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| **Title** | **The Case of Chestnut Grove: A Town Council Simulation** |
| **Introduction** | Students explore the interconnectivity of science, technology, ethics, and politics in this town council simulation. The fictional small town of Chestnut Grove, where there are no more chestnuts due to the invasive disease *chestnut blight*, is given a donation of GM (genetically modified) American Chestnuts by a local seedling company as a gift for the town’s bicentennial celebration. Students will take on the roles of mayor, town council members, specialists, representatives from special interest groups, and concerned citizens to discuss the issue. Students will research and prepare their argument, and work together to come up with the solution. At the conclusion, students will write a letter to the company either accepting or rejecting their offer, and explaining why they have reached that conclusion.  Excerpt from student page:  Chestnut Grove, a small tight-knit community of 5,000 people, has a problem. Their namesake tree, the American chestnut, once the most common tree in the area, has disappeared. Invasive *chestnut blight* has caused a local extinction of the population. Gentry Seedlings, a local company specializing in genetically modified trees has volunteered to donate 100 genetically modified (GM) American chestnuts, modified to be resistant to the tree disease, to the town for the town’s bicentennial celebration in May of next year. The proposal has come before the Town Council to vote to accept these trees. This has become a heated debate topic between members of the town, and a community meeting has been called for residents to ask questions to experts and representatives from various organizations, as well as share their opinions and give feedback on any plans generated by the council. |
| **Curriculum Alignment** | AP Environmental Science-  Competency Goal 7: The learner will build an understanding of environmental decision making.  Objective 7.02 Analyze cultural and ethical considerations regarding the environment; Environmental worldviews; Sustainable development.  Biology-  Competency Goal 3: The learner will develop an understanding of the continuity of life and the changes of organisms over time.  3.04 Assess the impact of advances in genomics on individuals and society.- Applications of biotechnology. |
| **Learning Outcomes** | As a result of this activity, students will:   * Investigate environmental issues from a variety of perspectives * Be able to offer and support convincing arguments, taking into account impacts, development, and ethical considerations * Work cooperatively to reach a solution to an environmental problem |
| **Time Required and Location** | OVERALL TEACHER PREPARATION NEEDED: 15 minutes (to make copies and get activity organized)  OVERALL CLASS TIME NEEDED: 45- 120 minutes (1/2 block to 1.5 blocks); dependent on optional in class prep time and assessment time, and student involvement; recommended to be spread out over several days  - Preparation- overview and introductions- 15-20 minutes (students will select characters, be exposed to the problem)  - OPTIONAL class prep time- depends on level of students and access to internet at home; may give students in class time in the media center or computer lab to research their viewpoints on the issue, or may allow students to complete this totally outside of class (recommended- 20-30 minutes in-class prep time)  - Simulation- 30-60 minutes (can be adapted to fit more or less time, but is dependent on how much the students will actually talk to each other in class)  -OPTIONAL Conclusion (may be completed in class individually, as a whole class, or in groups- or may be completed at home)- 20-30 minutes |
| **Materials Needed** | copies of student sheets (“Preparing for the Meeting”)  classroom setup- town council seating at front of room; forward facing seating throughout room  podium (or similar structure; music stands work as well for this) for people to address the council  OPTIONAL:  Computer with internet access for research  Costuming or name placards to identify ‘characters’ for the simulation  TECHNOLOGY RESOURCES:   * computers with Internet search access are optional but useful * check to see internet availability of students at home; this may help determine need for research time in class |
| **Participant Prior Knowledge** | Students:   * students should already be familiar with the concept of invasive species (examples of invasives, problems caused by invasives, how they are usually transported) * students should have experience in persuasive writing and debate; students should be able to convey and support a general argument (if not done in a previous course, try the below activity)   + cut out slips of paper with ‘As seen on TV’ (or other consumer) products listed on them, and pass them out (students can actually do this, and then take up the slips and pass back out to other students)   + flip a coin for each student     - if it lands on heads, the student has to make a convincing argument as to why the class should buy this product and be able to back it up     - if it lands on tails, the student has to make a convincing argument as to why the class should NOT buy the product and be able to back it up   + students have 3-5 minutes to prepare an argument and present them to the class   + the class can evaluate their argument   + this can also be done with small groups   Teachers:   * teachers need to make copies in advance * on a day previous to the actual simulation, characters need to be determined; students can sign up, or they can be assigned   + this is at teacher discretion based on student population (try to split up ‘friend groups’) |
| **Activities** | * Part 1: Determine characters of students   + Recommended for advanced students- give them one week to prepare their arguments   + If possible, allow small amounts of time in class for groups of similar backgrounds to meet briefly to discuss what they plan to say and get feedback * Part 2: Allow time for research- may be in class or time outside of class * Part 3: Simulation   + Check for student understanding with pre-questioning     - What are invasive species?       * Species that are nonnative to an area and have a negative impact on the native populations     - What are the problems of invasive species?       * Habitat destruction, no natural predators, offset population dynamics and cause population declines of native species     - Which invasive species was responsible for the decline of the chestnut?       * Chestnut blight     - How might the chestnut be modified to survive in the presence of this tree disease?       * Be modified to be resistant to the disease   + Have the room set up with the town council at the front, and the other chairs/desks facing forward. Place a podium or other ‘talking location’ in the middle of the classroom in front of the town council’s table.   + Start off by reading the problem. Allow the town council members to make opening statements.   + Determine what margin should be used for decisions- 2/3 (67%) is most common     - On a panel of 5, this will mean 4 of 5 (80%)     - On a panel of 7, this will mean 5 of 7 (71%)   + Facilitate discussion by the use of leading questions:     - What environmental impacts should be considered in this decision?     - What social and cultural issues need to be addressed?     - What are the major concerns of planting GM seedlings in Chestnut Grove?     - Should Chestnut Grove accept these trees?       * Allow the Town Council members to call for a vote.     - If Yes-       * Where will these be planted?       * Who will make decisions of what happens to the trees?     - If No-       * What are the major reasons that led to a vote of ‘no’?       * How will this affect the town’s relationship with Gentry Seedlings? * Additional resources (handouts, etc) available in supplemental resources field |
| **Assessment** | * Teacher may assess the simulation by using oral cues to determine understanding   + Look for students giving concise, supported arguments.   + Students should not be ‘reading’ from the handouts they have; if they truly understand the information, they will be able to explain it in different words and combine information from different sources into one argument. * Written assessment- may be done in groups, as individuals, or as a class:   + Write a formal letter to Gentry Seedlings, explaining whether the town is voting to accept the offer or not, and explain why. If you are planning to accept the trees, explain what you plan to do with them. |
| **Critical Vocabulary** | Genetically modified organism (GMO)- organism whose genetic makeup has been modified by genetic engineering  Genetic engineering- insertion of an alien gene into an organism to give it a beneficial genetic trait  Invasive species- also generally called nonnative species, alien species, and exotic species- species that migrate into an ecosystem or are deliberately or accidentally introduced into an ecosystem by humans |
| **Modifications** | * Pre-assign students into different groups. Students who have a hard time organizing information, for example, should probably not be cast as the ‘experts’ but should have to do some research in order to increase their skills. Suggestion- concerned citizens. * The assessment options also can be modified based on student population and goals of the lesson. If one main focus is to get the students to be able to work on writing skills (especially significant for 9th and 10th grade to prepare for the 10th grade writing test), then have students complete their letter individually. Another option is an essay, written below in alternate assessments. |
| **Alternative Assessments** | * The 10th grade writing test focuses on definition based writing, and asks students typically to write an article. One option for students in 9th and 10th grade to help them prepare for this is to ask them to write an article about genetic modifications.   + Write an article for a local magazine publication about genetically modified trees. Focus on the pros and cons of genetic modification, and take a stand on whether you feel the town should accept these trees and why. Include information from this simulation, your own research, and your own experiences. * Students may be scored based on their speaking in class. Example- tell each student they need to bring up at least 2 additional points, and provide either refuting or supporting statements for two other points. Score based on this participation. * Students may be grouped for the writing assignment. |
| **Supplemental Information** | * Possible Adaptations to Activity: This activity can be easily adapted to various levels as well as course enrollment numbers. Additional characters can be added, including media reporters, additional local politicians, or additional residents (on both sides of the issue). Lower level students may be given more guidance (time in class to complete “Preparing for the meeting” Handout, or preparing in groups), while upper level students may be given a week outside of class to prepare on their own. * There are 24 parts written for the activity. There are additional spaces placed for 8 additional parts for a class of up to 32 students. For smaller classes, subtract from some of the citizens and selected experts. The town council number should not go below 5.   Supplemental Handouts (available at end):   * Teacher Handout to assign characters   + This activity was designed for a class of 24, with additional character spaces for up to 32 students. The 8 blank spaces on the handout can help tailor the activity to an individual class or area. For example, if you have a large university nearby, you might have additional professors, or grad students, present. You may wish to have additional local environmental organizations. You may elect to have a few high school students present as some of your citizens. Use the extra spaces to adapt the meeting population to your needs. * Student page- Preparing for the Meeting * Sample article handouts on Chestnut Blight * Website list for research |
| **Comments** | * There are several ways to lengthen or shorten the class time involved with this activity, depending on time. Check the individual categories for suggestions. * Some classes do not need leading questions; if they ‘go with it’- let them. Sometimes they end up with better direction and arguments than we as teachers could ever dream of. ☺ * This activity was designed with an AP Environmental Science class in mind, but is easily adapted for Biology and Earth/Environmental Science courses as well. |
| **Author Info** | Heather Earp teaches at West Johnston High School in Benson (Johnston County Schools), where she has been a member of the Science Department since 2003. She has taught numerous science courses including Biology, Honors Biology, Honors Anatomy and Physiology, Earth/ Environmental Science, Environmental Science, Honors Environmental Science, and Advanced Placement Environmental Science. She is a graduate of East Carolina University, where she was a NC Teaching Fellow, and holds a BS degree in Science Education with a concentration in Biology. She holds AP Certification in Environmental Science and K-12 AIG Certification. She has served as a College Board reader for the AP Environmental Science exam. This lesson was developed as part of the Kenan Fellows program through NC State University; Heather is studying Sustainable Forestry and the Use of Biotech Trees for Sustainability and Bioenergy. |

The Case of Chestnut Grove

Chestnut Grove, a small tight-knit community of 5,000 people, has a problem. Their namesake tree, the American chestnut, once the most common tree in the area, has disappeared. Invasive *chestnut blight* has caused a local extinction of the population. Gentry Seedlings, a local company specializing in genetically modified trees has volunteered to donate 100 genetically modified (GM) American chestnuts, modified to be resistant to the tree disease, to the town for the town’s bicentennial celebration in May of next year. The proposal has come before the Town Council to vote to accept these trees. This has become a heated debate topic between members of the town, and a community meeting has been called for residents to ask questions to experts and representatives from various organizations, as well as share their opinions and give feedback on any plans generated by the council.

|  |  |  |
| --- | --- | --- |
| **Title** | **Information** | **Student Name** |
| Mayor | Native of the area; wants to see chestnuts in the area |  |
| Town Council 1 | Generally against anything GM |  |
| Town Council 2 | Has a forestry degree |  |
| Town Council 3 | Knows nothing about trees or nature |  |
| Town Council 4 | Owner of the local organic food store |  |
| Town Council 5 | Works at a biotech lab |  |
| Town Council 6 |  |  |
| Town Council 7 |  |  |
| Gentry Rep. | Wants the town to accept the offer |  |
| EPA Rep. | Concerned about GM DNA mixing with native species |  |
| Forest Biotech Rep. | Wants to educate the public on positive side of biotech |  |
| Grassroots Rep. | Wants the area to accept chestnuts; called “Operation: Reforest!” |  |
| Chestnut Soc. Rep. | State rep for the American Chestnut Society |  |
| Organic Group Rep. |  |  |
| Town arborist | Concerned for native tree species, but wants to see chestnuts again |  |
| University Scientist | Conducting research on GM chestnuts |  |
| Invasive species expert | Expert on invasive species, especially tree diseases |  |
| Forestry association | Expert in tree diseases and impact on forests |  |
| Grassroots member | Member of “Operation: Reforest!” |  |
| Grassroots member | Member of “Operation: Reforest!” |  |
| Grassroots member |  |  |
| Grassroots member |  |  |
| Citizen 1 | Family has lived here for many generations |  |
| Citizen 2 | Local organic farmer |  |
| Citizen 3 | Just relocated from another state |  |
| Citizen 4 | Family once owned most of Chestnut Grove land |  |
| Citizen 5 | Forester |  |
| Citizen 6 | Remembers her grandparents talking about chestnuts |  |
| Citizen 7 | Local developer; doesn’t want more trees to have to cut down to build a new mall |  |
| Citizen 8 |  |  |
| Citizen 9 |  |  |
| Citizen 10 |  |  |

The Case of Chestnut Grove

**Preparing for the Meeting**

Chestnut Grove, a small tight-knit community of 5,000 people, has a problem. Their namesake tree, the American chestnut, once the most common tree in the area, has disappeared. Invasive *chestnut blight* has caused a local extinction of the population. A local company specializing in genetically modified trees has volunteered to donate 100 genetically modified (GM) American chestnuts, modified to be resistant to the tree disease, to the town for the town’s bicentennial celebration in May of next year. The proposal has come before the Town Council to vote to accept these trees. This has become a heated debate topic between members of the town, and a community meeting has been called for residents to ask questions to experts and representatives from various organizations, as well as share their opinions and give feedback on any plans generated by the council.

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Role: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Position on whether Chestnut Grove should accept the offer: Yes No

Why/why not?

How does the fact that the trees are genetically modified affect your decision?

Suppose the town decides to accept the offer and gets 100 GM American chestnuts.

1. Where should the town place the trees?
2. How heavily should the trees be regulated?
3. What questions do you have about these trees long-term?

Suppose the town decides to reject the offer and does not get the 100 GM American chestnuts that the company is offering.

1. What factors most influenced the decision?
2. How will this affect the future of Chestnut Grove?
3. What are the biggest questions left unanswered?

The Case of Chestnut Grove

**Information on Chestnut Blight**

Source: Forest Encyclopedia Network

URL: <http://www.forestencyclopedia.net/p/p2919>

Chestnut blight ( *Cryphonectria parasitica*) has probably had the most pervasive influence on forest structure and composition in the Southern Appalachians of any disease or insect. Prior to the introduction of this disease, the American chestnut (*Castanea dentata*) was the tallest and most dominant hardwood species in the Eastern United States. It grew in vast stands from Maine to Florida, with the largest trees occurring in the Southern Appalachians (Schlarbaum and others 1997). After the introduction of the **fungus**, which probably arrived on nursery stock from Asia around 1900, native chestnut trees, which had no resistance, quickly succumbed. The fungus enters a host through cracks or wounds in the bark and multiplies rapidly. It producessunken cankers which expand and girdle the stem, killing everything above the canker, usually in one growing season. Fungus spores can be transported by wind or on the feet of migrating birds and insects. The disease, therefore, can spread rapidly--about 24 miles per year (Schlarbaum and others 1997). By 1929, nearly all counties in the Southern Appalachians were infested; and by about 1940, most of the standing chestnut trees were dead (SAMAB 1996e).

The chestnut blight fungus kills the above-ground portion of trees but does not affect root systems. Therefore, American chestnut persists throughout its former range as **root sprouts** growing in the understory. These sprouts generally live for 5 to 10 years before being top-killed by the blight. Often chestnuts sprouts reach heights of 25 feet or more, but they rarely flower and bear fruit before dieback. Despite the persistence of spouts, there is a gradual loss of this genetic resource. Areas with extensive chestnut rootstocks should be identified and silvicultural practices that favor its shade-intolerant regeneration should be employed to protect or enhance sprout survival.

## Restoration of Chestnut

There have been two primary research approaches to restore chestnuts to American forests: the use of hypovirulent strains and breeding.

### Hypovirulence research

Hypovirulence is a virus disease that weakens and slows the chestnut blight virus. Hypovirulence allows a chestnut tree with no resistance to blight to form slow-growing swollen cankers normally produced only on resistant trees. Scientists have been trying to manipulate hypovirulence to develop an economical biocontrol for blight. However, several obstacles to this approach exist, including: (1) the blight spreads very rapidly in nature, while hypovirulence spreads very slowly; and (2) there are many types of virulent strains in the forest which resist transfer of the virus responsible for hypovirulence. Despite these limitations, hypovirulent strains have been used to effect recovery from chestnut blight in certain situations (Scibilia and Shain 1989, Anagnostakis 1990, MacDonald and Fulbright 1991, Brewer 1995). For example, some positive results have been achieved by using molecular biology to transfer the debilitating genes of the virus into the fungus (Choi and Nuss 1992b, Schlarbaumand others1997).

### ****Breeding research****

Two strategies have been pursued to breed a blight-resistant American chestnut: (1) breeding within the American chestnut gene pool and (2) hybridization with Asian chestnut species.

Breeding within American chestnut populations was begun with the occasional surviving trees that were thought to possess some resistance. Enzymatic studies of inner bark tissue revealed small resistance differences among trees (Samman and Barnett 1973, McCarroll and Thor 1985). Cross pollinations were made among putatively resistant trees, but resistance could not be increased to an acceptable level and the approach was abandoned (Thor 1978, Schlarbaumand others1997)

Resistance in **Asian chestnut species**, particularly *C. mollissima* (Chinese chestnut) and Japanese chestnut (*C. crenata*) was evident to scientists in the early 1900s. Early breeding programs were initiated by state and federal agencies in the 1930s. However, the initial hybrids generated by these programs were not as blight resistant as the oriental chestnut parent. To increase resistance, these first hybrids were crossed back to a resistant oriental parent. Unfortunately, this strategy produced trees that were short and branching, and not competitive in eastern forests (Schlarbaum and others1994). A number of breeding programs were more successful with the backcross method, which aimed to transfer blight resistance from Chinese chestnut to American chestnut, while retaining the desirable growth, form, and adaptability of the American chestnut (Burnhamand others1986, Burnham 1990). These trials produced two partially blight-resistant first backcrosses (BC1), the "Graves" tree and the "Clapper" tree, which were first generation hybrids (Schlarbaumand others1997).

Although these early breeding programs did not produce a blight-resistant American chestnut, they left a valuable legacy of knowledge and germplasm. There is now evidence that only a few **genes control blight resistance** in Chinese chestnut, specifically, two or three incompletely dominant genes. A genetic map of chestnut with regions associated with blight resistance was identified, and could be used to screen newly germinated nuts for blight resistance. This approval may enable several generations of backcrossing to be bypassed. The American Chestnut Foundation estimates that by 2012, nuts will be produced from the most blight-resistant breeding lines that can be used in reforestation (Schlarbaumand others1997).

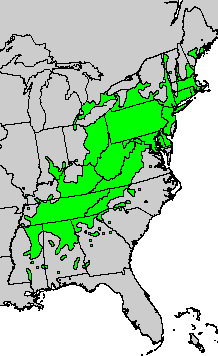
Promising results have also been seen with an integrated management approach for American chestnut revival. This approach combines hypovirulence (by inoculation) with blight-resistance (grafted). In Virginias Lesesne State Forest, trees grafted with blight resistant strains and inoculated with hypovirulence have been thriving for 20 years, but they are surrounded by nonresistant chestnuts, which are continuously killed back by the blight.

The Case of Chestnut Grove

**Information on Chestnut Blight**

Source: Forest Pathology

URL: <http://www.forestpathology.org/dis_chestnut.html>

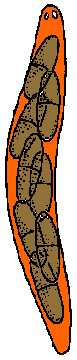
Native range of American chestnut. From Little, E.L., Jr., 1977, Atlas of United States trees, volume 4, Minor Eastern Hardwoods: U.S. Department of Agriculture Miscellaneous Publication 1342, 17 p., 230 maps.

## Disease triangleHosts

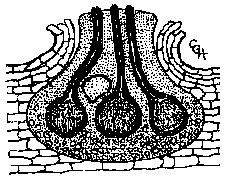
American chestnut (*Castanea dentata*), whose native range is shown at left, is highly susceptible to the disease. European chestnut (*C. sativa*) is also quite susceptible. Chinese chestnut (*C. mollissima*) is resistant; a small canker can occur. Some oak species (*Quercus* spp.) get minor bark infections that can produce inoculum.

If you could custom design the ideal tree species, you couldn't come up with a better one than American chestnut. It was a huge, majestic tree, with a very straight stem. The wood was nearly ideal. As George Hepting (Δ) has written, "Not only was baby's crib likely made of chestnut, but chances were, so was the old man's coffin." One of its good qualities was high durability. The heartwood could be used in situations where decay was a hazard. The tree was common. It made up about 50% of most eastern hardwood forests. It grew fast, and would regenerate itself by root sprouts vigorously. The nuts were edible, not only by wildlife but also by humans. It was an important food source for all. "The farmer's hogs were fattened on chestnuts, and, to no small degree, his children were also" (Δ). Chestnut was also prized as a landscape tree.

## Disease trianglePathogen

The pathogen is *Cryphonectria parasitica.* It is an ascomycete, and produces perithecia in small stromata. They can appear at any time of year when conditions are suitable. The perithecial necks are very long and come together where they protrude through the bark. The ascospores are forcibly ejected and wind-dispersed.

Perithecia of *Cryphonectria parasitica* in a stroma. The perithecia contain many asci with 8 ascospores each. The ascospores are forcibly ejected and carried in air currents.

Usually prior to perithecia, pycnidia are produced in the same small stroma or in other stromata. They also can appear any time of year. The conidia ooze out in a tendril after rains. They are quite small, as small as 4 x 1 µm wide. In that little conidium is all the information and machinery necessary to wipe out one of the most important tree species in North America. Conidia may be carried by rain splash or catch a ride on an insect or bird.

In 1913 a USDA plant explorer found the fungus in its native land of China. There it was hardly a pathogen, colonizing dying twigs and small patches of bark.

## Disease triangleEnvironment

Within the range of environmental conditions found in the geographic range of chestnut, there do not appear to be important differential effects of the environment. Environmental conditions are conducive to disease throughout the range of chestnut.

## Disease Cycle

Conidia and ascospores can infect wounds, even very small ones that don't go all the way to cambium. It is thought that insects of various kinds make most of the infection courts.

The fungus grows in the inner bark and cambium, producing small brownish mycelial fans. Even after the branch or stem is girdled and killed, the fungus continues to colonize it, producing ever more inoculum.

## Symptoms

Chestnut blight is a canker disease. Perhaps it is called blight because infected branches and stems die quickly, as in a shoot blight. But it doesn't just infect shoots; it infects branches and stems of any size.

The cankers are of the diffuse type. They grow rapidly and in most cases continue to develop until the stem is girdled and killed; then they continue to colonize the dead tree.

## Distribution

In North America, chestnut blight is present in the entire native range of the host and has moved to areas of planted chestnut far from the native range. It is also present in Europe, and the pathogen is native to China, where it causes an inconsequential disease of Chinese chestnut.

## Management

We will never have chestnut like we did in 1900, at least not in the next few hundred years. But there are two areas of hope for some form of recovery.

**Breeding for resistance**. Chinese chestnut is somewhat resistant. The fungus causes persistent perennial cankers rather than diffuse cankers. It can slow the fungus down. Reproduction is limited. But chinese chestnut is not such a great tree. So traditional breeding followed by backcrossing is underway. Although it is slow and a grope in the dark, there has been success in developing individuals with characteristics of American chestnut after hybridization and three successive generations of backcrossing (Δ). Now the challenge is to make them homozygous for blight-resistance alleles. There are also plans to introduce resistance genes into chestnut directly.

**Hypovirulence** literally means "lesser virulence." Soon after epidemics began in European chestnuts, it was observed in Italy and France that some cankers spontaneously slowed down or stopped. Experiments and observations showed that the trees involved were no more resistant than other trees:

|  |  |
| --- | --- |
| Aggressive isolate | Isolations from normal cankers gave fast-growing isolates. When they were inoculated into new trees, normal, lethal cankers resulted. |
| Hypovirulent isolate | Isolates from the cankers that slowed or stopped growth looked different from isolates from normal cankers. They grew more slowly and didn't fruit well. These isolates didn't cause much of a canker when reinoculated, so are called **hypovirulent**. |
| Mating of isolates | It was found that hypovirulence was in some cases transmissible. If they allowed a hypovirulent and normal isolate to grow together, the normal isolate became hypovirulent in many cases. When they had an active canker produced by a virulent isolate, and inoculated with the hypovirulent isolate, the canker slowed down and started to heal in some cases. |

It was later found that hypovirulent isolates have a piece of double-stranded RNA, which doesn't normally occur in fungi. It is now considered that the dsRNA is a **virus** in the family Hypoviridae, and essentially causes a disease in the fungus, making it less virulent.

Hypovirulence has had limited success against chestnut blight (Δ). It shows promise in some locations in Europe and in Michigan in the United States. However, it has failed almost completely in eastern North America. Therapeutic treatment of individual cankers is successful in most cases, but the success of hypovirulence at the population level depends on the natural spread of viruses. It is not clear how well the hypovirulent strains can reproduce, disperse, and make contact with virulent strains in nature. Factors limiting spread of the virus are not well understood.

One natural barrier to virus spread is hyphal fusion among individuals of the fungus. Hyphal fusion is necessary to transmit the virus. When hyphae can fuse and exchange material, they are said to be vegetatively compatible, and in the same **vegetative compatibility group**. In North America, we have more VC groups than they do in Europe, so getting the virus to spread around in nature is going to be difficult. But there is a lot of hope that it may yet succeed.

## Other Issues

Most forest pathologists like tree diseases. Generally, I would like to see a diseased tree more than a healthy one. Although human society generally has a goal of reducing such diseases, if the truth be told, sometimes we root for the pathogen, just because it's such fun to see a disease really do a job.

But chestnut blight is a different story. What it did to American forests is no joking matter. It's a tragedy. Noone who loves forests can think about the decimation of such a fantastic and abundant tree species as anything else. An informal article by George Hepting (Δ) gives some insight into the role of chestnut in American life as well as the chaos that ensued in scientific and political circles as society struggled to deal with the new disease.

There is an emotional hook there that other diseases just don't have. Even today, many years after the American chestnut was essentially wiped out as a forest tree, there are many ordinary citizens deeply interested in doing something to bring it back.

The reason there is little resistance in American Chestnut is that the pathogen was introduced. In 1904, the disease was observed in the New York Zoo killing chestnuts, but there is reason to suspect it was here as early as 1893 (Δ). The pathogen was later found to be native to China and was apparently introduced on nursery stock. In Asia the fungus was a weak parasite. In America, it spread very quickly and never met a tree it couldn't kill. It spread up to 50 miles per year over the natural range of chestnut.

By 1940, chestnut was destroyed as a commercial species. Today, incredibly, chestnut still survives in much of its former range, but only as sprouts from the old root systems. The roots and root collar are resistant. In many places, various oaks have replaced it. In the oak stands, you can hardly find chestnut. When the oaks are cut, fairly dense sprouts of chestnut pop up, trying to do their thing. But before they can get big enough to sexually reproduce, the damn disease cuts them down. They don't seem to stand much chance of adapting.

**Biotechnology and Genetic Engineering in Forest Trees**

**David E. Harry** and **Steven H. Strauss**

Department of Forest Ecosystems and Society

Oregon State University

Corvallis, Oregon 97331

david.harry@oregonstate.edu, steve.strauss@oregonstate.edu

As with agricultural plants and animals, technical innovations in genetics, genomics, and related disciplines are also being developed for forest trees. However, the nature of trees and forests, and the wider range of products that we expect from them compared to crops, creates new challenges and opportunities.

In addition to wood and fiber products, forest managers must also balance trade-offs in producing ecological and social services. Inevitably, controversy develops over management goals and technologies. This includes where, how, and *whether* genetic technology and breeding in any form is appropriate. The goal of this essay is to review forest biotechnology, with a focus on its most controversial form, genetic engineering (GE).

**Question: What is forest biotechnology?**

**Answer:** Forest tree biotechnology emerged during the 1980s and encompasses a developing collection of tools for modifying tree physiology and genetics to aid breeding, propagation, and research (Burdon and Libby 2006). As is described elsewhere in this series, biotechnology is not a single approach, but instead encompasses tissue culture, micropropagation, genetic engineering, and genetic markers. The same is true for biotechnology as applied to forest trees. Over the past two decades, these various methods have become increasingly sophisticated, but all are still considered under the larger umbrella of forest tree biotechnology (FAO 2004).

Of all biotechnology methods, genetic engineering has received the most attention and scrutiny by regulators and the general public. At least part of this is due to the nature of the technology itself — artificially recombining genes from different organisms and bypassing natural barriers to sexual reproduction. In addition, new biochemical or signaling pathways to increase stress tolerance, or new products such as novel bioproducts, can be engineered. The movement of genes using conventional breeding techniques is limited to sexually compatible species, usually close relatives, and new biochemical or signaling pathways cannot normally be bred, as these require very long periods of evolution to develop.

**Question: How does forest biotechnology differ from traditional breeding?**

**Answer:** Traditional breeding and biotechnology share many common goals, principles, and practices. Practitioners of both methods are working to enhance the overall health and adaptability of forest populations or to improve production of desired goods and services.

Rather than representing distinct approaches, traditional breeding and biotechnology are better described as encompassing an overlapping collection of tools. In general, traditional breeding relies more heavily on sexual crosses and observations of trait phenotypes, whereas biotechnology tends to encompass methods that require one or more laboratory- or greenhouse-intensive steps to provide more precision, or a wider range of outcomes, than could be obtained using phenotypic selection alone.

Forest biologists are applying biotechnology in forest trees because these methods can help save time, reduce costs, or accomplish new goals. For example, genetic markers are beginning to be integrated into traditional breeding programs to enhance genetic diversity, speed the notoriously slow rate of progress over generations, and to reduce the costs of selection. Other approaches, such as embryogenesis as a means of multiplication and amplification of the best performing clones, is seeing increasing use in conifer forestry.

**Question: To what extent is genetic engineering of forest trees underway?**

**Answer:** Genetic engineering of trees, like that of other plants and animals, involves isolating genes from one individual, asexually inserting them into another individual’s cell, and then coaxing that modified cell to regenerate into a new individual. In most cases, gene segments from different species have been manipulated and spliced together in the laboratory before inserting them into a recipient cell. However, as methods improve, genomic knowledge of a diversity of species grows, and GE may increasingly employ genes, with or without further modification, that have been obtained from the same or closely related species (Schouten et al. 2006).

The pace of gene discovery in many forest tree species has increased substantially due to technical advances in high-throughput genomic tools, including genome sequences (e.g., Tuskan et al. 2006, Grattapaglia et al. 2009). A key feature is that the asexual insertion process typically involves a small number of well-defined genes (one to a dozen). This contrasts with sexual reproduction in which copies of all genes, typically tens of thousands, are combined together following fertilization.

The first genetically engineered tree, reported by Fillatti et al. (1987), was developed by a team of scientists from the University of Wisconsin, the U.S. Forest Service, and the biotechnology company Calgene (now part of Monsanto). Since then, dozens of other forest tree species have been genetically engineered for research purposes, though none have seen commercial use in the U.S. Traits such as herbicide tolerance and insect resistance that have been widely used in commercial agriculture in the U.S. were also shown to be highly effective in field-grown forest trees. In China, genetically engineered poplar trees containing insect resistance (Bt) genes have been deployed that are very similar to those used in agricultural crops.

Wood-specific genes are of particular interest (Groover 2005). For example, early results altering lignin production (an important constituent of wood) demonstrated potential to reduce environmental impacts of pulp production (Pilate et al. 2002). There have also been a number of studies demonstrating modified wood properties useful for making pulp or ethanol, among other traits.

The only commercialized tree in the U.S. to date is papaya, a horticultural tree which was made virus resistant via GE methods; no genetically engineered forest trees have yet been commercialized. A virus-resistant plum tree has been authorized by the U.S. Department of Agriculture (USDA) and the U.S. Food and Drug Administration (FDA) and is awaiting final approval by the U.S. Environmental Protection Agency (EPA), and a cold-tolerant eucalyptus is now under consideration for commercial authorization at USDA. Both of these might not see widespread use for a number of years. The same general regulatory framework as applies for other crops also applies to genetically engineered trees; depending on the trait, one or all of the USDA, EPA, and FDA may be involved.

**Question: What are the expected environmental and economic benefits for genetic engineering of forest trees?**

**Answer:** The use of GE is often motivated by both economic and environmental goals. Herbicide tolerance should provide lower cost, more efficient, and less energy intensive means for weed control in plantations. Pest tolerance should improve yields, reduce product degradation, and in some cases reduce the use of pesticides. In other cases, GE can help protect or restore native trees in wild forests, such as following invasion of an introduced pest. Modified wood should reduce the energy and chemical requirements for processing wood into pulp and/or biofuels. Salt tolerance should allow trees to be established on poor, degraded lands. Trees engineered to take up or break down chemicals in the soil (bioremediation), may provide lower cost and less environmentally damaging ways to reduce toxicity of former industrial sites.

**Question: Are there environmental concerns associated with the genetic engineering of forest trees?**

**Answer:** More than ever before, forest practices are evaluated in the context of ecosystems, yet as the world’s population grows, forest lands will be increasingly asked to provide more from less (Salwasser 2004). One way to meet some of these demands is through intensively managed industrial forest plantations, where genetically engineered trees could play a large role (Sedjo 2003). Plantation forests often have low diversity in tree species and low overall biodiversity at some life stages, both of which are sometimes considered undesirable. To avoid confusion, it is desirable to discuss the direct effects of genetic engineering separately from the indirect effects of plantation systems. Here we focus on direct effects.

As with other kinds of tree breeding, genetic engineering introduces novel or modified traits that could have unintended effects. For example, herbicide tolerance may create problems in control of trees when they are considered weeds. Because most trees can spread in the environment, mostly through pollen and seeds, this can create problems outside the original target area. Because of the undomesticated state of most forest trees compared to most agricultural and horticultural species, they can spread and establish more readily. Forest trees can send pollen or seeds over considerable distances, often several miles (Smouse et al. 2007). Such undesired long-distance gene flow has already caused legal problems in other genetically engineered crops, such as bentgrass, alfalfa, and sugar beets. In recent litigation involving alfalfa and sugar beets, courts have ruled that failure to intensively consider economic impacts associated with gene dispersal violates the National Environmental Policy Act (e.g., Endres and Redick 2008). Thus, a precedent exists for similar controversies due to gene flow in forest biotechnology.

This propensity for gene dispersal in trees has prompted considerable effort to use genetic engineering to produce trees that flower poorly or not at all (Brunner et al. 2007). Whereas some field-grown poplars and eucalypti have shown dramatically reduced male fertility, most efforts to reduce fertility are still at an early stage. With proven technologies available today, fertility can be drastically reduced but not eliminated entirely. Thus, some gene flow is likely to occur, and the persistence and effect of introduced genes over time will depend on their initial frequency and how they affect the viability or competitive ability of progeny (Ellstrand 2006).

The uncertainty of future evolutionary and ecological effects creates enormous challenges for risk assessment and thus regulatory decisions. Though similar uncertainties exist for other kinds of breeding as well, these are unregulated due to their long-standing public and legal acceptance.

Other potential concerns include:

1. Persistence in the field. Whereas most agricultural crops are annuals, trees are typically long-lived, and species such as poplar and eucalyptus often vigorously resprout after they are cut. This longevity can be problematic if plants need to be removed, whether they are genetically engineered or not.

2. New traits such as modified wood can also have unforeseen side effects, such as reduced vigor under stress. In conventional breeding, the alleles under selection have already undergone some degree of natural selection, and thus are less likely to have large deleterious effects on tree health than are the new alleles produced by genetic engineering. However, it must also be realized that just because an effect is unintended doesn’t mean there is a safety concern.

3. Genes that enhance stress and pest tolerance could be advantageous for trees outside of plantations, helping them to establish in the wild. So although these traits might provide environmental benefits by helping forests thrive, some scientists are concerned that such increased vigor or new forms of pest resistance might also have undesired effects, such as by reducing populations of nontarget insects valued for biodiversity.

**Question: Does genetic engineering of forest trees offer unique advantages for improving forest health?**

**Answer:** Genetic engineering can offer a unique tool to manipulate how plants grow, what they might produce, or how they respond to stress. Because GE circumvents sexual barriers, novel genes can be introduced from virtually any species, or they can be newly created or modified based on fundamental scientific principles. In some instances, such as resistance to certain introduced pests, it may be impossible — or extremely slow and difficult — to find a source of innate genetic resistance within a species or its sexually compatible relatives. It may be that genetic engineering is the only practical way to introduce resistance genes in a useful time frame.

With pressures from factors such as an increasing global economy and climate change, the threats of exotic pests and climate stresses are growing ever more significant; there are literally dozens of major forest tree species under serious threat throughout or in some parts of their ranges (Strauss et al. 2009a). Seriously threatened species include elms, ashes, dogwoods, beeches, oaks, maples, and firs.

The chestnut blight in North America is a striking example. No resistant American chestnut trees have been found since the disease was introduced to America in the early 1900s. Even after many decades of interbreeding with Asian species, resistant hybrids are only now starting to be released, and are unlikely to have the full set of resistances and environmental adaptation needed for long term survival over American chestnut’s former wide range. A combination of approaches, including genomics, cloning of the best trees, and genetic engineering is providing renewed hope that fully resistant trees can be developed (Wheeler and Sederoff, 2009).

**Question: Apart from its use for breeding, is genetic engineering a powerful scientific tool?**

**Answer:** Genetic engineering is the most powerful tool for studying gene function in biology today, including forest trees. For example, GE can be used to manipulate the level or timing of gene expression with specificity and precision that is not provided by any other approach. Armed with a more thorough understanding of gene function, scientists can modify the frequency of different natural gene variants (alleles) with conventional breeding that is augmented by genetic markers. Thus, genetic engineering, used only as a tool for research, can substantially augment breeding by the insights it can provide.

**Question: Despite their value, why are there no commercialized genetically engineered forest trees?**

**Answer:** Several factors have contributed to delays. First, in many tree species the methods for gene insertion and regeneration of healthy trees do not exist, or are too slow and costly to develop for each desired variety. For many desired traits, the causative genes are unknown, or the traits are too complex to modify with one or a few genes, given current knowledge.

Moving beyond a greenhouse to outdoor studies is essential to understand the ecological impact and value of newly inserted genes, but securing approval for such studies from USDA’s Animal and Plant Health Inspection Service (APHIS) has become increasingly costly and difficult, especially for university and other public sector scientists (Strauss et al. 2009b). Complete containment of all pollen and seeds from large trees during such studies is especially problematic.

Finally, for many companies the economic benefits are unclear when all costs and the long time frame for trees are considered. There is also real concern that marketplace restrictions, such as the Forest Stewardship Council certification scheme that excludes all genetically engineered trees, even when used in contained and environmentally motivated field research, will prevent sale of the products in desired markets (Strauss et al. 2001).

**Question: What is the future of forest biotechnology?**

**Answer**: There is a great deal of progress being made on the use of non-genetically engineered techniques in commercial breeding, especially cloning methods and genetic markers. The main limits appear to be economic rather than biological. Reduced costs of sequencing and genotyping, coupled with dramatic increases in throughput and efficiency, have resulted in rapid progress in non-genetically engineered applications in biomedicine as well as in plant and animal agriculture. We also expect expanded application of these techniques to forest trees.

There is currently limited investment in genetic engineering applications outside of a small number of companies and a few public researchers, primarily because of the regulatory and market acceptance issues discussed above. Likewise, regulatory issues are also causing large problems in agriculture. Existing regulatory processes are being reexamined, and are expected to change considerably in upcoming years. What should arise from this is a balance that stresses that actual benefits as well as actual risks. Still, the nature of change and its effects on research investment and commercial uptake are likely to be the main drivers of GE development in forestry. Increasing food, water, and fiber shortages associated with population growth and climate change, and the consequent stresses on ecological and social systems, may compel greater acceptance and less strident forms of regulation.

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|  | A row of non-transgenic and transgenic cottonwoods in a research trial in Oregon. The transgenic trees were highly resistant to the cottonwood leaf beetle due to expression of a cry3a type of *Bacillus thuringiensis* endotoxin gene.  Transgenic poplars in plant tissue culture undergoing propagation. These plants are ready for transplanting to soil for further growth and outplanting. |
|  |

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Recommended Research Websites

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2. NC State University- Forest Biotechnology- <http://www.ncsu.edu/project/forestbiotech/>
3. The American Chestnut Foundation- [www.acf.org](http://www.acf.org)
4. Environmental Protection Agency- [www.epa.gov](http://www.epa.gov)
5. Teacher’s Domain- video <http://www.teachersdomain.org/resource/ket08.sci.life.gen.amchestnut/>
6. US Forest Service- TreeSearch (publication search)- <http://www.treesearch.fs.fed.us/>
7. US Dept. Of Agriculture- Forest Service- <http://www.srs.fws.usda.gov/>
8. Powerpoint by Ron Sederhoff of NCSU- <http://www.forestbiotech.org/pdf/Fagacea_Genomics_American_Chestnut-Ronald_sederoff.pdf>
9. Invasive Species- [www.invasive.org](http://www.invasive.org)
10. Genetic Engineering and Biotechnology News- <http://www.genengnews.com/>

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