Forest Scientist Views of Regulatory Obstacles to Research and Development of Transgenic Forest Biotechnology

Steve H. Strauss, Mikaela Schmitt, and Roger Sedjo

ABSTRACT

Despite many dozens of research projects, hundreds of field trials, and a long commercialized fruit tree, virus-resistant papaya, there continues to be very little public or private sector activity in the United States that is directed toward development of transgenic forest trees. We therefore undertook a survey of scientists knowledgeable in forest biotechnologies, breeding, ecology, and regulation to assess if they believed that the regulatory regime in the United States presents a significant obstacle to research or commercial development. Conducted in 2007, there were a total of 90 respondents (60% response rate) from throughout the United States. The large majority believed that regulations, in particular containment requirements during field evaluation, posed significant obstacles to development. Top priorities for research included development of gene containment methods and field studies of wood and abiotic stress modification. Priorities for regulatory reform included development of a tiered system and provisional authorizations to enable long-term field research.

Keywords: genetic engineering, genetic modification, tree biotechnology, genomics, survey

Genetic engineering (GE), commonly called genetic modification (GM), and the resulting organisms (GEOs, GMOs, and transgenics), are defined in science and regulation by the process used to produce them (Irwin and Jones 2006). They contain genes that have been inserted or modified via an asexual rather than a sexual process, and the sources of genes can be from the modified organisms, similar organisms, or from distant organisms. Typically, the genes have undergone some form of human-directed modification using recombinant DNA methods before insertion. GE methods are routine throughout all genetic biology and have been used to produce large numbers of pharmaceuticals, industrial enzymes, and several forms of GE crops that are now widely grown throughout the world (International Service for the Acquisition of Agri-biotech Applications 2008).

The only trees that have been authorized for commercial purposes are a virus-resistant papaya in Hawaii and insect-tolerant poplars in China. A virus-resistant plum has recently been deregulated by the USDA, but awaits decisions from the Environmental Protection Agency (EPA) and the USDA (Scorza et al. 2008). In the United States, the extent of field research in GE trees—a good indicator of applied, developmental research—has become highly restricted, being limited to a few academic laboratories and companies (Information Systems for Biotechnology 2008). There had been numerous confined field studies with the large majority in the USA; as of January 2008, *Populus* led all other genera with 189 authorized field tests. The traits studied included herbicide tolerance, insect resistance, disease resistance, improved growth, modified form, reduced fertility, heightened stress tolerance, and enhanced phytoremediation. In addition to the traits with direct environ-

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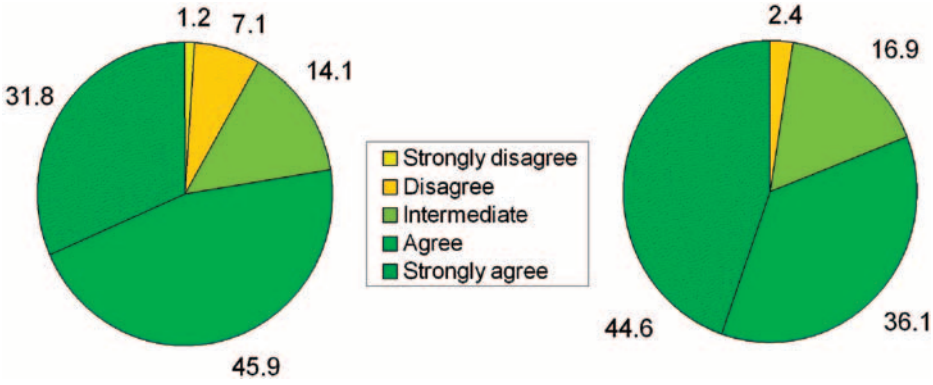

Figure 1. Effect of regulation on research and commercial development. Respondents were asked, "For the following statements, possible answers were strongly disagree, disagree, unsure, agree, or strongly agree. (A) Regulatory requirements pose a substantial obstacle to field research on GE trees. (B) Regulatory requirements pose a substantial obstacle to commercial development and breeding with GE trees."

mental benefits, many of these traits also support the goal of improved productivity as a continuing means to improve both the economic and the environmental output by reducing the land requirement for plantation forestry (Victor and Ausubel 2000). It is therefore reasonable to assume that many GE traits may have broad environmental as well as economic value to companies and society.

The goal of this study was to ascertain the degree to which the knowledgeable scientific community believes that regulatory requirements present a significant impediment to field research and commercial development, and why. Toward this goal, we targeted a broad-spectrum of the relevant scientific community, largely in the United States, that is familiar with forest tree genomics and biotechnology, including breeding, biology, ecology, and regulation. We report that a large majority believe that regulations in the United States pose substantial barriers to research and commercial development.

Materials and Methods

We sent up to three e-mail requests to 151 scientists in the United States and Canada in the summer of 2007 that were known from the literature, participation in meetings, and professional contacts to be knowledgeable about the science or regulations concerning tree biotechnology. A total of 88 were at universities, 30 were in government, and 33 were in the private sector. We included a few Canadians because of their expertise and the functional similarity of the United States and Canadian systems, which are harmonized in a number of respects. We sought a broad-spectrum of expertise, including scientists for whom applications of GE trees were not their goal, but that are familiar with the underlying genetic methods. This included forest tree breeders, ecologists, physiologists, genomics scientists, and some crop biotechnologists familiar with GE regulatory issues in forestry. The survey was administered by the use of an online form using "surveymonkey" software (www.surveymonkey.com/). There were 37 survey questions, including questions to help us understand the level and kind of expertise of the respondents, and their broad views on regulation and research needs (online Appendix I, RFF 2009). For 37 respondents who indicated willingness on the survey, we followed up the web-based questionnaire with a short telephone survey to enable them to more fully describe their views.

Results

Nature of Surveyed Population

A graphical summary of responses to all questions is provided online (online Appendix II, RFF 2009). There were a total of 90 respondents (59.6% response rate), of which 60 were at universities (66.7% response rate), 10 were government scientists (11.1% response rate), and 20 worked in private institutions (22.2% response rate). We were informed that the low response rate by government scientists was the result of an administrative decision by the USDA, who recommended that their scientists not take part in the survey to avoid possible embarrassment with respect to their knowledge of regulations. A total of 50 organizations were represented, including 28 academic organizations, 15 companies, and 7 government agencies (2 from Canada). The highest level of education for most was a PhD (92.1%), with a minority having a Masters (6.7%) or BS (6.7%). Most respondents were men (80.0%), which seems representative of the composition of the profession as a whole, and most were between the ages of 40 and 59

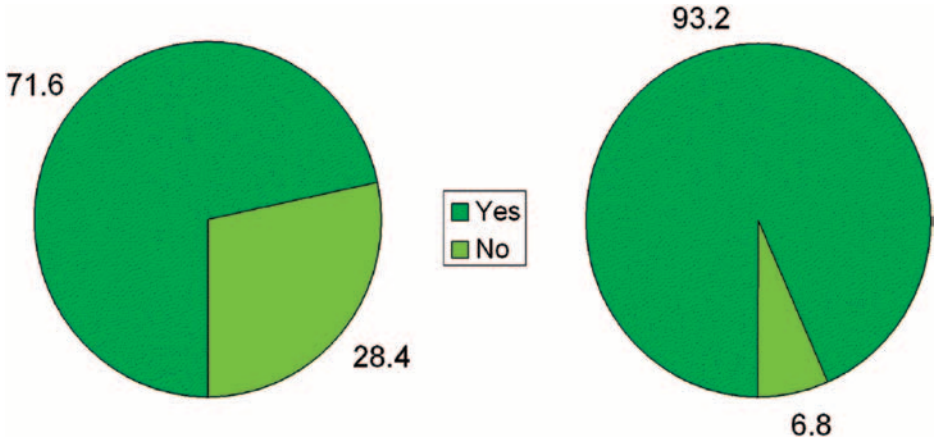

Figure 2. Containment requirements as regulatory obstacles. Questions asked were "(A) Do you believe containment requirements have an adverse impact on the continued research and commercial development of GE forest trees? (B) Under current regulations, all GE-imparted traits are precluded from release into the environment during field research, regardless of their effect on fitness or tree characteristics. This makes research with many kinds of species and environments difficult or impossible, or requires harvest when trees are still young (i.e., before flowering). Do you believe that a system that provided different confinement requirements during research for different kinds of genes and their associated traits (based on expected familiarity/safety) would significantly reduce regulatory burden?"

years (83.1%). Just over one-third (38.1%) indicated a "main area of research" was "transgenic plants"; a slightly lower proportion (32.1%) worked on "plant genomics and nontransgenic biotechnology"; and the remainder were those working in "ecology/ecophysiology" (14.3%), "breeding" (11.9%), and "regulation or administration" (3.6%). Of the respondents, 73.0% "use DNA methods (molecular genetics) in their work." Twenty percent indicated membership in one of the major national environmental organizations, and 47.1% indicated membership in professional forestry and/or agriculture organizations. There were 90.7% who correctly understood that methods such as "*Agrobacterium*" are not "commonly included under conventional tree breeding," and 98.9% correctly indicated that tools such as "genetic transformation" are "commonly included under genetic engineering." The large majority (95.3%) correctly answered that there are no "legal commercial-scale plantings of GE forest trees in the USA," and 90.1% knew that "scientists are required by regulations to prevent the dispersal of viable GE [organisms] into the environment" during research.

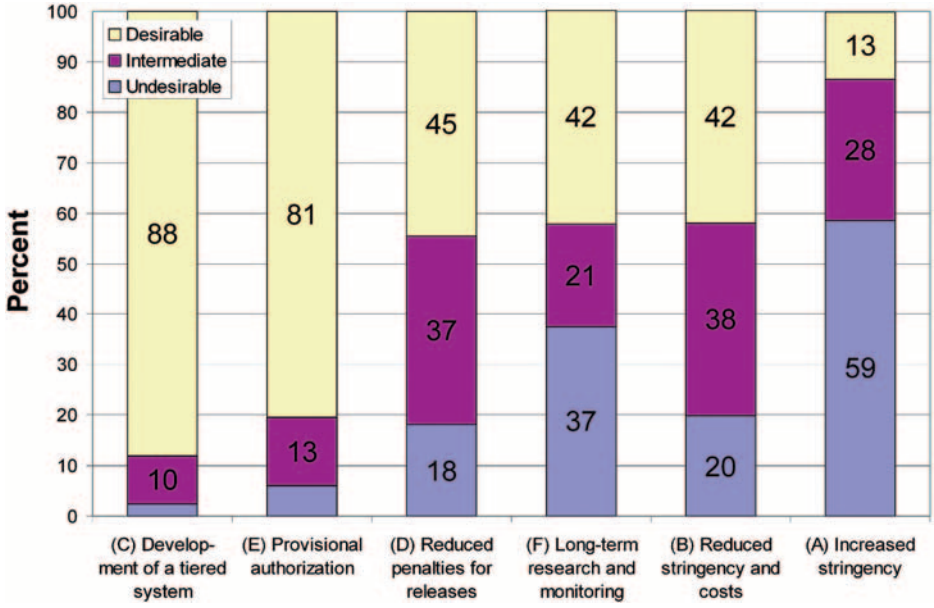

Figure 3. Desired changes to regulations. Respondents were asked "Which of the following are regulatory changes do you believe are needed. Rank list below as highly undesirable, undesirable, neutral, desirable, or highly desirable. (A) Increased stringency at all levels to avoid mistakes like in the past with GE plants; (B) Reduced stringency and costs at all levels so more research and companies are attracted to the area; (C) Development of a tiered system that, for example, adjusts the stringency of regulations to consider such factors as previous experience or familiarity with the genes to be introduced and the source of such genes (e.g., those derived from trees or plants), and yet maintains stringent regulations for novel and risky genes and products (e.g., new medical or industrial compounds produced in trees, or new pesticidal substances); (D) Reduced penalties for small releases from field experiments so that the legal risks to researchers do not prevent long-term ecological and economic research through the flowering age of trees; (E) Provisional or limited authorization (e.g., limited area and duration of planting) so that commercial activities with low to moderate risks can go forward; (F) Requiring long-term research and monitoring activities to answer ecological questions not feasible to study in short-term or small-scale research experiments prior to any deregulation." Percents for "undesirable" in A and B are 2.4 and 6.1, respectively.

Views on Regulations

A small minority (2.3%) of the respondents indicated that they "believe that the PROCESS of GE imparts large risks." In contrast, most (95.3%) responded that the risks are "product specific." A large majority (77.7%) of respondents agreed or strongly agreed with the statement that "regulatory requirements pose a substantial obstacle to field research on GE trees." When essentially the same statement was provided but with respect to "commercial development and breeding with GE trees," the majority grew stronger, with 80.7% agreeing or strongly agreeing and only 2.4% disagreeing and none strongly disagreeing (Figure 1). To help understand these responses, we asked about whether the need for strong containment is a significant factor. Nearly three-quarters of the respondents (71.6%) indicated that they believed "containment requirements have an adverse impact on the continued research and commercial development of GE forest trees," and 93.2% believed that "a system that provided different containment requirements during research for different kinds of genes" would significantly reduce regulatory burdens (Figure 2).

When asked about several "regulatory changes you believe are needed," large majorities indicated that it would be desirable to see the "development of a tiered system" (88.0%) and "provisional authorization" to allow commercial activities with low to moderate risk to go forward" (80.5%). The full text of the former reads, "Development of a tiered system that, for example, adjusts the stringency of regulations to consider such factors as previous experience or familiarity with the genes to be introduced and the source of such genes (e.g., those derived from trees or plants), and yet maintains stringent regulations for novel and risky genes and products (e.g., new medical or industrial compounds produced in trees, or new pesticidal substances)." A small minority considered that increased stringency was desirable (13.4%; Figure 3).

To attempt to understand the extent of bias introduced into the results from those who are actively studying GE plants as a main area of research versus other scientists who are not working on transgenic applications but know DNA methods, we segmented the population into two parts based on answers to questions 12 (only those who said they used DNA methods in their research were included in this analysis) and 9 (main area of research—"transgenic" was compared to other categories). We considered these classes as the knowledgeable "GE practitioners" versus the knowledgeable "nonpractitioners." The views about the obstacles provided by regulations were very similar among the two groups; however, as expected, the practitioners tended to more often "strongly agree" versus to simply "agree" that regulations pose "substantial obstacles" to research and to commercial development (online Appendix III, RFF 2009).

Views on Relevant Research

Because GE is a young technology and its underlying science of molecular and

genomic biology is also rapidly expanding, we asked what were the "main changes in research activities that you think would be required if the goal was to promote application-oriented research and commercial development in the use of GE forest trees." Twelve options were provided, and their ranks are shown in Figure 4 and detailed responses are provided in Table 1. Nearly all the areas had substantial ratings, indicating the wide recognition that research is needed across the full spectrum of options; all but one area had ratings at or above 50% for high to very high priority. The area that had the highest overall favorable rating as well as the highest rate of "very high" ratings was "sterility/containment options and efficiency." Not far behind in Table 1 were field studies of value from modified wood (f, i), improved abiotic stress tolerances (f, vi), gene transfer/regeneration efficiency (c), and translational genomics based on GE methods (a). The two areas with the highest "high priority" scores were improved abiotic stress tolerances (f, vi) and improved reliability of gene expression (d). However, there was a nearly continuous range of rankings among all the choices. The area with the lowest ranking was that of using forest trees as bioreactors, although it still had a combined priority of 40.9%.

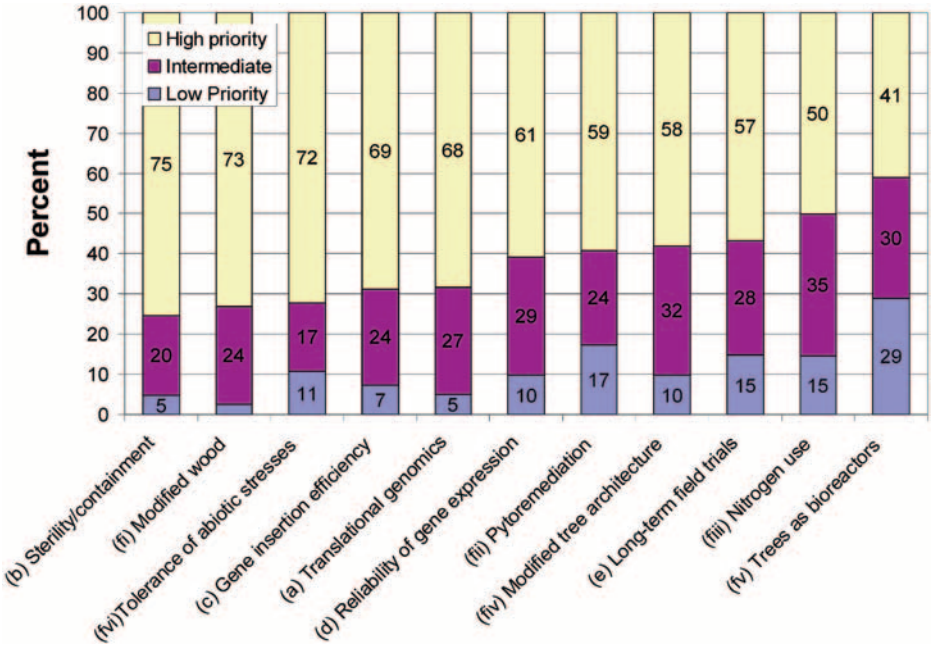

Figure 4. Research priorities. Respondents were asked "What are the main changes in research activities that you think would be required if the goal was to promote application-oriented research and commercial development in the use of GE forest trees. Rank the following areas as very low priority, low priority, intermediate, high priority, or very high priority." The value for low priority for "(fi) modified wood" was 2.4%.

Views on Overall Constraints

To try and put GE and regulations in a broader perspective, we asked, "what is the main constraint . . . that limits broader application-oriented research and commercial development of GE trees." Six areas of a total of 20 were ranked as of high concern (above 50%; Table 2 and Figure 5). Of note is the importance of cost as an important constraint. "Regulatory costs and uncertainties at the commercial release level" was ranked number one as the highest area of concern (65.7%). Other costs include the "high costs of field research with GE trees" (58.6%), "high cost of laboratory/greenhouse, and associated genomics studies, to support application-oriented GE research" (54.3%), and "regulatory costs and uncertainties at the field testing level" (52.2%). The other areas of highest concern were "legal and liability risks from unintended release" (60.0%) and "marketplace rejection or trade concerns" (55.1%).

To help put the risks from GE in context with broader kinds of genetics-associated risks of plantation forestry in the United States, we asked about the relative risks of different kinds of intensive plantation systems (Figure 6). In three of four cases presented, the largest category was "case dependent," indicating that risks of GE trees compared with other kinds of risks depends on the specific genes and systems. However, only a slim or near majority (49–53%) chose this option. One-quarter to one-third believed the risks were equivalent. The use of exotic and interspecies hybrids, however, gave a lower rate of case dependency (38.6%), and more than one-third considered the risks of GE to be lower than for exotics or hybrids (also 38.6%).

Finally, to assess scientific judgment of the practitioners versus the nonpractitioners about the appropriateness of regulatory requirements, we asked if regulatory requirements for research or commercial use are too demanding (online Appendix IV, mentioned previously). The two groups were very similar with respect to research, with the exception that only a significant number of nonpractitioners (19%) disagreed that the regulations were too demanding. The differences were more striking with respect to commercial use, where very few nonpractitioners strongly agreed that regulations were too demanding (13%) compared with practitioners (55%), and a substantial fraction (31%) disagreed that they were too demanding whereas only 2% of practitioners did.

Discussion

Because of the complex nature of the technology and regulations and the many possible views regarding GE science and technology, we did not attempt to survey all scientists or the general public. Instead, we targeted a large number and diverse array of forest science practitioners that should be knowledgeable about genetics and biotechnology. The survey responses suggested that we came close to our target. The response rate was good and there was considerable diversity in the organizations represented. The respondents were also technically sophisticated; most had PhDs and their responses to questions on regulation, breeding, and GE methods showed they understood the issues and survey questions, and could thus provide scientifically meaningful answers.

The survey suggested that containment is a difficult regulatory hurdle. Interestingly, the responses show that those surveyed understood that this issue is far simpler to deal with at the field trial level, likely because some meaningful data can be realized before the experimental plot is destroyed at an age mandated by regulatory permits to prevent flowering. This makes containment easier to accomplish for trees with their multiyear delay in onset of reproduction than it is for most agricultural crop species, where repro-

Table 1. Desired potential research to promote GE applications, in response to "Q32. What are the main changes in research activities that you think would be required if the goal was to promote application-oriented research and commercial development in the use of GE forest trees. Rank the following areas as very low priority, low priority, intermediate, high priority, or very high priority."

Answer options	Priority (%)						
	n	Very low	Low	Intermediate	High	Very high	Priority ranking
a. "Translational genomics" studies on how to produce valuable traits with GE methods based on genomics information (gene sequence and expression databases)	82	0	4.9	26.8	**43.9**	24.4	5
b. Sterility/containment options and efficiency	85	1.2	3.5	20	**41.2**	34.1	1
c. Gene insertion and plant regeneration efficiency so more genotypes and species could be affordably modified; in addition, more complex gene constructs and specific insertion of DNA into tree DNA could be accomplished.	83	0	7.2	24.1	**39.8**	28.9	4
d. Improved reliability of gene expression to reduce testing periods	82	0	9.8	29.3	**46.3**	14.6	6
e. Increase long-term field trials to promote regulatory agency comfort with data from short-term field trials	81	3.7	11.1	28.4	**38.3**	18.5	9
f. Field studies to estimate value and thus improve the "benefit/risk equation" considered by regulators, such as of (rank each below):	69	2.9	5.8	29	**42.0**	20.3	—
i. Modified wood/lignin to promote pulping/biofuels	82	0	2.4	24.4	**42.7**	30.5	2
ii. Improved ability to detoxify chemicals in the environment	81	3.7	13.6	23.5	**39.5**	19.8	7
iii. Improved ability to use nitrogen and other fertilizers for increased growth	82	0	14.6	35.4	**37.8**	12.2	10
iv. Modified crown form and tree architecture to promote yield, product quality, and carbon sequestration	81	0	9.9	32.1	**43.2**	14.8	8
v. Production of new compounds using trees as bioreactors (enzymes, biological plastics, new fuels, vaccines)	83	8.4	20.5	30.1	**33.7**	7.2	11
vi. Improved tolerance of abiotic stresses such as from salt, drought, and heat	83	0	10.8	16.9	**47.0**	25.3	3

The *n* column represents the number of participant responses. Bolded numbers represent the maximum response count. The priority ranking column represents the addition of "very high priority" and "high priority" responses, with 1 being the highest priority, and 11 being the lowest priority.

duction to seed or fruit is essential for most research evaluations. Pollen and seeds from agricultural crops can move and mix with non-GE crops or wild/feral plants, establish in seed banks, or be mishandled by humans. The vast majority of tree field trials are therefore removed after one or a few years to avoid these risks of spread. Because seeds and pollen from flowering trees can move very far because of wind, water, or animal vectors (Slavov et al. 2004), the regulatory system stringently filters applications where flowering might lead to establishment or mating with wild relatives (e.g., USDA 2007a). This makes commercial-scale research—where it is necessary to examine the majority of a production rotation—extremely difficult to perform. The very strong responses to the questions surrounding containment requirements, especially for commercial applications, suggest that the respondents appreciate this difficulty. The interest in modifications to regulations toward a tiered system and provisional deregulation, which presumably would allow long-term studies and environmental releases for certain classes of transgenic products, also suggests an appreciation of the need for relaxed containment to enable research and development of those products to go forward.

Despite the recognition that a large number of obstacles exist with regard to commercializing GE trees, cost was identified as the major constraint to research and commercial development. Among the several costs identified, "regulatory costs and uncertainties at the commercial release level" was ranked as the greatest obstacle. This perception is supported by estimates of regulatory approval of GE annual crops, which are on the order of tens of millions of dollars or more (Kalaitzandonakes et al. 2007). The long time span and large size of GE tree studies, particularly environmental impact studies, and the interest in commercializing multiple transgenic tree events (Bradford et al. 2005), suggest that costs for environmental regulatory compliance for GE forest trees will be even higher, and especially so in cases where the EPA-regulated transgenes are included. Thus, detailed studies of gene flow to wild relatives, and ecotoxicological impacts, are likely to be required. Although the EPA refers to regulated genes as PIPs (plant incorporated protectants), their regulations cover much more than novel toxins such as those from *Bacillus thuringiensis*. Any disease resistance or growth-regulating genes introduced via transgenic methods appear to also be covered (EPA 2009).

The majority of the respondents believe that the trait and product, not the process, are the main determinants of relative

Table 2. Constraints on companies or agencies that limit research and commercial development on GE forest trees, in response to "Q33. What is the main constraint on companies or agencies that limits broader application-oriented research and commercial development on GE forest trees? Please rank these factors as low, intermediate, or high."

Answer options	Percent (%)					Priority ranking
	n	Low	Intermediate	High	Unsure	
a. Inadequate knowledge of the genes, and how to modify them, for traits of most interest such as yield and stress tolerance	71	22.5	32.4	42.3	2.8	8
b. Instability of traits, or impairment of elite varieties from mutation due to GE process	70	55.7	25.7	8.6	10.0	17
c. High cost of laboratory/greenhouse, and associated genomics studies, to support application-oriented GE research	70	7.1	34.3	54.3	4.3	5
d. High costs of field research with GE trees	70	4.3	27.1	58.6	10.0	3
e. High costs of making all trees and roots inviable at the end of field studies	70	30.0	30.0	27.1	12.9	11
f. Unwillingness of potential collaborating companies/agencies/research stations to host GE tree research on their lands	70	15.7	44.3	27.1	12.9	12
g. Institutional restrictions against application-oriented GE tree research	70	48.6	22.9	12.9	15.7	14
h. Marketplace rejection or trade concerns	69	8.7	23.2	55.1	13.0	4
i. Inability to understand, obtain, or afford, the needed intellectual property licenses for the needed genes, methods, and germplasm	70	18.6	37.1	34.3	10.0	10
j. Regulatory costs and uncertainties at the field testing level	69	5.8	27.5	52.2	14.5	6
k. Regulatory costs and uncertainties at the commercial release level	70	4.3	10.0	65.7	20.0	1
l. Legal and liability risks from unintended release, or of associated lawsuits due to high level of controversy associated with GE products	70	4.3	21.4	60.0	14.3	2
m. Personal ethical concerns of researchers about doing GE work in general, and/or with trees	69	72.5	17.4	2.9	7.2	19
n. Researcher reluctance due to concerns about:	24	41.7	25.0	12.5	20.8	—
i. Commercial interests	67	58.2	23.9	7.5	10.4	18
ii. Intellectual property	68	45.6	30.9	13.2	10.3	13
iii. Technology ownership	67	49.3	28.4	11.9	10.4	15
iv. Appropriate corporate behavior and accountability	67	53.7	23.9	9.0	13.4	16
v. Limited public acceptance	68	22.1	26.5	42.6	8.8	7
vi. Ecovandalism	67	17.9	37.3	35.8	9.0	9

The priority ranking column recognizes the "high" responses from participants and ranks them on a scale from 1 to 19, with 1 being the biggest constraint and 19 being the smallest constraint.

risk—in agreement with many scientific evaluations of GE issues (e.g., National Research Council 2002). However, when compared with plantations with interspecies hybrids or exotic tree species, a substantial number rated GE as generally of lower risk, and those citing case dependency declined compared with the other cases presented, such as use of clones and short rotations. This suggests the perception of a double-standard in regulation. This is likely to be true because a novel kind of exotic organism, which can differ in thousands of coevolved genes and the emergent adaptive traits that they encode, usually presents a far stronger ecological novelty than does the introduction of one or a few genes (Strauss 2003). They can also have numerous changed symbiotic and pathogen/herbivore associations in their new environments. Indeed, many cases of serious ecological perturbations from exotic trees have been documented (e.g., Webster et al. 2006), whereas significant ecological impacts from GE trees are speculative.

However, there is clearly an operational presumption of harm from the transgenic process and all of its products that has been incorporated into regulations. The added adaptive diversity in wild and feral tree populations due to environmental release of transgenes may on net be beneficial rather than deleterious, both to trees and the extensive biodiversity that depends on them. This may be especially likely in the face of major threats to forest trees from changing climate and the proliferation of pests that threaten basic forest ecosystem function (pest threats and responses are summarized by Chornesky et al. 2005).

In addition to regulation, there are a number of other obstacles to commercial development of GE forest trees (Sedjo 2006). These include difficulties in obtaining the complex freedom to operate for the highly patented assemblage of GE technologies; a risky marketplace given controversies over GE crops and trees that limits investment; inability to do even fundamental, contained, and environmentally oriented GE field research by Forest Stewardship Council certified companies and governments (Strauss et al. 2001); a deteriorating research milieu in the United States given the growth of real estate investment trusts and timber investment and management organizations (Seneca Creek 2005); competition from overseas

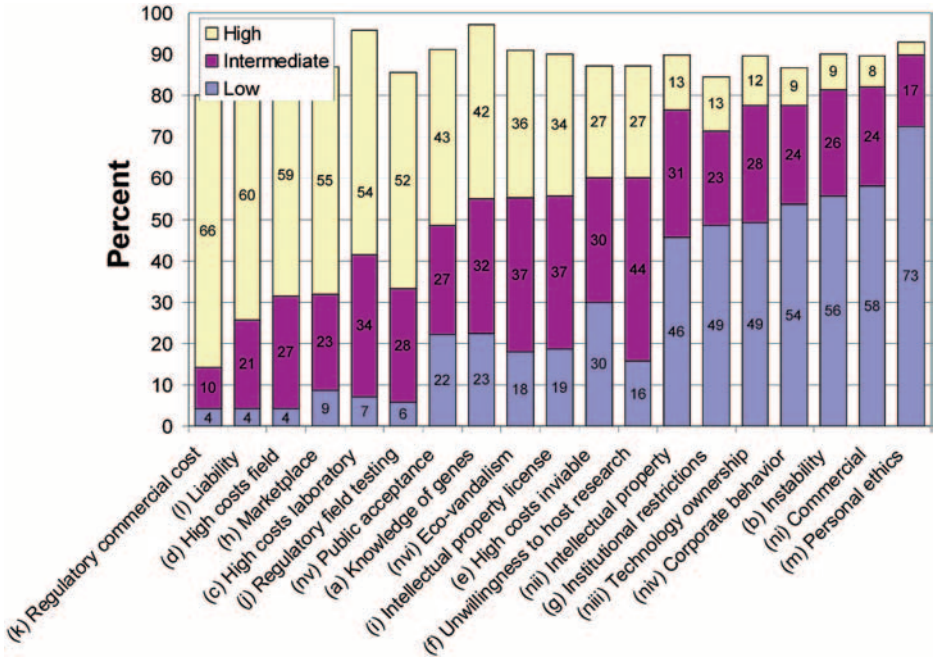

Figure 5. Constraints to development. Respondents were asked "What is the main constraint on companies or agencies that limits broader application-oriented research and commercial development on GE trees? Please rank these factors as low, intermediate, or high." The value for "high" for "(m) personal ethics" was 2.9%.

forestry investments; and the high cost in intellectual resources, equipment, and biological reagents—compounded by the long time frame—for GE research on trees. Thus, it is perhaps surprising that scientists consider regulatory constraints to be so significant. It ranked number one when compared with these and many other constraints. It may be that scientists view the legal bottlenecks provided by federal regulation as the most stringent and slow to change given the strong political influence on them and the great inertia to making internationally coordinated modifications. It may also be because regulations are viewed as impeding the field research needed to identify useful products and demonstrations of efficacy and safety. Without such demonstrations most of the private sector is unlikely to try and move forward with commercial applications. This finding also supports the concerns about the opportunity costs of regulations that were expressed by the Society of American Foresters (SAF) in their recent position statement on Forest Tree Biotechnology (SAF 2008). Our findings provide support for changes in regulations—such as establishment of tiers and exemptions for low risk and familiar GE traits—that are under consideration by the USDA in their proposals for regulatory reform (USDA 2007b). These changes would make research and development less prohibitive, thus possibly leading to commercialization in those cases where research suggests that there are substantive economic or environmental benefits under operational forestry conditions.

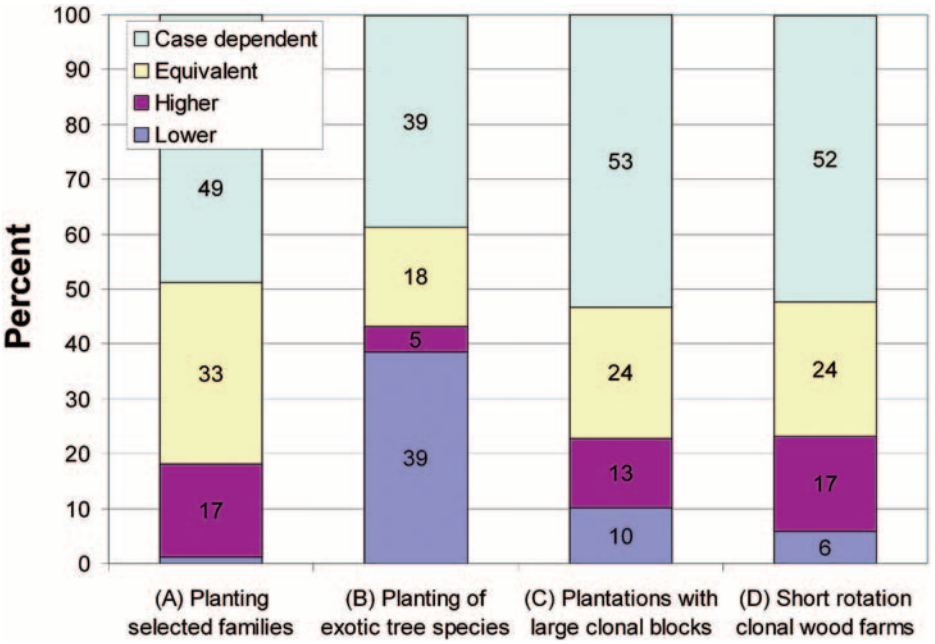

Figure 6. Relative risks of GE versus other forms of intensive silviculture. Respondents were asked "Generally speaking, do you believe that the ecological risks from uncontained commercial uses of GE trees in the USA are lower, equivalent, or higher compared to: (A) Planting of highly selected tree families from several generations of tree breeding; (B) Planting of exotic tree species and hybrids from different continents or regions; (C) Plantations with large (100–200 ha) clonal blocks; or (D) Irrigation and fertilization in high density, short rotation (2–10 year) clonal wood farms." The value for "lower" (A) was 1.1%.

Conclusions

The scientists targeted in this survey largely agree that the regulatory regimes in the United States present a significant obstacle to research and commercial development. Our results strongly suggest that containment requirements during field evaluation, in particular, pose significant obstacles to research and commercial development. Without a method for relaxation of those requirements, at least for some classes of genes, traits, species, and environments, research and development to the point where commercial benefit can be judged appear to be difficult and costly for the majority of companies, and even more so for public sector researchers and breeders. A number of research priorities were identified as important to improving chances for commercial application; among the highest priority were gene containment methods and field studies of wood and abiotic stress modification. Priorities for regulatory reform included development of a tiered system and provisional authorizations to enable long-term field research to proceed. Most of the scientists surveyed appear to believe that without a more discriminating product- versus GE process-focused regulatory system,

transgenic forest biotechnology may be unable to deliver on its technical potential.

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