Opening Pandora's Box: Governance for Genetically Modified Forests

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Planting genetically modified (GM) or transgenic forest trees for wood production is now feasible on a commercial scale worldwide. What are the benefits? What are the risks? This became an open question two years ago on December 10, 2003, when the United Nations declared that every sovereign nation should decide on its own whether or not to use genetically modified forests for carbon sequestration.

Although feasible on a commercial scale, we are still in the early stages of GM technology for forest trees. Some of the major determinants shaping risks of commercial-scale use include type(s) of inserted DNA construct or transgene,[1] but also 1) reproductive biology of the forest species, and 2) the forest production or silvicultural systems.[2] To date, GM forest trees are being tested in small trials worldwide. Only China is planting GM forest trees on a commercial scale.

Central to the issue of GM forest trees is the question of biosafety. Will effective biosafety protocols eventually become available, or should we accept that escape of GM forest trees is inevitable and study ecological consequences instead? Here I present the argument for the latter and propose a public-private partnership for this purpose, a technology trust.

Commercial GM Forests: Predicting the Long-term Consequences

Each nation sanctioning genetically engineering forest trees must decide 1) what biosafety protocols should be considered, if any, and 2) weigh the consequences in the event that gene flow from GM forest plantations to the surrounding forest is not deterred. Two opposing schools of thought are emerging in response to these two queries. The first is the Biosafety Premise, which ascertains that effective biosafety protocols will eventually be possible for GM forest trees. The opposing view, the Ecological Premise, is that transgene escape into the indigenous forest is inevitable, so studying ecological consequences deserves a higher research priority than continuing research leading to better biosafety protocols. Each nation must also consider the lengthy timeframe inherent to forest policy. To quote poet Wendell Berry: “Invest in the millennium. Plant a sequoia.” Here we are reminded that the impact of GM commercialization, whether harmful or not, will outlast a human life span and certainly extend well beyond the purview of regulatory oversight.

Biosafety Premise: Biosafety measures can prevent transgene escape from GM forest trees

In the U.S. and Canada, regulatory agencies now recognize that one set of regulations do not fit all plants. GM forest trees are only one of many examples that require customized guidelines. Consider the case of biocontainment zones commonly used for GM crop plants. The width of the biocontainment zone around the transgenic planting is usually determined by gene flow data collected experimentally,[3] but the distance for wind-pollinated conifers occurs on the scale of kilometers that is too vast to be deterred by a biocontainment zone around the GM planting. Using detailed model simulations of pollen and seed trajectories in a turbulent atmosphere shows that escape of seeds or pollen beyond a 1-kilometer periphery of the transgenic planting has a 100% certainty.[4,5] Biosafety for GM conifers will not parallel protocols used for GM agricultural plants.

At the heart of the biosafety issue for any GM forest species is the question of how to manage for long-distance dispersal (LDD). Preliminary model simulations show that, although local neighborhood diffusion (LND) accounts for roughly 99% of the seeds and pollen, the dispersal process of real interest is LDD, which accounts for dispersal of the remaining 1%. With long-distance dispersal, seeds and pollen are vertically uplifted above the canopy by updrafting air currents, where they are rapidly moved on the order of kilometers from the source.[5] Transgene escapes via LDD pose the greatest risk of remote GM colonization for forest trees.

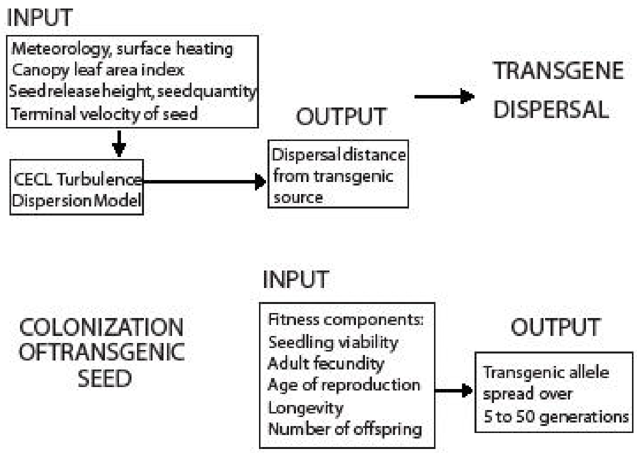

Figure 1. Schematic diagram showing the variables and the outputs for two sets of predictive models. The first model predicted for local neighborhood dispersal (LND) and long-distance dispersal (LDD) for genetically modified (GM) *Pinus taeda* seeds in the southern U.S. The second model used population genetics theory to predict colonization rates of GM seed escapes into surrounding ecosystems.

Models predicting LDD distances for *Pinus taeda* (**Fig. 1**) not only predict dispersal distances but also point to some testable hypotheses germane to developing biosafety protocols. Proponents argue that this type of research is too preliminary to be conclusive. Consider the following four caveats as indications of how much more research still remains to be done on GM forest biosafety.

1) Published LDD predictions and associated diffusion rates for GM colonies[4,5,6] (**Fig. 1**) model dispersal from the GM source into a continuous forest canopy composed of the same species at the same age and height. This means that LDD predictions cannot be extrapolated accurately to the case where the GM planting is surrounded by a taller forest canopy at its periphery. Using old-growth forests as a biocontainment zone around a commercial transgenic plantation is an interesting but untested hypothesis for reducing transgene escapes. This complex scenario could be modeled using mechanistic approaches but reducing, not deterring, gene flow from GM trees is the likely outcome.

2) A lower volume of dispersed seeds and pollen corresponds to a drop in the absolute number of LDD escapes. If number of LDD escapes is the risk criterion, one could hypothesize that even leaky reproductive sterility methods can provide an acceptable biosafety protocol. Absolute suppression of reproduction may not be needed. If so, how low must diaspore volume drop before LDD escapes fall below an acceptable level? How does one determine the acceptable level? The leaky mitigation hypothesis can also be addressed using mechanistic models coupled with gene flow models. Here, too, the argument is for reduced gene flow, not an absolute deterrent.

3) LDD predictions are so specific to the mating system particulars of each forest tree species that this question must be considered on a case-by-case basis. To date, dispersal distance and colonization predicted for GM seedlings are specific to the mating system of one forest tree species, *Pinus taeda*. But all forest trees are not wind-pollinated; some plantation species are insect-pollinated or even self-pollinated. Even among wind-pollinated pines, some require fire for seed dispersal. Age of reproductive onset varies widely among commodity forest species, as does the volume of seed and pollen dispersed each year. Many forest tree species produce a high number of empty seeds due to physiology or pest predation. In any event, predictions of LDD numbers are sensitive to these input variables (**Fig. 1**) from each species' mating system, so generalizations from one commodity species may not apply to each species in question. Gene flow modeling is needed over a wider range of species.

4) Dispersal is only the first part of the gene flow equation. We still do not know much about actual gene flow via LDD at this time for any forest tree species. LND dispersal distance has a close corollary to average gene flow distances reported using organellar markers, so LDD, as a rare event, goes undetected in most experimental gene flow studies. Escaped LDD pollen can travel long distances for many hours or even days, so it is subjected to harsh conditions during flight. What is the viability for LDD pollen? Is it capable of germination or even fertilization? Experimental data on viability along

these intermediate steps are needed before dispersal distances can be translated into actual gene flow estimates.

Ecological Premise: Emphasis should be on ecological consequences, not deterring GM escape

Proponents here argue that gene flow from GM plants is inevitable so research funding should be directed away from developing sophisticated methods of mitigating transgene dispersal and re-allocated to the study of ecological consequences of transgene colonization.[7] Similarly, Canadian regulatory agencies also view transgene escape in forest trees as inevitable,[8] and once the escape of transgenes has occurred into feral forest tree populations, it cannot be reversed. If biosafety protocols prove futile given the scale of gene flow from certain GM forest commodity species then only two choices remain: 1) abandon the GM technology for forest trees; or 2) opt for deregulation of GM forest trees.

Indeed, some nations may decide that a moratorium on GM forest trees is the best fit. For others, pressure to deregulate GM forest trees will come from the market place if GM technology is viewed as a critical part of the portfolio for preserving national competitiveness in global markets. Plantations do provide a disproportionate share of the world's wood relative to the land area they occupy, so here the relevant ecological question becomes whether transgenic forest plantations, justified as a means of sparing timber harvests in more fragile forested ecosystems, will do harm to the very resource they purport to protect.

Despite market forces, deregulation must be balanced against the impact of transgene escapes on small family forests that surround larger corporate forest plantations. In the U.S., it seems doubtful that even the most affluent of the family forest owners will be early adopters of transgenic seedlings for their own forest regeneration, but with deregulation these owners will have to contend with the unknown consequences of transgene escapes coming from adjoining plantations. Transgenic effects of GM forest trees, once released, constitutes a Pandora's Box. Will the effects be beneficial, benign, or harmful? This unanswered question is troubling for those who seek deregulated use of transgenic pine plantations and the question is deeply disturbing to those who view the forest as symbolic of nature itself.[a]

Studying ecological consequences of deregulation implies a short timeframe for detecting transgene effects, whether good, neutral, or bad. By favoring short timeframes for research, we must overlook evolutionary consequences as a criterion for decision-making. Consider the following example. Pines, among the oldest seed plant lineage on earth, have persisted for nearly 200 million years. Few advocates of GM pine plantations in the 21st century have considered this decision from the perspective of evolution. Many pine species have an open-ended hybridization system, so conditions can favor indefinite persistence of transgenes in groups of neighboring or sympatric species, also known as species complexes.

Species complexes with a reticulating, open-ended fate of hybrids, known as the homogamic hybrid system, occurs in several forest tree species.[9] From this system, one can predict the conditions that will lead to a persistent fate for any transgene. A DNA construct or transgene escapes from a transgenic pine plantation into sympatric populations of a closely related species. Interspecific hybrid adults are fertile and readily cross not only with the original parent species but are also capable of hybridizing with other related species. The transgene can persist indefinitely under two conditions: 1) if the transgene confers a positive selective advantage; or 2) if the transgene is selectively neutral within a large random-mating population.

In some cases, deregulation will result in a sharp tradeoff between meeting global wood demand while ignoring unknown ecological (and evolutionary) consequences. A better alternative is proposed here: form a public-private partnership or a technology trust for studying ecological consequences of GM forest trees.

A Caveat to the Ecological Premise: A Technology Trust

An alternative to deregulation is to form a technology trust—a short-term regulatory solution for collecting data on risks and benefits.[2] The technology trust, formed as a public-private research partnership has three parts: 1) a subset of transgenic forest field tests designated as long-term study sites for collecting relevant data for sound benefits and risk analyses; 2) a technology tax on transgenic forest field testing which carries a hold-harmless provision to the payee or protection against future liability claims; and 3) formalizing a federal gene conservation program as a hedge against molecular domestication of forests. Relevant data on benefits and risks would be openly available and published in peer-reviewed journals. The technology trust would thus provide a platform for public dialogue about emerging technology. The proposed technology trust could be designed and run with scientific oversight from government, university, and private-sector research organizations.[2]

The main advantage of a technology trust is that it provides experimental data. It protects national forests against risks inherent to molecular domestication on private lands. And it opens public dialogue on the risks and benefits associated with for-profit research in long-lived forests. The latter is important in the U.S. and other developed nations where private investment is funding the creation of novel GM trees at a rate that is outpacing biosafety and scientific assessment of ecological impact. In the case of the U.S., no platform for public dialogue has been formalized, yet this nation is the world's most powerful advocate for biotechnology advance.

In summary, using GM technology for forest trees is raising controversy but this is the least of genomics-based technology yet to come. Using a snippet of DNA inserted into chromosomes of naturally-occurring plants and animals is only the beginning, not the finish, of the controversy. Compare this recombinant DNA technology to the commercial potential of synthetic DNA genomes. With new technology looming in the future, now is the time to center dialogue on the real question behind the controversy of GM forests, a question which has no parallel in medicine or agriculture biotechnology: what are the limits to our biotechnology governance in the natural world? Will we protect fragile ecosystems at the interface with production forests? At the very least, a technology trust is essential for shaping the fate of the forest itself—and a necessary part of the portfolio for any nation deciding to go forward with the use of GM forests for carbon sequestration.

[a] On November 10, 2005, the Global Justice Ecology Project and the STOP GE Trees Campaign announced the release of *A Silent Forest: The Growing Threat, Genetically Engineered Trees*, a 45-minute documentary narrated by Dr. David Suzuki, host of PBS *The Nature of Things*.

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