

The advantages and disadvantages of the application of genetic engineering to forest trees: a discussion

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Summary

This review briefly examines moral arguments for and against genetic engineering (GE) technology in trees, finding equal support for both sides of the debate. Subsequently, environmental costs and benefits are reviewed. Due to the complexity of tree–environment interactions, clear-cut answers are not forthcoming. However, some environmental risks are deemed to be potentially serious; the nature of such risks and possibilities for their containment are described. Assessment of such risks should be undertaken by interdisciplinary teams including ecologists and microbiologists, with the onus being on biotechnological scientists to prove, to the satisfaction of consumers, that the technology they produce is safe. A well-functioning regulatory mechanism is necessary if benefits of GE technology are to be maximized while keeping to a minimum any associated risks.

Introduction

The relatively new technology of genetically modifying forest trees (a succinct description of these techniques is given by Moffat, 1996) has, similar to other fields of biotechnology, been the centre of a heated public debate. Within the scientific community, there are those who stress what they believe to be the potential risks associated with engineering novel organisms, while other authors point towards the economic and environmental benefits they believe tailor-made trees can provide. Opinions expressed by the general public are more extreme, with some groups, such as the Forest Stewardship Council (Soil Association, 1998), banning the use of all genetically

engineered trees in forests they certify in Britain, while others (e.g. Cantley, 1998) call for deregulation and an acceleration of the introduction of genetically modified organisms (GMOs) for economic and environmental reasons.

Ever since the Neolithic Revolution some 10 000 years BP humans have been domesticating plants and animals to increase their utility to human society (Diamond, 1998). Until the 1980s, this was restricted to the selective breeding of organisms with desirable traits or the vegetative propagation of individuals with desirable traits. Thus, for example, varieties of agriculturally important species such as maize and wheat have been modified by traditional breeding techniques for thousands of generations, and are now orders

of magnitude more useful to humans than their non-modified ancestors (Harlan, 1992; Smartt and Simmonds, 1995). Forest trees on the other hand, because they have traditionally been less valuable to human societies due their abundance in natural forests, and because of their long generation time relative to the life spans of potential breeders, were not subjected to traditional breeding methods until the end of the nineteenth century (Wright, 1976). Thus after a maximum of three generations of artificial selection in the most frequently used forest species, trees remain genetically and phenotypically very similar to their wild cousins (Wright, 1976).

Rapid global deforestation rates combined with increasing demand for timber products – due to increased world human population and increasing living standards (FAO, 1999) – have focused scientific and commercial attention on improving the genetic stock of forest trees in order to improve productivity and quality. The simultaneous development of genetic engineering (GE) and other biotechnology techniques have rendered the accelerated modification of some forest trees using GE techniques possible, and in the eyes of some, desirable and commercially viable. Traits currently the subject of GE research include herbicide resistance, increased vigour, pest and pathogen resistance, increased tolerance to biotic stresses, and improved timber quality (Riemenschneider *et al.*, 1988; Bauer, 1997; Dickson and Walker, 1997; Tzfira *et al.*, 1998). Before examining the potential gains and conjectural risks associated with these GE technologies, some exploration of moral aspects of GE is attempted. After all, were it to emerge that GE is intrinsically immoral, as some people apparently believe, then scientists, ethically concerned as we are, should steer clear of the matter altogether.

Ethics of genetically engineering forest trees

There are three main moral concerns with regard to GE of forest trees. The most widespread is the concern that genetically modified plants threaten the health of humans and the integrity of natural and anthropogenic ecosystems (e.g. Strauss *et al.*, 1995; Raffa *et al.*, 1997; James *et al.*, 1998). The concern is that even if negative effects do not become apparent immediately, there is a high

possibility that complex ecosystem and autecological dynamics will render them harmful in the future. Citing the 'precautionary principle', some opponents of GE therefore demand that all GMOs be scrutinized for all potential negative traits in extensive laboratory and field tests before they are released into the environment (e.g. Soil Association, 1998). As will be discussed in section 3, most proponents of GE do admit the existence of some risks, but maintain that in some cases, the benefits are likely to outweigh the costs, and that due attention should be paid to the likely economic and environmental benefits of 'tailor-made' trees. Further, they point out that it is impossible to prove that *anything* will not occur (Strauss, 1998), and that GE opponents' criteria are therefore impossible to fulfil.

Secondly, concern is expressed over the likelihood that large, profit-driven companies will be the sole providers of the genetic material for millions of hectares of plantation forest in many different countries, and that their commercial interests will inevitably collide with the interests of local people and the protection of the environment (cf. Grace, 1997). While a valid concern, it is not unique to the GE debate, but is rather a matter related to crop ownership and management in general. As such, it is beyond the scope of this paper, and will receive no further investigation.

A third concern is that 'playing God' by tampering with an organism's genome is intrinsically wrong, and that inserting foreign genes into an organism is especially despicable and fundamentally different from traditional breeding techniques. Proponents of GE see no reason to have greater ethical qualms about altering an organism's genetic make-up directly than indirectly by selective breeding, especially since, in their view, the *end product* of the GE intervention is often *not* fundamentally different from that derived over a longer time scale by traditional methods (Griffin, 1996). Moreover, Cronk (1995) stated that the phenomenon of DNA being laterally transferred between taxonomically widely separated organisms does in fact occur in nature. Although rare, in evolutionary terms it can be significant.

Since this last concern is more a matter of personal faith than one that can be solved by reasoned and logical debate (Soil Association, 1998), it may be wise to accept that some introduction of transgenes to the environment is inevitable due

to strong political and economic forces, and that time spent on pondering ethical cons of this nature is time that could be better spent on considering a 'practical scientific response' to potential risks (Cronk, 1995).

Proponents of GM also have at least one quasi-moral reason for its application to forest trees. Pullman *et al.* (1998), for example, stressed that since world demand for paper products is predicted to increase rapidly, and because the land base on which trees can be grown is declining, primarily due to areas being set aside for conservation purposes, there will be a global shortage of fibre – which is considered by some to be morally undesirable – unless trees can rapidly be rendered more productive.

General advantages associated with GE techniques in tree breeding

Despite some important exceptions, which will be discussed in later sections, tree breeders using GE techniques attempt to modify similar traits to those that have been selected for by traditional tree breeders. A major difference is the speed and accuracy with which genetically improved material can be created without necessarily disturbing other genes in an otherwise favourable constellation, and subsequently integrated into forest regeneration programmes (Cheliak and Rogers, 1990; Dickson and Walker, 1997). However, many authors (e.g. Griffin, 1996; Tzfira *et al.*, 1998) in favour of new biotechnological methods stress these are nevertheless 'sandwiched between traditional tree breeding from start to finish' (Williams, 1998). Another important difference is that it is now possible to incorporate into the genome of forest trees, using techniques outlined in Raffa *et al.* (1997), transgenes from species that would not otherwise hybridize due to evolved barriers in sexual reproduction (Griffin, 1996). For example, genes coding for rapid flower development in the herbaceous plant *Arabidopsis thaliana* have been inserted into the genome of *Populus* spp. to accelerate the onset of sexual maturity for breeding purposes (Weigel and Nilsson, 1995). The reduced time taken to achieve improved genotypes is considered a key advantage of GE in forest trees (Cheliak and Rogers, 1990).

Upon selecting suitable breeding stock, traditional tree breeders would have to wait for upwards of 10 years before progeny were sexually mature in order to undertake the further time-consuming task of repeated back-crosses in order to isolate the desired trait. Trees are frequently self-incompatible or subject to inbreeding depression, both of which either limit or prohibit the back-crossing process altogether. Apart from the long time period involved, due to the phenomenon of linkage, the desired trait is often only expressed in conjunction with distinctly undesirable traits. Thus, progress in conventional tree breeding is slow and unpredictable (Walter *et al.*, 1998).

Foresters, like agriculturalists and horticulturalists, sought to circumnavigate this problem by introducing more productive non-indigenous plants. In well-documented cases numerous such plants have since gained weed status, and are causing damage to many countries' ecosystems as well as being expensive to control (e.g. Hughes, 1995). Genetically engineering precise beneficial characteristics into existing non-weedy trees is thought by some to be a superior method of increasing productivity (e.g. Tzfira *et al.*, 1998).

Transgenes conferring desirable traits to forest trees can be divided into two categories (Pullman *et al.*, 1998). The first group of genes govern agronomic traits (i.e. the ability of the tree to grow vigorously) and includes genes that code for resistance to pests and diseases, as well as those that code for tolerance of environmental stresses such as drought or saline soils. The second group of genes govern traits that improve production efficiency, product quality and product value. Examples include genes that render wood more suitable for paper-making, or increase the value of wood for the construction industry (Baucher *et al.*, 1998; Pullman *et al.*, 1998; Tzfira *et al.*, 1998). The following section looks at these two categories in greater detail.

Genetically engineered improvement of agronomic traits

Herbicide resistance

The first ever genetically engineered tree was a *Populus* sp. carrying a gene for herbicide resistance, which was produced in the late 1980s (Moffat, 1996). To date, this has been the largest

area of research in GE, and Tzfira *et al.* (1998) consider direct herbicide detoxification and reduction of target enzyme sensitivity to be one of genetic engineering's major successes.

The introduction of a herbicide resistant transgene, such as *Roundup Ready*^R, facilitates weed control during early silvicultural management of poplars, because over-the-top spraying is rendered feasible (Dickson and Walker, 1997) on the otherwise glyphosate-sensitive trees. The *Roundup Ready*^R transgene confers resistance to glyphosate, a broad-spectrum herbicide considered environmentally benign because it breaks down relatively quickly into non-toxic end products. Competition with weeds for water, soil nutrients, and sunlight can otherwise seriously inhibit the successful establishment and subsequently retard the harvesting of many silvicultural tree species. Costs to the forester are therefore reduced as beating up, alternative motor-manual weed control, and retarded tree growth are avoided. The reduced need for tillage control of weeds can lead to reduced erosion (James *et al.*, 1998), but is likely to lead to increased use of herbicides (albeit the more environmentally friendly types), which could have a negative effect on the environment.

Resistance to folivores, fungi and bacteria

Traditionally, foresters have applied chemical toxins to control outbreaks of forest pests, but in some cases this is becoming unacceptable for environmental and financial reasons. New GE methods of pest resistance, which function to enhance the tree's existing defence mechanisms, potentially offer environmental and economic benefits. Currently, the most frequently used mechanism is to insert a transgene coding for a toxin from the bacterium *Bacillus thuringiensis* into the forest tree genome. For example, this mechanism is currently used in *Populus* spp. to protect against predation by the beetle *Chrysomela tremulae* (Moffat, 1996). Raffa *et al.* (1997) stated that one of the major benefits of this technology is that pesticides can be targeted directly and solely at the pest herbivores, since only organisms ingesting leaf material are affected. Furthermore, the *B. thuringiensis* toxin has low avian and mammalian toxicity.

Because laboratory and field tests have demonstrated that pests can develop resistance to the *B. thuringiensis* toxin (Tabashnik, 1994; Bauer, 1997), the suppliers of the transgenic seedlings (in whose long-term interest it is to ensure sustainable pest resistance in their products) are developing strategies to maintain susceptibility to the toxin within the pest populations. So far they have concentrated on minimizing the contact of the target pests with the *B. thuringiensis* toxins in time and space. For example, by linking the expression of inserted genes to wound-inducible promoters, a certain level of predation would be tolerated before the tree's transgenic defences began to operate; further improvements in increasing the sensitivity of such promoters are nevertheless required before this technology becomes viable in the field (Strauss, 1998).

Other strategies include incorporating heterogeneity into the gene pool of a transgenic stand. For example, the likelihood of the pest *Malacosoma disstria* becoming resistant to toxin in clones of *Populus* is reduced by incorporating into the stand less toxic *Populus* clones that withstand substantial defoliation without serious subsequent growth reduction (Strauss, 1998). A further example, again of *Populus* clones, is engineering for resistance using different mechanisms: two different clones, both exhibiting resistance to *M. disstria*, are protected by transgenes that code for foliar phenolic glycosides and bud resins, respectively (Strauss, 1998). A further strategy in reducing the likelihood of pests developing resistance is to establish refugia, i.e. plots with non-resistant plants, so that pests not under any selective pressure to develop resistance can survive, interbreed and hence dilute the resistance (Brookes, 1998).

Moffat (1996) stated that transgenes conferring resistance to white pine blister rust in *Pinus lambertiana* and to fusiform rust in *Pinus contorta* may be available within the next 5 years.

Thus there is evidence that genetic engineering techniques will be able to confer a degree of sustainable pest resistance to forest trees. This promises financial benefits to the forester and, because less and fewer pesticides are applied, environmental benefits to society at large.

Resistance to abiotic stresses and increased vigour

Authors have reported resistance to various abiotic stresses. These include frost, salt, drought, flooding, and tolerance of heavy metal toxicity. For example, research by Meyer *et al.* (1999) demonstrates how low-temperature-induced expression of the carrot (*Daucus carota*) antifreeze protein is achievable in *Arabidopsis thaliana*, rendering the plant more tolerant to frost. Modification of root systems and leaf performance are targets for genetically engineered improvements likely to confer increased vigour. It may also become possible to genetically engineer trees for optimal adaptation to specific local climates or even specific management regimes. For example, Rugh *et al.* (1998) reported the ability of transgenic yellow poplar (*Liriodendron tulipifera*) to convert highly toxic ionic mercury to less toxic elemental mercury, and indicate the possibility of their use in the phytoremediation of mercury-polluted sites. Tzfira *et al.* (1998) stated that by blocking a tree's reproductive pathway, energy resources can be redirected to vegetative growth. A study on the growth rate of *Pseudotsuga menziesii*, for example, found growth to be 16 per cent lower when cones were produced compared with growth during non-reproductive stages.

As Pullman *et al.* (1998) pointed out, modification of trees' adaptation to environmental stresses will enable foresters to grow more desirable commercial tree species on a broader range of soil types and planting sites. Wood procurement costs could be reduced by growing trees faster on a smaller land base, and subsequently by reducing transport costs as trees can be grown closer to the pulp or saw mills.

Increased biotic stress tolerance and vigour are thus considered by proponents of GE as likely to increase yields relative to inputs of land, time and capital, and hence increase foresters' profits (Tzfira *et al.*, 1998).

Improved timber quality

Foresters can generate better incomes from their trees by increasing the quantity of timber sold, but also by improving the quality. Several GE

techniques of achieving this objective are discussed, although as Pullman *et al.* (1998) conceded, relatively little is currently understood about the molecular mechanisms that control many timber characteristics. These include early-wood-latewood transitions, cellulose synthesis, microfibril angle, fibre cell length, and cell wall thickness. Some workers (e.g. Dickson and Walker, 1997) believe that tree geneticists should attempt to differentiate their genetically engineered trees to provide products tailor-made for the customer's requirements, and also to specifically select for improvement of those properties that are hard to manipulate by improving the machines and techniques used in the processing industries.

Timber density and quality

Timber density, as a general indicator of wood quality, is a qualitative timber trait thought to be amenable to improvement using GE methods, although efforts are still at an early stage. Dickson and Walker (1997) have calculated that a 25–50 per cent increase in the stiffness of *Pinus radiata* corewood could increase the revenue from New Zealand's timber export by \$250 million. More desirable trunk shape (Pullman *et al.*, 1998), reduced grain spiralling and shake (Soil Association, 1998) as well as the increased uniformity of the timber from the point of view of shape and physio-chemical characteristics (Tzfira *et al.*, 1998), are further GE innovations thought to be in the pipeline that could enhance the utility of future timber.

Modified lignin content

The pulp and paper industry is confident that GE techniques will be able to improve the suitability of various forest trees for pulping, as described in detail by Pullman *et al.* (1998).

An improvement of the pulp characteristics depends mainly on an ability to modify the lignin content of wood, either by quantitatively reducing it or by altering its biochemical structure to enhance its extractability during the pulping process (James *et al.*, 1998). For example, Baucher *et al.* (1998) reported enhanced lignin extractability during chemical pulping in pines

and poplars caused by transgenically down-regulated levels of CAD2 activity. Similarly, Hu *et al.* (1999) have reduced lignin production in poplars by an anti-sense down-regulation of 4CL, another component of the lignin biosynthesis pathway. Such timber characteristics could reduce the amounts of energy and chemicals needed to treat the pulp, and also yield a better quality paper, thus conferring both economic and environmental benefits. However, Booker and Sell (1998) warned that wood has been optimized by natural selection to confer stability and a means of transportation for essential substances within the tree, not to provide marketable timber. Attempts to genetically modify wood structure may jeopardize this function, and lead to increased wind breakage, cavitation, etc. Dickson and Walker (1997) saw less of a risk here, and suggested that although decreasing the lignin content of the wood might have negative side effects on the tree's stability and defence, altering its composition would probably not have such negative consequences. Mackay *et al.* (1997) reported a naturally occurring mutant with reduced lignin content and no apparent negative side-effects.

If, in an effort to reduce net CO₂ emissions from non-renewable fuel sources, wood were to become more widely used as a fuel in industrialized countries, similar technology could be used to increase the lignin content of wood, and thus enhance its calorific value (Moffat, 1996).

Disadvantages associated with the application of GE techniques to tree breeding

This essay investigates only potential environmental risks caused by the introduction of GE trees into the environment. However, negative environmental impacts cause economic and social costs.

Scientists working in the fields of ecology and molecular biology have identified various environmental concerns potentially stemming from the widespread use of genetically modified forest trees. Although to date transgenic organisms have caused no documented adverse environmental impacts (Strauss, 1998), experience gained from the well documented cases of

purposefully and involuntarily introduced non-indigenous plants having 'escaped' and subsequently caused the extinction of native species suggests that negative impacts are possible when novel organisms are introduced into an ecosystem (Hughes, 1995; Yang, 1997; Strauss, 1998; Ewel *et al.*, 1999). Along a different vein, some workers are concerned that transgenically enhanced resistance to some tree pests and pathogens is not only unsustainable, but will in fact aid pests and pathogens to evolve better resistance to currently effective chemical and biological control agents.

Thus while Raffa *et al.* (1997) are critical of those who raise every conjectural hazard that could possibly result from the introduction of GE trees, they find that three categories of risk should be of concern (cf. also Yang, 1997) because (1) a clear mechanism based on biological understanding of the novel organisms and their recipient ecosystem can be delineated; and (2) a relevant precedent exists. These risks are:

- the possibility of GM trees, or their transgenes, 'escaping' their plantation, developing weed status, and disrupting the surrounding ecosystem or human landscape;
- the possibility of resistant biotypes evolving, and their subsequent impact; and
- the possibility of novel by- or end products of GE trees altering bio-trophic processes in their recipient ecosystem. The following section will describe and evaluate each of these categories in turn.

Hazards associated with transgene spread

As stated succinctly by James *et al.* (1998), 'the risk of a transgene spreading in the environment depends on the likelihood for out-crossing or horizontal gene transfer, and the phenotype the gene imparts'. The many cases of exotic plants becoming weedy are precedents for the possibility of novel organisms escaping and causing ecosystem damage.

The likelihood of transgenes spreading by out-crossing depends on the sexual compatibility and physical proximity of the transgenic stand with other species. Such criteria may be partially fulfilled by many forest tree species, which are

often dioecious, usually wind-pollinated hence producing pollen mobile over long distances, and may be planted in the proximity of wild relatives. In a limited preliminary study, Purrington and Bergelson (1995) found some evidence to suggest that GE mustard plants were significantly more 'promiscuous' than their wild or conventionally bred cousins; thus increased instances of tree hybridization with related species are a possibility.

Though there is little direct evidence for the occurrence of gene transfer to phylogenetically unrelated organisms via bacterial vectors, potential mechanisms have been described (James *et al.* 1998). Ahuja (1997) saw little risk of transgenes escaping to natural ecosystems because, since all ecological niches will already be occupied and hence not open for invasion, the former will act as natural 'buffers and diluters'. However, many natural ecosystems, such as the Feynbos in South Africa, do not always resist invasion from non-indigenous plants (Ewel *et al.*, 1999). Ahuja (1997) apparently assumes that transgenic plants are intrinsically less fit than their wild competitors. It may be that trees engineered for productivity-related traits are less fit than their wild-type counterparts in natural ecosystems, in which case the likelihood of their becoming invasive is low. However, it is not inconceivable that some traits, or a mutation generated by a transgenic insertion, could confer a selective advantage to the GE tree. This is a fair assumption given that many traits related to tree productivity enhance vegetative development at the expense of reproductive development. In human-dominated ecosystems, however, where niches are artificially vacant, escapees are more likely to cause management problems.

If such out-crossing does cause hybridizations, the concern is that even if the original transgenic organism is considered perfectly innocuous, there is a potential for its novel constellation in the hybrid genome to elicit unexpected and potentially hazardous traits in the genotype.

A transgenic tree initially thought to be environmentally unproblematic could, due to altered gene expression or epigenetic changes (Phillips *et al.*, 1994) – there is some evidence that certain transgenes may render their host genome unusually unstable (Raffa *et al.*, 1997) – and due to interactions with a changing environment,

nevertheless develop hazardous traits. Apart from by sexual reproduction, as discussed above, it could reproduce vegetatively by several mechanisms, and be translocated by animals or water (Raffa *et al.*, 1997). Although no such effects have yet been documented, Ahuja (1997) stressed that many of the GE trees field-tested so far were planted on small plots which do not represent the full spectrum of potential transgene–environment interactions. Furthermore, none of the trees can be more than 12 years old at most.

The previous two paragraphs indicate that there is widespread uncertainty associated with GE trees and their interactions with ecosystems. This is expressed clearly by Yang (1997), who stated that 'assessing the environmental fate and impact of transgenic trees lags behind the ability to create them'.

Despite these potential risks, it is important to remember that a transgenic tree can only escape and become a potential problem if it is more competitive than other species in its ecological niche. Some of the traits conferred transgenically upon forest trees are highly unlikely to enhance their competitive ability. Such traits include modified lignin content (James *et al.*, 1998) and reproductive sterility (see next section). Herbicide resistance is also unlikely to confer any selective advantages in ecosystems where no herbicides are applied, although in human landscapes this could preclude control with current herbicides. Transgenes for improved vigour, for improved tolerance of environmental stresses, and for pest resistance, theoretically pose a risk, although as discussed earlier, pests may with time evolve resistance to insecticidal plants.

Engineered sterility

A potential solution to the problem of genes escaping by sexual reproduction is to genetically engineer the trees for sterility. Mechanisms include inhibiting the production of flowers, pollen or seed, or by inserting the transgenic material into trees' chloroplasts rather than nuclei, since the former are normally absent from pollen (for details and difficulties, see Strauss *et al.*, 1995). A non-functional sterility mechanism proposed is to engineer for later sexual maturity, so that trees can be harvested before they can sexually reproduce (Strauss, 1998). This technology has the potential to substantially reduce

the natural reproduction of transgenic organisms, a trait which is also of obvious benefit to biotechnology companies in order to prevent their technology being pirated. Furthermore, it may assuage public concern over conjectural environmental risks (Strauss, 1998). Nevertheless, this technology would have no effect on reducing the non-sexual spread of transgenes, and is unlikely even to confer guaranteed sexual sterility in the near future (Strauss *et al.*, 1995).

Hazards associated with resistant biotypes

As mentioned earlier, there is some concern that trees containing transgenes conferring pest toxicity could lead to the pests evolving resistance to these toxins. Precedents for this are agricultural pests that have become immune to frequently applied agricultural pesticides or that have overcome resistant crop cultivars (Strauss, 1998). Such immunity among forest pests is rare, because tree-feeding insects, unlike agronomic insects, are subject to markedly variable exposure patterns, relatively infrequent treatments, and incomplete spray deposition – sources of variability likely to be lost in trees engineered for pest resistance (Strauss, 1998).

Apart from lost pest resistance, which could be disastrous if the pests cannot be controlled using alternative methods, potential consequences of resistant biotype evolution are altered selection pressures, release from competitors, dispersion and cross-resistance (see Raffa *et al.* (1997) for more details and for possible mitigation strategies).

Depending on the behaviour of the insect pests (i.e. migration rates), it has been suggested that wild-type individuals of the same species in forests situated nearby to transgenic plantations could provide refugia for susceptible pest genotypes (James *et al.*, 1998). However, as was discussed earlier, such wildtype forests provide a potential means of escape for just such transgenes, although, as discussed, the risk could be reduced if transgenes for sterility are also incorporated into the forest tree's genome.

Since cloning is used in association with GE technology, stands of GE trees are likely to exhibit low genetic diversity unless specific efforts are made to vary the transgenes used. This fact, unless the stand is equipped with transgenes for

some form of pest resistance, is likely to render the trees more vulnerable to pest attack than their wild-type relatives (Libby, 1982). This said, many conventional plantations, and indeed natural stands, also exhibit very low genetic diversity, and biotechnology techniques could be used expressly to enhance diversity in GE trees if effective regulations were instigated (Libby and Ahuja, 1993).

Altered multi-trophic processes

The third and final identified concern discussed here is that gene products from transgenic organisms might have a negative impact on the recipient ecosystem. Mechanisms for this include enhanced competitiveness of GE trees as a consequence of pest resistance or physiological tolerance of environmental stress, the acquisition of such traits by existing weedy organisms via incorporation of escaped transgenic material (as discussed above), or the direct or indirect impact of insecticidal transgene products on biotic communities, natural food webs, and ecosystem processes (Strauss, 1998). Precedents for the latter include the negative impacts associated with exotic pests and the side effects of pesticide application and toxic pollutants (Raffa *et al.* 1997). Historically, ecologists have experienced great difficulty in predicting the outcomes of complex community- and ecosystem-level interactions (Strauss, 1998), but some suggested consequences of insecticidal transgene products are reductions in seed dispersal and pollination.

However, whether or not there is an accumulation of transgenically produced toxins depends on the nature of the toxin. Raffa *et al.* (1997) are unaware of any instances where insect predators have suffered as a consequence of their prey having fed on plants genetically manipulated to produce *Bacillus thuringiensis* toxins, but concede that more stable transgenically produced toxins may be more problematic. They stress that the least understood component of risk assessment concerns the potentially adverse affects of novel toxic products on soil organisms, especially if the toxins are non-specific. Potential breakdown products of the transgenic toxins, as well as the possibility of stable toxins accumulating in the soil over time, must also be taken into account.

Conclusions

The following conclusions are drawn concerning the potential advantages and disadvantages of the use of genetic engineering technology in forest trees.

- 1 Moral arguments exist both for and against the use of GE in trees.
- 2 Tree plantations and the wider ecosystems of which they are part are so complex as to preclude simple answers about the environmental risks of using GE trees (James *et al.*, 1998). Some environmental concerns are potentially serious, and *judicial* use of the precautionary principle should be used, taking into account both potentially adverse environmental effects and the costs of foregone potential benefits transgenic trees can provide.
- 3 Given the complex nature of the risks, an interdisciplinary approach including ecologists and molecular biologists is required.
- 4 A risk deserves serious consideration if (a) established mechanisms support its potential occurrence, and (b) there is a relevant precedent (Raffa *et al.*, 1997). After a case-specific analysis, it may be possible to reduce the potential risks of introducing a given GE tree to an acceptable level by taking into account various attributes of the transgenes, the parent trees, the phenotypic expression of the introduced genes, and interactions with other organisms in the ecosystem (Strauss, 1998).
- 5 Because of the widespread consumer distrust of GE technology, the onus should be on the biotech scientists to (a) demonstrate that at least some of the environmental concerns are unfounded; and (b) educate the public in GE issues to the extent that average people are in a position to develop their own informed opinions on the use of GE (Griffin, 1996).
- 6 Although most informed ecologists are perhaps not convinced that the types of GMOs *currently* being tested will actually become noxious weeds, since the aim of biotechnology companies is to 'produce transgenic organisms that have higher fitness under a broad range of environmental and biotic stresses' (Purrington and Bergelson, 1995) and they are likely to at least partially succeed in this goal in the medium to long term, it is necessary to ensure the regulatory machinery for prohibiting the

spread of environmentally harmful transgenic trees is in good working order.

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