest Service publication that urged landowners to cut down any chestnuts they owned – dead or alive.... All at once, he understood why virtually no mature chestnuts had survived the blight. They'd never been given the chance... Rutter had always been certain some other factor played a hand in the chestnut's demise. That other factor 'turned out to be us.'"*[135]

The American chestnut was already under tremendous logging pressure when the blight was introduced. The trees that remained at that time were subjected to yet more pressure from efforts to create "breaks" to prevent the spread of the blight and to salvage remaining timber before the AC trees succumbed to the disease. Many of those "salvaged" trees might in fact have been resistant to the blight and provided stock for a natural regeneration of the species.

Budde and colleagues (2016) argue that preemptive and salvage logging *"should be employed in initial and locally restricted cases of first-disease incidence. However, as soon as several disease centers are emerging, it can become counterproductive due to the removal of high numbers of healthy and some potentially resistant trees....We argue that the evolutionary potential of tree species to respond to new emerging diseases should not be underestimated...and international cooperation in limiting disease spread and the provision of early invasive pest or pathogen detection systems are essential."*[136] A 2018 study by Six and colleagues, for instance, found that some pine trees in areas of western North America infested with mountain pine beetle were resistant to the pest and had common genetic characteristics, indicating potential for heritable resistance.[137]

The mechanics of salvage logging further disturbs soils, kills seedlings and may contribute to spreading pests and pathogens. Foster and Orwig (2006) argue for doing nothing rather than salvage logging: *"Despite dramatic physical changes in forest structure resulting from hurricane impacts and insect infestation, little disruption of biogeochemical processes or other ecosystem functions typically follows these disturbances. Indeed, the* *physical and organic structures produced by these disturbances are important natural features providing habitat and landscape heterogeneity that are often missing due to centuries of land use."*[138]

CLIMATE CHANGE: THE ELEPHANT IN THE FOREST

Climate change is perhaps the gravest of the many threats faced by forests and tree species. Its impacts include heat, droughts and wildfires, flooding and shifting rainfall, as well as the intensification of industrial forestry and land conversion created by incentives for renewable energy that promote biomass/bioenergy. Bunnel and Kremsater (2012) state that, *"challenges in predicting responses of individual tree species to climate are a result of species competing under a climate regime that we have not seen before and they may not have experienced before."*[139]

The magnitude of climate impacts on forests, now and into the future, is difficult to fully comprehend. In a comment submitted to the planning team for Helena-Lewis and Clark National Forests in Montana, ecologist Lance Olsen summarizes the literature: *"Forests affect the climate, climate affects the forests, but there's increasing evidence of climate gaining the upper hand. Lines of evidence pointing in this direction includes forest dieoff at regionally "massive" scale (Breshears et al 2005); tree species being forced into new distributions "unfamiliar to modern civilization" (Williams et al 2012); extensive loss of suitable climatic habitat for the familiar aspen and for at least four conifers familiar to the US Rocky Mountain region (Funk et al 2014); ongoing and expected "increased tree mortality through drought, heat stress, and insect attacks, with manifold impacts on forest ecosystems" (Anderegg et al 2015); chronic and acute disturbance "pushing many temperate forests toward and over resilience thresholds" (Millar and Stephenson 2015); indicators of forest decline across the 48 United States (Cohen et al 2016); and a (critical?) slowing down of forest growth in the interior western US (Charney et al 2016)."*[140]

The scope of these dramatic changes mean that it is severely challenging, if not impossible, to predict and plan the future evolution of forests, and their responses to a changing climate.

CAN BIOTECHNOLOGY PROVIDE SOLUTIONS?

Some argue that the restoration and protection of our forests will require "all the tools in the kit," including biotechnology. However, technological fixes such as GE trees cannot possibly be developed fast enough or safely enough to be useful, and as long as the underlying causes of forest demise are not addressed, those tools will be ineffective or piecemeal at best. Furthermore, genetic engineering could potentially exacerbate rather than alleviate the problems. Focusing resources on genetically engineering trees is a distraction from the profound and system-wide changes that are needed to ensure a future with healthy forests. (for examples see box on page 39)

MEASURES TO ADDRESS THREATS TO FOREST HEALTH

HALT deforestation and forest degradation;

ADDRESS economic drivers that lead to unsustainable scale of demand for wood/fiber and land;

PROTECT remaining intact forests, including by recognizing the territorial rights of Indigenous Peoples and forest-dependent communities;

CURTAIL industrial forestry practices, including planting of industrial monocultures and non-native species, use of synthetic fertilizers and agrichemicals, and mechanized management;

REJECT salvage logging and allow natural regeneration;

END the unnecessary global trade of live plants, raw logs and woodchips;

STRENGTHEN regulations that govern the trade and transport of plant materials; and

URGENTLY adopt measures to reduce greenhouse gas emissions and halt climate change.

CONCLUSIONS

The genetic engineering of American chestnut trees for blight resistance is still in its infancy. Results from OxO-engineered AC are preliminary and based only on testing of young trees in controlled conditions. The long-term stability of blight resistance remains questionable. The risks of introducing GE AC into forests are numerous and difficult to assess, and regulatory agencies are ill-equipped to evaluate a GE forest tree intended for deliberate spread through wild forests. The deregulation of GE AC is clearly premature, but it is nonetheless being strongly promoted and supported as a public relations tool to win over a wary public averse to the use of biotechnology on forest trees.

Winning over public sentiment toward the use of GE trees is of great interest to commercial forestry industries seeking deregulation of a variety of other trees engineered specifically for commercial applications, including plantation forestry, pulp and paper and bioenergy uses. Similarly, the biotechnology industry at large, armed with potent new tools for genetic manipulation, wants to win over public support for the expanded use of biotechnology, including in wild ecosystems, by promoting it in the context of species conservation and restoration.

Given the irreversibility of the release of GE AC into nature; the questionable long-term effectiveness of OxO-engineered blight resistance; the unpredictable future of impacts of climate change on forests; and the serious threat of *Phytophthera*, which is anticipated to spread and for which there is currently no solution, the ultimate success of AC restoration must be considered highly questionable. Is it worth taking the risks of introducing GE AC?

CAN CHESTNUTS RECOVER WITHOUT THE INTRODUCTION OF THE GE AC?

The chestnut blight is pervasive and few, if any, trees remain unaffected. Remaining stumps continue to send up sprouts but appear most likely to eventually succumb. It is possible that traditional breeding or backcross breeding programs will ultimately prove successful, but these non-GE restoration efforts also face many of the same challenges, from *Phytophthera* and other pathogens, and a changing climate.

Taking a long view of forest health offers some encouragement. While we tend to think of forests as static, and nurture a vision of the way they ought to be that mirrors how they look now or did in recent history, historical records show that forests are constantly undergoing dramatic change, with species blinking in and out of existence and ranges shifting over time. For example, we can take heart from looking at the history of the eastern hemlock, which went into a rapid and near complete decline about 5,000 years ago, likely resulting from a pest outbreak, but has gradually returned over a period of about a thousand years.[141] Minimizing human intervention in forest ecosystems may be the best medicine we can offer.

THE PRECAUTIONARY PRINCIPLE

It is possible that the introduction of genetically engineered American chestnut could increase rather than decrease stress on our forests – for example, if unanticipated harms result from the introduction of GE trees or the effort to reintroduce GE AC fails after having diverted resources and attention from measures needed to address the underlying causes of forest demise.

Some might argue that we should assess potential risks to the extent that we are currently capable, and continue to study the GE AC after it is released into forests. However, in the case of forest ecosystems, the scope of our lack of knowledge, the scale of potential risks, and the likelihood that any problems would be irreversible, dictates that the precautionary principle is the appropriate framework for responding to the proposed introduction of GE AC. It is simply not worth taking the risks to forest ecosystems and human communities, nor is it worth lending the associated political and social support to other applications of GE trees.

JOIN US IN OPPOSING THE DEREGULATION OF THE GENETICALLY ENGINEERED AMERICAN CHESTNUT TREE WWW.STOPGETREES.ORG/CHESTNUT/

References

1 National Academy of Sciences, Engineering and Medicine. 2019. Forest Health and Biotechnology: Possibilities and Considerations. The National Academies Press.

2 State University of New York College of Environmental Science and Forestry. 2019. Restoring the American chestnut. https://www.esf.edu/chestnut/

3 State University of New York College of Environmental Science and Forestry. About ESF. https://www.esf.edu/chestnut/about.asp

4 Nelson CD, Powell WA, Merkle SA, Carlson JE, Heberd FV, Islam-Faridi N, Staton ME, Georgi L. 2014. Biotechnology of Trees: Chestnut. In: Ramawat KG, Mérillon J-M, Ahuja MR (Eds), Tree Biotechnology. CRC Press, Boca Raton, FL, 3 – 35.

5 Powell WA, Maynard CA. 1999. Antimicrobial Peptides. US Patent Number 5,856,127.

6 Newhouse AE, Schrodt F, Liang H, Maynard CA, Powell WA. 2007. Transgenic American elm shows reduced Dutch elm disease symptoms and normal mycorrhizal colonization. *Plant Cell Reports*. 26: 977–987.

7 Livingstone, D.M., Hampton, J.L., Phipps, P.M., and Grabau, E.A. 2005. Enhancing resistance to Sclerotina minor in peanut expressing a barley oxalate oxidase gene. *Plant Physiol*. 137(4) 1354-62.

8 Donaldson, P.A., Anderson, T., Lane, B.G., Davidson, A.L., and Simmonds, D.H. 2001. Soybean plants expressing an active oligomeric oxalate oxidase from the wehat gf-2.8(germin) gene are resistant to the oxalate secreting pathogen, *Sclerotina sclerotiorum. Physiol.Mol. Plant Pathol*. 59: 297=307

9 Dong, X., Ji, R., Guo, X., Foster, H;, Chen, C., Dong, C., Liu, Y., Hu, Q., and Liu, S. 2008. Expressing a gene encoding wheat oxalate oxidase enhances resistance to Sclerotina sclerotiniorum in oilseed rape (*Brassica rapa*). Planta. 228: 331-340

10 Liang, H., Maynard, C.A., Allen, R.D., and Powell, W.A. 2001. Increased Septoria musiva resistance in transgenic hybrid poplar leaves expressing a wheat oxalate oxidase gene. *Plant Mol. Bio*. 45: 619-629

11 Williams, B., Kabbage, M., Kim, H-J., Britt, R. and Dickman, M.B. 2011. Tipping the balance: Sclerotina sclerotorum secreted oxalic acid suppresses host defenses b manipulating the hot redox environment. *PLoS Pathogens*. 7(6)

12 Welch, A.J., Stipanovic, A.J., Maynard, C.A. and Powell, W. 2007. The effects of oxalic acid on transgenic *Castanea dentata* callus tissue expressing oxalate oxidase. *Plant Science*. Vol. 172(3): 488-496.

13 Zhang B, Oakes AD, Newhouse AE, Baier KM, Maynard CA, Powell WA. 2013. A threshold level of oxalate oxidase transgene expression reduces Cryphonectria parasitica-induced necrosis in a transgenic American chestnut (*Castanea dentata*) leaf bioassay. *Transgenic Research*. 22: 973–982.

14 Steiner, K.C., Westbrook, J.W., Hebard, F.V., Georgi, L.L., Powell, W.A., Fitzsimmons, S.F. 2017. Rescue of the American Chestnut with Extraspecific Genes following its destruction by a naturalized pathogen. *New Forests*. 48:317-336.

15 Ibid.

16 Newhouse AE, Polin-McGuigan LD, Baier KA, Valletta KER, Rottmann WH, Tschaplinski TJ, Maynard CA, Powell WA. 2014. Transgenic American chestnuts show enhanced blight resistance and transmit the trait to T1 progeny. *Plant Science*. 228: 88– 97.

17 Newhouse, Andy. 2018. Transgenic American chestnuts for potential forest restoration: Scientific successes, regulatory challenges. Presentation. https://vimeo.com/266566530

18 Collinge DB, Jørgensen HJL, Lund OS, Lyngkjær MF. 2010. Engineering Pathogen Resistance in Crop Plants: Current Trends and Future Prospects. *Annual Review of Phytopathology* 48: 269–291.

19 Anderson, Jonathan P, et al. 2010. Plants versus pathogens: an evolutionary arms race. *Functional plant biology*.37(6): 499512.

20 Wu, X., Zhang, C., Li, H. 2018. Characterization of Papaya ringspot virus isolates infecting transgenic papaya Huanong No.1 in South China. *Scientific Reports* 8(1): 8206.

21 Collinge DB, Jørgensen HJL, Lund OS, Lyngkjær MF. 2010. Engineering Pathogen Resistance in Crop Plants: Current Trends and Future Prospects. *Annual Review of Phytopathology* 48: 269–291.

22 JR Simplot Company. 2014. Petition for Determination of Nonregulated Status for InnateTMPotatoes with Late Blight Resistance, Low AcrylamidePotential, Reduced Black Spot, and Lowered Reducing Sugars: Russet Burbank EventW8. https://www.aphis.usda.gov/brs/aphisdocs/14_09301p.pdf

23 Kubisiak, T.L., Hebard, F.V., Nelson, C.D., Zhang, J., Bernatzky, H., Huang, H., Anagnostakis, S.I., Doudrick, R.I. 1997. Molecular mapping of resistance to blight in an interspecific cross in the genus castanea. *Phytopathology* 87: 751-759

24 Powell, W. 2014. The American chestnut's genetic rebirth. *Scientific American*. March. http://web.ecologia.unam.mx/laboratorios/genomica/biotech/articulos_curso/scientificamerican0314-68.pdf

25 National Academies of Sciences, Engineering, and Medicine 2019. *Forest Health and Biotechnology: Possibilities and Considerations*. Washington, DC: The National Academies Press.

26 Clark, S. L. et al. 2018. Eight year blight (*Cryphonectria parasitica*) resistance of backcross-generation American chestnuts (*Castanea dentate*) planted in the southeastern United States. *Forest Ecology and Management*. 433:153-161. 27 Ibid.

28 Antoniou, M. 2018. Bound to Fail: the flawed scientific foundations of agricultural genetic engineering (part 2). *GM Watch.*

29 David Suzuki quoted in *A Silent Forest: The Growing Threat, Genetically Engineered Trees*, directed by Ed Schehl, Three Americas. https://vimeo.com/51481514.

30 National Academy of Sciences, Engineering and Medicine. 2019. Forest Health and Biotechnology: Possibilities and Considerations. The National Academies Press.

31 David Suzuki quoted in *A Silent Forest: The Growing Threat, Genetically Engineered Trees*, directed by Ed Schehl, Three Americas. https://vimeo.com/51481514.

32 Steinbrecher RA & Lorch A. 2008. "Genetically Engineered Trees & Risk Assessment: An overview of risk assessment and risk management issues." Federation of German Scientists. http://www.econexus.info/sites/econexus/files/GE Tree_FGS_2008.pdf.

33 Convention on Biological Diversity. COP 8 Decision VIII/19Forest biological diversity: implementation of the programme of work. https://www.cbd.int/decision/cop/default.shtml?id=11033

34 FSC Policy on GMOs: FSC-POL-30-602 EN_FSC GMO Policy 2000.pdf Criterion 6.8 Use of Genetically modified organisms shall be prohibited.

35 Cooney, R. 2004. The Precautionary Principle in Biodiversity Conservation and Natural Resource Management. IUCN policy and global change series. https://www.scribd.com/document/4772482/Biodiversity-Precautionary-Principle

36 National Academies of Sciences, Engineering, and Medicine 2019. *Forest Health and Biotechnology: Possibilities and Considerations*. Washington, DC: The National Academies Press.

37 Barnes, J.C. 2018. Anticipating the biogeography of blight resistant AC. Poster presentation, The American Chestnut Foundation, Huntsville, AL. https://research.ncsu.edu/ges/files/2017/10/JessicaBarnes-Winner-TACF2017Poster.jpg

38 Newhouse, A et al. 2018. "Darling" American Chestnut. Presentation to The American Chestnut Foundation annual meeting, Huntsville, AL. https://www.acf.org/wp-content/uploads/2018/11/Newhouse-f2018.pdf?x27388

39 National Academies of Sciences, Engineering, and Medicine 2019. *Forest Health and Biotechnology: Possibilities and Considerations*. Washington, DC: The National Academies Press.

40 Newhouse, Andy. 2018. We nearly Killed These Trees, Biotech Can Bring Them Back. *Washington Post*. 29 May. https://www.washingtonpost.com/news/theworldpost/wp/2018/05/29/biotech/?noredirect=on&utm_term=.3cb5c3483997

41 Cantu, L. 2015. Protesters arrested at ArborGen. *The Summerville Journal Scene*. September 29. https://www.journalscene.com/archives/protesters-arrested-at-arborgen/article_10cdc704-70cf-5000-abb9-04e9bf56fe5e.html

42 Beckers et al. 2016. Lignin engineering in field-grown poplar trees affects the endosphere bacterial microbiome. *Proceedings of the National Academy of Sciences of the United States of America*. 113(8):2312-2317.

43 Beckers, B., Op De Beeck, M., Weyens, N., Van Acker, R., Van Montagu, M., Boerjan, W., Vangronsveld, J. 2016. Lignin engineering in field grown poplar trees affects the endosphere bacterial microbiome. PNAS. 113 (8): 2312-2317.

44 Newhouse, A and Powell, W. 2019. Environmental Interactions with Transgenic American Chestnuts. https://www.esf.edu/chestnut/poster.htm

45 Steinbrecher, R. and Lorch, A. 2008. *GE Trees and Risk Assessment*. Federation of German Scientists.

46 Nelson CD, Powell WA, Merkle SA, Carlson JE, Heberd FV, Islam-Faridi N, Staton ME, Georgi L. 2014. Biotechnology of Trees: Chestnut. In: Ramawat KG, Mérillon J-M, Ahuja MR (Eds), Tree Biotechnology. CRC Press, Boca Raton, FL, 3 – 35.

47 Zhebentyayeva, T., Chandra, A., Abbott, A.G., Olukolu, B.A., Jeffers, S.N., James, J.B., Station M.E., Herbard F.V., Georgi I., Sisco P.H., and Nelson C.D. 2014. Genetic and genomic resources for mapping resistance to Phytophthora cinnamomi in chestnut. *Acta Horticulturae* (ISHS). 1019:263-270

48 Robinson, AC. 2016. Measuring *Phytophthora* resistance phenotypes in segregating testcross families of hybrid American chestnut trees. Honors thesis, University of Tennessee. https://core.ac.uk/download/pdf/51197622.pdf

49 Treena I. Burgess, John K. Scott, Keith L. Mcdougall, Michael J. C. Stukely, Colin Crane, William A. Dunstan, Frances Brigg, Vera Andjic, Diane White, Tim Rudman, Frans Arentz, Noboru Ota and Giles E. St. J. Hardy. 2016. Current and projected global distribution of *Phytophthora cinnamomi*, one of the world's worst plant pathogens. *Global Change Biology*, 23(4): 1661-1674.

50 Hinchee, Maud. 2012. Quoted in *Microbe Magazine*. January. http://www.asmscience.org/content/journal/microbe/10.1128/microbe.7.18.1

51 National Academies of Sciences, Engineering, and Medicine. 2019. *Forest Health and Biotechnology: Possibilities and Consideration*s. Washington, DC: The National Academies Press., pg 107

52 Pinchot, Leila. 2014. American chestnut: A test case for genetic engineering? *Forest Wisdom*. Spring-summer: 8-9, 15. https://www.fs.usda.gov/treesearch/pubs/48671

53 Charman, K. 2005. The Shape of Forests to Come. *World Watch Magazine*, May/June. 18(3). http://www.worldwatch.org/node/576

54 Kellison, R. 2007. Forest biotechnology: Its place in the world. *Proceedings of the 29th Southern Forest Tree Improvement Conference*. Southern Forest Tree Improvement Committee. Sponsored Publication (No. 51, pp. 7-14). http://www.fsl.orst.edu/wfga/proceedings/2007_Proceedings.pdf#page=21

55 Forest Health Initiative. http://foresthealthinitiative.org

56 Minutes of the Meeting of the Science Cabinet of the American Chestnut Foundation, The Holiday Inn, Bristol, Virginia, April 17-18, 2009 https://www.acf.org/wp-content/uploads/2016/10/Apr09TACF_SciCab.pdf

57 The American Chestnut Foundation. 2015. Transgenics and chestnuts. Frequently Asked Questions. https://www.acf.org/wp-content/uploads/2016/09/Transgenics-FAQ-1.pdf

58 State University of New York College of Environmental Science and Forestry. 2014. William Powell, Annual Report for June 1, 2016 – May 31, 2017 https://www.esf.edu/efb/annualreports/1617/documents/Powell1617.pdf

59 See for example: National Institute of Food and Agriculture, USDA. 2018. Bioeconomy, Bioenergy, Bioproducts: Strengthening Bio-Based Systems to Support Our Nation's Energy Independence. https://nifa.usda.gov/bioeconomy-bioenergy-bioproducts

60 Chang, S. et al. 2018. GE of trees, progress and new horizons. *In Vitro Cellular & Developmental Biology-Plant* 54:341-376.

61 Al-Ahmad, H. 2018. Biotechnology for bioenergy dedicated trees: meeting future energy demands. Z. Naturforsch. C. 73(1-2): 15-32, https://www.ncbi.nlm.nih.gov/pubmed/28455953

62 Biofuelwatch 2018. Dead End Road: The false promises of cellulosic biofuels. https://www.biofuelwatch.org.uk/2018/dead-end-road/

63 Hodson, 2014. Redesigned crops could produce far more fuel. New Scientist. https://www.newscientist.com/article/dn25354-redesigned-crops-could-produce-far-more-fuel/#.Uz3-ycfNcUk

64 Van Noorden, R. 2014. Transgenic trees make easy-chew wood for biofuels. Nature. https://www.nature.com/news/transgenic-trees-make-easy-chew-wood-for-biofuels-1.14992

65 Lawsuit filed to halt release of genetically engineered eucalyptus trees across the American south. https://www.centerforfoodsafety.org/press-releases/791/lawsuit-filed-to-halt-release-of-genetically-engineered-eucalyptustrees-across-the-american-south

66 Klocko, A.L., Lu, H., Magnusen, A., Brunner, A.M., Ma, C., Strauss, S.H. 2018. Phenotypic Expression and Stability in a LargeScale Field Study of Genetically Engineered Poplars Containing Sexual Containment Transgenes. *Frontiers in Bioengineering and Biotechnology*. 6.

67 Oregon State University. 2019. Forest Biotechnology Lab. People.forestry.oregonstate.edu/steve-strauss/

68 Northwest Advanced Renewables Alliance. First commercial flight using biojet fuel made from wood. https://nararenewables.org

69 See grants listed at Genomic Science Program, US department of Energy. 2019. https://genomicscience.energy.gov/research/DOEUSDA/2018awards.shtml

70 For more information, see Biofuelwatch. Resources on Biomass. https://www.biofuelwatch.org.uk/biomassresources/resources-on-biomass/

71 U.S. International Trade Administration. 2016. Top Markets Report Renewable Fuels Sector Snapshot. https://www.trade.gov/topmarkets/pdf/renewable_fuels_biomass_wood_pellets.pdf

72 Food and Agriculture Organization of the United Nations. 2010. Global Forest Resources Assessment 2010. FAO Forestry Paper 163. http://www.fao.org/3/a-i1757e.pdf

73 Multiple signatories. A Call for Conservation with a Conscience: No Place for Gene Drives in Conservation. http://www.etcgroup.org/files/files/final_gene_drive_letter.pdf

74 Revive and Restore. https://reviverestore.org/about-us/

75 Revive and Restore. Wooly Mammoth Revival. https://reviverestore.org/projects/woolly-mammoth/

76 International Union for the Conservation of Nature, 2018. Genes for Nature? An Assessment of Synthetic Biology and Biodiversity Conservation. https://www.iucn.org/theme/science-and-economics/our-work/other-work/synthetic-biology-and-biodiversity-conservation

77 Fernandez, I., Marti, A. and Dodd, R. 2018. Using CRISPR as a Gene Editing Tool for Validating Adaptive Gene Function in Tree Landscape Genomics. *Front. Ecol. Evol.* 6:76

78 Fan, D., Liu, T., Jiao, B., Li, S., Hou, Y., Luo, K. 2015. Efficient CRISPR/Cas9-mediated Targeted Mutagenesis in Populus in the First Generation. *Sci. Rep*. 5: 12217

79 USDA. 2018. Secretary Perdue issues USDA statement on plant breeding innovation. Press Release. March 28. https://www.usda.gov/media/press-releases/2018/03/28/secretary-perdue-issues-usda-statement-plant-breeding-innovation

80 *The Bur*. Spring 2004. https://ecosystems.psu.edu/research/chestnut/newsletters/newyork-news/the-bur-vol.14-1-2004

81 State University of New York College of Environmental Science and Forestry. 2014. William Powell, Annual Report for June 1, 2013 – May 31, 2014. https://www.esf.edu/efb/annualreports/1314/Powell1314_000.pdf

82 The University of Georgia. Office of the Vice President for Research, 2004 and 2009 Annual Reports. https://research.uga.edu/docs/reports/2004/OVPR-Annual-Report-FY2004.pdf; https://research.uga.edu/docs/reports/2009/Annual-Report-FY2009.pdf

83 Global Justice Ecology Project. 2017. GMO American Chestnut: For Forest Restoration or for making money? https://www.youtube.com/watch?v=3hecM7xWvdM

84 Forest Health Initiative. FHI Committees. http://www.foresthealthinitiative.org/committees.html

85 The American Chestnut Foundation. 2015 Internal Revenue Service Form 990. https://www.acf.org/wp-content/uploads/2017/04/TACF-2015-Form-990-PUBLIC-INSPECTION-COPY.pdf?x86657

86 The American Chestnut Foundation. 2016 Internal Revenue Service Form 990. https://www.acf.org/wp-content/uploads/2017/11/TACF-FYE2017-Form-990-PUBLIC-INSPECTION-COPY.pdf?x90065

87 The American Chestnut Foundation. 2017 Internal Revenue Service Form 990. https://www.acf.org/wp-content/uploads/2018/11/TACF-FY18-Form-990-PUBLIC-INSPECTION-COPY.pdf

88 State University of New York College of Environmental Science and Forestry. 2017. William Powell, Annual Report for June 1, 2016 – May 31, 2017. https://www.esf.edu/efb/annualreports/1617/documents/Powell1617.pdf

89 State University of New York College of Environmental Science and Forestry. 2010. William Powell, Annual Report for June 1, 2009 – May 31, 2010. https://www.esf.edu/efb/annualreports/0910/PowellAR0910.pdf

90 The American Chestnut Foundation. 2015. Transgenics and chestnuts. Frequently Asked Questions. https://www.acf.org/wp-content/uploads/2016/09/Transgenics-FAQ-1.pdf

91 The American Chestnut Foundation. 2013 Annual Report. https://www.acf.org/wp-content/uploads/2016/05/2013_Annual.pdf

92 Fletcher Challenge, International Paper, Monsanto, Westvaco, Genesis. 1999. Fletcher Challenge, International Paper, Monsanto Company and Westvaco Corporation announce forestry biotechnology joint venture. Company press release. April 6. http://globaljusticeecology.org/wp-content/uploads/Arborgen-original-PR-1999.pdf

93 Powell, William. Evaluating Environmental Impacts of Maturing American Chestnut Trees Produced by Transgenic Relative to Conventional Breeding. United States Department of Agriculture. Sep 1, 2012. https://reeis.usda.gov/web/crisprojectpages/0229536-evaluating-environmental-impacts-of-maturing-american-chestnut-trees-produced-by-transgenic-relative-to-conventional-breeding.html

94 Swartz, Josh. 2018. The 'most ambitious' species restoration project in the world. wbur. https://www.wbur.org/endlessthread/2018/04/27/that-old-chestnut

95 US Endowment for Forestry and Communities. https://www.usendowment.org

96 US Endowment for Forestry and Communities. Forest Health Initiative. https://www.usendowment.org/what-we-do/forest-health/forest-health-initiative/

97 Forest Health Initiative. 2019. Policy. http://www.foresthealthinitiative.org/policy.html

98 Forest Health Initiative. 2019. http://foresthealthinitiative.org/

99 State University of New York College of Environmental Science and Forestry. William Powell, Annual Report for June 1, 2010 – May 31, 2011. https://www.esf.edu/efb/annualreports/1011/PowellAnnualReport1011.pdf

100 State University of New York College of Environmental Science and Forestry. William Powell, Annual Report for June 1, 2009– May 31, 2010. https://www.esf.edu/efb/annualreports/0910/PowellAR0910.pdf

101 Forest Health Initiative. 2009. New Effort Will Investigate Potential of Biotechnology to Aid in Addressing Forest Health Crisis. News Release. Jan. 30. http://www.usendowment.org/images/Forest_Health_Initiative_Press_Release_01-30-09.pdf and https://sref.info/news/articles/new-effort-will-investigate-potential-of

102 Redick, Thomas. Legal barriers and potential benefits of biotech trees. http://foresthealthinitiative.org/resources/Legal_Barriers_and_Potential_Benefits_of_Biotech_Trees.pdf

103 Duke Energy. Bringing back the American chestnut. https://sustainabilityreport.duke-energy.com/2012/environmental-footprint/bringing-back-the-american-chestnut/

104 Institute of Forest Biosciences. Initiatives of the IFB. https://forestbio.org/IFB/initiatives/

105 Institute of Forest Biosciences. Partners. https://forestbio.org/IFB/partners/

106 Constanza, Adam. 2018. Regulation of GE trees in the US and beyond. Are forest trees treated differently? National Academies of Sciences, Engineering and Medicine. http://nas-sites.org/dels/files/2018/02/Adam-Costanza-Presentation.pdf

107 Wilson, A, Latham, R, and Steinbrecher, R. 2006. Transformation-induced mutations in transgenic plants. Biotechnology and Genetic Engineering Reviews. 23, December: 209-237. https://www.econexus.info/publication/transformation-induced-mutations-transgenic-plants

108 Constanza, Adam. 2018. Regulation of GE trees in the US and beyond. Are forest trees treated differently? National Academies of Sciences, Engineering and Medicine. http://nas-sites.org/dels/files/2018/02/Adam-Costanza-Presentation.pdf

109 Genetic Engineering Network. 1999. Media release quoting anonymous communique, July.

110 Tickell, Oliver, Clover, Charles. 1999. *London Daily Telegraph*, 17 July. quoted in *Earth Island Journal*, Brave New Forests, 22 December 1999.

111 Weiss, Rick. 2000. Forests the next biotech battlefield. *The Washington Post*, 27 August.

112 The Campaign to Stop GE Trees. 2019. About The Campaign to Stop GE Trees. http://stopgetrees.org/about

113 Quoted from letter sent by FSC Director-General Kim Carstensen to the Campaign to STOP GE Trees dated 9 March 2015 https://fsc-watch.com/2015/04/24/will-fsc-ever-kick-out-suzano-over-ge-trees/

114 Forest Stewardship Council. Policy on GMOs. https://ca.fsc.org/preview.fsc-pol-30-602-2000-fsc-interpretation-on-gmos-genetically-modified-organisms.a-843.pdf

115 Programme for the Endorsement of Forest Certification. Requirements for Sustainable Forest Management Standards - Part 1: Temperate, boreal and plantation forests. http://consultations.pefc.org/consult.ti/ST_1003_200x_p1/

115 Programme for the Endorsement of Forest Certification. Requirements for Sustainable Forest Management Standards - Part 1: Temperate, boreal and plantation forests. http://consultations.pefc.org/consult.ti/ST_1003_200x_p1/viewCompoundDoc?docid=489364&partId=491668&sessionid=&vot eid=

116 Sustainable Forestry Initiative. 2015. SFI 2015-2019 Standards and Rules. https://www.sfiprogram.org/wp-content/uploads/2015_2019StandardsandRules_FINAL_web_Section9-July2018-1.pdf

117 Convention on Biological Diversity. COP 8 Decision VIII/19Forest biological diversity: implementation of the programme of work. https://www.cbd.int/decision/cop/default.shtml?id=11033

118 Gibson, Lisa. 2011. Genetic Engineering Hang-Up: Lawsuit highlights a barrier to biotechnology advancements in the US. *Biomass Power & Thermal Magazine*. April. https://globaljusticeecology.org/biomass-industry-responds-to-stop-ge-trees-lawsuit/

119 U.S. Department of Agriculture, Animal and Plant Health Inspection Service. 2017. USDA Requests Public Input on dEIS for Deregulation of Freeze-Tolerant GE Eucalyptus. https://www.aphis.usda.gov/aphis/ourfocus/biotechnology/brs-news-and-information/2017_brs_news/deis_eucalyptus

120` *Sustainable Pulse*. 2015. Brazilian Farmers Occupy and Cancel Approval Meeting for GMO Trees. 5 March. https://sustainablepulse.com/2015/03/05/brazilian-farmers-occupy-cancel-approval-meeting-gmo-eucalyptus-trees/

121 Needham, Mark et. al. 2015. Forest Health Biotechnologies: What are the Drivers of Public Acceptance? https://view.officeapps.live.com/op/view.aspx?src=http%3A%2F%2Fforesthealthinitiative.org%2Fresources%2Fbiotech_public_acceptance_Needham.pptx

122 Koranyi, Adam. 2018. Analysis of Survey on Public Acceptance of Forest Health Biotechnologies. https://wp.me/p4Jilv-1Cm

123 Newhouse, Andy. 2018. Transgenic American chestnuts for potential forest restoration: scientific successes, regulatory challenges. Presentation. April 24. https://vimeo.com/266566530

124 National Academies of Sciences, Engineering, and Medicine. 2019. *Forest Health and Biotechnology: Possibilities and Considerations*. Washington, DC: The National Academies Press. page 108.

125 *Mint Press*. Genetically engineered trees: An environmental saviour or dangerous money making scheme? https://www.mintpressnews.com/genetically-engineered-trees-environmental-savior-dangerous-money-makingscheme/199567/

126 Thompson, Helen. 2012. The chestnut resurrection. *Nature*. http://www.nature.com/polopoly_fs/1.11504!/menu/main/topColumns/topLeftColumn/pdf/490022a.pdf

127 US Environment Protection Agency. Climate impacts on forests. https://archive.epa.gov/epa/climate-impacts/climate-impacts-forests.html

128 Trumbore, S. et al. 2015. Forest health and global change. *Science*. 349.

129 Anagnostakis, S. 1995. The pathogens and pests of chestnuts. *Advances in Botanical Research*. 21. Academic Press.

130 Fisher, M.C., Gow, N.A.R., Gurr, S.J. 2018. Tackling emerging fungal threats to animal health, food security and ecosystem resilience. *Phil. Trans R. Soc*. B. 371.

131 Liebhold, A. M., E. G. Brockerhoff, L. J. Garrett, J. L. Parke, and K. O. Britton. 2012. Live plant imports: the major pathway for forest insect and pathogen invasions of the US. *Frontiers in Ecology and the Environment*. 10:135–143.

132 Roy, B.A., Alexander, H.M., Davidson, J., Campbell, F.T., Burdon, J.J., Sniezko, R., and Brasier, C. 2014. Increasing forest loss worldwide from invasive pests requires new trade regulations. *Front Ecol Environ*. 12(8): 457-465

133 National Academies of Sciences, Engineering, and Medicine. 2019. *Forest Health and Biotechnology: Possibilities and Considerations*. Washington, DC: The National Academies Press.

134 Hartmann et al. 2014. Resistance and resilience of the forest soil microbiome to logging-associated compaction. *J. Int Soc. for Microbial Ecology* 8: 226-244

135 Freinkel, S. 2007. American Chestnut: The Life, Death and Rebirth of a Perfect Tree. University of California Press.

136 Budde, K.B. et al. 2016. The Natural Evolutionary Potential of Tree Populations to Cope with Newly Introduced Pests and Pathogens – Lessons Leans from Forest Health Catastrophes in Recent Decades. *Curr Forestry Rep 2*: 18-29.

137 Six, D. et al. 2018. Are Survivors Different? Genetic-Based Selection of Trees by Mountain Pine Beetle During a Climate Change-Driven Outbreak in a High-Elevation Pine Forest. *Frontiers in Plant Science*. 23 July.

138 Foster, D.R. and Orwig, D.A. 2006. Preemptive and Salvage Harvesting of New England Forests: When Doing Nothing is a Viable Alternative. *Cons. Bio*. 20(4): 959-970.

139 Bunnell, F.L., & Kremsater, L. L. 2012. Migrating Like a Herd of Cats: Climate Change and Emerging Forests in British Columbia. *Journal of Ecosystems and Management* 13(2):1–24.

140 Lance Olsen (2018) Comments submitted to US Forest Service regarding Helena-Lewis and Clark National Forest Plan Revision and DEIS.

141 Potter, K. M., Jetton, R. M., Dvorak, W. S., Hipkins, V. D., Rhea, R., & Whittier, W. A. 2012. Widespread inbreeding and unexpected geographic patterns of genetic variation in eastern hemlock (*Tsuga canadensis*), an imperiled North American conifer. *Conservation Genetics*. 13(2): 475-498.

BIOFUELWATCH USA
680 Sherman Hollow Road
Hinesburg, VT -5461
+1.802.482.2848

BIOFUELWATCH UK
phone: +44.131.6232600
biofuelwatch@gmail.com

GLOBAL JUSTICE ECOLOGY PROJECT (Main Office)
266 Elmwood Avenue, Suite 307
Buffalo, NY 14222-2202
+1.716.931.5833
info@globaljusticeecology.org

GLOBAL JUSTICE ECOLOGY PROJECT (Florida Office)
PO Box 627 720 Lucerne Ave.
Lake Worth, FL 33460-9998
+1.561.536.5430
ruddy@globaljusticeecology.org

CAMPAIGN TO STOP GE TREES
266 Elmwood Avenue, Suite 307
Buffalo, NY 14222-2202
+1.716.364.1188
contact@globaljusticeecology.org