PAPERS

Certification of genetically modified forest plantations

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SUMMARY

The use of recombinant DNA and asexual gene transfer methods to genetically modify (GM) plantation trees, also called genetic engineering, has been treated variably by the diverse systems that certify forest management practices. Only one system, the Forest Stewardship Council (FSC), bans all uses, including contained field research, and this prohibition applies regardless of whether genes derive from the same or different species, or whether the trait imparted is a small modification to physiology or a novel property. In contrast FSC allows consideration of benefit versus risk for other practices of intensive plantation management that may have complex or irreversible ecological consequences, including the uses of exotic populations or tree species, hybrids, or clones; biological control organisms; and fertilizers, herbicides, and pesticides. We review FSC's stated concerns about GM plantations and show that all of them are likely to be soluble given research and monitoring of GM plantations during early stages of development. We argue that the FSC ban makes it very difficult for certified companies to participate in the very field research required to resolve the concerns, and forgoes an opportunity to direct research toward desired applications of GM. It also severely constrains the ability to use the rapidly growing knowledge of genomes to attain a number of environmental benefits – themselves often requirements of certification standards. These might include production of more wood from less plantation land, wood that results in less pollution during pulping or energy generation, means for containment of highly bred or exotic species, reduced use of undesirable pesticides and herbicides, and mitigation of damage to soils as a result of mechanical weed control.

Key Words: biotechnology, transgenic, genetic engineering, gene flow, transgenes, wood

INTRODUCTION

Forest certification

Forest and forest product certification systems have grown rapidly in recent years, developing in parallel with the many international, national, and regional initiatives attempting to define and promote sustainable forest management (SFM[1]) (Carbarle et al. 1995, Lawes et al. 1999). The area certified under the most widely adopted international system, the Forest Stewardship Council, is now over 22 million hectares (FSC 2001a), nearly all of which has occurred since 1995. The Sustainable Forestry Initiative (SFI) Program of the American Forestry and Paper Association (AFPA) reported 30 million hectares enrolled in North America (American Forestry and Paper Association 2001), also primarily in the last few years. The intent of certification is to provide a market-based mechanism to encourage and reward SFM (Kajiwara and Malnick 1999), and thereby provide a market advantage over less responsible forestry practices.

The goals of SFM are complex and are defined by social as well as biological criteria. Sustainably managed forests can include those managed to retain as many of their natural ecological qualities as possible while extracting commercial products, to areas managed

[1] Acronynms used in this paper are: ABRG:Antibiotic resistance gene, Bt:Bacillus thuringiensis, CSA: Canadian Standards Association – Canadian Certification System, DSS:Decision support system, EMS:Environmental Management Systems, eNGO: environmental non-governmental organization, FSC: Forest Stewardship Council, GM: genetic modification, GMO:genetically modified organism, HR:herbicide resistance, IP:Intellectual Property, IR:insect resisatnce, ISO: International Organization for Standardization, LEI:Lembaga Ekolabel Indonesia, PEFC: Pan-European Forestry Certification, SFI:sustainable forestry initiative, SFM:sustainable forest management, UKWAS:UK Woodland Assurance Scheme WWF: Worldwide Fund for Nature

primarily as wood farms, and thus bearing little resemblance to natural ecosystems in structure or ecology. Wood farms can indirectly contribute to conservation of natural forests because they reduce pressure on wildlands for intensive exploitation and satisfy social demands for wood products and economic development, locally and internationally (Romm 1994). Certification guidelines reflect this complexity; both near-wild forests, and industrial plantations that are intensively managed—often based on highly-bred or exotic species—have been certified under a number of different systems (Coventry 2001).

There are two major forms of certification. Performance-based approaches, such as FSC, stipulate specific environmental conditions and management practices that must be met for a forest tract to be certified. Systems-based approaches, which are the basis of the system adopted by ISO 14000 series of EMS (International Organization for Standardization, Environmental Management Systems), assess the quality of an organization's management process, including how it sets its policies, targets, and control procedures. Increasingly both systems require specific conditions *and* management procedures to varying degrees, and are designed to complement the many international, national, and regional laws and policies that have been put in place in recent decades to promote SFM (Lucier and Shepard 1997, Haener and Luckert 1998).

Genetic modification

GM refers to the use of recombinant DNA and asexual gene transfer methods to isolate, modify, and reintroduce genes into organisms. This includes genes that have their origins in different species and those isolated and modified, then reintroduced, into the same species. Because of their amenability to GM, plants have been modified far more than any other multicellular organism, and the use of commercial GM crops has grown extremely rapidly since their first introduction in the early 1990's. During 2000, GM crops accounted for one-fifth of the corn planted, one-half of the soybean, and nearly three-quarters of the cotton in the United States (where approximately two-thirds of the GM crops are grown worldwide; Carpenter and Gianessi 2001). The major traits used in commercial practice have been herbicide, insect, and disease resistance.

The value of GM crops varies greatly depending on where and how they are used The main benefits to date have been reduced management costs, improved yields, reduced insecticide or herbicide use, and preferential use of low toxicity herbicides (Fernandez-Cornejo *et al.*, 2000, Wolfenbarger and Phier 2000, Carpenter and Gianessi 2001). For example, the Rockefeller Foundation-funded National Center for Food and Agricultural Policy estimated that cotton growers reduced insecticide use by 2.7 million pounds and made 15 million fewer insecticide applications per year since the introduction of insect resistant cotton (Carpenter and Gianessi 2001). In addition to these agronomic traits, a great variety of new kinds of GM crops are under development that are intended to promote health (e.g., vitamin or oil enhancement, or reduced allergenicity), or produce novel compounds such as vaccines.

Despite its initially rapid growth, the uptake of GM crops has slowed considerably in recent years in North America, primarily because of concerns about export markets. Strong consumer and NGO resistance to GM crops, and rigorous labeling and food safety laws—particularly in Europe and Japan (Gaskell *et al.* 2000)—have made international sales of many GM products difficult. The demand for products that are completely devoid of GM can be challenging as there is often some inadvertent mixing of GM and non-GM crops during harvest and distribution, wide dissemination of pollen can enable some GM progeny to occur long distances from their origin, and very small levels of GM can be detected by a number of sensitive and inexpensive methods. In addition, a number of eNGOs (environmental non-governmental organizations) have expressed strong reservations about GM crops, and some have promoted vandalism and boycotts against GM products and retailers. Greenpeace has launched a worldwide campaign that targets *all* uses of GM in agriculture. Because some of the same large NGOs that have been criticizing GM agriculture have also been active in promoting forest certification (FSC 2001b)—and many of the biological and social issues raised by GM agriculture are also germane to forestry—the reluctance to include GM under forest certification is not surprising.

FSC certification guidelines and GM

The constraints put on the use of GM trees differs widely between certification systems. The FSC is the most categorical, with Criterion 6.8 simply stating that GM trees shall not be used. The SFI certification system requires applicants to "...use sound scientific methods and follow appropriate federal and state regulations and other international protocols" (American Forest & Paper Association 2000, Guideline 4.1.2.1.6). In contrast, several other schemes apply no additional constraints. For example, the PEFC (Pan European Forestry Certification) Management Guidelines refer to maintaining the genetic integrity of forests, but "has no specific considerations towards genetic engineering" (Viliotis 2000, pers. comm.). Similarly, the CSA (Canadian Standards Association) and LEI (Lembaga Ekolabel Indonesia) also have no specific language regarding GM technology, other than compliance with national laws. The ISO 14000 series contains guidelines on what must be contained within an EMS, but forest managers decide the performance standards that must be met, and there is no specific requirement to include GM nor guidance on performance levels.

The FSC policy against GM was included by consensus during the discussions that took place during 1992 through 1994 that led to the formation of FSC, and was included with the Principles and Criteria approved by ballot at the end of 1994. Its policies therefore show an early concern over GM by its constituents. The ban was reaffirmed by the FSC General Assembly in 1999 (T. Synnott, FSC, pers. comm., 2001). A motion to rescind the ban was proposed by two members from the economic chamber the same year (Motion 9); however, it received little support. The motion cited the desirability of research, and the probability of social, economic, and environmental benefits via reduced use of agrotoxics and processing chemicals; pest resistance; and reduced land area required for plantations. Because FSC's ban of GM stands alone among certification systems, and their rationale for concern over GM is explicit, this paper will focus on their policies when discussing the benefits and safety of GM in certified forestry systems.

GM TECHNOLOGY IN FORESTRY

The role of plantations in satisfying growing world demand for wood products

The demand for wood continues to grow in proportion to rising population and standard of living (FAO 1999, Bazett 2000). At the same time, natural forests continue to be exploited or lost at an alarming rate, particularly in the developing world, primarily as a result of agricultural clearing and unsustainable logging. This puts large numbers of plant and animal species that depend on forests at risk of extinction, damages aquatic systems, disrupts local communities, and endangers local and global climatic cycles (Abramovitz 1998). Urgent measures are needed to protect forests, while also finding alternative sources for wood to meet local and global demand.

Although a variety of solutions are likely to be needed for forest and community protection, it appears that plantations are capable of supplying a large proportion of future industrial wood demand (Evans 1992, Nambiar and Brown 1997; Whiteman and Brown 1999), and that it can be done from a relatively minor land area (Victor and Ausebel 2000). Sedjo and Botkin (1997) estimated that intensive harvesting would need to occur on 20% to 40% of the world's forested lands to meet current demands, but that it could instead be satisfied with 2% to 8% of the forest land area managed as plantations. Plantations account for only 0.2% to 17.1% of the forest area in several southern hemisphere countries, yet plantations produce 50% to 95% of those countries' wood production (Nambiar 1999). FSC recognizes this function of plantations; Principle 10 states that plantations should: "complement the management of, reduce pressures on, and promote the restoration and conservation of natural forests" (FSC, 2001c). Intensive management, including genetic improvement, can reduce the area needed for plantations further.

Rationale for GM

For the foreseeable future, GM forest trees are expected to have their major benefits in intensively managed plantation forests. Tree breeding has proven itself repeatedly to be an important means to improve the yield and quality of plantation forests wherever they are grown (Zobel and Talbert 1984). GM can add to this already successful enterprise by providing specific traits under better managerial control, and with improved efficiencies not available via conventional breeding. Similar improvements in productivity and quality have occurred during the domestication of many food crops (Diamond 1997); thus, both conventional breeding and GM can be viewed as routes to domestication of forest crops. GM has been considered by some to be more important to forestry than to annual crop agriculture because the constraints to sexual breeding imposed by the long life cycle and outbreeding system of mating are so much more severe in forest trees (Bradshaw and Strauss 2001). In addition, trees have undergone very little domestication compared to most crops (Sutton 1999), so opportunities for genetic improvement via both conventional breeding and GM are likely to be immediate and substantial.

Scope of GM for plantation trees

GM can now be applied to a wide variety of tree species, though the efficiencies vary considerably (e.g., Brunner *et al.*, 1988, Tzfira *et al.*, 1988). For example, while virtually any poplar genotype can be transformed, most conifer and eucalypt genotypes still present considerable challenges. GM can be used both to impart new properties such as herbicide resistance, generally using genes or parts of genes developed in other more easily manipulated species; but GM can also be used to selectively alter the expression of native genes in a manner that would be very difficult via conventional tree breeding methods. An example is control of the expression of native genes important to control of flowering so that breeding can be accelerated, or flowering prevented entirely. The latter would help reduce concerns that progeny of GM trees might have undesirable effects in surrounding environments.

The growing field of genomics—characterized by the rapid acquisition of knowledge on gene sequences and functions—is providing many new possibilities for understanding and controlling the properties of trees (*e.g.*, Allona *et al.*, 1998, Sterky *et al.*, 1998). It provides conventional tree breeders with new tools to assess genotypic variation and improve efficiency of selection. However, without GM breeders are still limited to the use of sexually accessible genetic variation and are constrained by the rate at which that that variation can be incorporated into production through matings. By combing genomic knowledge with GM, it is feasible to create new, dominant alleles that are rare or absent in native populations, and then to insert them into juvenile trees of a variety of genotypes. This allows the modification of specific traits within a diversity of highly bred genotypes.

Traits of interest

Many of the traits that are currently being targeted via GM are expected to have both a positive impact on the economics of plantation forests, and/or reduce the environmental impacts of plantation forestry and paper production (Sedjo 1999). Traits related to wood quantity and quality are key amongst the targets for GM of forest trees. Wood can be modified in a great number of ways, both chemically and anatomically, by varying the expression of key genes that participate in xylem differentiation (reviews in Dean 2001 and Dinus 2001). Given this diversity of opportunity, and the very large economic benefit possible for even modest changes in wood quality and yield, domestication could proceed in many different ways depending on the processes used for manufacture of wood, paper, chemical, or energy products. Some promising results with poplars in recent years include the field demonstration of GM trees containing wood whose lignin structure required less chemical to remove from pulp, thus providing economic and environmental benefits; GM trees that, in the greenhouse, grew more rapidly and had lower total lignin content, and thus may provide pulp yield and environmental benefits; and young GM trees with increased growth rate and fibre length, potentially increasing both pulp yield and pulp strength (reviewed in Baucher *et al*., 1998, Dinus *et al.,* 2001).

Tree growers are interested in herbicide and insect resistance (Tzfira *et al.,* 1998) for the same reasons that farmers have rapidly adopted them where available. Farmers anticipate that they will contribute to less costly and environmentally safer weed and pest control than their current practices, particularly when they are employed as components of integrated pest management systems. Such resistance may also enable an increase in tree yield if levels of pest or weed damage are reduced below that attainable with alternative management methods. With FSC and some other certification standards requiring reduction in chemical usage the scope for such increases in yield and reduction in cost are likely to grow.

For herbicide resistance, environmental benefits may include:

1. Preferential use of non-persistent, broad-spectrum, low eco-toxicity herbicides,
2. Permit weed populations to become more abundant before needing to apply herbicides, thus reducing costs, chemical inputs and promoting biological diversity.
3. Reduced need to till soil or mow weeds, with potentially large benefits for reducing soil erosion; conserving soil flora and fauna, and organic matter; promoting root system health; and reducing fossil fuel consumption
4. Increased ability to tolerate better-developed and more diverse non-crop communities (i.e. weeds) in association with the planted crops, thereby promoting biodiversity.

Although most of today's herbicides are vastly less harmful to the environment when compared to previous generations of products, the environmental benefits of herbicide resistance are expected to become even greater in the future. Genomic methods should enable agrochemical companies to identify even more plant-specific and less persistent herbicides and the corresponding resistance genes.

For insect resistance, the obvious benefit is the reduction in usage of biological or synthetic insecticides, or improved survival and yield, when a pest problem occurs. Resistance also avoids the risks of exotic biological control agents—which are often ineffective and can evolve to attack non-target, native species (Strong and Pemberton 2000). Insect resistance can also improve plantation economics by stimulating improved growth rate (Meilan *et al.,* 2000) or reducing mortality. With the limited diversity of genes available, however, pest resistant GM trees would need to be deployed carefully and selectively—integrated with other control methods in short-rotation systems—if they are to provide a sustainable resistance strategy (Raffa 1989, Strauss *et al.,* 2001).

Modification of flowering and maturation have also been significant focal areas for research. The primary aim of flower manipulation is to minimize the unwanted spread of transgenes into natural, feral, or managed populations. However, several other benefits could also be obtained. By reducing the metabolic drain of reproductive development, prevention of flowering is expected to increase wood production – perhaps substantially in some species (Strauss *et al.,* 1995). In hermaphroditic species, male sterility could greatly reduce the expense of producing inter- or intra-specific hybrid seed. It would also reduce the health impacts of highly allergenic tree pollens (e.g., Cryptomeria: Strauss et al., 1995). The ability to induce early flowering could increase the options available for conventional breeding in short-rotation species by allowing many more crosses and types of germplasm to be studied per unit of time and cost. If vegetative maturation could be manipulated, it might allow the directed restoration of juvenility to facilitate cloning. By using systems for eliciting gene expression via application of low levels of specific chemicals (e.g., alcohol: Jepson *et al*. 1998) it should be possible to induce genes that stimulate flowering or rooting only when desirable; these genes being silent for the remainder of the life cycle (genes that induce flowering could also be segregated away). With this kind of 'developmental engineering,' GM could be used to increase breeding and propagation efficiency with respect to use of sexually accessible genetic diversity, rather than to impart novel traits to plantation trees.

Prevention or postponement of most flowering would greatly reduce the frequency with which herbicide resistant trees would appear in unintended places, where they would complicate weed management. Likewise, it would be beneficial to restrict the large-scale spread of GM insect resistant trees because of the difficult to predict consequences for pest management programmes and non-target organisms. On the other hand, we expect that genes for wood modification would have modest impact beyond what is already experienced with gene flow from highly selected genotypes in plantations, where wood qualities and adaptive properties already vary greatly among species, provenances, hybrids, clones, and families. However, this decision would ultimately depend on the biological significance, and extent, of the specific wood characteristic altered.

Flowering control could also prevent some ecological impacts that are now accepted as routine environmental consequences of tree planting. In cases where large plantations surround small areas of wild stands, avoiding gene flow could help to prevent the 'outbreeding depression' or 'genetic assimilation' that can cause maladaptation or drive small populations to extinction. Hybridization with non-transgenic crops has been implicated in the extinction of at least five wild relatives of food crops, and the Californian walnut (*Juglans hindsii*) (Ellstrand *et al.,* 1999). Flowering control via GM might therefore be valuable for achieving other requirements of certification; for example, 6.3 line 209 of the FSC-UK certification guidelines states that "…dilution of the local gene pool is [to be] minimized..." (FSC-UK 1999).

Probably the most ecologically significant application of controlled flowering, however, would be to impede the future spread of invasive exotic tree species into native populations. Because of their large size and frequent dominance of ecosystems, invasive tree species are some of the most damaging invaders of any kinds of organisms, and the extent and ecological consequences of their spread are often not appreciated until long after their introduction (Hughes 1994, Richardson 1998). Thus, a lack of invasiveness now does not preclude the possibility of future invasion. Pine plantations in the southern hemisphere provide some of the most notorious illustrations of invasion, and prevention of flowering via GM—were it available now—would be welcomed there for reducing the spread of plantation trees (D. Richardson, pers. comm., 2001).

Finally, as genomics and gene transfer capabilities continue to develop, GM is expected to become capable of imparting resistance to damaging pests for which conventional breeding or biocontrol have been unsuccessful. Because of accelerated global trade and travel, it is likely that trees will face ever-increasing threats from exotic pests for which they have little or no innate resistance. Several major problems have already occurred, including Chestnut blight, Dutch elm disease, and white pine blister rust. New diseases, such as sudden oak death are extremely worrisome (Rizzo and Bailey 2000). Asexual gene transfer, often using genes from a congeneric wild relative of the threatened tree species that has coevolved with the pest in its native range, could be important for producing resistant genotypes. Because resistance genes often occur naturally in tandem repeats (Richter and Ronald 2000), and unlinked genes can be simultaneously transferred after ligation (recombinant linkage) or cotransformation, several resistance genes could be transferred to provide multigenic resistance. GM would be important where it was impossible, or too slow, to produce well-adapted, resistant genotypes via hybridization and subsequent backcrossing. The benefit of this tactic could apply not just to new plantations, but to newly planted 'wild' forests also. For example, if a programme of replanting with resistant GM trees over a number of years were started within a decade after disease spread on a continent was first recognized—and was concurrent with efforts to protect existing trees and slow disease progression—the ultimate ecological impact of the disease on forest ecosystems might be attenuated.

Research applications

Even without the intent to use GM in commercial plantations, field trials of GM trees are an important genomics research tool. By isolating single genes and reinserting them so that their expression is changed, scientists can directly infer their biological roles. Most such work seeks to study the effects of suppressed genes (i.e., effective 'mutants'), simulating the recessive alleles that are abundant within natural populations but rarely expressed. No other method, including advanced genomic methods such as 'gene-chips', provides a similar level of insight into the influence of specific genes on tree development. As discussed below, a number of options—including the use of a sterile host genotype—are available for greatly diminishing environmental risks of such field trials.

CONCERNS OVER GM PLANTATIONS

Public concern over GM crops has risen in recent years. The concerns are greatest in Europe (Gaskell *et al.*, 2000), however, they have also grown in North America, where they show a striking polarization (Priest 2000). Few are neutral about biotechnology; most people appear to either favour it or are concerned about it.

Views on biotechnology also show only a weak relationship to level of education (Priest 2000). It is also widely known that diverse social and cultural factors influence perception of risk and ethical assessment of biotechnology and other technologies (e.g., Finucane *et al.*, 2000). As a result of the similarity in traits, methods, and social control between GM crops and trees, the public concerns over GM agriculture appear to transfer directly between them. Because the FSC system considers social as well as ecological and economic factors, and is a market based system, public concerns over GM will be important to their treatment of GM trees. Nonetheless, we emphasize biological issues in this paper, as these have a strong influence on perceptions of risk and ethical judgements.

Plantation certification

Before discussing the concerns over GM plantations, it is important to understand what practices are currently permissible within certified plantation forests. Under the FSC system, certification can be obtained for intensively managed plantation forests so long as they are not a result of recent conversion from native forests. However, because of the very distinct goals and environmental issues presented by plantations, additional principles and criteria are applied (Principle #10: plantations: FSC 2001c). The principles recognize:

1. The important environmental function of plantations in reducing pressure on natural forests (prologue).
2. Landscape level biodiversity considerations as predominant, including riparian areas and set-asides, with the explicit understanding that planted stands will often have limited biological diversity within them (Principles 10.2, 10.3, 10.5).
3. Clear-cutting as a tool for economic management, so long as the units are not of extreme size, and are arranged to promote landscape considerations (10.2).
4. The use of chemicals, though it requires that they are used only where needed, and are chosen so that the least toxic and least persistent forms are employed (10.7).
5. The acceptability of exotic tree species, where they outperform native species and have been studied for a reasonable time period, and will be monitored (10.4, 10.8).
6. Active management to promote good soil structure and fertility (10.6).
7. The acceptability of exotic biological control agents and the employment of integrated pest management approaches (10.7).

FSC's plantation guidelines do not preclude most practices of high intensity management for wood yield. Although they stipulate selective, rational use of intensive management methods, and allow regional certification guidelines to impose further constraints on management intensity and species composition, it is understood that the portions of these plantation estates that are intensively managed for wood production are, in effect, wood farms. As a consequence, some of the most intensive forest plantation operations in the world, including the fast growing exotic pines and eucalypts planted in the southern hemisphere, have been certified by FSC-accredited organizations (FSC 2001a). In addition to exotic tree species, these plantations sometimes include the large scale planting of a small number of families, clones, or hybrids from intensive breeding programmes; monoclonal stands; rigorous density and weed control; fertilization; and short rotations (for example., 5-30 years). These kinds of programmes, particularly those developed to the stage of clonal testing and deployment, are the ideal places for GM to add value to forestry by adding specific traits to proven, well adapted genotypes (Griffin 1996).

In FSC's plantation guidelines, only synthetic chemicals (pesticides, herbicides, fertilizers), and physically, singly manipulated genes (GMOs), are singled-out to be avoided as much as possible, or banned entirely, respectively. FSC Principle 6.8 simply states the "use of genetically modified organisms shall be prohibited" (FSC 2001c). Though some chemical use is currently permitted, FSC has the long term aim of complete elimination of chemicals (Synnott 2001). The requirement to avoid GM and ultimately chemical use is based on avoiding their potential adverse impacts, but it gives little consideration of the impact of alternative measures to achieve the same yield improvements or level of weed control. Decision support systems for chemicals currently under development in the UK attempt to address this shortcoming by giving an abbreviated cost/benefit analysis of each chemical and the alternative control measures.

Environmental risks of GM plantations

Forest biotechnologists and NGOs have recognized the possibility for undesired environmental consequences from GM trees for many years (*e.g.,* Raffa 1989, Strauss *et al.*, 1991 & 1995, Duchesne 1993, Owusu 1999, Campbell 2000). It has also long been recognized that GM is not a panacea, nor is it a replacement for traditional breeding. Like products of breeding programs, GM needs to be researched thoroughly, then used carefully and selectively after field trials that span many years and different environments have demonstrated their health, stability, and delivery of economic and/or environmental benefits.

In 1999, FSC issued it's first written justification for exclusion of GM trees (Table 1). Some of the concerns are intrinsic to GM as a method of introducing genes. These include: the effects of the gene transfer process on tree health, the stability of transgenic traits, and the use of antibiotic resistance genes. Most of FSC's concerns, however, are not unique to GM, but are relevant to plantation forestry in general. These concerns include: the adaptability and ecological impacts of tree genotypes that are newly bred for specific properties (for example, rapid growth, wood quality), or are entirely new to an area (novel hybrids, provenances, exotic species); the management of tree genetic diversity in relation to the many choices of species and genotypes; and the choice of silvicultural methods for managing productivity and biodiversity across plantation landscapes. Although the effects of reduced flowering are highlighted, this is also an issue for plantation forestry; short rotations and high planting density generally result in little flowering prior to harvest compared to wild trees.

Similarly, another concern that has been expressed regarding GM trees, restricted access to germplasm, is not an issue confined to GM, but is also common with conventional breeding programmes. This is especially true where large corporations have invested in their own costly, long term breeding programmes. However, many of these improved materials, including *in vitro* propagated clones and elite families, are frequently available for sale. Tree breeders have always sold stock at a premium, and GM could help to formalize such intellectual property (IP) rights.

Management and research approaches to address certification concerns

Table 2 elaborates the concerns over GM by explaining the management context. It also suggests ways in which the use of GM, and/or further research, might mitigate or avoid such concerns.

Gene transfer bottleneck

The possibility of a genetic bottleneck is a concern for intensive plantation forestry generally, particularly where clones are used, and is not unique to GM *per se*. At present, industry could deploy very few highly productive clones widely, but they rarely do so. The reasons for this are two-fold. First, there is significant biological risk, and therefore investment risk, when the genetic base is too narrow. Disease susceptibility, for example, would devastate stands that were genetically identical. The second reason is that there are often significant clone by site interactions—meaning that single clones are often not superior on all sites across a landscape. As a consequence of these two factors, current management practice is to deploy a number of clones at any given time in any forest management unit. These fundamental constraints are unlikely to change substantially with GM.

For some species (for example, poplars) nearly any tree can be transformed, allowing GM forms of a diverse array of genotypes clones to be produced. For others, such as pine and eucalypts, until gene transfer methods are improved so that they can address many genotypes efficiently it is likely that only a small fraction of a plantation landscape would include any GM trees. However, these might include the most productive clones, or they might be used on sites with the most difficult management problems (for example., for weeds and herbicide-resistant trees).

Biodiversity and flowering

The reduction in biodiversity due to loss of flowers and fruits is primarily an issue of stand vs. landscape biodiversity management, and whether the preservation of flowering under short rotations makes an important biodiversity contribution. As pointed out above, this is an issue that is not unique to GM, but is also germane to conventional short-rotation plantations, particularly those involving exotic species which are likely to have fewer co-evolved species associated with flowering. FSC's plantation principles emphasize landscape biodiversity management. In addition, for wind-pollinated species with very small fruits, such as in poplars where the seeds lack virtually any endosperm, the fruits and flowers appear to provide few benefits for wildlife when compared to masting or insect-pollinated species.

However, for species where the loss would be significant, and where within stand, flower-associated biodiversity are considered important, it may be possible to tailor GM methods accordingly. Because of the many different genes that take part in the multiple phases of flower and fruit development, there are correspondingly numerous ways to use GM to affect reproduction. By targeting late-acting floral genes, for example, it is likely that infertile flowers could be engineered that still produce petals and nectar, or even seedless fruits (Varoquax *et al.,* 2000).

Invasiveness and non-target effects of pest resistance genes

The invasiveness of any introduced plant is a concern. Nonetheless, all certification systems, including the FSC, accept plantations comprised of exotic trees, some with known invasive, ecologically disruptive effects (Richardson 1998), so long as they are monitored and some mitigation occurs. For GM trees, the only genes of those currently under development that might be capable of imparting an increase in fitness in wild populations are major genes for pest resistance such as Bt (encoding an insect-specific toxin derived from *Bacillus thuringiensis*). Other genes, such as those for herbicide resistance, modified wood quality, or reduced flowering—because they provide no benefit where herbicide is absent or take species away from their phenotypic norms produced by natural selection—are probably of no value, or detract from fitness, in the wild (James *et al.*, 1988). Bt, however, due to its specificity, affects only a small proportion of herbivores and insect taxa; affected pests are usually much less damaging in wild forests than in plantations, and the genes are widely known to be vulnerable to counter-evolution by pests to render them ineffective (Gould 1998). This is a concern greatest for long-lived trees. These genes are therefore unlikely to provide a significant or sustained benefit in the wild—if indeed they provide a net benefit at all. Additionally, to minimize the chances for increased invasiveness, one could require that if GM trees with Bt genes are employed near to wild relatives, highly effective genes for sterility must also be transferred and closely monitored.

Of possible concern are non-target effects of pest resistant GM trees. Within plantations, these need to be considered in the context of their intensely modified ecology which, by their nature, already have many non-target effects on flora and fauna. They also need to be compared to the use of conventionally bred pest resistant species, varieties, and clones—whose non-target effects are likely to be substantial, but are largely unstudied. For example, where resistance of a new variety is the result of an unusually abundant native terpenoid, significant effects on predatory insects, their parasites, and soil microorganisms are likely. If sterility genes are also employed, or exotic species are used that do not establish significant feral populations, non-target effects should be largely restricted to plantations themselves.

Antibiotic resistance genes

Forest scientists had generally assumed that because the U.S. Food and Drug Adminstration concluded that some antibiotic resistance genes pose extremely small risks even when consumed as food in GM crops, these genes would be extremely safe, and thus widely accepted, for uses in fibre crops such as trees (Strauss *et al.*, 1997). These genes can be chosen so they are of minor medical or veterinary importance, and constructed so that they cannot function in micro-organisms without extensive further mutation. In addition, soils naturally possess numerous microbes, many with their own genes for resistance to various antibiotics, and these genes are often on plasmids that can be transferred among microbial species. Efforts to measure horizontal gene transfer from plants to microbes at an ecologically meaningful rate have failed (Syvanen 1999). Indeed, spontaneous mutations giving rise to antibiotic resistant bacteria are several orders of magnitude more likely than asexual DNA transfer from GMOs (McHughen 2000). Nonetheless, the concept of antibiotic resistance genes in cultivated plants is obviously not appealing to the public, and antibiotic resistance genes will be banned from European GM crops in the near future. It is therefore likely that they will be excluded from newly developed GM trees as well. Many new tools are being developed that allow the selection of genetically modified plants and that are not reliant on antibiotic resistance (for example Ebinuma *et al.*, 1997).

Stability of gene expression for flowering genes

Transgenes have been observed to lose their activity in a number of species, a phenomenon known as gene silencing (Fire 1999). This problem is generally circumvented in commercial programs simply by producing a very large number of independently produced GM plants, and then screening for stable ones over many environments and several years of trials. Fortunately, field trials of GM trees, largely poplars, have so far shown that gene silencing is extremely rare (Strauss *et al.*, 2001). However, without field studies it is impossible to specify precisely how frequently the phenotypic expression of sterility-inducing genes might break down, and thus disperse transgenes via pollen or seed. It is difficult to estimate what the frequency of breakdown might be from published research on plants as only the most stable and vigorous trees after several years of field tests would ever be used on a commercial scale. By contrast, academic researchers generally study the entire population of transgenics produced, and often emphasize, rather than discard, the unstable ones in their analyses (as they are biologically most interesting). It is also difficult to generalize from other species how the extent of instability can vary widely among plant species, transgenes, and gene transfer/regeneration methods. Moreover, instability is generally considered to be much lower under vegetative propagation than under sexual propagation, but only the latter has been studied to a substantial degree. We are aware of no published studies of stability under vegetative propagation that are at a scale relevant to commercial programs—which would include a large number of transgenic lines, field sites, and years of analysis (Strauss *et al.*, 2001). This is clearly an area requiring more detailed study, especially under conditions relevant to commercial use.

To make the probability of breakdown as low as possible, it is possible to employ redundant sterility systems (more than one gene and genetic mechanism) and associated genetic elements, such as insulator and MAR (matrix attachment region) elements that increase the reliability of transgene expression (Nap *et al.*, 1996, Bell *et al.*, 2001). In the future, it may also be possible to mutate genes permanently (site-directed mutagenesis); however, this is currently too inefficient for practical use. Several genes useful for imparting sterility have already been isolated from poplar, eucalypts, and pines that could be used for any of several molecular strategies for engineering sterility.

Until there are many years of experience to show otherwise, sterility systems should be regarded as a very strong risk reduction measure, and thus employed with the knowledge that there is a possibility for small transgene releases. During research, any releases are likely to diluted to an extremely large degree once away from the source by commercial non-GM seed and pollen in the area (assuming the research trials occur near to, and preferably within, commercial plantations). Nonetheless, because pollen can travel very large distances from trees, a small proportion of it will reach a very large area. It will therefore be important to conduct scientific evaluations beforehand to ensure that the genes employed in such studies are unlikely to have a significant ecological impact. A key advantage of GM in this regard is that the detailed biochemical actions of genes are known in advance, allowing informed considerations of the nature of potential impact. An example would be the use of marker genes (for example, fluorescent genes, which would also facilitate detection). The sterility genes themselves, if they fail and are thus dispersed are expected to reduce tree fitness should they be reactivated. But they will be too small a proportion of pollen to cause significant sterility in a normally flowering stand and will have no appreciable effect in their hosts if they remain inactive. They should therefore pose little concern. Other safety measures that could be taken, particularly where there are wild relatives, include the use of research plantations that are widely separated from wild stands; female GM trees in dioecious species like poplars, and species that are sexually incompatible with the nearby related species (for example, use of GM aspens in an area where cottonwoods are the native poplars).

BRINGING CERTIFICATION AND GM TOGETHER

The need for GM field research

Consideration of the measures listed in Table 2 shows that it is mostly research that is needed before GM techniques can be reconsidered for acceptability under certification standards. In particular, field research is needed so that the risks and benefits of GM trees can be observed directly. A mix of basic and applied research is needed, and it must be chosen and conducted in such as way that it is relevant to both the economic and environmental needs of local growers and other stakeholders. Although transgene instability is not expected to be a large problem—as a number of researchers around the world have so far found in field studies of poplars (Strauss *et al.*, 2001)—it requires careful study. Beyond this, none of the research needs listed in Table 2 seem insoluble, nor require breakthroughs in technology.

However, the current FSC ban on all GM, even for research purposes, makes it difficult for certified companies to participate in resolving the concerns FSC has raised, and for developing novel GM approaches based on advances in genomics. Research plots, if they are spatially proximate and organizationally associated with commercial management areas, cannot include GM trees (R. Hrubes, Scientific Certification Systems, pers. comm., 2001). This is problematic as academic researchers rarely possess the necessary land and facilities required for the extensive field testing of GM trees. It is also often very difficult to get the long-term funding needed for forestry research of this kind from governmental agencies—whose time horizons are typically two to three years, and whose focus is generally fundamental biological research. Producing and field testing a GM tree generally requires at least five years, or much longer, if flowering and traits related to ultimate yield and wood quality are being studied. Industry participation is therefore critical. As industry enrolment in FSC grows, the ban on research is likely to become an increasingly significant factor impeding the completion of the objective, long-term research that is needed to address FSC concerns.

Exclusion of GM as a method

As stated above, high level scientific panels, including those of the United States National Research Council (2000) and the Ecological Society of America (Tiedje *et al.*, 1989), have affirmed that the traits imparted, and not the method used, should be the primary focus of benefit and safety analyses of GMOs. GM plants can be produced with diverse gene transfer methods, including systems that remove most extraneous DNA, and remove or avoid antibiotic resistance genes. While efficiency and precision vary, gene transfer is clearly effective at delivering new traits. The record of successful use of commercial GM crops in North America, where in 1999 GM crops covered 45 million hectares without obvious adverse or unexpected effects (McHughen 2000), illustrates that stable GM traits can be delivered over many years and at large scales. As discussed above with respect to GM poplars, field results with GM trees so far appear very promising.

It is also difficult to attribute a unique risk to GM due to the genetic change it causes during gene transfer. Other methods for propagation and generation of variability—including *in vitro* culture, mutagenesis, and wide crosses—are not excluded by FSC. These are known to induce complex mutagenic events such as changes in epigenetic states, alteration of ploidy levels, or increased mobility of transposable elements (Bennetzen 2000, Kaeppler *et al.*, 2000), and are widely used in horticultural breeding programs. Interestingly, methods that *purposely* attempt to alter the expression of genes via random insertion of strong enhancers of gene expression fail to produce any detectable plant phenotypes in the great majority of cases, even in a plant species like *Arabidopsis* and poplar with little repetitive DNA (Weigel *et al.*, 2000, C. Ma, pers. comm., 2001). The genome is well buffered against most insertional perturbations. Although there remains considerable work ahead to demonstrate the stability and health of specific kinds of GM trees—particularly for species that, unlike poplars, have not yet been widely grown in the field—the collateral genetic variation generated by the GM method does not appear to present risks qualitatively dissimilar from those of other certifiable practices.

Are the biological risks of GM congruent with other certifiable management risks?

Currently, large areas of plantations that are intensively managed and highly bred are certified. It appears that by careful management of soils and continued tree improvement the wood yield from plantations can be maintained, and even improved, over successive rotations (Evans 1988, Powers 1999). Certification standards implicitly acknowledge the impacts of intensive management, and the need to mitigate its effects.

Invasiveness of exotic tree species

South Africa is almost entirely dependent on exotic species for wood and pulp—particularly eucalypts, pines, and Australian acacias (wattle) (von Maltitz 2000). These genera, particularly the latter two, can be highly invasive, especially in the Fynbos and veld-grasslands. Yet forestry companies in South Africa have hundreds of thousands of hectares of FSC-certified forest (von Maltitz 2000). Compared to invasive tree species—which impose a complex array of novel traits and their thousands of underlying novel genetic interactions into an ecosystem—the ecological alterations from transgenes are obviously very limited.

Precaution vs. practicality: biocontrol and chemical use

Many persons and institutions that are concerned about GMOs have invoked the precautionary principle as a reason to delay their development or marketing[2]. However, it it seems excessive to use this as a reason to ban GM research entirely. It also appears to be inconsistent with decisions made by certification bodies with respect to other kinds of genetic improvement. The case of exotic tree species was described above. There is also evidence that hybridization, particularly where exotic species are involved, is a risk factor for promoting the emergence of new invasive plant species (Ellstrand and Schierenbeck 2000). Should all hybrids be banned from certified plantations under the precautionary principle?

The introduction of non-native species for biological control of exotic pests is specifically warranted by FSC principles after studies have been conducted to suggest it appears safe to do so. For example, in the UK the great spruce bark beetle *Dendroctonus micans* is a pest of exotic spruce plantations and costly crop losses can be controlled by the exotic predatory beetle *Rhizophagus grandis*. Thus, Section 6.9 (Line 270) of FSC UK Standards states the "…use of non-native biological controls such as *Rhizophagus grandis* may be desirable to control non-native pests." The use of this exotic beetle reduces economic costs and insecticide application, but as an evolving entity that contains thousands of new interacting genetic networks, its interactions with the environment can not be completely predicted. Its release therefore poses non-trivial, irreversible risks to non-target organisms—as the many problems from released biocontrol agents attests (Strong and Pemberton 2000). GM releases are also technically irreversible; however, because they involve one or a few intensely characterized genes, not an ecologically novel organism, the biological uncertainty would appear to be far smaller.

Forest chemical use presents many environmental uncertainties. Many chemicals, including insecticides, are at present permitted under FSC, and hence UKWAS (UK Woodland Assurance Scheme) guidelines (UKWAS 2000), that could have some have potentially significant, and poorly known, environmental impacts (Coventry 2000). These chemicals are currently included because of the lack of suitable alternatives, economic constraints, and because certification guidelines and law helps to ensure that they are used in a careful manner. The intense regulation to which GM trees would be subject in most places would have a similar mitigating effect.

Similarly, a diversity of herbicides are currently permitted in FSC certified forests. However, they must not be on FSC's list of prohibited chemicals (which means they are not highly toxic or persistent), and they must be used parsimoniously (Synnott 2001). FSC acknowledges that chemical use can have environmental advantages. In a draft document on chemical use, it states that "…there are some cases where controlled use of some chemical pesticides (such as some herbicides for minimum tillage agriculture, or for control of some exotic pests) may be preferred for environmental reasons…" (Synnott 2001). Compared to mechanical cultivation, we expect that use of a rapidly degraded, low eco-toxicity, and highly immobile herbicide will involve less risk of soil erosion or compaction, damage to soil organisms and roots, and sedimentation in associated aquatic systems. It would also be likely to require much less total energy, cause less oxidation of soil carbon, and lead to release of less fossil and soil carbon (as well as other fossil-fuel associated pollutants) into the atmosphere. A draft DSS to guide vegetation control on FSC-certified forests in Great Britain (Decision Support System: UKWAS 2000) noted that "guidance is based on the premise that pesticide usage should not be the automatic method of first choice for controlling pests and weeds…,". However, it went on to discuss chemical options in detail, and even stated that "…herbicides that have low toxicity should be favoured…[and] in many cases a carefully directed spray of broad spectrum product will be the most effective option and offer the least risk to non-target species…" Furthermore, it points out that alternative, non-chemical weed control

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[2] "*When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause-and-effect relationships are not fully established scientifically*" (Wingspread Consensus Statement on the Precautionary Principle 1999).

practices such as mowing can present unique problems: "…mowing creates a grassy weed flora that is harmful to trees...[and] can result in soil compaction ... and pollution from exhausts and spillage of fuel and lubricants." When compared with hand or mechanical cutting of weeds, spot applications of herbicide will also reduce impacts on flora, and associated fauna, to a small proportion of the total area.

It is not a surprise to most weed scientists that careful use of chemicals can provide a net environmental as well as economic benefit. We believe that it is also likely that, for some weed control problems, herbicide-tolerant GM trees might leverage this advantage further. For example, one or two post-emergent treatments that incorporated an herbicide-tolerant tree might suffice whereas multiple pre- or post-planting treatments, of either herbicide, mowing or tillage, may be needed in non-GM plantations. This is likely because weeds close to trees often cannot be treated effectively because of potential damage to trees from cultivation or herbicide contact, frequently necessitating 'insurance' pre-planting (or pre-bud flush) treatments, or the use of herbicides with a residual activity which will provide weed control through the growing season. Because herbicides are used rarely in the life of a stand in forestry, there is little chance that herbicide resistant races will emerge (Strauss *et al.*, 1997) - one of FSC's stated concerns over herbicide resistant GM trees (Table 1).

Benefits of allowing the use of GM under certification systems

We have presented a number of reasons why we believe that the generic ban by FSC, particularly for research, does not appear to be warranted when compared to risks inherent in other certified practices. However, can a case be made to reverse this ban based on the attainment of *diverse* environmental values? A green certification organization such as FSC should wish to strongly encourage research into new options for management where there is a potential for multiple environmental benefits.

Table 3 summarizes what we believe to be legitimate reasons why scientifically based certification systems should not prevent research and development of GM trees. Most of these have already been discussed, indicating that substantial progress has already been made toward their attainment. We therefore do not consider these hypothetical or improbable benefits. Only for item 7, resistance against exotic pathogens, has there not yet been a milestone reached toward its attainment. However, given the impressive progress in mapping and isolation of resistance genes in recent years, this may not be far away (e.g., Cervera *et al.* 1996). Given this broad spectrum of potential environmental benefits, we believe that a generic ban on GM-including for research that would investigate/examine these possibilities-does not seem appropriate in a system that seeks to promote environmental improvement of plantation forestry.

TABLE 1 *FSC concerns about GM trees (FSC 1999). We assigned the bold summary term (for example.'clonal diversity:') to each item. Management context and research solutions for each of the concerns are presented in Table 2*

Summary of FSC concerns
1 Clonal diversity: Plantations using one or few transgenic clones will contain less landscape-level diversity than is currently found in plantations using species or varieties resulting from traditional tree-breeding.
2 Antibiotic resistance: Asexual transfer of genes from GMOs with antibiotic resistance to pathogenic micro-organisms and/or suppression of mycorrhizae and other micro-organisms, arising from use of GMOs with antibiotic resistance.
3 Herbicide resistance: Gene in sexual progeny moves to trees in environments where those trees are undesirable and where the target herbicide is used, and/or increased weed resistance to herbicide, and/or increased use of herbicide arising from use of GMOs with herbicide resistance.
4 Insect resistance: Increased resistance of target insect pests, and/or deleterious effects on natural enemies of the target insects, and/or deleterious effects on non-target insects such as butterflies, pollinators and soil microbes, arising from use of GMOs with insect resistance.
5 Wood modification: Changes to structural integrity, adaptation and pest resistance of trees, rate of decay of dead wood, and soil structure, biology or fertility, arising from use of GMOs with modified lignin chemistry.
6 Transgene dispersal: Dispersal of transgenes to wild or weed populations, with potentially negative impacts, from non-sterile GMO trees, or from those with incomplete or unstable sterility.
7 Restricted access: Restricted or monopolistic access to advantages arising from high costs or limited availability of GMO trees.
8 Flower-associated biodiversity: Reduced biodiversity of organisms dependent on flowers and fruits, arising from use of sterile GMOs.
9 Adaptability: Reduced adaptability to environmental stress, changes to interaction with other organisms, and increased weediness or invasiveness, in GMO trees with new features.

TABLE 2 *Summary of FSC concerns about GM trees (Table 1) in relation to forest management and research opportunities*

FSC Concern	Management and Context Factors	Research Needs
1 Clonal diversity	· Produce GM versions of multiple clones · Deploy GM clones slowly and progressively over the landscape as developed and tested · Focus on proven clones, selected sites	· Improved gene transfer efficiency · Improved clonal propagation efficiency · Field trials that provide stability and safety data to allow faster & lower cost regulatory approval of multiple clones
2 Antibiotic resistance (ABR)	· Extremely low gene transfer rate from plant cells to microbes known · Plant ABR genes not expressed in microbes · ABR genes, transfer, naturally common in many soil microbes · ABR genes not expected to suppress root microflora	· Adapt genetransfer systems that donot use antibiotic resistance genes to trees · Compare microflora of GM and non-GM trees · Field trials should allow mycorrhizae-less unhealthy trees to be removed prior to commercial use
3 Herbicide resistance (HR)	· Infrequent herbicide use in forest plantation life cycle avoids herbicide resistant weed races · Herbicide use directed to the goal of reduced total ecological impact for HR gene chosen	· HR gene as selectable marker in transformation to replace AB gene · Flowering control system to minimize HR gene dispersal · Field and weed control trials with GM trees to measure economics/ecotoxicity compared to alternatives
4 Insect resistance (IR)	· Conventionally bred/selected IR clones may have similar or much larger non-target effects · Non-target, environmental effects may be lower than for alternative methods (*e.g.*, sprayed pesticides) · Long-term ecological risks for non-target damage may be lower than for exotic biocontrol agents · Use in integrated pest control system, with planned refugia, multiple genes · Genes directed to specific tissues to minimize non-target effects	· Develop promoters that direct gene expression to high levels in specific tissues damaged by insects · Testing of effectiveness of diversity of genes · Field tests to measure pest control benefits, tree vigor · Studies of insect ecology and dispersal in relation to refugia and non-target effects · Field tests to study non-target effects compared to variation among varieties, plantation species, and control alternatives
5 Wood modification	· Large variation in wood quality and effects on soils and microorganisms, already present among species, varieties, families, clones · Breeding for altered wood quality a common objective for breeding programmes · Wood/foliage quality and chemistry vary dramatically among alternative tree species under conventional plantation practices, with large effects on soil and plant diversity	· Identification of diverse genes controlling wood chemistry so the most specific, least harmful, gene targets can be chosen · Field testing of effects of diverse candidate genes on wood quality in field trials · Rotation length trials to study value of wood in commercial products, stability of trait, tree health, and soil quality

TABLE 2 *Continued*

FSC Concern	Management and Context Factors	Research Needs
6 Transgene dispersal	· Transgene dispersal may be of lower consequence to genetic health or invasiveness of native or naturalized populations than accepted levels of gene flow from highly bred conventional varieties · Short and long-term risks for major ecological impacts may be considerably larger for exotic germplasm, especially where tree genera known to be invasive, than for transgenes · Flowering prevention, even if imperfect, would provide major benefit by greatly reducing extent of spread from exotics, GM trees, and highly bred varieties	· Field testing of GM trees first in limited areas with high degree of sexual or physical isolation, or using innocuous genes (*e.g.,* fluorescence genes) · Field trials over many years and sites (through to normal flowering) for desired effects, stability under field conditions · Testing of stability enhancing elements, multiple gene 'insurance' strategies · Testing gene control systems in GM trees to allow flowering under specific conditions so breeding can continue
7 Restricted access	· IP control stimulates investment in research, breeding, biotechnology by ensuring benefits flow back to developers · Biologically and geographically diverse forestry operations require important local research and development, providing strong leverage to obtain favorable IP license terms · Protected materials usually available for purchase from developers, as commonly occurs with conventionally improved varieties	· Development of international and regional GM consortia to share costs of research, IP, public education, biosafety research, and development of data for regulatory approval. Work closely with, and modeled upon, operating breeding consortia · Provision of research and commercial licenses from large patent holders under simple, non-restrictive terms to consortia and participating companies so the most cost-effective, commercially relevant research can be chosen up-front (required because of long time frame for forestry research)
8 Flower-associated biodiversity	· Biodiversity management primarily based on landscape rather than within-plantation attributes · Short rotations (little or no flowering), high tree density, are the major sources of reduction in flowering tissues under conventional management · Loss of flowers and/or fruits not important for native biodiversity in many plantation species (for example poplar, exotic pines) · Greater wood productivity of non-flowering GM trees allows increased landscape & global allocation to conservation areas	· Isolation of diverse genes that can control different aspects of flowering, depending on production goals and ecological constraints (for example, male vs. female sterility, complete avoidance of flowering vs. normal flowers with pollen/seed inviability, and full fruit development but with inviable seeds · Field testing of GM trees to verify that specific alterations to reproductive tissues are achieved, stable
9 Adaptability	· Tests and monitoring of health, vigour, invasiveness similar to those undertaken with any new species, provenance · Increased invasiveness due to pest resistance imparted by major genes unlikely and limited, ecologically and evolutionarily unstable · Risks of ecological impact due to long-term changes in invasiveness far lower than for a novel exotic species known to be capable of invading (for example, pine, eucalypt, poplar)	· Estimate degree of unintended variation in vigour for specific species, gene transfer methods · Improve gene transfer method so that low levels of unintended variation imparted · Laboratory methods to predict stability, unintended variation · Field trials to estimate level of unintended variation, identify population size needed to select healthy, stable trees · Monitoring of GM trees and their progeny over long-term for health, invasiveness

TABLE 3 *Seven reasons for environmental certification systems to embrace research and development of GM trees*

	Potential environmental benefit
1	**More economic yield from less land:** The most environmental important contribution from GM is to enable companies, and society, to reduce the amount of land that is allocated to the productive portions of plantations in favour of wild lands and biodiversity corridors. An indirect social outcome of increased plantation productivity.
2	**Improved economics of biofeedstock production:** As renewable sources of energy and materials grow in prominence in upcoming years to reduce greenhouse gases, producing biomass as cost-efficiently as possible may be critical to its wide adoption.
3	**Less polluting biofeedstocks:** Even small changes in the chemical or physical qualities of wood that enable it to be converted to energy or products more effectively can provide enormous savings in chemicals or energy consumed, and CO_2 generated, during processing.
4	**Genetic containment:** Genetic integrity of wild stands can be protected from dispersal of pollen and seeds from exotic and highly bred species via genetic modification of flowering.
5	**Reduced use of undesirable pesticides and herbicides:** GM pest or herbicide resistant trees can enable some pesticide sprays to be avoided entirely, or those chemicals with the most desirable environmental properties preferred.
6	**Soil health:** Genetic modification for resistance to selected herbicides is expected to promote rapid growth of tree seedlings while reducing vegetation management practices that cause soil erosion, harm soil organisms, promote carbon loss, and damage roots.
7	**Exotic pathogen defence:** Genetic modification is likely to provide a future option for imparting resistance to tree species under threat from exotic, ecologically damaging pathogens for which innate resistance is rare or lacking.

TABLE 4 *A certification oversight system that could be applied to research and development of GM trees*

	Levels of containment, monitoring, deployment
1	**Preliminary research:** Complete containment. Small-scale tests where trees are not permitted to flower. Tree health and trait stability assessed. All tissues made inviable, and sites monitored, after completion of tests. Used for routine research. Limited area.
2	**Extended research:** Partial containment. Next level of study if preliminary research is successful. Used for testing when small releases are considered to present negligible risk. Tree health and trait stability assessed. Environmental measurements (for example, soil quality, insect fauna) may be made, depending on trait imparted. Gene flow monitored with marker genes to insure it is below agreed levels if flowering occurs. Limited, but larger area.
3	**Pre-commercial trial:** Gene flow monitored only if considered to be of concern to environment or relevant to trait imparted. Testing of operational management strategies. Tree health and trait stability measured. Trees harvested at rotation age. Large, near-commercial block plantings.
4	**Initial commercial release:** Adaptive management to verify trait stability over years and sites, monitoring of systems for deployment and environmental management, tree health and yield documented. Progressive deployment pending favourable results.

A missed opportunity to guide rational development

It would seem to be a foregone conclusion that the vast increases of knowledge of genome structure and function that are being obtained can lead to new avenues for tree breeding, and as argued above, are likely to provide diverse environmental benefits. It would also seem clear that, because of the impediments to breeding of trees, that GM will often be the most efficient, precise means to produce some types of modifications. If these assumptions are true, then it is a matter of when and where, rather than if, GM trees will be employed. Thus, it would seem prudent to consider how best to insure they are developed and deployed responsibly.

As with any other technology, there is potential for misuse of GM trees, particularly in countries that lack effective regulations governing production and testing, or are under extreme short-term pressure to obtain economic benefits. For example, excessive use of single kinds of pest resistant GM trees will likely make the effectiveness of the genes short-lived. Herbicide tolerant trees could result in overuse, rather than improved use, of herbicides. Trees with modified wood, if deployed before adequate field testing, could lead to an increase in pest problems. These risks are well known, and do not differ in kind from those faced routinely by breeders or forest managers. New clones, provenances, or species—whether developed using GM or any other breeding system—need to be tested carefully, and expanded progressively—and the newer they are the slower the scale-up should be. Years of careful research would therefore pass before GM trees would see significant commercial use in most of the world irrespecitve of certification.

Certification systems, particularly those of international organizations like FSC with their requirement for detailed accounting of all environmental dimensions of plantation systems, would seem to be in an ideal position to help promote the safe development of GM trees. The possible misuse of GM trees in countries that do not have adequate oversight bodies was one of the primary concerns of the WWF-supported report on GM trees (Owusu 1999). Through a robust protection protocol we believe that research could proceed at little risk to the environment (Table 4).

Green image

FSC depends on the strong endorsement, and lack of serious criticism, from the major environmental and social NGOs that are its members for the public credibility of its eco-friendly label. FSC's success also depends on marketing itself effectively, for which it must establish a credible brand that is widely recognized. Developing consumer recognition requires, among other things, a 'threshold volume' of products on sale. If this volume of products is available, certification will have a market presence and may continue to grow. The influence of buyers-groups—for which NGO support has been critical (Fletcher and Hansen 1999)—are instrumental to market development, both in exercising a preference for certified timber, and in communicating that preference to their customers. Having a clear and simple green image, uncomplicated by GMOs with their diverse ecological and social complexities, is likely to be important for wide recognition—especially in the GMO-averse European market. Consumers who are seeking a 'natural' product do not want to be confused by all the shades of grey that biotechnology presents (Somerville 2000). We recognize that these brand and marketing issues are a major constraint in the short-term, and mean that acceptance of GM forest crops in certification is unlikely for many years. However, we believe these reasons, essentially based on the need for commercial success of certification, should not be an obstacle to further research into the potential and risks of GM.

CONCLUSIONS

GM trees are unlikely to ever have a role in the large majority of the world's forests. It is only in intensively managed, clonal plantations, where an array of intensive genetic and silvicultural methods are already in use to increase yields and quality, that GM appears to be useful for the foreseeable future. It is widely recognized that such highly productive plantations can reduce pressures on natural forests, and GM appears capable of increasing this benefit. This could be achieved firstly by increasing their productivity and secondly by reducing other high impact or high-risk management practices.

This paper has focused on biological, silvicultural, and economic considerations of GM. Although there are legitimate social issues as well, we believe that they can be settled once the biological issues surrounding GM are resolved. Knowledge of the true benefits and risks—which only research can provide—will ultimately be required for ethical decisions about where, and whether, GM is commercially appropriate.

Because of the diversity of physiological and ecological considerations associated with the large number of potential transgenic modifications, each application needs to be considered on its own merits. Considering GM as though it were one biological enterprise—and its effects inherently good or bad—does little to advance consideration of its appropriate uses. Perhaps the most damaging effect of the ban on GM by FSC is that it helps to perpetuate this unproductive generalization, and the polarization in views it seems to encourage.

We have argued that there are a number of tangible, environmentally and economically beneficial applications of GM that could be on the horizon for intensive plantation forestry. Some of the innovations involve the addition of new traits, such as wood modified to possess novel chemical properties to meet economic and environmental goals, while others use GM to provide more control over flowering and propagation to increase efficiency of utilizing innate genetic diversity. However, demonstrating the value and safety of proposed applications ultimately requires field trials, which very often involve industry partners because of the time, land, and plantation technology required. Several means for conducting field trials with a high degree of environmental safety were described. Instead of impeding GM research and development through its ban on field trials in certified forests, we suggest that FSC should consider taking a pro-active role in helping to ensure that trials, and commercial uses that may result, are developed in an environmentally sound manner.

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