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THE POTENTIAL ENVIRONMENTAL, CULTURAL AND SOCIO-ECONOMIC IMPACTS OF GENETICALLY MODIFIED TREES

Background document to the in-depth review of the forest programme of work

Note by the Executive Secretary

I. INTRODUCTION

1. In paragraph 3 of decision VIII/19 B, the Conference of the Parties requested the Executive Secretary to collect and collate existing information, including peer-reviewed published literature, in order to allow the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) to consider and assess the potential environmental, cultural, and socio-economic impacts of genetically modified trees on the conservation and sustainable use of forest biological diversity, and to report to the ninth meeting of the Conference of the Parties. The present note has been prepared in line with these guidelines.

2. The Secretariat compiled the available information on the potential impacts of genetically modified trees from Parties, relevant organizations, and peer reviewed publications and obtained comments from the International Union of Forest Research (IUFRO) Task Force on Forests and Genetically Modified Trees. A summary of this information is contained herein. More information on the views from Parties and relevant organizations on the potential environmental, cultural and socio-economic impacts of genetically modified trees is available as an information document (UNEP/CBD/SBSTTA/13/INF/7).

3. In order to facilitate the collation of information on genetically modified trees, the Secretariat distributed a questionnaire on 4 May 2006 to Parties and relevant organizations inviting them to provide information. Nine out of 35 Parties which had responded by September 2007 indicated having plantations of genetically modified trees, mostly for experimental purposes. Twenty-three Parties reported having platforms, committees or other forums to address genetically modified trees, generally taking the form of advisory and/or regulatory boards and/or committees. Thirty of the responding Parties

* UNEP/CBD/SBSTTA/13/1.

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indicated that they had implemented guidelines or regulations to minimize the impacts of genetically modified organisms. Though there were few references to the specific environmental, cultural or socio-economic impacts of genetically modified trees, some countries indicated that these potential impacts could be considered under existing guidelines or regulations. All views from Parties and relevant organizations that were received by September 2007 are compiled in the above-mentioned document UNEP/CBD/SBSTTA/13/INF/7.

4. Genetic manipulation is not a new practice. Historically, agriculturalists have relied on techniques, such as cross breeding and cross fertilization, to encourage the emergence of positive traits in plants and animals. However, with the rapid development of biotechnology over the last 30 years the degree to which organisms can be manipulated has increased drastically, allowing natural species boundaries to be crossed (CBD 2003). As a result, genetically modifying or engineering living organisms has become one of the most controversial and polarizing issues related to biotechnology.

5. While biotechnology, as defined by the Convention on Biological Diversity, broadly refers to "any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products for specific use", genetic modification specifically refers to "the use of recombinant DNA and asexual gene transfer methods to alter the structure or expression of specific gene traits" (FAO 2004, p. 4). Given this distinction and the aforementioned decision the following document will only address genetically modified organisms.

6. To date, the majority of the work on genetically modified trees has focused on research to evolve better tree development methods and to answer basic biological questions (FAO 2004). El-Lakany (2004) suggests that this is the type of research which will likely be the most important result of biotechnology and Finstad et al. (2007) highlight that genetically modified trees represent tools to further our understanding of genetics. However, research related to the development of trees with altered lignin content, stress tolerance and insect, disease and herbicide resistance has also been conducted (FAO 2004). It is these later areas of research which have generated most of the concern on genetically modified trees as these modifications have both potentially positive and negative impacts. Generally, these impacts (summarized in annex I) can be classified into three categories: environmental, cultural and socio-economic. However, it should be noted that these three spheres are innately linked, as what occurs in the environmental realm will also have an impact on cultures and socio-economic conditions (Mathews and Campbell 2000). These potential impacts need to be valuated on the basis of their actual effects as compared to the effects of the comparative, current or alternative practices. As a result of these potential environmental, cultural and socio-economic impacts and the lack of a definitive conclusion on this topic, genetic engineering or modification has been the source of much debate (van Frankenhuyzen and Beardmore 2004).

7. The most commonly targeted tree genus for genetic manipulation is *Populus*, though there has been reported research on 19 other genera including *Pinus*, *Liquidambar* and *Eucalyptus* (El-Lakany 2004; FAO 2004). The Food and Agriculture Organization of the United Nations (FAO) reported that as of 2004 there had been more than 210 field trials of genetically modified trees with the majority of these occurring in the United States (FAO 2004). More recently, a review of the database of field trials available at the Information Systems for Biotechnology web site (http://www.isb.vt.edu/) indicates that there have now been over 360 approved field releases of genetically modified forest tree species in the United States alone, with almost 500 in total for all tree species. Moreover, based on the information from field trials, it appears that the amount of publicly funded research projects on genetically modified trees is decreasing while privately funded research is increasing (FAO 2004).

8. Many of the issues associated with genetically modified crops also apply to genetically modified trees, as the modifications developed for crop species are similar to those being developed for trees. In addition, much of the research conducted on genetically modified trees has utilized technologies

developed for use in agriculture (Peña and Séguin 2001). While trees differ substantially from agricultural plants, the biosafety questions raised by genetic modification are essentially the same across the two domains and the debates in both fields have paralleled one another (Finstad et al. 2007; Merkle et al. 2007). However, the practicalities and constraints of conducting research on genetically modified trees do differ from those related to agriculture.

9. More than 20 years have passed since the introduction of the first transgenic tree (Sederoff 2007). However many issues related to genetically modified trees still need to be addressed and studied. When compared to agricultural crops, there have been relatively few experiments conducted to determine the effects of genetically modified long-lived species such as trees (Halpin et al. 2007). Unlike other genetically modified plants which grow quickly and can reach reproductive maturity relatively early in their development, trees require long periods of time to complete their reproductive cycles (Farnum, Lucier and Meilan 2007). For example, loblolly pine (*Pinus taeda L.*) generally only begins to flower after about 16 years while harvesting tends to occur after 20 to 35 years of growth depending on the desired use of the tree (Farnum, Lucier and Meilan 2007). Therefore, research on genetically modified trees requires several years of monitoring, requiring that trees remain in the environment for longer periods than agricultural crops. In addition, the interactions between forest trees and their environment are generally less understood than those associated with their agricultural counterparts (Finstad et al. 2007). A tree can be an ecosystem to a host of other species. Furthermore, the amount of molecular biology research conducted on trees is much smaller, both in terms of funding and the number of research teams, than that conducted on agricultural crops (Farnum, Lucier and Meilan 2007; Peña and Séguin 2001). For these reasons, the development of genetically modified trees and the research on their potential environmental, socio-economic and cultural impacts remains in its infancy (Hayes 2001). As a result, both proponents and detractors of genetically modified trees are currently operating without sufficient scientific data to understand and characterize with scientific certitude the potential risks associated with the use of genetically modified trees (Campbell and Asante-Owusu 2001). Moreover, different interpretations of the available information make the development of any consensus on this issue a challenge (Gartland and Oliver 2007).

10. A major source of complexity in the genetically modified tree debate is that the impacts of transgenic trees are likely to vary depending on several factors including the trait which is modified or introduced, the evolutionary history of the organism being modified and the size and location of the plantation (Hayes 2001; Peterson et al. 2000). Moreover, when several modified traits are introduced into one tree, determining their synergistic impact is difficult, even if the impacts of the individual traits are known (Johnson and Kirby 2001). As a result of these complexities and given the infancy of the field, Hayes (2001) noted that “Many of the potential biodiversity issues raised to date may prove to be unimportant and other issues that currently have yet to be hypothesized may emerge” (p. 172).

II. POTENTIAL ENVIRONMENTAL IMPACTS

11. The potential environmental benefits derived from genetically modified trees vary with the type of trait introduced. It is speculated that trees with reduced lignin content will be easier to process into paper as the need for chemicals and the amount of energy required for processing the cellulose would be reduced (Halpin et al. 2007; van Frankenhuyzen and Beardmore 2004; Johnson and Kirby 2001; Mathews and Campell 2000). Consequently, the amount of pollution originating from pulp mills could be decreased. Similarly, trees with increased lignin would also confer environmental benefits. One of the anticipated benefits of this type of modification is that fewer trees would need to be harvested to meet consumption needs. Trees with increased lignin content would have higher caloric value and would therefore be a more efficient fuel source (Gartland, Kellison and Fenning 2002). Similarly, higher levels of lignin would increase timber strength theoretically allowing for the development of stronger construction materials (Mathews and Campbell 2000). Therefore, modifying lignin content could potentially reduce the pressure on natural forest as timber demand could be more easily met. However,

Hayes (2001) notes that any offsite implications of genetically modified trees are largely dependant on how the lands freed from harvest pressures are managed or used.

12. While modifying the lignin content of trees would have a potential positive impact on the environment, it also raises several environmental concerns. For example, reduced lignin content may decrease the fitness of trees (van Frankenhuyzen and Beardmore 2004; James et al. 1998). As lignin makes it difficult for insects to digest plant materials, its reduction could make it easier for insects to consume plant material and lead to larger populations of tree defoliators (van Frankenhuyzen and Beardmore 2004). It has also been hypothesized that decreased lignin content could render trees more vulnerable to viral diseases (van Frankenhuyzen and Beardmore 2004). Furthermore, engineering trees to have lower lignin levels may potentially affect soil structure and chemistry by accelerating rates of decomposition (Farnum, Lucier and Meilan 2007; van Frankenhuyzen and Beardmore 2004; Campbell and Asante-Owusu 2001). However, a four-year study by Halpin et al. (2007), in which poplars were modified to express antisense transgenes to generate improve pulping efficiency, found that both modified and non-modified trees were subject to modest insect damage, that there was no change to disease resistance and that there was no difference in the carbon and nitrogen biomass of the soil below the trees. However, it was also observed that the genetically modified poplars emitted slightly more CO_2 during root decomposition, especially during the first month, suggesting that the poplars with modified lignin had a quicker decomposition rate than their non-modified counterparts (Halpin et al. 2007). Although all these features can be assumed and might be seen in research trials, in practice, only transgenic trees that have desirable agronomic features, such as disease, pest resistance, and form, and that meet the desired productivity over their life span until harvest, will be planted commercially.

13. A further genetically modified tree trait which may have potential positive effects on the environment is insect resistance. It is suggested that, by developing trees which produce toxic chemicals affecting defoliators and other tree pests, the need to apply broad spectrum pesticides in forested areas would be decreased (Farnum, Lucier and Meilan 2007; Campbell and Asante-Owusu 2001; Hayes 2001; Mathews and Campbell 2000; James et al. 1998). This approach has already been applied to genetically modified crops where, for example, toxins originating from *Bacillus thuringiensis* (Bt) vars. *kurstaki* and *tenebrionis*, have been added to plants such as tomatoes, tobacco, corn, potatoes and poplars to confer insect resistant properties (James et al. 1998). Insect resistance, achieved through the expressions of endotoxins from Bt is already one of the most commonly induced traits in commercial agricultural crops (O'Callaghan et al. 2005). As the insecticidal agent would be targeted specifically to organisms feeding on tree tissues, only pest insects would be exposed to the toxin, thereby reducing the exposure to non-pest insects (Mathews and Campbell 2000; James et al. 1998). As such, insect resistant traits might help to preserve a greater insect diversity than if conventional non-target pesticides were applied. Moreover, if insect resistant traits were conferred into endangered or threatened tree species, thereby increasing resistance, restoration and conservation could be promoted. Parallel to this, trees could be engineered to resist or combat the impacts of invasive alien species (van Frankenhuyzen and Beardmore 2004). There are cases where traditional pesticide treatments are not effective and where genetically modified approaches may provide a solution. For example, for wood boring insects such as the Emerald ash borer (*Agrilus planipennis* or *Agrilus marcopoli*), external application of pesticides is not an effective treatment (USDA 2006) whereas engineering resistance into the cells of the tree itself could provide for effective pest control. Similarly, transgenically induced disease resistance may allow for the restoration of species such as American chestnut (*Castanea dentata*), which have been greatly affected by disease (Hayes 2001).

14. Modifying trees for insect resistance is not without risk. One concern is that insect resistant traits in trees may lead to the increased development of pesticide resistant species (van Farnum, Lucier and Meiland 2007; Frankenhuyzen and Beardmore 2004; Campbell and Asante-Owusu 2001; Peña and Séguin 2001; Mathews and Campbell 2000). James et al. (1998) note that the likelihood of pesticide resistant biotypes evolving increases the longer pest species are exposed to toxins and the larger the area

over which genetically modified trees are planted (which increases the likelihood of exposure). The development of resistance has already been seen with the use of more traditional pesticide application techniques such as with Bt sprays (Royal Society of Canada 2001). A further concern is that insect resistance in trees would reduce the number of phytophagous and pollen-feeding insects present in a forest; this is a particular concern for specialist species (Johnson and Kirby 2001). Reductions in insect numbers could have larger effects throughout the food chain and potentially modify predator-prey relationships and biodiversity more broadly (Farnum, Lucier and Meilan 2007; Hayes 2001). Furthermore, as most plants are subject to pressure from multiple herbivores, there is a potential for non-target herbivores (minor pest species) to be affected as well (Royal Society of Canada 2001). Though genetically modified trees with insect resistant traits only directly affect herbivores, there is a potential for insectivores or carnivores to ingest these toxins by feeding on herbivore tissues (Royal Society of Canada 2001). However, in their research, O'Callaghan et al. (2005) found no evidence that toxins conferring insect resistant traits accumulated in the food chain. It has also been noted that the effects of insect resistant transgenic plants depend on several factors, including the potential for predators to be exposed to the toxin and its inherent susceptibility to it (O'Callaghan et al. 2005).

15. While insect resistance traits in trees may suppress one insect pest, it has been suggested that these traits may result in increased numbers of secondary pests (Johnson and Kirby 2001). For example, in their examination of food biotechnology, the Royal Society of Canada (2001) notes that while the use of Bt transgenic crops decreased the application of pest-targeted insecticide sprays, it also increased problems with secondary pests. A further concern over insect resistance is the potential adverse effect on soil structure if detrital plant material retains its toxicity thereby affecting decomposition by insects (Johnson and Kirby 2001). There has also been concern over the potential leaching of toxic materials from insect resistant trees into forest soils through root systems (O'Callaghan et al. 2005). The Royal Society of Canada (2001) mentions two studies were these two processes have been observed. First, it was found that the transgenic corn cultivar NK4640Bt, modified to express the Bt toxin gene cryIAB, exudes the toxin through its roots into the rhizosphere. Second, cotton var. Coker line 81 (cry1AB) and line 249 (cry1AC) were found to release measurable amounts of the Bt toxin into the soil when plant material decomposed. However, it was unclear as to what the impact of this would be because, as mentioned above, the insecticidal proteins which have been utilized thus far degrade rapidly and have a restricted spectrum of toxicity (Campbell and Asante-Owusu 2001). Johnson and Kirby (2001) also note that without comparative research it is difficult to determine the impacts of genetically modified insect resistance on the environment compared to more traditional methods of insect control. Moreover, O'Callaghan et al. (2005) highlight that the effects of insect resistant crops on non-targeted species, particularly those living in soil systems, are largely unknown, and that research examining the effects of insect resistance on entire ecosystems is lacking. In addition, there has been little research conducted on the effects of genetically modified plants on pollinators feeding on nectar or pollen (Royal Society of Canada 2001). This is particularly problematic as there may be diverse guilds of pollinators for a given species (Royal Society of Canada 2001).

16. Herbicide resistance has been one of the main foci of the work on genetically modified plants (Johnson and Kirby 2001). The development of herbicide resistant traits in trees could result in several environmental advantages. In particular, herbicide resistance could allow for the application of relatively benign broad spectrum herbicides in plantation forests, thus reducing the need to apply multiple herbicide treatments (van Frankenhuyzen and Beardmore 2004; Mathews and Campbell 2000). Furthermore, the application of broad spectrum herbicides in plantations could reduce soil erosion by decreasing weed removal through tilling (Mathews and Campbell 2000; James et al. 1998). A specific advantage in forest systems, as compared to agricultural systems, is that herbicide applications would likely be limited to the first few years during forest establishment, rather than on an ongoing annual basis. Herbicide resistance would allow more cost-effective and successful establishment of highly productive industrial plantations.

17. Herbicide resistant trees also represent several environmental risks. By promoting the use of specific herbicides, herbicide resistant trees may lead to increased selection pressure for resistant weed biotypes as well as reinforce the use of broad spectrum herbicides (van Frankenhuyzen and Beardmore 2004; Johnson and Kirby 2001; Thomas 2001; James et al. 1998). Furthermore, Johnson and Kirby (2001) note that as broad spectrum weed control is generally used at the early stages of the development of plantations, when a variety of forest and forest edge species are present. Therefore, until there is canopy closure, there could be a negative impact on biological diversity in a forest tree plantation (including insect and bird species which depend on a variety of habitat and food sources). Lastly, as with insect resistant trees, there is a possibility that the application of broad spectrum herbicides will eventually result in the development of plant biotypes which are resistant to herbicides (Farnum, Lucier and Meilan 2007; Thomas 2001). However, in order to understand what the overall impacts of genetically modified herbicide resistance will be, a better understanding of current herbicide use and its impacts on biodiversity is required (Campbell and Asante-Owusu 2001).

18. A further area of research with potential dividends for the environment is the development of stress tolerant trees. By promoting or adding traits which make trees resilient to abiotic stress, the viability of trees can not only be increased, but it may also become possible to use these trees in the phytoremediation of contaminated soils (van Frankenhuyzen and Beardmore 2004; Peña and Séguin 2001 Mathews and Campbell 2000). Peña and Séguin (2001) mention one example where poplar was modified to remediate soil containing chlorophenols. Their large root system, long lifespan and ability to draw water from the soil make trees ideal tools for phytoremodiation (Peña and Séguin 2001). Similarly, by modifying trees for increased productivity, it is assumed that high yield plantations could reduce the need for old growth logging, thereby allowing biodiversity conservation in these areas (van Frankenhuyzen and Beardmore 2004; Hayes 2001). Furthermore, as more wood fibre could be harvested from a given area of land, some of the land used for natural tree harvest could potentially be taken out of production, increasing the land available for biodiversity reserves.

19. While there are several environmental benefits associated with genetically modified trees with traits for greater resilience to abiotic stress, several concerns associated with their use have also been identified. Hayes (2001) notes that increased productivity would not necessarily result in more forest area being protected. Moreover, allowing trees to better cope with environmental stress will increase fitness and may lead to some trees becoming invasive, potentially resulting in a loss of biodiversity (James et al. 1998). In addition, if the genes conferring increased resilience were to escape through horizontal gene flow or other vectors, affected wild species could potentially become invasive (van Frankenhuyzen and Beardmore 2004; Campbell and Asante-Owusu 2001; Mathews and Campbell 2000). However, when long lived perennial species like trees are concerned, determining potential invasiveness is problematic (Johnson and Kirby 2001).

20. As previously noted, some experts have raised concerns over the effect of genetically modified trees on soil quality. Soils are some of the most complex habitats on earth, with one gram of agricultural or forest soil from temperate regions containing thousands of species (Royal Society of Canada 2001). Given this complexity, the impact of genetically modified plants on soil systems is not well understood. This fact is illustrated by the inconsistencies in the studies on the interactions between soil and genetically modified plants (O'Callaghan et al. 2005). O'Callaghan et al. (2005) report that only a small quantity of research has been devoted to understanding the impacts of genetically modified organisms on soils and that it has tended to focus on Bt in cotton and maize. The persistence of other transgene-related substances has generally not been addressed (O'Callaghan et al. 2005). However, Lilley et al. (2006) refer to a study in which 25 peer-reviewed articles examining the effects of 9 different species of genetically modified plants was conducted. In 16 of the cases minor changes to the soil community or structure were observed. These changes included effects on the diversity of bacteria and nematodes, fungal counts, the number of protozoa and woodlice mortality. However, for the most part, these studies were only conducted over one growing season and the majority of the impacts were found to be transient.

Furthermore, O'Callaghan et al. (2005) refer to a laboratory study in which the Bt endotoxin originating from genetically modified maize was rapidly degraded and where no detectable levels of the toxin was found after 14 days. Another study examining deoxyribonucleic acid (DNA) persistence found that the genetically modified DNA originating from genetically modified poplar leaves under natural conditions was not present in soils for more than four months (Hay et al. 2002). Although only one of the above studies specifically examined genetically modified trees, these studies can be used as examples of the type of potential impacts that genetically modified trees might generate as many of the expressed traits examined are the same as those currently being developed in trees.

21. One of the most frequently cited environmental concerns in discussions related to genetically modified trees, or genetically modified organisms generally, is the potential for novel genetic materials to escape into wild gene pools (Merkle et al. 2007; van Frankenhuyzen and Beardmore 2004; Campbell and Asante-Owusu 2001; Johnson and Kirby 2001; Mathews and Campbell 2000; James et al. 1998). This can occur in several ways including the transfer of transgenes through pollination or the hybridization of genetically modified organisms with wild relatives. For reasons such as this, James et al. (1998) state that "Once genetically modified trees become reproductive it is nearly impossible to guarantee high levels of gene containment because of the extreme mobility of seeds and pollen and the proximity of wild interfertile relatives" (p. 410). Furthermore, although not exclusive to genetically modified trees, it has been postulated that bacteria may serve as vectors for the transfer of transgenic genes between organisms which are phylogenetically unrelated (Mathews and Campbell 2000). It is assumed that if transgenic traits, such as increased resilience or insect and herbicide resistance, were to enter wild gene pools the potential environmental implications could be significant, although this is dependent on the persistence of this single allele in the entire gene pool of intercrossing plants. If the gene confers a much greater ability to compete, the trees with the transgenic trait could have an impact on the overall diversity of a particular ecological system or landscape (Brunner et al. 2006). However, predicting the outcome of transgenes in wild plant populations is more difficult than determining if gene flow is likely to occur. This is due to the absence of empirical data explaining the fitness benefits and costs of transgenic traits in non-targeted species (Royal Society of Canada 2001). Determining fitness, even in targeted tree species, is difficult due to the generation interval, the lengthy juvenile periods and the large size of many trees (Farnum, Lucier and Meilan 2007). Ultimately, the spread of transgenes will be dependant on the manner in which they affect the survivability and reproductive success of the affected species. For these reasons, the Royal Society of Canada (2001) notes that "To fully understand the dynamics of transgenic escape, large-scale demographic studies are required in which the complete life histories of populations are monitored over several successful years" (p. 129). To date, there is little data elucidating the persistence of DNA originating from genetically modified trees in the natural environment (Hay et al. 2002).

22. In an attempt to reduce the risks of transgenic escape, several methods of mitigation have been proposed. These methods are similar to the genetic use restriction technologies (GURTS) which have already been proposed for use in agricultural crops. By either disrupting pollen production or by preventing trees from flowering, it is argued that the spread of genetically modified material could be prevented. Another method for controlling the spread of transgenic material is engineering trees to reach sexual maturity later in their life cycle, so that trees can be harvested before they begin to produce pollen (Mathews and Campbell 2000). According to Brunner et al. (2007), the methods to prevent the escape of transgenes from modified trees can be divided into 5 major approaches: mitigation (linking any survival benefits from transgenes to genes which are only beneficial under farm or plantation settings), excision (the removal of transgenes from gametes prior to the release of the tree), gene suppression (the impairment, at the protein, DNA, or ribonucleic acid (RNA) levels, of genes essential to reproduction), ablation (the destruction of floral tissues with the use of a cytotoxin) and repression (the postponement of flowering). However, these methods are not without concern.

23. Specifically, with regards to planned sterility, it has been postulated that by eliminating pollen and flowers, a large portion of the food web would be disrupted as the production of fruits and nuts

would be prevented (Farnum, Lucier and Meilan 2007; Johnson and Kirby 2001). For example, more than half of the brownheaded nuthatch's (*Sitta pusilla Latham*) diet is composed of seeds from pine trees such as the loblolly pine (*Pinus taeda*) (Farnum, Lucier and Meilan 2007). Should these seeds no longer be available, species such as the brownheaded nuthatch would be deprived of an important food source. Moreover, while planned sterility or harvesting trees before they are reproductive may guard against the spread of transgenes, these techniques would have no effect on non-sexual transfers of transgenic material such as vegetative reproduction (Fanum, Lucier and Meilan 2007; Mathews and Campbell 2000). For instance, some members of the *Populus* genus can reproduce from broken branches and twigs (Farnum, Lucier, Meilan 2007). Perhaps most worrisome, however, is that if genes for planned sterility (so called terminator genes) escape into wild gene pools, the potential consequences on the environment could be severe. Furthermore, given the current level of understanding of genetically modified trees and the genomic and technological studies which have been conducted, it is not yet possible to determine the most effective containment method for transgenic trees nor the reliability of the methods developed so far (Brunner et al. 2007). Therefore, according to Brunner et al. (2007), it would be ill-advised to trust that transgenes could be completely contained without more studies on the subject. The effectiveness of any method in preventing total gene flow might be difficult to evaluate precisely. However, the recent discovery of the genetically modified-gene-deletor technology, which was proven to be effective in providing 100 per cent containment in tobacco (Luo et al. 2007), suggests that gene flow through sexual reproduction (pollen and/or seed) could be prevented.

24. A further environmental concern on the use of genetically modified trees is the general uncertainty surrounding their impacts. Van Frankenhuyzen and Beardmore (2004) note that somaclonal variation can result in the manifestation of tree abnormalities and Matthews and Campbell (2000) suggest that there is a possibility that the new genetic traits entering the ecosystem could affect the bio-trophic processes in their host ecosystem. However, trees selected for commercial use will presumably be selected not only on the performance of the introduced trait, but also on other assessed traits such as growth, form and disease resistance. Matthews and Campbell (2000) go on to state that "There is widespread uncertainty with genetically engineered trees and their interaction in the environment" (p.377). To date, the information regarding the long term impacts of genetically modified trees are largely confined to hypotheses presented by both detractors and proponents of genetically modified trees (IUCN 2004).

III. POTENTIAL CULTURAL IMPACTS

25. The cultural impacts of genetically modified trees are difficult to quantify since little research has been carried out in this area and determining what constitutes a positive or negative impact can often be a subjective issue. For these reasons, only speculative impacts can be highlighted. One potential positive impact of genetically modified trees is the protection and conservation of culturally important tree species such as the American chestnut (*Castanea dentata*) or American elm (*Ulmus americana*) which have been in decline as a result of disease (Farnum, Lucier and Meilan 2007; Merkle et al. 2007; Hayes 2001). Traditional breeding methods used to develop disease and insect resistance in agricultural crops are difficult to apply in forests due to the long lifespan of trees (Merkle et al. 2007). Therefore, for tree species that are in decline, the incorporation of insect or disease resistant traits can increase the viability of selected species. Similarly, increasing the productive potential of genetically modified trees could reduce the harvest pressure that many culturally important species now face.

26. There are also several cultural concerns with regards to the genetic manipulation of trees. Transgenic escape in particular has the potential to impact the natural landscape by altering its composition and consequently affecting local cultures. A loss of culturally important species could occur as a result of increased competition between modified and non-modified organisms. If the use of genetically modified trees becomes widespread, local tree species might be displaced. The unintentional development of insect and herbicide resistant species resulting from the escape of insect and herbicide

genes could alter species compositions and reduce the number of species present in a given location, thus forcing cultures to adapt to changing biodiversity conditions. Peterson et al. (2000) note that genetic modification will potentially reduce the "local specificity and adaptation of agricultural processes, which increases both social dependency on external inputs to agriculture and decreases the ability of local agroecosystems to adapt to local environmental contexts". Therefore, the use of genetically modified trees could result in the marginalization of certain groups in the short term and in the loss of traditional ecological knowledge in the long term.

IV. POTENTIAL SOCIO-ECONOMIC IMPACTS

27. Genetically modified trees have the potential to allow for the development of several economically beneficial traits. These economic advantages are summarized by Thomas (2000) who states that "GM trees offer the opportunity to domesticate trees, to tailor characteristics more closely to the requirement of commercial forestry and the end-user of forest products" (p.93). However, genetically modified trees also present several potential socio-economic drawbacks.

28. Using genetic engineering to alter the lignin content of trees could be socio-economically beneficial in several ways. Lignin makes up between 15 and 35 per cent of the dry weight of trees and removing this lignin is a costly process (Peña and Séguin 2001). By reducing the lignin content in wood, fewer chemicals and less energy would be required for its processing, thereby increasing its pulping efficiency (Halpin et al 2007; van Frankenhuyzen and Beardmore 2004; Campbell and Asante-Owusu 2001; James et al. 1998). Research conducted on hybrid poplar suggests this possibility (Peña and Séguin 2001). The need for fewer inputs and greater quality of the end product would result in economic gains. Conversely, increasing the lignin content of trees would lead to a higher lumber density and consequently a better quality of timber and a higher value product. For example, Mathews and Campbell (2000) refer to a study conducted in 1997 by Dickson and Walker in which it was estimated that a 25 to 50 per cent increase in the stiffness of the corewood of Monterey Pine (*Pinus radiata*) would translate into an increase of $250 million in New Zealand's timber exports (Mathews and Campbell 2000). Similarly, engineering trees to have desired physical characteristics, such as increased timber uniformity, could increase the overall market value of genetically modified timber (Mathews and Campbell 2000). It has also been hypothesized that trees could be modified to suit different management regimes (Johnson and Kirby 2001). For example, fruit trees could be developed to grow to a limited size and height allowing for more trees to be planted in an orchard and allowing for more efficient and cost effective fruit harvesting (Peña and Séguin 2001).

29. However, the potential socio-economic consequences of using trees with modified lignin content are not all positive. Mathews and Campbell (2000) caution that since trees have been naturally selected through evolutionary processes to provide stability and effective nutrients transport (as opposed to improved pulping efficiency), attempts to manipulate tree lignin may have adverse impacts on tree health leading to productivity losses. Van Frankenhuyzen and Beardmore (2004) present a similar perspective and suggest that trees with altered levels of lignin may be less viable than their non-modified counterparts. As a consequence, trees engineered with this trait may have adverse economic impacts as a result of higher tree mortality.

30. With regards to pest resistance, the use of genetically modified trees may provide several economic advantages. For example, it was found that apple, poplar, spruce and larch engineered to express the Bt toxin experienced fewer larval feedings (Peña and Séguin 2001). Similarly, Lachance et al. (2007) report that several lines of white spruce (*Picea glauca*) engineered to express the cry1Ab gene from Bt were lethal to spruce budworm (*Choristoneura fumiferana*) larvae. Aside from increasing the viability of trees and reducing losses to folivores, fungi and bacteria, these types of modifications could also decrease the need for pesticides and consequently reduce the input costs associated with tree production (Mathews and Campbell 2000). The United States Department of Agriculture estimates that

there are billions of dollars of forest products at risk from the Emerald ash borer (*Agrilus planipennis* or *Agrilus marcopoli)* alone, for which the only currently effective treatment is to destroy infected trees and those in the surrounding area (USDA 2006). Similarly, the use of herbicide-resistant trees will allow producers to apply broad-spectrum herbicides to control weeds, thus reducing the need for traditional and costly methods of weed control such as multiple herbicide applications and tilling (Mathews and Campbell 2000). Furthermore, with fewer weeds present in plantations there will be less competition for resources, and trees will be able to grow more efficiently (Johnson and Kirby 2001).

31. Trees modified to express disease-resistant traits could also result in increased productivity and the development of safer and/or more nutritious foods with longer shelf lives (Thomas 2000). For example, through genetic engineering, scientists have been able to develop varieties of papaya which are resistant to the papaya ring spot virus (Gonsalves et al. 2007). Similarly, *Prunus* plants have been modified to be resistant to the plum pox virus and transgenic apple and pear have been modified to be resistant to the bacteria *Erwinia amylovora*, which leads to the development of fire blight (Peña and Séguin 2001). Therefore, genetically modified trees have the potential to influence the financial well-being of fruit producers and to impact food security.

32. Increased resistance of genetically modified trees to abiotic stress could mean a more efficient growth, consequently improving productivity (Johnson and Kirby 2001). Moreover, by engineering species to be more resilient to adverse growing conditions, trees could be planted on soils where they have not previously been able to survive. This would also allow the use of trees in the phytoremediation of contaminated soils, creating a cost effective method of restoring land that could not be used otherwise (Farnum, Lucier and Meilan 2007; Peña and Séguin 2001). Furthermore, Gartland, Kellison and Fenning (2002) note that forestry initiatives using air and soil pollution tolerant trees promise to generate investment returns, especially when used in urban environments. In addition, economically valuable species could be modified to be grown in various locations outside their traditional range, allowing for greater production areas (Mathews and Campbell 2000).

33. Another positive economic impact related to the genetic modification of trees is the reduced amount of time required to develop improved phenotypes. Rather than relying on standard cross breeding methods, which have traditionally been lengthy development processes, genetic engineering allows for much quicker phenotype development and for breeding goals to be met rapidly (Mathews and Campbell 2000). For example, it was shown that the flowering of a variety of transgenic aspen was possible after 7 months of vegetative growth, whereas this would have required between 8 and 20 years under normal circumstances (Peña and Séguin 2001). Therefore, by making the breeding results observable more rapidly and reducing development times, genetically modified trees can potentially generate economic benefits.

34. Genetically modified trees represent numerous potential economic advantages. However, experts have raised several general economic concerns associated with their use. For example, Hayes (2001) suggests that the use of high productivity plantations could lead to a decrease in the perceived social and economic value of non-modified trees or natural forest as the economic gains from these types of forests would not be as large as those received from genetically modified forest plantations. Hayes (2001) goes on to suggest that this change in people's perceptions could lead to an increase in the conversion of natural forests to transgenic plantations. If this trend develops, it would most likely result in a loss of forest biodiversity. A further economic concern relates to the fact that poor wood producers will not be able to have access to genetically modified trees given their relatively high cost (Thomas 2000). Therefore, producers who lack economic resources will be denied access to new tree species and markets. For this reason, Thomas (2000) raises the concern that genetically modified trees will generate profit for certain actors in the private sector while poorer communities will be further marginalized.

35. One of the economic concerns related to the use herbicide and pest resistant trees is the potential evolution of resistant pest species. Should pest species become resistant to currently effective chemical and biological control methods, the cost of controlling pest outbreaks would increase (Mathews and Campbell 2000).

36. In monetary figures, Farnum, Lucier and Meilan (2007) cite a report by Sedjo where the use of herbicide resistant trees is estimated to reduce production costs by approximately US$ 1 billion per year and that trees modified to have lower lignin levels could generate between US$ 7.5 and US$ 11 billion per year worldwide. However, while there could be economic advantages associated with the development and use of genetically modified trees, with exceptions such as the papaya example cited above, these advantages have yet to be clearly demonstrated and quantified (El-Lakany 2004). Moreover, since implementing improved silviculture practices continue to offer significant potential for economic gains, the economic rational for introducing genetical modification technology is unclear (El-Lakany 2004). The long time period between the beginning of research projects on genetically modified trees and when benefits begin to accrue makes tree engineering a risky economic proposition (van Frankenhuyzen and Beardmore 2004).

V. INFORMATION FROM GOVERNMENTS

37. In paragraph 4 of decision VIII/19 B, the Conference of the Parties invited Parties, other Governments and relevant organizations, including indigenous and local communities, as well as relevant stakeholders, to provide views and information to the Secretariat for inclusion in the assessment on genetically modified trees. To facilitate this transfer of information, the Secretariat distributed a questionnaire to the parties in which they were invited to report on their current use of genetically modified trees, the presence of any platforms, national committees or other forums to address the issues associated with genetically modified trees and any guidelines or regulations for minimizing the impacts of generically modified trees. As of 30 September 2007, 35 countries had responded. All views from Parties and relevant organizations that were received by 30 September 2007 are presented as an information document (UNEP/CBD/SBSTTA/13/INF/7).

38. The majority of responses received originated from European countries, with a few from Asia and the Pacific, the Caribbean and North and South America. No responses were received from African countries. Given the relatively limited number of responses, it is not currently possible to discern any global trends on the use of genetically modified trees from this data; however the information provided does allow for a foray into the issue.

39. Twenty-six per cent of countries answering the questionnaire indicated that they currently had plantations of genetically modified trees within their borders. Moreover, in all cases with the exception of the United States, these plantations were for experimental purposes. Most of the responding countries did not indicate the purpose of their research activities. However, Belgium indicated that it was working on improving wood production and quality, while United States research activities appear to be related to augmenting the disease resistance of certain species. The species grown in these plantations varied, with both fruit- and wood-trees being planted. While the majority of plantations were established outside, Belgium indicated that their trees were grown in indoor facilities as were a portion of those present in Finland.

40. Sixty-six per cent of the reporting countries indicated that they have developed platforms, committees or other forums to deal with genetically modified organisms. However, it appears that most of these platforms have been developed to deal with genetically modified organisms broadly rather than genetically modified trees specifically. Furthermore, with the exception of one country, all countries reported that they had platforms, committees or discussion forums to address the use of genetically modified trees.

41. The majority of the platforms used by the responding countries were boards and committees. However the frequency with which these platforms operated varied. In some instances, these committees are continuous while in other instances, they meet every one or two years or as situations dictate. In some instances, these platforms are primarily advisory in nature in that they make recommendations and suggestions but no legally binding decisions, while in other instances they have legal authority. Several countries, including Finland, Australia and the United States, reported that they had a combination of both advisory and regulatory platforms in regards to genetically modified organisms. Moreover, several countries, including Belgium, Finland and France, indicated that they use Internet-based tools as platforms to address genetically modified organisms.

42. Eighty-six per cent of responding countries indicated that they had guidelines or regulations for minimizing the impacts of genetically modified organisms. However, the majority of these guidelines related to genetically modified organisms broadly and did not specifically focus on genetically modified trees. In most countries, trees were treated the same way as other genetically modified organisms and were not given a separate or special consideration.

43. As the majority of countries which responded to the questionnaire sent by the Secretariat were from Europe, countries made frequent reference to the guidelines of the European Union as being an influencing factor in the shaping of domestic guidelines. Moreover, there were few references to the environmental, cultural or socio-economic impacts of genetically modified trees, though some countries indicated that these potential impacts could be considered under existing guidelines or regulations.

VI. CONCLUSION

44. Considerable uncertainty on the use of genetically modified trees exists and the scientific data needed to assess the potential impacts of these trees is not currently available. The research on genetically modified tree development has outpaced the research on the potential impacts of such technologies (Farnum, Lucier and Meilan 2007). Much of the needed data must come from medium to large field releases with monitoring occurring over one full rotation (van Frankenhuyzen and Beardmore 2004). As the pollen of some species can travel large distances (pine pollen for instance can travel distances of up to 600 km, though the average distance is likely to be between 50 and 100 metres), the monitoring used in studies must also cover large distances (Farnum, Lucier and Meilan 2007; Gartland, Kellison and Fenning 2002). To date, such studies have not occurred, and in many countries they are not permitted (van Frankenhuyzen and Beardmore 2004). Furthermore, the potential impact of products originating from transgenic trees on the human food chain has generally been ignored, despite the fact that a number of food, cosmetic and pharmaceutical products originate from trees (Merkle et al. 2007). The potential impacts of genetically modified trees need to be quantified according to the species used and to the context of their use (Peterson et al. 2000). For these reason, coming to any definitive conclusion on the potential environmental, cultural of socio-economic impacts related to the use of genetically modified trees is not possible.

45. Writing on genetically modified organisms more broadly, Peterson et al. (2000) state that: "[T]he balance of evidence suggests that genetically modified organisms have the potential to both degrade and improve the functioning of agroecosystems. Depending on which genetically modified crops are developed and how they are used, genetically modified crops could lead to either increases or decreases in pesticide use, the enhancement or degradation of the ecological services provided by agroecosystems, or the loss or conservation of biodiversity"(p. 4). Given the scientific uncertainties surrounding the use of genetically modified trees, many, including Campbell and Asante-Owusu (2001), echo the guidance of the Conference of the Parties in paragraph 2 of decision VIII/19 B by emphasizing that the precautionary approach should be applied when considering the use of genetically modified trees.

Annex I

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

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

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

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

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

Annex II

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