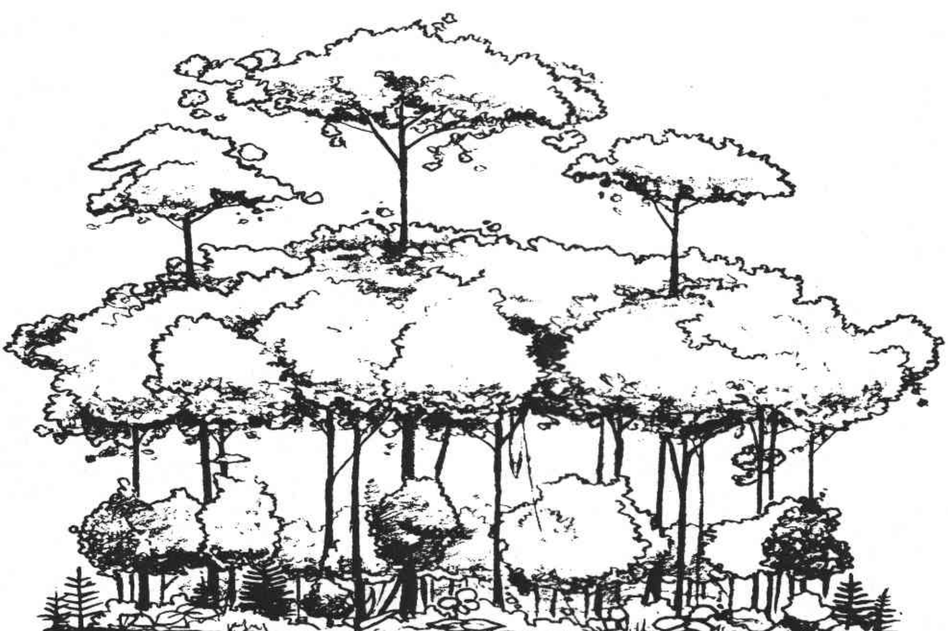
MANAGING FOREST ECOSYSTEMS

Landscapes, Genomics and Transgenic Conifers

Edited by
Claire G. Williams



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Managing Forest Ecosystems

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Aims & Scope:

Well-managed forests and woodlands are a renewable resource, producing essential raw material with minimum waste and energy use. Rich in habitat and species diversity, forests may contribute to increased ecosystem stability. They can absorb the effects of unwanted deposition and other disturbances and protect neighbouring ecosystems by maintaining stable nutrient and energy cycles and by preventing soil degradation and erosion. They provide much-needed recreation and their continued existence contributes to stabilizing rural communities.

Forests are managed for timber production and species, habitat and process conservation. A subtle shift from *multiple-use management* to *ecosystems management* is being observed and the new ecological perspective of *multi-functional forest management* is based on the principles of ecosystem diversity, stability and elasticity, and the dynamic equilibrium of primary and secondary production.

Making full use of new technology is one of the challenges facing forest management today. Resource information must be obtained with a limited budget. This requires better timing of resource assessment activities and improved use of multiple data sources. Sound ecosystems management, like any other management activity, relies on effective forecasting and operational control.

The aim of the book series ***Managing Forest Ecosystems*** is to present state-of-the-art research results relating to the practice of forest management. Contributions are solicited from prominent authors. Each reference book, monograph or proceedings volume will be focused to deal with a specific context. Typical issues of the series are: resource assessment techniques, evaluating sustainability for even-aged and uneven-aged forests, multi-objective management, predicting forest development, optimizing forest management, biodiversity management and monitoring, risk assessment and economic analysis.

The titles published in this series are listed at the end of this volume.

Landscapes, Genomics and Transgenic Conifers

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CHAPTER 11

ECONOMIC PROSPECTS AND POLICY FRAMEWORK OF FOREST BIOTECHNOLOGY IN THE SOUTHERN U.S.A. AND SOUTH AMERICA

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Abstract. An economic framework is presented for analyzing forest biotechnology with a focus on the case of transgenic forest trees in the southeastern U.S., Uruguay, and South America. Prospective economic benefits of forest biotechnology could reach hundreds of millions of dollars per year, but greatly increased research expenditures will also be required to achieve this potential. Commercial use of transgenic forests also must overcome biological, social, and policy issues related to social values as well as risk and control of dispersion that are unique with forest species. Benefits are likely to be realized earlier in South America than in the U.S., where timber growth rates and financial returns are much higher and clonal technology more prevalent, especially with *Eucalyptus* species. All major South American countries have ratified the Protocol of Cartegena on Biosafety, which requires risk assessments for the use of biotechnology of agricultural and, by extension, forestry. More detailed research can assess benefits, costs, and risks of transgenic forest trees and other biotechnology innovations using the framework presented here.

1. INTRODUCTION

Forest biotechnology research promises substantial returns through the development of genetically modified or transgenic forest trees. Benefits identified to date have focused on enhancing timber productivity and the quality of timber products, but other benefits such as enhanced conservation of biological diversity and bioremediation are also possible. Other applications of forest biotechnology also

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offer the substantial benefits of tree improvement and breeding (LI *et al.*, 1999, MCKEAND *et al.*,2003) at a rapidly accelerated rate and with greater improvements in desirable tree characteristics. Research and development of transgenic forest trees also will prompt social and economic issues, ranging from evaluation of economic feasibility and economic benefit, ecological and social impacts, and the promulgation of regulatory institutions to ensure safe deployment and acceptance of transgenic trees.

We begin by outlining the opportunities and discussing a framework for evaluating the direct and secondary economic effects of these advances. We then examine general policy issues with an emphasis on the role and perspectives of forest certification programs. An examination of policy responses in Uruguay provides insights into the potential for technology deployment in South America and the potential for shifts in production and trade patterns.

2. OPPORTUNITIES FOR FOREST BIOTECHNOLOGY

In theory, transgenic forest trees have DNA constructs (transgenes) which makes them a form of genetically modified organisms (GMOs). This technology is a promising opportunity in plantation forestry but also has substantial drawbacks. It could provide higher yields, better wood quality, lower risk associated with pests and pest management, as well as offer engineered genetic diversity at the cell, stand, ecosystem level, all much faster than waiting for generations of tree breeding and testing and plantation establishment. However, the research and development costs and risks are much higher, and seedling costs will be higher at least in the short run. There also are major technical challenges, social issues, environmental risks, and market acceptance questions.

In the European Union, forest trees consisted of 17 out of 1,649 agricultural GMO trials, or about 1% of the total as of 2001. The EU licenses for environmental releases of forestry GMOs have ranged from one to three per year (LINDGREN 2003). In the United States, there have been 150 field trials for GMOs. These have focused on poplar, pines, walnut, and cottonwood (http://:www.isb.vt.edu/cfdocs/fieldtests1/cfm.

LUCIER *et al.*,(2002) suggested five scenarios that illustrate potential future impacts of biotechnology in the forest sector. Transgenic trees are the most immediate applications of forest biotechnology, but many other promising opportunities exist. For silviculture, transgenic trees can enable significant improvements in timber yields and resource use efficiency. We also could move toward more landscape management, with short-rotation wood production concentrated on sites that are well-suited to intensive management. Genetic mapping and identification, and gene conservation and banks could protect intra- and inter-species diversity.

For wood quality, biotechnology could enable improvements in fiber length, angle strength, and density. Better wood quality enables improvements in product quality and energy efficiency. Biotechnology also could enable new pulping technology based on selective enzymatic cleavage of lignin polymers. New biopulping technology might greatly reduce capital costs and improve pulp yields, product quality, and environmental performance (LUCIER *et al.*, 2002).

Forest biotechnology could enhance environmental management by more efficient bio-treatment of wastewater and conversion of solid residuals into bio-energy. Trees could be modified to adapt to contaminated sites, for sequestering carbon on marginal lands, or for ecological restoration. We could achieve enhanced biodiversity based on gene mapping. New bio-processing technologies could enable conversion of wood and wood residuals into valuable chemical feedstocks. New trees could produce endogenous chemicals or bio-pharmaceuticals that are extracted from wood prior to conversion into traditional products (LUCIER *et al.*, 2002). There might be many other market or nonmarket benefits of the applications of forest biotechnology.

3. ECONOMIC ANALYSES

Based on the prospective benefits listed above, one could take various approaches to analyzing the economic benefits and costs of transgenic forest trees. This section discusses the economic theory and an analytical framework that could be used to make such assessments in detail, and illustrates some of these potential economic benefits based on currently existing data or prior research literature. A thorough and complete analysis of such research benefits and costs will take more effort, but we will at least provide some concepts for discussion and future research.

3.1. Economic theory

An initial set of economic considerations focuses on the decision of producers to adopt biotechnology alternatives in timber production. Ultimately the actions of producers reveal the outcome of these considerations in determining whether or not deployment of the technology is feasible. Components of their decision-making calculus would include expected costs versus benefits and risk profiles, including an understanding of who bears these risk burdens. Risks include the probability of crop failure, damage by natural disturbance regimes, environmental damages spilling over from the plantings, the possibility of a backlash in public opinion, and simple market risk—i.e., demand and supply factors that determine prices in the future. Risks and risk burdens are especially important considerations in the deployment of any GMO.

Enhanced financial returns would derive from two qualitatively distinct changes in the timber production function. One is a simple outward shift in the timber volume produced over time, which could reduce the maturity age for a timber stand or increase the volume harvested at the maturity age. The other is a change in the quality of the timber volume produced that could be valued in the market (i.e., either a more uniform timber crop or a physical/chemical property that enhances the utility of the fiber). More uniform crops would reduce harvesting costs while altered fiber properties could reduce costs in a downstream production process such as pulping.

Productivity gains can be viewed as a continuation of a long line of productivity enhancing research in the southeastern United States. Tree breeding and fertilization programs have resulted in a more than doubling of timber productivity in the region over the past 50 years. Research that reduces the losses due to insects or diseases likewise enhances supply. These types of productivity gains (using transgenic trees or other technologies) are readily evaluated by the landowner because the gains are realized on site. That is they do not depend on the development of a new market for a qualitatively distinct product.

In contrast, economic returns to changes in physical/chemical properties of fiber depend on developments in downstream technologies and demands for the properties. For example, changes in pulping quality must be identified by consumers of pulpwood. Another key element for financial success is some means of branding or identifying the enhanced product. Clear product demarcation can be guaranteed by secure production chains, for example where the consumer of the fiber also grows the timber. However, recent divestitures of forest management from wood products divisions of forest products firms raise additional challenges in this regard.

In addition to the questions that producers face when evaluating the decision to adopt and deploy a biotechnology alternative, there are economic issues surrounding the potential social welfare impacts of new technology. Adoption may provide a competitive advantage for individual producers, but the impacts on consumers and total economic welfare may or may not be substantial. The total economic impact of the new technology depends on how the technology affects supply or demand relationships for timber. Enhanced productivity typically shifts supply outward—i.e., more timber is supplied for the same price—and causes prices to fall. Lower prices increase consumer welfare by allowing increased consumption with the same budget.

3.2. Economic welfare analyses

Several national studies have shown that shifts in the supply of or the demand for timber products causes discernable economic welfare impacts in the U.S. Demand for timber products from the U.S. was influenced by strong restrictions on lumber imports from Canada, its largest trading partner in this sector between 1986 and 1991. The largest shift in timber supplies resulted from the approximately 85 percent reduction in timber production from federal forests in the western United States starting in 1993 (harvest reductions of about 10 billion board feet).

These two episodes provide useful insights into the relative magnitude of welfare impacts from additional changes in timber productivity. WEAR AND LEE (1993) estimated that the Memorandum of Understanding on Softwood Lumber Imports resulted in a significant impact on production in the U.S. The shift yielded about \$0.4 billion (15%) in additional benefits to the lumber-producing sector and reduced consumer welfare (prices increased) by about \$2.00 per household per year. In the case of the public harvest reductions since 1992, the supply contraction resulted in gains of up to \$1 billion for southern producers and a loss of about \$10.00 per household per year in consumer benefits. While these episodes applied to the lumber sector it is hard to imagine that biotechnology would have a more substantial influence on the structure of supply. Social benefits from technology changes in the forest sector are likely to be relatively small (not inconsistent with this range of \$2 to \$10 per household per year).

Changes in the timber production technology not only alter how products flow from land but also the uses to which land is dedicated. Changes in timber prices relative to the competitive uses of forest land will give rise to land use change in a privately held landscape. In addition, increased productivity allows more production to be concentrated on a smaller land base.

Differences in the regulatory environment between countries could amplify the distributive effects of the modified organism. Returns to the comparative advantage of a superior product would accrue in countries that allow planting of the GMO, as long as no market restrictions were imposed on GMO products in importing countries. Production and trade patterns would adjust accordingly. While we lack any detailed estimates of how transgenic trees could alter productivity or wood quality, it is likely that the latter type of change is more likely to alter distributions of benefits and trade patterns because of the resulting changes on the demand for products from native trees and the exclusivity of the production technology.

3.3. Potential southern U.S.A. impacts

Timber market projections conducted to support the Southern Forest Resource Assessment (PRESTEMON AND ABT 2002; WEAR AND GREIS 2002) provide some insights into how timber markets could potentially be affected by productivity gains. Baseline projections suggest that roughly 12 million acres of forest losses associated with urbanization forecast to 2010 would be offset by price induced afforestation activities (e.g., timber prices increasing relative to agriculture prices leads to tree planting). Productivity gains give rise to timber price declines (outward shifts in supply), thereby decreasing the area in forest cover and increasing agricultural uses relative to this base case.

While additional productivity gains would give rise to a loss of forest area, the composition of forests would also be affected. PRESTEMON AND ABT (2002) show that productivity gains would concentrate intensive or plantation management on a smaller land base and leave a higher proportion of forests in a naturally regenerated condition. Net changes from their projections indicate that increased productivity would gives rise to an overall decrease in areas of both plantation and naturally regenerated forests, suggesting the possibility of social costs related to other benefits of forests not included in the timber market estimates.

Changes in the quality of fiber—in essence, developing markets for a new products—are not as easily evaluated because they involve structural change in timber markets rather than a shift in an existing supply or demand relationship. The introduction of a superior pulpwood product would cause the demand for the standard pulpwood product to retract. Prices would fall for the standard product and rise for superior pulpwood. Higher rents would accrue to those holding the patent for the new modified organism and lower returns would flow to those producing pulpwood using unmodified native organisms.

LUCIER *et al.* (2002) made a simple estimate of the potential economic impacts of forest biotechnology in general that creates better investment returns, which will in turn increase timber supply in the U.S. South. Given the southern pine 1995 harvest of 5.5 billion cubic feet and a blended stumpage price of $0.80/cubic foot, the approximate annual softwood total stumpage cost was $4.4 billion. The potential cost reduction for same volume, with 5% supply shift and 0.4 supply and demand elasticities, would be $220 million per year. There also would be increased regional output of about 5% for same total cost, leading to greater revenue, profits, and regional competitiveness. Of course, forest biotechnology is not likely to be applied just in one region, which may alter comparative advantages among the timber supply regions in the world. But overall, it is apt to lower marginal costs of producing timber, shift the supply curve for timber out, and lower equilibrium supply and demand price levels.

Another promise of forest biotechnology is that it will greatly reduce or eliminate major forest diseases, and perhaps pests. CUBBAGE *et al.* (2000) calculated the potential South-wide impacts of fusiform rust elimination. The historical fusiform rust research program has provided $40 to $60 million per year of benefits. There is a potential for practical elimination of fusiform rust, with many molecular markers for fusiform rust resistance already identified. The annual benefit of complete elimination would range from $120 million to $920 million, with median of about $200 million. The current forest biotechnology research costs are likely less than $10 to $20 million per year in the United States, although this level of investment surely will need large increases to realize the predicted benefits of forest biotechnology. The identification of fusiform rust resistance genes using biotechnology has been one of the salient results in the short run, illustrating that such significant gains are possible.

3.4. World timber investment returns

Successful adoption of transgenic forest trees could significantly alter the financial returns to forest investments throughout the world. Preliminary research by CUBBAGE *et al.* (2005) estimated the investment returns for plantations in South America. Eucalypts (*Eucalyptus* spp.) have the greatest internal rates of return, ranging from 13% to 25% per year for typical industrial applications in Uruguay, Argentina, and Brazil. *Pinus radiata* in Chile had average internal rates of return of 17%, and *Pinus taeda* in Uruguay, Argentina, and Brazil had rates of return ranging from 10% to 17%. Average internal rates of returns for typical plantations in the United States were closer to 9% to 12%.

The excellent returns in South America are based on excellent growth rates coupled with moderate costs. This combination is apt to attract the most investment in transgenic forest trees to the southern hemisphere as well. The calculated rates of return did not include land purchase costs, which have increased rapidly in South America due to demand for soybean production, especially in Brazil. Inclusion of land costs would decrease the preceding timber investment internal rates of returns by 5 to 10 percentage points per annum, and have the most adverse effects on returns in Brazil. This would make average internal rates of return for new land and timber investments more comparable among the southern U.S. and the Southern Cone. Higher land costs will accelerate the trend toward more intensive forestry, including transgenic trees, in order to minimize the factor costs for scarce land.

Increases in yield or wood quality would generate significant economic benefits, and have substantial impacts on comparative advantages among countries and forest products trade. These impacts of increased growth or quality or changes in trade could then be examined for their economic welfare impacts and for the benefits and costs of the research itself.

4. POLICY ISSUES AND RESPONSES

4.1. Scientific and public concerns

Biotechnology, including for forestry, surely has significant hazards as well, commensurate with its large potential. Environmental press comments, and a host of comments and critiques on the Internet illustrate some of these issues.

Technical and financial issues abound with forestry applications. Biotechnology is easiest to use with a set of common clones, but there are few in *Pinus taeda*. The desire for a fixed-clonal technology for GMOs may impede breeding advances. Scientists will want to stick with old clones, and thus overuse the best clones. Transgenic technology is most likely to be practical for short rotation exotics, and may never reach *Pinus taeda* stage, at least in the U.S.A. Given the comparative levels of investments between agriculture and forest trees, it may be decades before transgenic forest tree benefits are realized. Medical biotechnology, for example, has probably received 1000 times more funding than forest biotechnology, and just beginning to see the first commercial successes after more than 30 years of research and development (LINDGREN 2003).

Transgenic forest trees need long field testing before deployment to test sterility and to ensure viability outdoors, e.g., making sure low lignin trees do not break apart in the field. Perhaps field tests should be longer for transgenic trees than other types of trials given higher risk and uncertainty. Transgenic forest trees are likely to spread given the fertile breeding habits of trees, such as with exotic pines in South Africa and Argentina. Contamination of native maize in Mexico and normal grains in Canada with transgenes has been reported already. Sterile forest trees, yet to be developed, are difficult and expensive. Use of terminator technology may fail, or succeed too well and infect native populations and lead to extinction. Also, the regulatory process is long and cumbersome (LINDGREN 2003). The number of transgenic escapes in systems other than trees has increased rapidly, and trees will surely be more difficult to contain than annual crops.

The biological uncertainties of GMOs beget social issues. Forests are perceived as the epitome of nature, with large spiritual values, and thus should be protected in a natural state. Playing God with (tree) genetics may be perceived as even less desirable than with human medical advances, by both green groups and religious conservatives. Transgenic forests will have neither the glamor of curing human ills or the pedestrian nature of agriculture, which domesticated most wild species decades ago. Domestication of forest trees is seldom a goal of anybody except forest geneticists, and the fear of kudzu-like Frankentrees is far more pervasive. More sabotage such as that claimed by the Earth Liberation Front (ELF) at Rhinelander, Wisconsin and the University of Washington seems likely. Many green environmental groups have already protested against GMOs, plantations, and timber harvests. All these issues will increase costs of transgenic forest trees. Indirect costs of transgenic forest trees include drawing scarce funding away from traditional, successful breeding and forest management programs with more immediate payoffs and much less risk.

GMOs may have market and government problems stemming from the social issues. As noted below, operational transgenic forest trees are proscribed in FSC certification standards, and may be addressed in other certification standards later. This may limit European market acceptance. Several U.S. retail lumber and office products firms have adopted or are considering a non-GMO policy. Government officials, legislators, and Congress members will be extremely careful and require many regulatory steps with GMOs in order to protect the public and their reputations.

LINDGREN (2003) concluded that forestry GMOs may be worth considering within decades if the rotation length is less than 10 years (reasonable testing time); exotics are planted (limited escape risk); clonal forestry is established (easy mass propagation available); there is an ongoing breeding program (adapted materials and competence for field testing available); and there is a good interface with science. Use of transgenic forest trees will require the will to make uncertain investment. If applied, such criteria would constrain applications in slow growing plantation species and in lower return regions of the world.

4.2. Forest certification

Some of these broader public concerns are reflected very specifically in the current forest certification programs, which govern forest operations on the brunt of the industrial forest land in the United States and Canada, and a small but increasing share of the industrial and other forest land in South America. These guidelines are particularly important for transgenic forest trees on forest industry lands in the short run.

Forest certification is designed to measure, monitor, audit, and improve forest management processes and practices at the forest level. In the United States, the Sustainable Forestry Initiative (SFI), which was initiated by the forest industry, is the dominant certification system. The Forest Stewardship Council (FSC), which was initiated by environmental nongovernment organizations, is less prevalent in the U.S., but remains a benchmark for green certification, and is more common in applications to industrial forest lands in South America. In partnership with other groups and the government, the forest industry in Brazil and Chile also have started forest certification programs termed Cerflor and Certfor, respectively, which have had significant enrollment by forestry companies in their countries.

THE U.S. SUSTAINABLE FORESTRY INITIATIVE (2002) generally accepts forest biotechnology when applied with due diligence to avoid the problems listed above, at least to the extent possible. Cerflor and Certfor also accept forest biotechnology, prudently applied. At this time, however, only FSC has explicit proscriptions against the use of genetically transformed trees for certified forest lands.

Key FSC standards related to tree improvement and forest biotechnology (FSC 2001; Smartwood 2001) include section 6.3.b. genetic, species, and ecosystem diversity. This includes 6.3.b.1, select trees for harvest, retention, and planting to maintain genetic diversity and species diversity of residual stand. Standard 6.3.b.2 requires that diverse native habitats be maintained; and 6.3.b.3 requires use of locally adapted seed of known provenance be used for artificial regeneration.

Standard 6.6 requires development and adoption of environmentally friendly non-chemical methods of pest management. Standard 6.8 requires that use of biological control agents shall be documented, minimized, monitored, and strictly controlled. Furthermore, it states that use of genetically modified organisms shall be prohibited. This includes a statement of: "Applicability Note: Genetically improved mechanisms (e.g., …Mendelian crossed) are not considered to be GMOs and may be used. The prohibition of GMOs applies to all organisms including trees." In addition, standard 6.8.a states that exotic predators used only as part of IPM strategy if other methods ineffective.

The FSC standards for tree improvement and forest biotechnology also limit plantations, especially of exotic species. They state that: 6.9 The use of exotic species shall be carefully controlled and actively monitored to avoid adverse ecological impacts; 6.9.a. that they should be contingent on peer-reviewed scientific evidence that any species in question is non-invasive and does not diminish biodiversity…use must be actively monitored; 6.9.b. owners must use control measures for invasive plants. Furthermore, they mandate that: 6.10 Forest conversion to plantations or non-forest uses shall not occur, except for (a) when it occurs as a limited portion of FMU; (b) does not occur in high conservation value forests; and (c) provides long term conservation benefits.

Plantations converted from natural forests after November 1994 normally shall not qualify for certification, unless the manager/owner is not responsible directly or indirectly for conversion. However, typical southern forests regenerated from old farm fields are not considered natural, so this may not be daunting as it appears. This characteristic flexibility also may carry over to FSC proscriptions on the use of GMOs as well. For example, one firm in Latin America had to destroy a multi-million dollar research program in transgenic eucalypts and burned all it transgenic plants in order to receive FSC certification for their forest lands. On the other hand, another American firm has reportedly received FSC certification for its forest lands, <u>excluding</u> some experimental trials that it currently has of transgenic trees. These are just anecdotes, but suggest that FSC will continue to wrestle with the treatment of GMOs. FSC has needed to be flexible to attract members into its programs, and must continue to be so given the recent development of new competing programs in Latin America.

5. REGULATORY RESPONSES: URUGUAY AND SOUTH AMERICA

Governmental policy responses clearly will affect development and deployment of transgenic forest trees and other applications of forest biotechnology. While responses are developing in the U.S., it is instructive to examine how South America is coping with this issue. This is especially useful, because transgenic forest trees are likely to be applied first in the southern hemisphere, where the forest rotations are much shorter and the financial returns much greater. Uruguay is particularly useful as a case study in this regard because it has many international forest products firms that have obtained FSC forest certification. All of these export the brunt of their raw material (roundwood or wood chips) or their manufactured products (lumber and plywood) to other countries. Due to its central geography and size, Uruguay also could serve as a scientific and business model in many respects for all of South America.

5.1. Level of forest biotechnology adoption in Uruguay

Research in forest biotechnology in Uruguay is currently underway in both private and public sectors, focused exclusively on tree improvement for fast growing species. Most research focuses on *Eucalyptus grandis* and *E. globulus*, two short rotations exotics widely planted in Uruguay since the promulgation of a forestry law in 1987 with a set of incentives and fiscal exoneration. To date, more than 700,000 ha of *Eucalyptus* and *Pinus* plantations have been established in the four regions of the country that qualify as forest priorities zones dues to their soil and climate conditions (DIRECCIÓN GENERAL FORESTAL 2005). International forest companies are well represented in these forest and plantation research programs (e.g., Botnia, Ence, Weyerhaeuser).

Table 1. Major Eucalyptus spp. and Pinus spp. tree improvement results and forest biotechnologies used in the INIA-Forestry Department in Uruguary.

Species	*Prospecting of genetic variability*		*Variety release*	*More than one generation cycle of improvement*	*Use of molecular markers*
	Local	*Introduced*			
Eucalyptus grandis	Yes	Yes	Yes	Yes	Yes
Eucalyptus globulus	Yes	Yes	Yes	Yes	No
Eucalyptus maidenii	Yes	Yes	Yes	No	No
Eucalyptus saligna	No	Yes	No	No	No
Eucalyptus dunnii	No	Yes	No	No	No
Pinus taeda	Yes	Yes	No	No	No
Pinus elliottii	No	Yes	No	No	No

Source: INIA-National Forestry Program data bases

Conventional tree breeding programs for *E. grandis* and *E. globulus* have long been pursued by both private and public institutions in Uruguay. The selection traits studied are growth and disease resilience. Two improvement cycles have been accomplished for both *E. grandis* and *E. globulus* and, since 2000, INIA's Forestry Department (Instituto Nacional de Investigación de Agropecuria) has released three varieties and nine clonal lines. The use of INIA *Eucalyptus* varieties could allow a growth increase of almost 15 to 30%, compared to mean growth currently obtained in commercial plantations. The annual growth gains expected with the use of clones compared to the use of unimproved seed are estimated to be more than 50% (BENNADJI 2004a).

Clonal forestry for *E. grandis* has reached a commercial scale in the northern and western regions of the country. Almost 4,000,000 clonal seedling were produced in 2003 and 4,000 ha of clonal plantations were established in the same period. In addition, INIA reports tree improvement and biotechnology progress in several species of *Eucalyptus* and *Pinus* (Table 1) (BENNADJI 2004b).

Forest biotechnology research in Uruguay at present currently falls into two broad categories: tissue culture and molecular markers. It does not include transgenic trees at this time. Tissue culture is used to enhance clonal propagation and as a tool to support large scale production of uniform materials. Micropropagation is used for the establishment of clonal gardens and for gene conservation. Molecular markers are used at a small scale to quantify genetic diversity between breeding populations and individual trees and to establish variety identification (genetic fingerprinting) (BENNADJI 2002). High costs currently prevent the application of micropropagation techniques to plantation establishment at the commercial level.

Field trials of a transgenic forest tree were reported for the first time in 1997 in the western region of the country, as an initiative of FOSA (Forestal Oriental), the Uruguayan branch of Shell. The transgenic trees were glyphosate-resistant *Eucalyptus grandis*. These field trials were stopped in 2000, when FOSA sought FSC certification.

5.2. Principal restrictions to the use of transgenic forest trees in Uruguay

As described above, there are considerable economic and socio-political challenges to adoption and deployment of transgenic forest trees. Production costs currently restrict widespread application. Technology application also requires a costly infrastructure of research, development, and deployment and building the human and financial capacity requires considerable resources. In addition, environmental NGOs stand in strong opposition to transgenic forest trees in Uruguay. Most major international pulp and paper firms in Uruguay have obtained FSC forest certification. These companies currently export all of their pulpwood roundwood or chips to Europe or Japan. These export markets and the FSC certifications have limited enthusiasm for GMOs in Uruguay.

Until 2000, the Ministry of Livestock, Agriculture and Fishery was in charge of the risk analysis of GMOs introduction in Uruguay. A scientific advisory commission supported the tasks of this Ministry. The commission was integrated by (i) the Public Health Ministry, (ii) the Environment Ministry, (iii) the National Institute of Seeds and (vi) the National Agricultural Research Institute. In August 2000, a Risk Evaluation Commission was officially created by decree and in 2001, Uruguay ratified the Protocol of Cartagena on Biosafety (PCBS).

Uruguay has a good legal framework for protecting intellectual property rights. As a member of the UPOV (Union pour la Protection des Obtencions Végétales), the country applies a set of legal rules for the protection of improved vegetative material of reproduction. On the other hand, Uruguay is also a signatory on the Convention on Biodiversity, which prohibits patents of living material.

5.3. Status of Transgenic Forest Trees in South America

In terms of adoption levels for transgenic forest trees, the situation among South American countries is quite heterogeneous. Argentina, Brazil, Chile, Mexico and Uruguay could be classified as advanced countries, compared to Andean and Central American Countries. There is a lack of information on transgenic forest tree field trials testing and only three trials of transgenic tree species *Eucalyptus globulus*, *Pinus radiata* and *Eucalyptus grandis* are reported in Chile and Uruguay; all three are directly supervised by the private sector. The transgenic traits are lignin modification and herbicide tolerance. However, most of the South American countries have committees or commissions in charge of transgenic risk analysis, usually related to agricultural species.

In Table 2, the status of the regulation and policy frameworks of some countries is presented. These regulatory frameworks put in place to oversee the experimental and commercial release of transgenic forest trees are broadly similar. However, the instruments were established for agricultural species and therefore do not fully account for environmental considerations surrounding genetically modified trees.

All of these Latin American countries have responded to concerns regarding genetically modified trees to one degree or another. All have now ratified the Protocol of Cartegena on Biosafety (PCBS) but not all have established institutional infrastructure for evaluating the risks and potential effects of these transgenic forest trees. In most cases, these institutions were established to evaluate genetically modified (GM) or transgenic crops and have yet to adopt protocols necessary for evaluating perennial plants such as forest trees.

Regardless of the investment in GM research and institutions to evaluate risks, the establishment of transgenic tree plantations may be trumped by the demand for FSC certification by forest products firms. Prohibition of transgenic forest trees by this certification body has and will likely have strong influence over the adoption of transgenic trees, reflecting the sensitivity of firms to public concerns regarding the environmental quality of their land management.

Table 2. Regulation and policies for GMOs in selected Latin-American countries.

Country	*Institution in Charge of the GMO Risk Analysis*	*Protocol of Cartegena on Biosafety (PCBS)*
Argentina	CONABIA (Comisión Nacional Asesora de Bioseguridad Agropecuaria)	Ratified May 2000
Bolivia	CNB (Comité Nacional de Bioseguridad)	Ratified April 2003
Brazil	CNTBio (Comisión Técnica Nacional de Bioseguridad)	Ratified November 2003
Chile	CALT (Comité Asesor para la Liberación de Organismos Transgénicos)	Ratified May 2000
Colombia	CTN (Comité Técnico National)	Ratified May 2003
Ecuador	-	Ratified January 2003
Mexico	-	Ratified august 2002
Paraguay	C.B (Comisión de Bioseguridad)	Ratified March 2004
Peru	CONABID (Comisión Nacional de Diversidad Biológica)	Ratified April 2004
Uruguay	CERVGM (Comisión de Evaluación de Riesgos de Vegetales Genéticamente Modificados)	Ratified June 2001
Venezuela	CNBio (Comisión Nacional de Bioseguridad)	Ratified May 2002

6. CONCLUSIONS

Forest plantations and forest biotechnology have been promoted with the promise of providing more of the world's wood fiber needs on a smaller land base, and as a means of sparing timber harvests on natural forests (SEDJO AND BOTKIN 1997; WORLD WILDLIFE FUND 2003). We have about 204 million ha of planted stands in total (5.3% of world forests), and 100 million ha of fast grown industrial plantations (2.0% of world forests) (FAO 2003; SIRY *et al.*, 2005). Plantations provide about 25% of world industrial wood fiber, and are projected to increase this share to about 40%. The U.S. South has about 12 million ha of plantations (SMITH *et al.*, 2001), and Brazil, Argentina, Uruguay, and Chile have almost 10 million ha of plantations, which grow much faster than in the U.S. Plantations provide the basis for and target of most of our genetic improvement efforts. Genetically improved trees and wood, achieved through traditional tree improvement programs, are generally accepted for private lands, both by forest industry and NIPFs.

Genetic improvement has been widely adopted throughout the world and implemented at moderate cost. Forest biotechnology promises to take us to another level technological innovation. It also can provide tools to identify and protect biological diversity at the molecular level, and perhaps provide means to achieve environmental remediation of industrial wastes. Forest biotechnology research is proceeding at a rapid pace, albeit with significant costs. However, transgenic forest trees and forest biotechnology will face far greater public opposition and regulatory challenges than any other forestry technology to date.

The decision to deploy transgenic trees will rest not only on estimates of their costs and returns but also on perceptions regarding risks. Returns will either increase productivity or provide qualitative changes in wood fiber. Our review suggests that annual benefits from transgenic forest trees and even forest biotechnology in general could be worth hundreds of millions of dollars per year, but only with successful research and implementation. Research costs would need to increase by tens of millions of dollars per year to realize these potential benefits—a level far beyond current expenditures. Risks of transgenic forest trees include standard concerns for production and market risk but also hazards associated with perceived or real environmental damages and backlash in public opinion.

Types of economic impacts depend on the nature of the effects of GMOs. For productivity enhancements, shifts in timber supply not unlike previous returns to research would shift production to smaller land bases and reduce timber prices. The proportion of intensively managed forest land would likely fall but so would the total area of forests in the U.S. South. Consumer benefits would accrue but, as previous studies have shown, because wood products are a small portion of the U.S. economy, total benefits are likely to be relatively small.

The economic impacts of a change in fiber quality could be more substantial, because it would reduce demands for pulpwood generated from native organisms. High prices for transgenic forest trees would lead to lowered prices for existing pulpwood products. In addition, because of differences in the timber growth rates and regulation of transgenic forests trees between countries, it is likely that altered comparative advantage would result in greater changes in production and trade patterns. Research and development in transgenic forest trees is more likely to be beneficial for the fast-growing, high-return plantations in South America.

Forest certification, which mandates and audits standards of forestry practice at the stand or ownership level, has potential for a much larger impact of forest management, tree improvement, and forest biotechnology. The Sustainable Forestry Initiative specifically requires that program participants demonstrate that they conduct or support forestry research in health and productivity, water quality, and wildlife and biodiversity. SFI encourages use of plantations, tree improvement, and forest management, and infers that forest biotechnology would be acceptable. With appropriate safeguards, exotics are legitimate under SFI, although there are not many exotic timber species being planted in the U.S. yet. SFI might offer specific opportunities in tree, stand, or ecosystem biodiversity for applying the science of tree improvement or forest biotechnology.

Forest certification by FSC requires that managers favor natural stands and biodiversity. FSC allows plantations and tree improvement with fairly extensive strictures to protect natural stands and ecosystems. It explicitly prohibits use of transgenic forest trees. FSC has been very flexible in decisions, allowing a large number of forests with exotic plantations to be certified if they have a large natural stand/reserve component as well. It does require refereed science to justify the use exotics and ensure that they do not cause any environmental harm. Its rigor has varied to a total ban of all transgenic plants ands trees for firms that are FSC-certified to a partial exclusion of the experimental lands that include transgenic trees. Debates over transgenic forest trees and GMOs will increase within the FSC as the prospects for operational use become more likely.

The case study of GMOs and transgenic forest trees in Uruguay and related regulations in South America is informative. Uruguay just began its significant forest plantation program in 1987 with a new forest law providing subsidies and favorable tax status for forest plantations of exotic species. Since then, it has begun prospecting for genetic variability, released varieties of several species, begun first and second generation tree breeding programs, and begun to use molecular markers for one species, *Eucalyptus grandis*. Uruguay has significant government oversight of agricultural and forest biotechnology applications, and does seek to employ the most modern technology to increase productivity and enhance export opportunities. Since 2001, Uruguay and every other major South America country have ratified the Protocol of Cartegna on Biosafety, which addresses transgenic agricultural crops, and trees by extension of those policies. This protocol establishes a structure for evaluating risks and potential effects of genetically modified organisms. The U.S. approach to regulation is even more complex and uncertain.

Public perceptions influence forest certification programs and the potential use of transgenic forest trees as well. Transgenic forest trees offer promise, charisma, and financial support, and issues. A distant promise is that of designer trees perfect for specific wood, paper, or environmental remediation applications, with known genetic diversity at the tree, stand, or ecosystem level. Given that even well-supported agriculture applications have been limited to modest herbicide resistance, the promise of complex wood quality or growth improvements seems distant. The production economics and costs and returns for transgenic forest trees are significant, and the social acceptance may be more challenging. FSC forest certification prohibits use of transgenic forest trees or for IPM, and several wood and paper retailers have or are considering adopting this policy. On the other hand, perhaps some of the outstanding recent medical breakthroughs, such as RNAi, can be duplicated in forestry at a much lower cost using similar technology. Maybe medicine and agriculture will pave the way for much less expensive subsequent forestry applications.

Increased government research in forest biotechnology is necessary, but costly, and the payoff will be distant. We still need to map the genomes of model tree species, discover molecular controls of key processes, assess ecological issues and opportunities, and understand risk management. We must link our forest biotechnology programs with traditional tree improvement, silviculture, and forest management, and vice versa. One avenue for this could be to use forest biotechnology to identify desirable characteristics, as described before, and then use vegetative propagation and/or somatic embryogenesis to rapidly ramp up and develop container stock for planting of superior trees. Perhaps this would avoid the social and certification antipathy for transgenic trees or other GMOs and still allow rapid implementation of the best science at reasonable costs.

Benefits of any forest biotechnology breakthroughs are likely to be realized soonest in South America, where timber growth rates are much higher, and clonal technology more prevalent, especially with *Eucalypts* species. All major Latin American countries have ratified the Protocol of Cartegena on Biosafety, which requires risk assessments for the use of biotechnology of agricultural and, by extension, forestry. More detailed research can assess benefits, costs, and risks of forest biotechnology using the framework presented here.

For example, biotechnology in medical applications and in the stock market achieved their most dramatic gains ever in 2002 and 2003. If possible, we should capitalize on such advances in medicine and agriculture, apply them well in forestry, answer pressing social or market questions, and then integrate biotechnology with existing tree improvement and forest research and development programs. With such advances, forest biotechnology and genetic improvement might help us achieve the widely accepted paradigm of Sustainable Forest Management that promotes economic, ecological, and social benefits for this and future generations.

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