Strangled at birth? Forest biotech and the Convention on Biological Diversity

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Against the Cartagena Protocol and widespread scientific support for a case-by-case approach to regulation, the Convention on Biological Diversity has become a platform for imposing broad restrictions on research and development of all types of transgenic trees.

The Convention on Biological Diversity (CBD) has become a major focus of activist groups that wish to ban field research and commercial development of all types of genetically modified (GM) trees. Recent efforts to influence CBD recommendations by such groups has led to the adoption of recommendations for increased regulatory stringency that are inconsistent with the views of most scientists and most of the major environmental organizations. We suggest that the increasingly stringent recommendations adopted by the CBD in recent years are impeding, and in many places may foreclose, much of the field research needed to develop useful and safe applications of transgenic trees. To move forward, improvements to regulations are needed that allow field research to be conducted at a reasonable cost and under workable levels of confinement, and researchers need to increase their activities through the Public Research and Regulation Initiative (PRRI) and other organizations to ensure that high-quality science informs CBD negotiations.

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A convention co-opted

Negotiated under the United Nations (UN) Environment Program, CBD was adopted in June 1992 and subsequently entered into force in December 1993. The CBD has been signed by 191 of the 192 members of the UN, making it one of the largest international treaties. The aim of the CBD is to promote the conservation and sustainable use of biodiversity, and the fair and equitable sharing of benefits from the use of genetic resources. Because transgenic organisms have the potential to affect biodiversity, special provisions of the CBD cover the use and trade in living modified organisms (LMOs, also known as genetically modified organisms; GMOs).

In 2000, the Cartagena Protocol on Biosafety was adopted based on the mandate in the CBD for a protocol on biosafety. It is supported by 147 members and its goal is to contribute to ensuring adequate protection, transfer and safe use in the field of GMOs that may have adverse effects on biodiversity. The focus of the Cartagena Protocol is transboundary movements, both intended and unintended. A main function of the Cartagena Protocol is to offer governments without national biosafety regulations a tool for informed decision making on the import of GMOs and to guide the development of national biosafety regulations.

Though the Cartagena Protocol has been ratified by almost all countries, many of the important details of the treaty are yet to be specified. They either are left up to the individual parties to implement as they see fit or have yet to be agreed upon. With respect to GMOs, this includes what is needed in risk assessments in specific cases; how to label GMOs during intercountry transfer; how to obtain public input; and how to deal with liability and redress for damages to biodiversity[1–4]. It also allows highly diverse interpretations of socioeconomic issues. Article 26 states that "the Parties…may take into account, consistent with their international obligations, socio-economic considerations arising from the impact of LMOs on the conservation and sustainable use of biological diversity, especially with regard to the value of biological diversity to indigenous and local communities." As discussed below, many of these uncertainties may present critical issues for forestry.

Will activists succeed in keeping the lid on transgenics tree research?

As biotechnologies are viewed in the CBD as having substantial potential benefits for biodiversity and sustainability, the goal of the Cartagena Protocol is not to prevent the use

Box 1 Diverse types and uses for transgenic trees

A main argument from scientists against broad bans or moratoria on all types of field studies with GM forest trees is that there is a large diversity of anticipated benefits and risks that need specific evaluation. The traits under study include wood chemistry, herbicide resistance, insect resistance, disease resistance, rate of growth, stature, salt tolerance, nutritional conditions, dormancy induction, onset of flowering, sterility, phytoremediation, cold tolerance, gene induction systems and rootability[33,34]. This diversity was underlined by the CBD's own background document prepared for the SBSTTA meeting in Rome in February 2008 (ref. 5,35), entitled "the potential environmental, cultural, and socio-economic impacts of genetically modified trees." In Annex 1 of that document, a long list of the kinds of potential environmental and socioeconomic and cultural impacts, both positive and negative, were enumerated and discussed. Similar lists of diverse benefits and impacts, as well as means for mitigation of undesired impacts, were provided in earlier reviews[31,36].

There is also a diversity of species being pursued in GM research. Frankenhuyzen and Beardmore identified 33 species of forest trees that had been successfully transformed and regenerated[31]. Although a majority of field trials have occurred in poplar (*Populus*) because of its status as a model organism for tree genomics and biotech, and most have occurred in the United States[34], field tests have also been conducted in a number of other tree species and geographies around the world[33,37]. Plantation trees predominate, with poplar leading (177 trials as of February 2008), followed by pine (129) and eucalypts (56)[38].

of transgenic or other biotechnologies but to guide their wise and safe use. But it is the risks, not the potential benefits, to biodiversity that have received the large majority of attention, mainly owing to the predominantly negative views of GMOs by some European Union (EU) member states and affiliated developing countries, and the prominence at the negotiations of nongovernmental organizations (NGOs), such as Greenpeace, that are conducting strong anti-GMO campaigns. The United States signed the CBD in June 1993 but has never ratified it[5], in part because of its hostile treatment of transgenic biotech—now a major feature of US agriculture and agricultural exports[6].

Only recently have GM trees and their role in forestry become an important feature of the anti-GMO campaigns. The rhetoric is often strong. For example, Anne Petermann of the Global Justice Ecology Project (http://www.globaljusticeecology.org/) stated that GM trees "…pose what many consider to be the most serious threat to the world's remaining native forests since the invention of the chainsaw"[7]. As with the broader GMO debate, the anti-GMO activists often cast the debate as people versus corporations. Petermann also wrote that there is "…mounting corporate pressure to deregulate GE [genetically engineered] trees so that they can be developed on a commercial scale for the future production of paper, biofuels, chemicals, plastics and other products"[7]. The benefits to broader society of these products, produced at reasonable costs on a potentially smaller land base than conventionally produced trees, are denied, disputed or ignored.

There is now a push for a moratorium or ban on all GM tree field tests through the Cartagena Protocol, including those which are strictly confined or done only for research. A similar effort to ban GM trees was mounted in conjunction with the negotiations surrounding the Clean Development Mechanism part of the Kyoto Protocol. Although the ban was not imposed, Clean Development Mechanism requirements for an environmental impact review and an executive board to provide oversight provides a means through which anti-GMO NGOs can continue to provide political influence. This is likely to make even research with GM trees very difficult in many countries[8].

As discussed below, the efforts against GM trees appear to be having a substantial influence on Cartagena Protocol recommendations and thus are likely to affect national and international regulations. Our aim is to examine the context for this campaign, and the extent to which it is consistent with scientific knowledge, the perspectives of scientific organizations and the views of the major environmental NGOs.

Biotechnologies and trees

A diverse array of biological technologies are being intensively pursued to support plantation forestry. These include clonal propagation, interspecific hybridization, use of exotic species, the use of a variety of molecular tools to intensify the selection of superior genotypes (DNA fingerprinting, genome mapping, gene identification and genome sequencing) and transformation[9]. However, of this diverse array of technologies, only transformation, defined by the use of direct modification and asexual insertion of DNA into organisms in the laboratory (that is, genetic engineering or modification), engenders attention from the CBD, strong government regulation and controversy over its use, even for research.

The goals for GM tree forestry are highly diverse, as are the locations, the species and the genes employed (**Box 1**). In addition to the use of genes from other species, genetic modification can involve changes of the expression of native genes to modify endogenous traits, such as wood structure, growth rate and tolerance of stress. Such activities have been increasing as knowledge of the genomes of trees increases, and genetic modification as a means to leverage genomic information is viewed as particularly important for trees versus annual crops because of the slow pace of tree breeding and the limited state of tree domestication[10]. Genomic information on major forestry species has increased dramatically in recent years. The entire genome sequence of the poplar tree (*Populus*, aspens and cottonwoods) was published by the US Department of Energy (DOE; Germantown, MD) in 2006 (ref. 11) and sequencing of the *Eucalyptus* genome, also by DOE, is currently underway. In addition to industrial purposes, efforts are underway to use recombinant technology to help rescue major tree species that have been devastated by exotic diseases, such as have occurred for chestnut and elm in the United States[12], to improve the efficiency of environmental cleanup[13] and to reduce the risks of ecological harm due to the spread of exotic tree varieties[14]. Products such as disease-resistant chestnut and elm should have direct benefits for promoting forest biodiversity by resurrecting key species that support many kinds of organisms in the ecosystems in which they occur.

Given the diversity of traits, species and environments under study, a case-by-case approach would seem to be the sensible way to proceed, and this basic approach is officially recognized in the Cartagena Protocol[2]. Annex III/6, under general principles governing risk assessment, states that "risk assessment should be carried out on a case-by-case basis. The required information may vary in nature and level of detail from case to case, depending on the LMO concerned, its intended use and the likely potential receiving environment." This principle fits well with the diversity of GM trees.

Views of scientific and environmental groups

Nonetheless, the activism against GM trees through the CBD has been against all forms of genetic modification, regardless of the goals or environmental benefits sought. This activism has also been in direct opposition to widespread scientific and professional opinion from around the world, including from ecologists (**Table 1**), that the trait, not the recombinant method,

should be the focus of ecological assessments. These views derive from some of the largest and oldest scientific and professional organizations knowledgeable on these issues, and are the result of intensive, high-level deliberations among diverse member scientists. A similar view was espoused in the Biosafety Regulation Sourcebook, created to help countries craft national regulations that are congruent with Cartagena Protocol rules and intentions: "The risk an organism or related activity may pose to the environment depends on the organism's properties and resulting interaction with the environment. This is the case regardless of whether those properties are the result of breeding technologies—either traditional techniques, or biotechnology—or 'natural' evolution. This fact has been and continues to be confirmed by leading international institutions including the OECD [Organization for Economic Co-operation and Development], FAO [Food and Agriculture Organization] and WHO [World Health Organization][15].

The majority of the major environmental NGOs also do not have policies that discriminate against all types of GMOs, with the notable exceptions of three large NGOs: Friends of the Earth, Greenpeace and the Sierra Club (**Table 2**). Although the three anti-GMO groups present themselves and their concerns as based on science, this disagreement on a fundamental principle that underlies scientific risk assessment suggests otherwise. In contrast, all of the major scientific organizations, and most of the major environmental NGOs, have not seen fit to promote indiscriminately anti-GM policies or campaigns.

Anti-GM tree campaigns

Active campaigns against GM trees through the CBD began in early 2004, with a coalition of small NGOs calling for a ban on GM trees

Table 1 Views of major scientific and professional societies on evaluation of genetically engineered crops and trees

Organization	Year created	Number of members	Total expenses at end of 2006	Quotation or position
American Medical Association[a]	1847	~278,000	$222,344,781[b]	"Federal regulatory oversight of agricultural biotechnology should continue to be science-based and guided by the characteristics of the plant, its intended use, and the environment into which it is to be introduced, not by the method used to produce it…" <http://www.ama-assn.org/ama/no-index/aboutama/13595.shtml>
American Council on Science and Health[c]	1977	NA	$1,845,871	"Current regulatory scrutiny, plus the excellent track record of GM food safety, gives us confidence that GM foods are rigorously scrutinized and that the technology is safe." <http://www.acsh.org/publications/pubID.289/pub_detail.asp>
American Society of Plant Biologists[c] (ASPB)	1924	~5,000	$5,418,347	"ASPB strongly endorses continued responsible development and science-based oversight of GE and all food production technologies and practices on a case-by-case basis." <http://www.aspb.org/publicaffairs/aspbgestatement.cfm>
American Seed Trade Association (ASTA)[c]	1883	~850 companies	$3,006,991	"ASTA strongly supports the safe use of new modern genetic methods in the continuing effort to improve crop varieties. The safety of crops modified by modern biotechnology is ensured through a most rigorous and comprehensive set of regulatory systems. The resulting varieties hold great promise for improving the food and feed supply of the world and promoting environmental sustainability, just as past accomplishments of plant breeders have benefited the world." <http://www.amseed.com/govt_statementsDetail.asp?id=43>
American Phytopathological Society[c] (APS)	1908	~5,000	$3,572,946	"(APS)… supports biotechnology as a means for improving plant health, food safety, and sustainable growth in plant productivity." <http://www.apsnet.org/media/ps/APS%20Biotech%20Statement.pdf>
Council for Agricultural Science and Technology[c]	1972	~38 scientific societies	$767,789	"Retain the current case-by-case safety assessment approach and continue to emphasize regulatory conditions carefully tailored to address risks identified for individual biotechnology-derived plant products. Agencies must maintain the flexibility to assure that rigorous, science-based safety assessments are conducted for each new product or product category." <http://www.castscience.org/displayNewsRelease.asp?idNewsRelease=118&display=1>
Ecological Society of America[c]	1978	~8,000	$3,609,200	"GEOs have the potential to play a positive role in sustainable agriculture, forestry, aquaculture, bioremediation, and environmental management, both in developed and developing countries." "We reaffirm that risk evaluations of GEOs should focus on the phenotype or product rather than the process…." <http://www.esa.org/pao/policyStatements/Statements/GeneticallyModifiedOrganisms.php>
Food and Agriculture Organization of the United Nations (FAO)[c]	1945	189 member nations	NA	"FAO supports a science-based evaluation system that would objectively determine the benefits and risks of each individual GMO. This calls for a cautious case-by-case approach to address legitimate concerns for the biosafety of each product or process prior to its release." <http://www.fao.org/biotech/stat.asp>
Genetics Society of America[c]	1985	~5,000	$3,123,807	"…it will be necessary to consider products on a "case-by-case" basis. In some cases, a GMO may not be different in any significant way from a classically bred organism." <http://www.genetics-gsa.org/pages/pp_benefits.shtml>
Institute of Food Technologists[a]	1939	NA	$15,934,326	"There is some evidence of overall improved environmental safety due to wider use of rDNA biotechnology. That is not to say that all rDNA biotechnology-derived products will be safe—they must be examined on a case-by-case basis before being commercialized." <http://members.ift.org/NR/rdonlyres/892A5152-5F08-4921-840C-03587DAA1F1B/0/iftreport_benefits.pdf>
International Society of African Scientists (ISAS)[c]	1982	NA	NA	"ISAS believes that agricultural biotechnology represents a major opportunity to enhance the production of food crops, cash crops, and other agricultural commodities in Africa, the Caribbean and other developing nations." <http://www.aspb.org/publicaffairs/agricultural/africanbiotech.cfm>

continued

Table 1 Views of major scientific and professional societies on evaluation of genetically engineered crops and trees (continued)

Organization	Year created	Number of members	Total expenses at end of 2006	Quotation or position
International Union of Forest Research Organizations [a]	1892	689 member organizations	NA	"The social discussion about risks vs. benefits of GMOs must move from a generic consideration of GMOs to the merits of modifying trees with specific traits to be used in specific environments and management regimes"[32].
National Agricultural Biotechnology Council (NABC)[a,c]	1988	>30 research-educational institutions in North America	NA	Whether or not a GEO requires bioconfinement "should be determined on a case-by-case basis...." <http://nabc.cals.cornell.edu/pubs/nabc_17/NABC17_complete.pdf> "...genetically improved products should be evaluated for safety on a case-by-case basis, utilizing all of the available information, including experience, to guide the assessment." <http://nabc.cals.cornell.edu/pubs/statement2000.pdf>
National Research Council[a]	1916	~6,000	Annual budget: ~$176 million	"...the product of genetic modification and selection should be the primary focus for making decisions about the environmental introduction of a plant... and not the process by which the products were obtained." <http://books.nap.edu/openbook.php?record_id=1431&page=67> "For purposes of decision support, the process of production should not enter into risk assessment." "The transgenic process present[s] no new categories of risk compared to conventional methods of crop improvement, but specific traits introduced by either of the approaches can pose unique risks." <http://books.nap.edu/openbook.php?record_id=10258&page=63> "Because both methods have the potential to produce organisms of high or low risk, the committee agrees that the properties of a genetically modified organism should be the focus of risk assessments, not the process by which it was produced." <http://books.nap.edu/openbook.php?record_id=9795&page=6>
Pontifical Academy of Sciences[c]	1603	~80 academicians	NA	"There is nothing intrinsic about genetic modification that would cause food products to be unsafe. Nevertheless, science and scientists are and should further be – employed to test the new strains of plants to determine whether they are safe for people and the environment, especially considering that current advances can now induce more rapid changes than was the case in the past." <http://www.vatican.va/roman_curia/pontifical_academies/acdscien/documents/sv%2099(5of5).pdf>
Society of American Foresters[c] (SAF)	1900	~18,000	$3,175,752	"SAF supports the continued evolution of federal regulations that affect forest tree biotechnology, particularly changes to make the regulations more focused on the products' safety and environmental impact, rather than on the process or method used to create them." <http://207.5.76.244/fp/documents/forest_tree_biotech.pdf>
Society of Toxicology[a]	1961	NA	$5,232,371	"...the potential adverse health effects arising from biotechnology-derived foods are not different in nature from those created by conventional breeding practices for plant, animal, or microbial enhancement." "...it is the food product itself, rather than the process through which it is made, that should be the focus of attention in assessing safety." <http://www.toxicology.org/ai/gm/GM_Food.asp>
The World Health Organization (WHO)[c]	1948	~191 member states	NA	"GM foods currently available on the international market have undergone risk assessments and are not likely to present risks for human health any more than their conventional counterparts. The potential risks associated with GMOs and GM foods should be assessed on a case-by-case basis, taking into account the characteristics of the GMO or the GM food and possible differences of the receiving environments." <http://www.who.int/foodsafety/publications/biotech/biotech_en.pdf>

[a]Obtained from reports and web pages that suggest a position on genetic engineering, not an official position statement. [b]Annual expenses at end of 2005. [c]Based on policy statement or position statement. NA, not available. Annual expenses for FAO, ISAS, NABC, IUFRO and WHO not available.

due to the high potential for wide dispersal of pollen and seed, which they argued goes against the basic tenets of the CBD[16]. This action appears to have been precipitated by the decision of the UN Framework Convention on Climate Change in December 2003 not to exclude GM trees in the Clean Development Mechanism. A small coalition against GM trees that formed late during those negotiations failed in getting them excluded from Clean Development Mechanism carbon accounting[8]. Later that year, GM trees were discussed at the fourth session of the UN Forum on Forests, where the anti-GMO NGOs present further argued for a global ban[17]. This action was continued during the second conference and meeting of the parties (COP-2, MOP-2) to the Cartagena Protocol on Biodiversity and the CBD during 2005 in Montreal, Canada[18], and again at COP-8 of the CBD in Curitiba, Brazil, where a request was made for the CBD to produce a report on the "potential environmental, cultural, and socio-economic impacts of genetically modified trees."

This report was first prepared in 2007 for a CBD-associated technical meeting in Montreal, then revised based on scientific reviews by PRRI (http://www.pubresreg.org/) scientists and others, and presented in final form at the CBD–Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) meeting in Rome in 2008 (ref. 19). The document enumerates the many and diverse benefits and risks from the use of GM trees. Interestingly, nearly all of the same list of benefits and risks would apply to many forms of conventional breeding and associated intensive plantation forestry, but this is not explicitly discussed nor is a comparative risk assessment for GM trees specifically called for in the CBD. The risks touted against GM trees are discussed in **Box 2**.

The anti-GM tree campaign grew in numbers to include 137 organizations that were represented in Rome and Bonn in 2008 (refs. 20,21), most of them very small, but now including several that claim to represent indigenous peoples whose main concerns are land use, multinational corporations and the spread of intensive plantations generally, not GM trees specifically. Also included were the larger anti-GMO NGOs, including Greenpeace, Sierra Club, World Rainforest Movement and Friends of the Earth.

CBD recommendations

Two resolutions have been accepted by the Cartagena Protocol about GM trees, both urging precaution with respect to their study and use (**Box 3**). Both statements refer to the propensity for wide gene dispersal as a problem for the CBD with its attention to transboundary movement of LMOs. However, they do not discuss why this concern is singled out compared to dispersal of non-GM trees, which often are moved over long distances from their native ranges in breeding programs, can be the result of intensive selection for trait modification, and may include exotic species and hybrids that do not naturally exist in the regions where they are planted. They also do not address that many of the GM traits, such as those proposed for ease in processing biofuels[10], are expected to domesticate, rather than to invigorate trees, and thus should reduce risk of spread and associated impact on biodiversity compared to currently used trees. In other words, the resolutions do not provide any suggestions for comparative risk assessment to help make proportionate risk assessment decisions for the many different kinds and environmental values of GM trees, as is required in the Cartagena Protocol[2]. In fact, they suggest the opposite—that all GM trees as a class should be put through extreme scrutiny and be given special attention in risk assessments, in direct opposition to the case-by-case and product-not-process principles supported by scientific and environmental organizations (**Table 1**). The presumption of hazard from all types of GM trees is not based on a demonstration of generic hazard but is rather a presupposition of environmental risk that is without any scientific justification.

The recommendations also do not suggest that environmental and economic benefits be considered at all, nor do they consider that the process of stringent risk assessment, including the long duration of assessments suggested, is likely to foreclose substantial economic and environmental benefits. Finally, they do not point to the very large potential for GM approaches to reduce some of the risks of gene dispersal from conventional trees, for example, by engineering traits that reduce fertility of exotic or invasive species[22,23], and make no distinction between the very different risks of confined and small-scale field studies versus large-scale commercial releases.

It is clear that the groups strongly opposed to GM trees wish to regulate them out of existence directly, or achieve the same outcome by using the CBD's recommendations to direct national regulations toward requirements that are extremely costly or effectively impossible to meet—conditions that have already been developing in recent years. In the United States, the costs and requirements for permission to conduct multiple-year field trials has grown substantially in recent years owing to the requirement that all such tests obtain full permits from the US Department of Agriculture[24]. In the European Union, there have been only 18 trials of forest trees authorized over a period of 17 years, and attempts to do even short-term contained field studies of trees with modified versions of native genes can run into major legal and political snags. If there are no field demonstrations of value in model genotypes, there will be no further development of commercially useful GM varieties. A high, costly hurdle for field testing discourages investment both by industry and public sector organizations (**Box 4**).

Looking to the future

There is clearly a considerable potential for progress in tree improvement using GM technology given the advances in molecular biology and genomics of forest species. There is also a pressing need for innovations given the increased climatic stresses on plantation forests expected, and the importance of forests for biological materials, renewable energy, carbon sequestration, biological diversity and other

Table 2 Views of major US environmental NGOs on GM crops and trees

Organization	Founded	Expenses 2006	Position
Friends of the Earth	1970	$3,568,260	"In the case of the Convention on Biological Diversity, it is clear that GMOs in general and GM trees in particular, constitute a violation of the convention…" "We therefore call upon all governments, especially the Parties to the Framework Convention on Climate Change and its Kyoto Protocol, to ban the release of GM trees." <http://www.wrm.org.uy/subjects/GMTrees/text.pdf>
Greenpeace	1971	$15,556,440	"Greenpeace is opposed to the release of genetically engineered organisms into the environment at the present state of knowledge and calls for a ban on the release of transgenic trees. As an interim measure a global moratorium on commercial releases and on larger scale experimental releases is recommended." <http://www.genet-info.org/fileadmin/files/genet/GE_Trees/2006_GP_GETrees.pdf>
Int. Union Conservation Nature (IUCN)	1986	$902,112	"Research into GM applications should continue and indeed accelerate but with 'eyes wide open', assessing each GM application on a case-by-case basis." <http://cmsdata.iucn.org/downloads/ip_gmo_09_2007_1_.pdf>
Natural Resources Defense Council	1936	$63,774,845	"…we do not have an official position on [genetically engineered crops and trees]…" (J. Powers, NRDC New York Media Relations Director, personal communication on Nov. 19th, 2008).
Sierra Club	1960	$83,432,700[a]	"Sierra Club has taken no positions regarding genetic engineering done in labs or in indoor manufacturing of pharmaceuticals." "Sierra Club opposes the out-of-doors deployment of genetic technologies [GM trees]." <http://www.sierraclub.org/biotech/trees.asp>
The Nature Conservancy (TNC)	1951	$671,580,417	"…the Nature Conservancy does NOT have any specific policy or position on GMOs." (M. Tu, TNC, personal communication on July 24, 2008)
Union of Concerned Scientists	1969	$12,576,026	"Risks must be assessed case by case as new applications of genetic engineering are introduced." <http://www.ucsusa.org/food_and_environment/genetic_engineering/risks-of-genetic-engineering.html>
Worldwatch Institute	1974	$873,521	"The Worldwatch Institute has no position statement or policy with regard to genetically engineered crops and trees." (Robert Engelman, Worldwatch, personal communication, July 25, 2008). A recent paper published by a staff member suggests case-by-case consideration of merits and risks for specific products. <http://www.worldwatch.org/system/files/EP145B.pdf>

Obtained from reports and web pages that suggest position on genetic engineering, not an official position statement. [a]Annual expenses at end of 2005. NA, not available.

Box 2 What are the risks?

The objections of anti-GMO groups to transgenic trees generally fall into two categories (for a more detailed discussion of the concerns associated with transgenic trees, see ref. 39): risks implicit to the use of recombinant technology and risks associated with specific GM traits under development.

With respect to generic concerns related to recombinant technology, the mutagenesis that accompanies the process is often portrayed by anti-GMO groups as unacceptably large. But molecular variation induced by genetic modification pales when compared with the level of genetic diversity among conventional varieties[40–43]. In a study of maize diversity in the absence of genetic modification, Morgante *et al.*[44] conclude that "the maize genome is in constant flux, as transposable elements continue to change both the genic and nongenic fractions of the genome, profoundly affecting genetic diversity." For trees, the variable effects of different gene insertions are often cited, yet the unpredictability associated with common methods of tree breeding, such as interspecific hybridization and long-distance geographic transfers, are ignored.

As to risks related to traits, such as lower lignin composition or fertility reduction, the scientific consensus is that such traits are not threats to wild forests, as often claimed, because they tend to reduce fitness, impeding their own spread. In addition, trees modified with these genes would have to pass many years of field tests for health, stability and adaptability before large-scale use in plantations, making large-scale plantation failure unlikely. What's more, the changes in ecological chemistry imparted by GM traits such as these tend to be modest compared with normal silvicultural manipulations and intensive breeding (e.g., planting density, vegetation control, shifts in planted tree species and interspecific hybridization), and there are many ways to mitigate impacts by stand-level and habitat management, such as the use of buffer strips, mosaic plantings or rotations with diverse species or genotypes. Such traits as herbicide tolerance will be accepted or rejected on the basis of how their use affects vegetation control and biological diversity both inside and outside of managed forests. Finally, horizontal gene flow, including that of selectable marker genes, has never been shown to occur in nature at a rate that is of ecological concern, nor are there reasons to expect that such transfers could create significant novelties in comparison to the extraordinary diversity of microbial genomes and antibiotic resistance genes[45,46].

Perhaps the most credible science-based concerns about GM trees relate to their potential for wide dispersal of seeds and pollen when they are allowed to flower. Although several forest tree species, including poplar, can also spread vegetatively, this way of propagation tends to be much more localized, much less frequent and can be far better controlled when required in regulations or in commercial practice. The strong concerns about gene dispersal are illustrated by these comments from Petermann[15] in her description of issues at the recent CBD meetings in Bonn, Germany: "The incidents of contamination [with GE [genetically engineered] agricultural crops] show that gene escape and GE contamination cannot be prevented once GE crops are released. This in turn suggests that the widespread planting of GE trees would over time lead to a persistent contamination of the world's native forests, with disruptive ecological consequences."

There is wide agreement from scientists that until very strong containment genes are developed, socially accepted and their efficiency verified in the field, some level of gene dispersal—either from pollen, seeds or vegetative propagules—is certain in most forestry species[14,39,47–49]. Moreover, the distances over which dispersal can occur are large, on the order of kilometers or more. This is mostly a consequence of the potential for long distance movement of pollen by wind and pollinating insects, and to a lesser but still considerable extent owing to movement by seeds. The latter can occur when seeds are very small, subject to movement by major storm systems, or are dispersed by animals such as birds. The limited level of domestication of most tree species contributes to this concern, as propagules are generally fit enough to survive in wild or feral environments.

However, the biological significance of this gene dispersal needs to be put into perspective. First, adventitious presence at a low level is also often prevalent with non-GM crops and trees and usually does not create significant ecological problems (it is an ongoing fact of agriculture and forestry using selectively bred and/or exotic genotypes). Second, compared with the diversity of wild forests, very few GM species are under commercial development that are sexually compatible with wild forests, or will be used in or very near to wild forests, and thus it will be extremely rare that transgenes could introgress into wild tree genomes to a significant degree, and thus become common in wild ecosystems. The area planted with GM forest trees is likely to remain relatively small; forest plantations comprise only ~5% of the world's forest cover[50]. Third, there may be potential benefits for wild tree species from some kinds of GM trees; for example, a wild tree might benefit by acquiring a trait enhancing stress resistance and thus acquire resilience in the face of new forms of biotic or abiotic stresses, perhaps brought on by rapid climate change[12,14]. Fourth, the quantitative amount of admixture may be so low as to be trivial in ecological impact, owing to distance and dilution from extensive wild forests, as a result of intentional use of (even imperfect) containment genes, and from the selective disadvantage imparted when domesticating traits are conferred[51]. Fifth, although concerns have been raised about the effects of containment genes on biodiversity were floral/fruit organs to be altered or removed, by appropriate technology selection (e.g., to selectively target tissues and gametes), and by the rational deployment on the landscape that is already common in plantation forestry, the impacts on biological diversity can be responsibly managed (references and discussion in ref. 14). And finally, it is not clear that GM-imparted traits have the capability to substantially and sustainably improve fitness such that there is sufficient spread and persistence to produce "disruptive ecological consequences"[6], especially given the continued high levels of environmental change and rapid pest evolution. In sum, as a result of all of these factors, most scientists emphasize not whether some gene dispersal will occur; they assume some level may occur for the foreseeable future, but focus on what the extent might be (how frequent, over what distance), and if any substantial adverse consequences (ecological, economic) are likely compared with the expected level of environmental change from other sources, and how these alterations compare to the benefits brought by the GM varieties.

Thus far, however, very few field studies have been conducted that are on the scale needed for useful ecological inferences, in large part because of the regulatory restrictions in doing so[31]. Cartagena Protocol recommendations appear to be putting national regulatory policies on a path toward making such research even more difficult, and for many purposes, impossible to carry out.

ecological services. Even so, progress in translating genomic science into application requires field studies and ultimately decisions from societies about what kinds of innovations are reasonable in the environment at the research and application stages. Unfortunately, applying the 'precautionary approach' or the much vaguer and politically malleable 'precautionary principle'[25] to GM trees, though recommended in recent CBD meetings and well-intentioned in its original goals, appears to confound progress with transgenic tree research.

The precautionary principle has been interpreted in a myriad of ways, depending on the political interests of the parties involved[26,27]. An excess of precaution can lead to calls for extensive and long-term studies of trivial biological issues compared with conventional breeding and silviculture, with costs so great as to effectively halt further investment by the private and public sector. As discussed by Kinderlerer, "A problem with the debate on precaution is that the absence of consensus within the scientific community, especially where weight is attributed equally to all scientists, provides ammunition for those who for many reasons wish to argue against the development of modern biotechnology"[4]. The very promise of novelty and innovation provided by modern biotech, with its new types of genetic innovations, becomes reasons to avoid all development under one view of strict precaution. Under an equally legitimate view, however, precaution demands that we pursue a wide array of options about future forestry and natural resource supplies, and because of their wide potential benefits, it would seem to provide a compelling reason to move forward with transgenic forest biotechnologies.

How the major uncertainties about the details of required risk assessments, unintended transboundary movement, and liability and redress will be worked out present special concerns for research on GM trees. The potential long distances of gene dispersal with trees make strict containment within national boundaries difficult in many places—especially when considered over many planting cycles. The responsibilities of users of LMOs under Article 17 of the Cartagena Protocol that governs unintended transboundary movements are unclear. The long life cycles of GM trees make empirical risk assessment studies of ecological effects slow and costly. It also remains unclear whether growers of GM trees will be held liable under Article 27 of the Cartagena Protocol for unintended dispersal, and how the socioeconomic impact provisions would encompass losses of income from such spread. The Cartagena Protocol was created to address impacts on biodiversity from new traits that result from use of LMOs, not the simple presence of GM DNA[15]. Yet, organizations such as the Forest Stewardship Council, a major international certifier of 'green' and socially responsible forestry and forest products, treats all GM trees, even contained and short-term field research with obvious environmental goals, as a major violation that would void certification. Its treatment of contamination by pollen, seeds or vegetative propagules of a non-GM certified forest or product, and the CBD consideration of such actions, are unclear[4,28]. It is also unclear what parties would be liable, and whether this would include growers, seed companies or regulators in government bodies that authorize field uses. The latter risk is of particular concern given the proliferation, yet lack of technical capacity, to adequately administer biosafety regulatory agencies in many countries. A report from the UN University Institute of Advanced Studies[29] concludes that: "there remains a significant lack of capacity in many developing countries…[and a] country that lacks capacity is more likely to bring in very restrictive systems in order to counterbalance its deficiencies….[Thus, the] lack of an effective biosafety regime undermines the potential for developing countries to consider the role of biotechnology in critical areas such as addressing climate change…"

Until recently, public sector inputs about biotech at the CBD have largely come from anti-GMO–oriented NGOs[30]. Only in the past few years have public sector scientists had a large presence, mainly through the PRRI (**Box 5**). The PRRI organizes and brings scientists to the negotiations to explain the value of transgenic biotech for public sector research and for broad public benefit, and to correct the biased, incomplete or false statements about LMOs that are frequently and loudly made by anti-GMO

Box 3 Precautionary approach and principle

Recent resolutions on GM trees taken at CBD/Cartagena Protocol associated meetings, if interpreted literally and used to guide national biosafety regulations, would clearly have a major chilling effect on field research on opportunities for commercial development of GM trees. The decision on GM Trees made at COP-8 in Brazil states in part: "The Conference of the Parties, recognizing the uncertainties related to the potential environmental and socio-economic impacts, including long-term and trans-boundary impacts, of genetically modified trees on global forest biological diversity, as well as on the livelihoods of indigenous and local communities, and given the absence of reliable data and of capacity in some countries to undertake risk assessments and to evaluate those potential impacts…recommends parties to take a precautionary approach when addressing the issue of genetically modified trees "[52].

The relevant section from the recent COP meeting in Bonn in 2008 (ref. 53) states that the CBD urges parties to "[1] reaffirm the need to take a precautionary approach when addressing the issue of genetically modified trees. Principle 15 of the Rio Declaration on Environment and Development [states that] In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation. [2] Authorize the release of genetically modified trees only after completion of studies in containment, including in greenhouse and confined field trials, in accordance with the national legislation where existent, addressing long-term effects as well as thorough, comprehensive, science-based and transparent risk assessments to avoid possible negative environmental impacts on forest biological diversity (where applicable, risks such as cross-pollination and spreading of seeds should be specifically addressed). [3] Consider the potential socio-economic impacts of genetically modified trees as well as their potential impact on the livelihoods of indigenous and local communities. [4] Acknowledge the entitlement of Parties, in accordance with their domestic legislation, to suspend the release of genetically modified trees, in particular where risk assessment so advises or where adequate capacities to undertake such assessment is not available. [5] Further engage to develop risk assessment criteria specifically for genetically modified trees…."

These recommendations impose obstacles that may be insurmountable for field research in forest biotech. Although the precautionary approach appears to be a less vague guideline than the precautionary principle, its meaning and implementation are still open to wide variation in interpretation. The recommendation from the Bonn meeting to address "long-term effects," even though GM trees are not generally allowed to flower or reproduce in the field under "containment," except in exceptional and often unaffordable conditions of isolation, appears to impose a Catch-22, meaning that there is no way for most countries and organizations to move forward. Given the enormous diversity in GM traits, benefits and biological safety, there is no scientific rationale that can support such indiscriminate and draconian restrictions.

Box 4 The importance of field trials

Whereas anti-GM tree activists see no field research as safe, field studies can be conducted with a very high degree of biological safety and genetic containment and are essential for research to proceed beyond the basics. In most tree species, it is considered a simple matter to conduct highly contained field studies of several years' duration because during that time frame most forest trees have not yet begun to flower, or the flowers are few, close to the ground, and most or all can be readily removed or bagged. Thus, the risk of spread by pollen and seed is low—arguably lower than for many annual crops for which flowering and seed/fruit production happens rapidly, and for which seed/fruit production (rather than wood production) is essential to the goals of the trial. In addition, regulatory authorities generally require monitoring for pollen, seed, seedling and vegetative spread from field trials, and where spread from these processes is a risk, they require removal of flowers before maturity and gamete release. They also require monitoring for, and destruction of, seedling and vegetative propagules up to several years after the trial is complete. In support of field testing, the Global Industry Coalition concerned with regulation of transgenic trees stated that 700 field trials of transgenic trees had been conducted worldwide, without any harmful effects on biological diversity identified[54].

Without field studies, the economic value of newly imparted traits in comparison to conventionally bred trees, and the extent of ecological impact, cannot be adequately assessed[31,38,55]. Indeed, the need for carefully conducted field experiments has been emphasized for other types of crops both to develop useful models of ecophysiology[56] and to enable transgenic or molecular marker–based improvement of complex traits, such as drought tolerance[57]. Even with physiological perturbations as striking as those from elevated CO_2—and for which there have already been abundant field studies—a recent article emphasized the critical need for more field trials to enable realistic assessments of the ecological effects of rising CO_2 levels. Soil and herbivore communities are vastly more complex than can be effectively simulated in a microcosm over a short time period, and plants in the field experience highly variable and strong fluctuations in climate and biotic pressures that materially change patterns of gene expression compared to the simple stresses imposed in controlled, greenhouse experiments[58]. There are many anecdotal stories of places where field and lab or greenhouse results strikingly disagree, but few of these are published. Two that we are aware of for transgenic trees include the *4CL* antisense gene and a *LEAFY* promoter::barnase sterility gene, both in poplar trees. Poplars transgenic for *4CL* exhibited double the rate of growth of controls in one small greenhouse study[59] but in a randomized field study by our group showed only a negligible growth advantage or poorer growth (S.S. *et al.*, unpublished data). In the other case, the floral sterility transgene had no effect on tree growth rate and health in a careful greenhouse trial but was later found to be strongly deleterious in the field[60]. As discussed in the text, there have been many hundreds of field trials already conducted without report of an adverse environmental impact—suggesting that field data can be gathered without significant environmental risk.

NGOs and parties. To the extent that PRRI continues to find scientists that are willing to spend time at these political fora, the CBD will be able to hear a more balanced view of the scientific issues. Similar concerns that nonscientific agendas have become prominent at the CBD, even at the purportedly technical SBSTTA meetings, and that few actual scientists are therefore willing to attend them, also pertains to many other issues under discussion at CBD meetings[30]. Even so, it is difficult to find scientists that are willing to take part as the quality of scientific discussions tend to be extremely low and highly combative, and so are often demoralizing to them. It also takes a considerable effort by PRRI to fund the high costs of international travel for the scientists. Another problem is that the pool of public sector scientists working on transgenic approaches to breeding, and who are thus interested in advocating for sound regulations, appears to continue to decline as a result of the huge regulatory costs and market obstacles to commercial use of the derived varieties. As pointed out by Kinderlerer, "Although it is likely that most of the almost 200 countries that are members of the Convention on Biological Diversity are using modern biotechnology in their research institutions and universities, few are considering the commercialization of products that are likely to be the subject of transboundary movement as defined in the Cartagena Protocol on Biosafety"[4]. Until more public sector scientists believe that GM trees can be used in field research without undue regulatory burden or risk from vandalism, and that they can pass regulatory approval and lead to

Box 5 The Public Research and Regulation Initiative

National regulations are strongly influenced by international agreements, such as the Cartagena Protocol on Biosafety. However, during the development of international agreements the public research sector, which counts tens of thousands researchers in several thousand research institutes in developing and developed countries, had not been represented in an organized way[30]. In 2004, the Public Research and Regulation Initiative was established with the objective of providing public researchers involved in modern biotech a forum through which they are informed about, and can be involved in, relevant international discussions such as the Meetings of the Parties to the Cartagena Protocol. The goal of participation in such meetings is to inform the negotiators about the objectives and progress of public research in modern biotech, to bring high quality science to the negotiations.

The PRRI has taken a stand on GM trees, and issued the following statement at CBD meetings: "Classical breeding has made major contributions to improving the productivity of plantation forests. However, the current challenges caused by population growth, climate change and fossil energy shortage cannot be met by conventional breeding alone. To meet our trans-generation responsibility, we have to find solutions today. We strongly believe that modern biotechnology, including genetic modification, can contribute significantly to finding solutions in these areas. Given the large potential environmental and socio-economic benefits of GM trees and the extensive safety record of the hundreds of field trials with GM trees conducted worldwide, there is no scientific justification for a blanket suspension of releases of GM trees. Field research is, in fact, the only way to get realistic answers to the many questions that were so well developed in the background document on GM trees."

useful products for society, there is unlikely to be the critical mass of scientists willing to take part in CBD and other regulatory negotiations.

Of most immediate concern are the increasingly strict regulations that impede or preclude even field research, and thus the increased foreclosure of opportunities for commercial development. These restrictions on research also provide a signal to companies and public sector institutions that investments in GM tree research are not likely to ultimately be usable or profitable. With respect to scientific concerns, these restrictions also make it nearly impossible to answer the questions that regulators want answered about comparative safety. As discussed by Frankenhuyzen and Beardmore[31] in their extensive review of GM trees, the: "…evaluation of … risks is confounded by the long life span of trees, and by limitations of extrapolating results from small-scale studies to larger-scale plantations. Issues that are central to safe deployment can only be addressed by permitting medium- to large-scale release of transgenic trees over a full rotation. Current regulations restricting field releases of all transgenes in both time and space need to be replaced with regulations that recognize different levels of risk (as determined by the origin of the transgene, its impact on reproductive fitness, and nontarget impacts), and consider potential benefits, and assign a commensurate level of confinement." Ecologists and biotechnologists largely agree that without field studies, science-based regulatory decisions are not possible. By recommending increased stringency (precaution) for all kinds of GM trees, the CBD is making the very studies needed to resolve regulatory quandries increasingly difficult and in many places impossible. The effective prohibition on all types of GM trees that negotiations surrounding the CBD recommendations are helping to promote is clearly against both its spirit and intent.

ACKNOWLEDGMENTS

The authors thank Julian Kinderlerer, Val Giddings, Piet van der Meer, Rachel Lattimore and Leslie Pearson for their helpful comments on the manuscript.

COMPETING INTERESTS STATEMENT

The authors declare competing financial interests: details accompany the full-text HTML version of the paper at http://www.nature.com/naturebiotechnology/.

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