

**Genetically-modified trees:
opportunities for dialogue**
A scoping paper for The Forests Dialogue

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1. This paper

This paper has been prepared for The Forests Dialogue's Scoping Dialogue¹ on genetically-modified forest (GM) forest trees. TFD "stimulates multi-stakeholder platforms for discussion, reflection and the promotion of collaborative solutions to difficult issues facing forests and people" (1):1. Consultation processes within TFD's Steering Committee and network identified the topic of GM trees as one that is both important and contentious, and therefore relevant to TFD. The topic also relates to a number of TFD's earlier initiatives, including that on Intensively-Managed Planted Forests², and to its current initiative on Food, Fuel, Fibre and Forest³.

There are a number of reasons why TFD engagement with the topic of GM trees is timely:

- on the one hand, there has been significant research progress relevant to the use of GM technologies in trees. Commercial plantations of GM trees have been established on a small scale in China, and the number of field trials of GM trees is increasing globally, principally in the Americas. Proponents of GM trees believe that their use offers a suite of benefits, and that there is considerable potential for and merit in their adoption;
- on the other hand, as with GM agriculture, there has been substantial civil society concern directed at the use of GM trees. Opponents of GM trees believe the risks associated with their use, and perhaps even their testing, are too great. Some opposition to GM trees derives from opposition to industrial-scale, intensively-managed forestry as a land use and production system. As a result, there are strong debates about GM trees in both the scientific community and in civil society;
- there is a window of opportunity, at a stage when there has been little deployment of GM trees, for open and productive dialogue about substantive issues associated with their further development and possible use.

The paper draws from the substantial body of recent literature on genetic modification in agriculture and forestry, including other reviews (eg (2)(3)(4)(5)) which provide background and context to the material presented here. The purpose of the paper is to inform, stimulate and help frame discussion at the Scoping Dialogue; that Dialogue explores and identifies the issues and opportunities for subsequent TFD engagement¹.

2. The topic

This paper discusses issues associated with the 'genetic modification' of forest trees, where that term is treated synonymously with 'genetic engineering' or 'transgenic', and is defined as "those [trees] that have been modified using recombinant DNA and asexual gene transfer methods" (6):76; other definitions (eg (7):5) also explicitly include the offspring of these trees. Genetic modification is commonly identified as one of the five major categories of forest biotechnologies; the others are propagation, molecular markers, marker-assisted selection and breeding, and genomics and related fields (8).

¹ For an explanation of the dialogue process, see TFD's Strategic Plan 2011-2015 (1), p7.

² environment.yale.edu/tfd/dialogues/intensively-managed-planted-forests/

³ environment.yale.edu/tfd/dialogues/food-fuel-fiber-and-forest/

This definition distinguishes genetically-modified (GM) trees from those that are the product of 'conventional' breeding or genetic improvement programs, and that are the basis of the significant and continuing gains realised by these programs in their relatively brief history (9)(10). Conventional programs may also make use of the other categories of biotechnologies, but rely on recurrent selection and sexual recombination of genes, rather than on transgenic methods, to generate desired variation and traits (3)(11).

3. Framing the issues

Over the past c. 20 years, the rapid advances in genetic technologies have transformed questions about genetic modification of plants from principally scientific and technical – “what is it possible to do?” – to increasingly ethical, social and political – “what is it appropriate to do?” (12):163. For these reasons, now, “the use of GM forest trees is viewed more as a political and environmental issue than as a technical or trade issue” (13):4.

These questions and issues are reflected in community, political and scientific debate about the use of genetically-modified organisms (GMOs) in agriculture and forestry, and in a body of academic work, principally but not exclusively in the social sciences, that reviews experience and learning from more than a decade of debate about GMOs, principally but not only about GM crops (eg (14, 15)(16)(17)(18)(19)(20)(3, 21)).

Simplifying for conciseness here, much of this academic work points out that the debate about GM technologies and crops is both embedded in and reflects the different values and worldviews of participants, and their different visions of desirable futures; their different understandings of the culture and conduct of contemporary science; and their interpretations of power relations between business, citizens and government in particular societies. Lassen and Jamison (16) suggested a framework for understanding 'discourses of concern in relation to genetic technology', reproduced below.

Table 1. Discourses of concern in relation to genetic technology

Source: reproduced from Lassen and Jamison (16), Table 1

Main concern	Central issues	Keywords
Social	Environment and health	Risk, uncertainty
Economic	Profitability and production	Cost/benefits, responsibility, power
Cultural	Religious and/or moral aspects	Ethics, rights, integrity

Discourses about GM crops have also been fundamentally shaped by the alignment of what has become known as the 'agbiotech model' for commercial use of biotechnologies with the promotion of GM technologies. As Murphy (3) explains, a conjunction of circumstances in the 1980s⁴ favoured the emergence of a business model that was based on the transgenic use of genetically straightforward traits (such as herbicide or insect resistance) that could be coupled with agrochemical inputs, and sold to farmers in a single package in exclusive sales contracts that precluded those farmers from saving and replanting the seed. Murphy argues that the pursuit of this agbiotech business model has generated a number of significant downsides for agriculture more generally, particularly through distorting investment in crop improvement⁵,

⁴ In essence, the privatisation in many countries of formerly public sector functions in plant breeding; major advances in commercialisable biotechnologies; patent and intellectual property rights regimes more favourable to transgenic than conventionally-bred plants; and the emergence of large multinational corporations that integrated agricultural chemical and seeds businesses.

⁵ By favouring GM rather than conventional breeding; by sustaining old technologies; and by focusing on transgenic modification of simple 'input' traits (principally herbicide tolerance and insect resistance) rather than more complex 'output' traits that might be more valued, and be more likely to be accepted, by consumers.

fostering an artificial and unhelpful dichotomy between GM & non-GM crops in public discourse, and alienating key actors in both agricultural value chains and civil society.

Analysis (17) of one particular GM crop issue, the segregation of GM and non-GM crops in Europe, illustrates how these discourses shape debate and outcomes. Levidow and Boschert (17) point out that protagonists used their framing of the issues to characterise the policy problem in particular ways (broadly corresponding to positions of less versus more restrictive regulation), and note the limits of 'science-based policy' in situations where the policy framing is so contested. Their characterisation of how different interests framed the discourse – legislators and regulators in managerialist terms, proponents of GM crops in terms of eco-efficiency, and opponents in apocalyptic terms – has resonance in discourses about GM trees. More generally, there appears to be general agreement with Kearnes et al's (14):291 commentary on the lessons that might be drawn from the GM debate in agriculture in the UK:

"Crudely put, the agricultural GM experience represents a warning, a cautionary tale of how not to assess an emerging technology and allay public concern."

Much of the literature about GM trees is informed by experience with GM crops. For example, Gamborg and Sandøe (12) (Table 2) and Hall (22) compare the characteristics of trees and crops in terms relevant to GM discourses; Doering (23) makes a similar comparison in terms of the forestry and food industries. Such analyses suggest that, whilst there are important points of differentiation, many of the elements of the discourses about GM crops are similarly relevant to tree crops.

Table 2. Comparison of forest trees and agronomic food crops

Source: reproduced from Gamborg and Sandøe (12), Table 8-1

Biological factors	Socio-economic and cultural factors
Forest trees are far less improved through selective breeding than agricultural crops	Forests are more accessible to the public than agricultural fields
Forest trees evidently have a much longer life than agricultural, even perennial, crops, and the forest persists much longer; rotations may span more than a hundred years.	Forests, unlike agricultural production units (fields), encompass everything from natural to semi-natural woodland to tree plantations.
As ecological systems, forests are much more structurally and functionally complex than their agricultural counterparts.	Forests produce several recognized goods and services at the same time.
Forest trees (by definition) do not produce edible goods (but timber, pulpwood, woodfuel and so on).	Forests have conferred upon them a diversity of social, cultural, symbolic and other values.

4. The GM trees discourses

Notwithstanding their differences, discourses about GM trees have followed an essentially similar pattern to those of GM agriculture. This is unsurprising, as much of the promotion of GM trees has mirrored that of GM crops under the agbiotech model.

Arguments in favour of GM crops have emphasized the benefits to farmers and society of increased productivity or value, to the environment from more environmentally-benign management practices, and that risks are low if well-managed and –regulated (eg (24)(25)). Herring (20) argues that opposition to GM crops can be understood primarily in terms of concerns around bio-safety and bio-property, and farmers' vulnerability to corporate control.

Discourses around GM trees includes these elements, but also others that differentiate trees from agricultural crops; notably, the 'naturalness' of forests and the longevity of trees, the corporate ownership of many intensively managed planted forests compared to the public and

non-industrial ownership of many 'natural' forests (12)(22), and some of the particular biological characteristics of trees compared to crops (Table 2; (26)).

The dominant framing of the discourses about GM trees is largely that established for GM crops, and might be summarised as in Table 3.

Table 3. Framing of discourses about GM trees

"Category"	"Core position"	Example protagonists
Strong proponents of GM trees	<ul style="list-style-type: none"> • GM technologies offer opportunities for realising a variety of benefits (eg productivity and intensification gains, adaptation to new environments, reduced environmental impacts of production) that either cannot be realised, or can only be realised less efficiently, through conventional breeding. • Risks vary with the GM technology and its use; they can be identified and assessed, and adequately governed by appropriate regulatory oversight. • Risks should be assessed in terms of products rather than process. 	Partners in the Institute for Forest Biotechnology ⁶ : these include forestry and forest products companies and universities conducting genetics research; most academics conducting this research
Conditional supporters or opponents of GM trees	<ul style="list-style-type: none"> • GM technologies have a role in forestry, but primarily in applications other than supporting intensively-managed planted forestry. • Higher levels of precaution and complementary action are necessary than those adopted for agricultural crops. 	FAO ⁷ ; some environmental NGOs ⁸ ; some academics
Strong opponents of GM trees	<ul style="list-style-type: none"> • Intensively-managed industrial-scale plantation forestry is environmentally and socially unacceptable. • Under the 'agbiotech' model, the benefits of GM technologies are captured largely by corporations and will be deployed in monoculture intensively-managed planted forests, disadvantaging the poor and smallholders. • The environmental risks and social costs of use of GM trees are unacceptable, and demand strong interpretation of the precautionary principle. 	Some environmental and social NGOs ⁹ : eg Friends of the Earth, Global Forest Coalition, Greenpeace, World Rainforest Movement; some academics

⁶ www.forestbiotech.org

⁷ See FAO. *Synthesis: current status and options for forest biotechnologies in developing countries* (12)

⁸ See, eg, Strauss et al 2009 (27), Table 2

⁹ As above; see also www.globaljusticeecology.org/stoptrees.php

5. Elements of the key arguments in the GM tree discourse

As evident from the preceding discussion, the key arguments about GM trees are associated with competing views of ethical and moral imperatives, of the future of land use and resource (including genetic resource and intellectual property) ownership, and of the gravity of probable risks compared to the expected benefits of GM tree use. These arguments have been thoroughly made and reviewed elsewhere (eg (2) (4, 11, 27) (28) (29)). Each of these is outlined briefly below.

Ethical considerations and moral imperatives

Views on the ethics and morality of GM trees cover the spectrum, from obligations to nature and society to prevent their creation and/or use (eg see discussion in (20)) to the 'ethical obligation to explore their potential benefits responsibly' (paraphrasing The Nuffield Council on Bioethics (30): xiv, for GM crops). Gamborg and Sandøe (2010) discuss how the discipline of 'ethics', focused on reflection and clarification of potential courses of action, can help illuminate complex trade-offs and make room for dialogue on such issues.

The future of land use and resource ownership

Opponents of intensively-managed industrial-scale planted forestry see GM technologies as enabling that form of forestry, which they criticise on both environmental and social grounds (eg (31), (32)). Critics of the 'agbiotech model' in GM tree development and deployment are concerned about the balance of private (especially corporate) and other societal interests in the development and use of GM technologies; about the private capture of genetic resources, technologies and intellectual property; and about the distortion of research and development priorities (eg (21)(33)).

The benefits and risks of GM trees

The majority of public debate has focused on the potential environmental risks of GM trees; that debate is part of wider discourses that also include consideration of economic and social issues, including those introduced above. For example, UNEP (4) provides a list of 'potential positive and negative impacts' of GM trees, reproduced as Appendix 1.

In the simplest terms, the anticipated benefits of GM trees include those from better adaptation to demanding or new environments, including those arising as a result of climate change (eg (34)); contributions to the intensification of production necessary to meet demand in the context of increasing competition for land (eg (35)); increased returns in the value chain from greater productivity or value recovery, or reduced costs (eg (36)); reduced environmental impacts associated with reduced chemical inputs in growing or processing (eg (37)); and recovery of species that might otherwise become extinct (eg (38)). Modification has focused on increasing resistance to abiotic stresses, such as cold or drought; on greater tolerance of herbicides, and greater resistance to pests and pathogens; on improving growth or wood properties; on phytoremediation capacity; and on modification of flowering, for example to engineer sterility (26, 39, 40).

The potential environmental risks of GM trees have been categorised (40) as those relating to transgene spread, associated with increased invasiveness by the transformed species, and with transfer of the gene to non-transformed relatives ('vertical' gene flow) or unrelated organisms ('horizontal' gene flow); impacts on non-target organisms and ecosystem processes, such as through impacts on pests and pathogens; and unstable gene expression and unexpected effects of genetic manipulation. These risks have been reviewed in detail by, amongst others, (26)(40)(41)(42). There is general agreement amongst those who are not implacable opponents of GM trees that genetic confinement, most probably through control of flowering, is likely to be a precondition for mitigating many of these possible environmental risks; but also that it is challenging to realise this goal in long-lived, fecund organisms such as trees (6, 43)(41).

A subsidiary strand of the benefits-costs discussion concerns the economic costs and returns of GM technologies compared to other breeding technologies, and the need for genetic improvement strategies to integrate both established and new technologies (3)(11)(44). For example, FAO (11) notes that GM technologies are most relevant to highly-domesticated populations, but that none of the world's planted forests are in this category; a few species can be classified as semi-domesticated, but the majority are undomesticated.

6. Governance and regulation of GM trees

The development, testing and use of GM trees are regulated both internationally and nationally, and through non-state regulation such as certification. The Cartagena Protocol on Biosafety of the Convention on Biological Diversity¹⁰ provides the principal international framework. Most countries have national regulatory mechanisms, although the extent to which they are developed and capacity for implementation vary. Non-state regulation can have strong impacts, exemplified by the Forest Stewardship Council's ban on certification of GM trees (21, 28, 45).

Both international and national regulatory regimes are built around risk assessment protocols. Proponents of GM trees argue that most current regimes are precautionary disproportionate to risk (46, 47); and for protocols such as Canada's, that take a product rather than process-based approach to applications of biotechnologies (48). GM tree proponents argue that the Cartagena Protocol has been used effectively to date by GM tree opponents to constrain the development of GM trees (28). Regulations at the national level vary, but are generally seen by GM tree proponents as disproportionately restrictive in Europe and the USA (eg (39, 46)(41)); they assert that the constraints on field testing are so great as to effectively ban it, which in turn precludes the evaluations necessary to address the environmental risk-related concerns of GM tree opponents. New regulatory arrangements, which have both proponents and critics, are being piloted in the USA (49).

Notwithstanding broad scientific agreement on the underlying principles that should apply to the testing and use of GM organisms (eg for the Ecological Society of America: (42); in the EU: (26)), stakeholder views on the appropriate level of precaution and the nature of regulation of GM trees remain strongly divergent and contested, internationally and nationally.

7. Current status of development and deployment of GM trees

The development, testing and use of GM trees remains at a relatively early stage - both in absolute terms and in comparison to the situation in GM agricultural crops. This is due in part to relative size of, and research investment in, the two sectors; in part to the biological characteristics of annual crops and trees, which make transformation and testing of the latter more difficult; and in part to the regulatory barriers applying to testing of GM trees (8)(43, 46).

Worldwide, more than 700 field trials with GM trees of 30 genera have been conducted (50)(51). The majority of these, nearly 600, have been in the USA; *Populus*, *Pinus* and *Eucalyptus* species comprise more than 70% of these (49). A large-scale field trial of genetically-modified eucalypts in the USA was approved in 2010; the validity of that approval was challenged by legal action (49)(52), but upheld (53). Eighty-four field trials have been approved in China, of which *Populus* and *Robinia* comprise 70% (54). Thirty-two trials have been reported in EU member states, the majority with *Populus* (26)(43); 18 trials of GM *Eucalyptus* have been approved in Brazil (55).

Currently, the only commercial plantings of GM trees are in China, where c 450 ha of *Populus* have been established (26, 54)¹¹.

¹⁰ bch.cbd.int/protocol/

¹¹ For comparison, a similar area of GM papaya fruit trees has been established in Hawaii, and some may have been planted in China (www.gmo-compass.org/eng/database/plants/59.papaya.html). The area of GM crops planted in 2010 was estimated at 148 million ha; 50% of this was soyabean; 31% maize; 21%

8. Possible starting points for dialogue

Dialogue at three levels seems necessary if there is to be progress towards broader agreement within societies about the roles and uses of GM trees. The first of these is the most fundamental, and focuses on discussion within civil society about the role of GM tree technologies. Dialogue at the second level would focus on the ways in which GM technologies are used. Dialogue at the third level would focus on the processes and standards by which the creation, evaluation, monitoring and adaptive management of GM trees are governed. While these levels of dialogue are interrelated and to some extent interdependent, they are also separable.

i. Dialogue in civil society about GM trees

A body of work reflecting on the learnings from the GM crop debate for GM trees or other new technologies emphasize the importance of meaningful dialogue within civil society to build shared understanding, informed by the social as well as the natural sciences (14, 22, 56)(12). As Boyd (56) notes, some of this dialogue concerns “putting science back into the debate”, to address scientific ambiguities and uncertainties; as she comments, “in the absence of knowledge, precautionary approaches will tend to prevail”. In the case of GM trees, such a dialogue might recognise – amongst other factors – the particular characteristics of trees *cf.* crops, and the variety of production systems relevant to tree growing (eg from very short rotation exotic plantation crops to very long rotation native and semi-natural forests).

Conversely, as Hall (22) notes, scientists participating in the dialogue have also to recognise the other societal values that shape opinions and decisions. Gamburg and Sandøe (12) emphasize the need for decision processes to be built around transparency and stakeholder participation, noting that these are no guarantee of success but also that they offer the best prospect of enduring solutions.

ii. Dialogue about the way GM technologies are used in trees

A second level of dialogue would explore the ways in which GM technologies are and could be used in trees and the forests sector. For example, FAO (11) and Williams (21) make the case, accepted by participants in the 2010 FAO Conference on Agricultural Biotechnologies (13), that forest biotechnology – including GM trees – should follow a different path to that of agricultural biotechnology¹². In their view, the greatest potential value of GM technologies in forestry is in helping facilitate adaptation to climate change and in processing technologies. Doering (23) suggests similarly that a ‘public-first’ strategy might be the most effective for promoting acceptance of GM trees; such a strategy would require a reversal in the decline in publicly-funded research and development relevant to GM plant breeding (3).

iii. Dialogue about the processes and standards for governance of GM trees

Dialogue at this level assumes societal acceptance for the creation and use of GM trees, for purposes and in ways agreed by dialogue at the higher levels. Such dialogue is likely to be build upon the agreement of principles, such as those established by the Institute of Forest Biotechnology (57), or proposed by the Ecological Society of America (42) or others (eg (58)); and upon already-established protocols, such as those established for risk assessment by the EU (26) and elsewhere (59), and critiques of them (eg (60)).

cotton; and 5% canola. 45% of GM crops were planted in the USA; Argentina and Brazil planted around 15% each; and Canada and India around 6% each (James 2010; www.isaaa.org/resources/publications/briefs/42/executivesummary/default.asp).

¹² Proposals (eg Murphy, 3) for the reform of the agbiotech model itself are also relevant here.

9. Conclusions

Like many other applications of new genetic technologies, GM trees have the attributes characteristic of 'wicked' policy problems¹³ (56). The history of prior discourses about GM crops both informs and handicaps those about GM trees, given the similarities and the important differences between crops and trees. Given the relatively early stage of development of GM trees, and that their use has so far been limited (with one modest exception) to small, short-term field trials, there is also the opportunity to shape the trajectories and outcomes of the use of GM in trees in ways that are no longer easy to do in the agbiotech sector.

Gamborg and Sandøe (12): 168-9 note that one of the principle learnings from societal debates about GM agriculture is "that if modern biotechnology is to stand a chance, three main conditions for public acceptance must be met: utility, low risk, and an assurance that the biotechnology is used in a decent way". But they also note that surveys suggest these are necessary but not sufficient conditions, and that "moral acceptability is a better predictor ... than risk or usefulness". Thus, a fundamental challenge for proponents of GM trees is build public trust (23), in part by finding ways of demonstrating to members of civil society that GM trees satisfy these conditions and tests.

Societies will continue to rely on technological advances, such as those offered by genetic modification (56); conversely, as aspects of the agbiotech debate (amongst many others) illustrate, scientific advances do not necessarily or inherently confer legitimacy or gain social acceptance. More profound social processes are necessary to engender legitimacy and acceptance of scientific innovation for which the balance of potential benefits and risks is uncertain, and this applies to GM trees as to other such technologies. In turn, those processes depend in part on frank and constructive dialogue such as that fostered by TFD initiatives.

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¹³ "Complex issues that are highly resistant to resolution" (Australian Public Service Commission. 2007. *Tackling wicked problems – a policy perspective*. www.apsc.gov.au/publications07/wickedproblems.htm)

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Appendix 1

Reproduced from UNEP 2007 (4), Annex 1.

Annex I

POTENTIAL POSITIVE AND NEGATIVE IMPACTS ^{1/} OF THE USE OF GENETICALLY MODIFIED TREES

<i>1. Potential environmental impacts</i>	
Positive	a) Reduced lignin content might reduce the need for chemicals and the amount of energy required for processing cellulose (Halpin et al. 2007; van Frankenhuyzen and Beardmore 2004; Johnson and Kirby 2001; Mathews and Campbell 2000)
	b) Pollution originating from pulp mills might be decreased and fewer trees would need to be harvested to meet consumption needs (Johnson and Kirby 2001)
	c) The need to apply broad spectrum pesticides in forested areas might be decreased because of insect resistant traits (Farnum, Lucier and Meilan 2007; Hayes 2001; Campbell and Asante-Owusu 2001; Mathews and Campbell 2000; James et al. 1998)
	d) Exposure of non-pest insects to pesticides might be reduced as the insecticidal agent would be targeted specifically to pests feeding on tree tissues (Mathews and Campbell 2000; James et al. 1998)
	e) Endangered or threatened tree species could be modified to resist or combat the impacts of invasive alien species by introducing insect resistance traits (van Frankenhuyzen and Beardmore 2004)
	f) Herbicide resistance would allow for the application of relatively benign broad spectrum herbicides in plantations, thus reducing the need to apply multiple herbicide treatments (van Frankenhuyzen and Beardmore 2004; Mathews and Campbell 2000)
	g) Trees with increased stress tolerance could be used in the phytoremediation of contaminated soils (van Frankenhuyzen and Beardmore 2004; Peña and Séguin 2001; Mathews and Campbell 2000)
	h) Modifying trees for increased productivity might reduce the need for old growth logging as high yield plantations could be used to fulfil timber needs (van Frankenhuyzen and Beardmore 2004; Hayes 2001; Strauss et al. 2001)
Negative	a) As lignin makes it difficult for insects to digest plant materials, reduced lignin content may decrease the fitness of trees (van Frankenhuyzen and Beardmore 2004; James et al. 1998)
	b) Decreased lignin might render trees more vulnerable to viral diseases (van Frankenhuyzen and Beardmore 2004)
	c) Trees with lower lignin levels may potentially affect soil structure and chemistry by allowing for accelerated rates of decomposition (Farnum, Lucier and Meilan 2007; van Frankenhuyzen and Beardmore 2004; Campbell and Asante-Owusu 2001)
	d) Insect resistant traits may lead to the increased development of pesticide resistant species (Farnum, Lucier and Meilan 2007; van Frankenhuyzen and Beardmore 2004; Campbell and Asante-Owusu 2001; Peña and Séguin 2001; Mathews and Campbell 2000)
	e) Insect resistance might reduce the number of phytophagous and pollen-feeding insects present in a forest (Johnson and Kirby 2001)
	f) Non-targeted herbivores (minor pest species) might be affected by insect resistant traits (Royal Society of Canada 2001)
	g) There is a potential for insectivores to acquire toxins through the ingestion of herbivores which have fed on insect resistant species (Royal Society of Canada 2001)
	h) While insect resistance traits may suppress one insect pest, these traits may result in secondary pests increasing in numbers (Johnson and Kirby 2001)
	i) If detrital plant materials retain their insect toxicity, it might have adverse effects on soil structure and decomposition as insects play crucial roles in these processes (Johnson and Kirby 2001)
	j) The leaching of toxic materials from insect resistant trees into forest soils through root systems might affect soil communities (O'Callaghan et al. 2005)
	k) By promoting the use of specific herbicides, herbicide resistant trees may lead to increased selection pressure for resistant weed biotypes as well as reinforce the use of

^{1/} The potential impact was considered "positive" when it would presumably result in one or more benefits for human or ecosystem health or well-being, and "negative" when it presumably would result in a disadvantage or threat for human or ecosystem health or well-being.

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	<p>broad spectrum herbicides (Farnum, Lucier and Meilan 2007; van Frankenhuyzen and Beardmore 2004; Johnson and Kirby 2001; Thomas 2001; James et al. 1998)</p> <p>l) Traits increasing resilience may lead to some trees becoming invasive, potentially resulting in a loss of biodiversity (James et al. 1998)</p> <p>m) If transgenes, conferring increased resilience were to escape into wild species, these species might become invasive (van Frankenhuyzen and Beardmore 2004; Campbell and Asante-Owusu 2001; Mathews and Campbell 2000)</p> <p>n) The potential for novel genetic materials escaping into wild gene pools carries unforeseeable risk (Merkle et al. 2007; van Frankenhuyzen and Beardmore 2004; Campbell and Asante-Owusu 2001; Johnson and Kirby 2001; Mathews and Campbell 2000; James et al. 1998)</p> <p>o) There is a possibility that the new genetic traits entering the ecosystem might affect the bio-trophic processes of the host ecosystem (Mathews and Campbell 2000)</p> <p>p) Somaclonal variation can result in the manifestation of tree abnormalities (van Frankenhuyzen and Beardmore 2004)</p> <p>q) Adaptability of forest stands and plantations to biotic or abiotic stressors might decrease due to increased use of clones (Carnus et al. 2006)</p>
	<i>2. Potential socio-economic impacts</i>
Positive	<p>a) By reducing the lignin content in wood its pulping efficiency might be increased as fewer chemicals and less energy would be required for its processing (Halpin et al. 2007; van Frankenhuyzen and Beardmore 2004; Campbell and Asante-Owusu 2001; James et al. 1998)</p> <p>b) Increasing the lignin content of trees would lead to a higher lumber density and consequently a better quality of timber and a higher value product (Mathews and Campbell 2000)</p> <p>c) Trees with increased lignin content would have higher caloric value and might therefore serve as more efficient fuel sources, and would theoretically increase timber strength allowing for the development of stronger construction materials (Gartland, Kellison and Fenning 2002; Mathews and Campbell 2000)</p> <p>d) Increased timber uniformity might increase the overall market value of genetically modified timber (Mathews and Campbell 2000)</p> <p>e) Trees could be modified to suit different management regimes (Johnson and Kirby 2001)</p> <p>f) Aside from increasing the viability of trees and reducing losses to folivores, fungi and bacteria, pesticide resistant trees might also decrease the need for pesticides and consequently reduce the input costs associated with tree production (Mathews and Campbell 2000)</p> <p>g) The use of herbicide resistant trees will allow tree producers to apply broad spectrum herbicides to control weeds thus reducing the need for more traditional and costly methods of weed control such as multiple herbicide applications and tilling (Mathews and Campbell 2000)</p> <p>h) With fewer weeds present in plantations, as a result of being able to apply herbicides, there might be less competition for resources and trees will be able to grow more efficiently (Johnson and Kirby 2001)</p> <p>i) Trees modified to express disease resistant traits might also result in increased productivity and the development of safer and or more nutritious foods with longer shelf lives (Thomas 2000)</p> <p>j) The increased resilience of trees would mean that they would be able to grow with greater efficiency consequently improving productivity (Johnson and Kirby 2001)</p> <p>k) Trees modified to be more resilient to adverse growing conditions could be planted on soils where they have not traditionally been able to survive allowing trees to be used in the phytoremediation of contaminated soils, creating a cost effective means of restoring land that otherwise could not be used (Farnum, Lucier and Meilan 2007; Peña and Séguin 2001)</p> <p>l) If economically valuable species could be engineered such that they could be grown in various locations outside their traditional home range, it might allow for greater production (Mathews and Campbell 2000)</p> <p>m) The amount of time required to develop improved phenotypes could be reduced (Mathews and Campbell 2000)</p>
Negative	<p>a) Trees with altered levels of lignin may be less viable than their non-modified counterparts and therefore might have adverse economic impacts as a result of higher tree mortality (van Frankenhuyzen and Beardmore 2004; Mathews and Campbell 2000)</p> <p>b) The use of high productivity plantations might lead to a decrease in the perceived social and economic value of non-modified or natural forest as the economic gains from these types of forests would not be as large as those received from genetically modified forest plantations (Hayes 2001)</p> <p>c) Poor producers of primary commodities in developing countries may not be able to have access to genetically modified trees given their relatively high cost thereby excluding these producers from certain markets and depriving them of access to new seed types (Thomas 2000)</p>

	<p>d) Should pest species become resistant to currently effective chemical and biological control methods, the cost of controlling pest outbreaks would increase (Mathews and Campbell 2000)</p> <p>e) The long time period between the commencements of research projects on genetically modified trees and when benefits begin to accrue makes tree engineering a risky economic proposition (van Frankenhuyzen and Beardmore 2004)</p>
	<i>3. Potential cultural impacts</i>
Positive	<p>a) Genetic modification might contribute to the protection and conservation of culturally important tree species which have been in decline as a result of disease (Farnum, Lucier and Meilan 2007; Merkle et al. 2007; Hayes 2001)</p>
Negative	<p>a) The unintentional development of insect and herbicide resistant species as a result of transgene escape might alter species compositions and reduce the number of species present in a given location thus forcing cultures to adapt to changing biodiversity conditions (Peterson et al. 2000)</p> <p>b) Genetic modification might reduce the effectiveness of context specific adaptations in agricultural methods, make local systems less adaptable and make some societies dependant on outside inputs (Peterson et al. 2000)</p>