Molecular Biology of Woody Plants
S. Mohan Jain & Subhash C. Minocha, Eds.
Dordrecht, Boston, London: Kluwer Academic Publishers
2000 (Published in the Netherlands)
The article is pp. 485-511

RESEARCH ETHICS FOR MOLECULAR SILVICULTURE

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Introduction

There has been little systematic work on the ethics of tree biotechnology. This paper synthesizes some general scholarship on technological ethics and agricultural biotechnology and suggests how it might be associated with tree biotechnology. The aim is to identify some current and potential issues for forest biotechnology and to elucidate the ethical assumptions and value commitments that lead people to conflicting opinions about the likely consequences of genetic engineering on trees.

New technology carries an implicit ethical rationale of producing benefits and improving quality of life. While researchers may give little or no explicit attention to ethics, advancement of knowledge and economic benefit, utilitarianism-one of the most venerable schools in ethical theory-provides an ethical warrant for technology to the extent that it tends to promote the greater good for the greatest number of people. Yet the total benefit of new technology can be substantially reduced by unforeseen and unwanted consequences. This paper will examine some of the unwanted-consequence issues associated with forest biotechnology. We will highlight some of the most serious risks associated with genetically engineered trees, as well as concerns for which there is little biological evidence. In each instance we will discuss whether disputes are based on fact or value judgement. When values are at the root of controversy over biotechnology, we will analyze the argument in terms of its general ethical approach, as well as its specifically ethical assumptions. Disputes over intellectual property rights (IPR's) have been a focal point for debate, and two disputed issues, impact on developing countries and impact on the practice of science, are singled out in our discussion.

From Research Ethics to Procedural Issues

At its most basic level, research ethics deals with norms that govern the practice of research, including norms for collecting and reporting data, for biosafety and for the use of human and animal subjects. Each area is governed by institutional committees that establish standards specific to the context and nature of the research in question. These committee decisions are supported by research on ethics that helps anticipate problems and identity weaknesses in institutional policy. There is little reason to think that tree biotechnology raises any special issues with respect to scientific misconduct, which is how research ethics is traditionally conceived. Yet genetic research and genetic technologies for medicine and agriculture have been contentious. Opponents of genetic technology have campaigned for regulation and labeling of products derived from genetic engineering. This contentiousness is the basis for identifying tree biotechnology as an area of science and technological development that raises a different class of ethical issues. Our chapter expands on the traditional notion of research ethics to encompass scientists' responsibility to be involved in decision making and public debate about he application of their science.

Worldwide, science and technology are pursued with the aim of improving quality of life, yet scientific and technological projects can go awry. They can lead to wholly unexpected and unwanted consequences. Those who conduct basic and applied research on a new technology (or on scientific projects that will lend themselves to technology) must be involved in an aggressive and sincere attempt to discern the full range of technology's consequences. In one sense, only scientists and engineers involved in the development of technological projects have the knowledge required for adequate technology assessment. Yet even when technical experts participate in such assessments they may tend to take a one-sided view of the ethical issues that unwanted consequences raise. Critics of the technology may speak for the larger public in bringing neglected issues to the attention of scientists and policy makers. In this sense, scientific knowledge is necessary, but not sufficient for implementing technology in a responsible way.

The existence of public opposition to biotechnology does not indicate that research or product development for biotechnology is ethically indefensible. In an ideal world, ethically oriented arguments for or against the technology would be evaluated for coherence and weight by impartial judges. In the real world, ethical arguments are often difficult to separate from statements made for strategic reasons. Opponents may base their resistance on perceived economic interests or on religious beliefs, for example. In such cases, it may be impossible to understand their underlying resistance toward genetic engineering as an ethical claim. Furthermore, some opponents have alleged sinister motives to applied molecular biologists, or predicted consequences of horrendous impact from their work. To some extent, these allegations appear to be rhetorical overstatements, intended less as a serious argument against biotechnology than as a way of getting one's point of view heard against the din of political chatter that competes for the ordinary citizen's attention. As such, anyone attempting serious work on ethical issues must apply some judgment regarding which opponents to take seriously.

Yet the mere existence of such critics does entail ethical responsibilities for researchers in molecular biology. Unlike standard research ethics, issues associated with unwanted consequences need to be

subjected to a two tiered analysis. First, one must examine reasons for opposing, regulating or otherwise qualifying any given application of genetic technology. An ethicist will bring conceptual tools for evaluating these reasons, and for identifying the key burdens of proof that are established by any given argument favoring or opposing biotechnology. This examination may end in a defense of biotechnology, or in a position that would either constrain or regulate it. The resulting arguments are "ethical" to the extent that they are explicit in stating the goals and moral presuppositions that form the basis for concluding that any application of the technology is good, bad or indifferent. However, the analysis does not end there.

At the second tier, we must consider how decision making on technological development and implementation is made-who will make the decision and what criteria will be used. Even if the science community reaches a consensus that the ethics of biotechnology are unproblematic, the presence of substantial public opposition and debate creates ethical issues at this second tier. On the one hand, if only scientists decide, then science has been put in a position of political authority, given the power to determine society's future with respect to issues that may affect economic interests, lay values and religious beliefs. This concentration of decision-making power in the hands of scientists is inimical to the ethical principles underlying participatory democracy. On the other hand, laypersons can make distressingly uninformed judgments about technical issues. They can be swayed by appeals that do not make a fair presentation of facts, or that lead them to misconstrue how their most deeply held values will be affected.

The tension between these two poles at the second tier of ethical decision making frames the key challenge for scientists and research administrators who work with any .form of genetic technology. Democratic societies are in the early stages of understanding the dilemmas posed by science-based policy making and technical change. The great biological and cultural significance associated with genes (as well as the checkered history of eugenics) has placed molecular biologists and the biotechnology at the forefront of these changes. A benign scientific dictator (who based decisions on research and development solely on good scientific knowledge and an informed concern for the public) might be thought to be bringing about the best balance of benefit

and risk. If one looks only at outcomes (e.g. benefits or risks to health,

wealth and well being), the benign scientific dictator may seem to he making an ethically justifiable choice. Yet whatever their intentions, scientific dictators cannot be ethical, because one must also be sure that decisions about the development and implementation of biotechnology are made in an ethically correct way. This means that even extreme religious and political opponents of recombinant DNA technology must have the *opportunity* to have their concerns heard. Because the issues at the second tier relate to the procedures by which the public becomes informed or participates in debate, and by which decisions are made, we call them procedural issues.

One of the key ideas in procedural ethics is that the outcome of a process may be less significant that the integrity of the process. Elections, for example, are procedures. Ethical analysis of elections does not focus on whether one candidate should or should not win the election, but on whether the procedures for conducting the election are fair and are adequately maintained. If we extend this idea to tree biotechnology, we would say that the particular result of a regulatory or policy decision is not the focus of procedural ethics. Procedural ethics considers whether the method of reaching that result gave affected parties adequate opportunity to have their views heard, or respected fundamental political liberties. However, unlike elections, new technologies do raise ethical questions at the first level, too. We wilt call these *substantive issues.* So there are substantive issues about whether a given application of biotechnology is ethically acceptable, and there are procedural issues about whether the economic and political methods for bringing about a technical change re consistent with democratic principles.

The logic and organization of this chapter ~- predicated on the judgment that procedural issues are the most important ones facing scientists and research administrators. Thi's judgment is based on two points that will be developed in the main Body of the paper. First, though there are crucial areas where substantive ethical issues affect the ethical acceptability of a specific application of tree biotechnology, in most cases opposition to biotechnology is overstated. Second, failure to respect the opinion and participatory rights of even those who mount overstated criticisms of biotechnology will create public distrust of genetic technology, and may threaten norms of democratic process. Scientists have an ethical responsibility to find ways for addressing procedural issues effectively. At this juncture it is difficult to say what those ways will look like. But if scientists are to engage the broader public at the procedural level, it is important for researchers to have knowledge of substantive reasons why genetic technology spawns opposition, even when those reasons are irrelevant to particular elements of a given scientist's research. As such, we will review some issues not presently relevant to the biotechnology of woody plants.

The general form of ethical assessment for genetic engineering in agricultural and forestry focuses on the risks associated with specific applications of genetic engineering. It does not attribute any special significance to the fact that technical change is induced by manipulation of **recombinant DNA.** As such, statements to the effect that recent developments in plant biotechnology are a natural extension of breeding techniques must be carefully stated. On the one hand, similarities between the old and the new plant science do provide researchers with a basis for believing that the likelihood of a worst case scenario is quite low. On the other hand, the claim that biotechnology is fundamentally similar to accepted techniques of plant breeding could as easily be used in an argument to subject all forms of agricultural research to higher standards of accountability as in a defense of biotechnology's acceptability.

There are some questions where biotechnology raises concern unique to the movement of genetic material. For example, how do (or don't) the various products of plant biotechnology conform to traditions for recognizing intellectual property'? Has the last decade of discovery in applied genetics encouraged society to think in terms of a genetic determinism that borders on racism? Finally, is movement of genetic material across species lines proscribed by certain religious views, and if so, how should people who hold these views be accommodated? These are important questions, yet most critics have worked within a framework of four categories of impact that are common to many technologies: human health, animal welfare, environment and social consequences. The rationale for this division is that we tend to apply different kinds of ethical criteria in each of these categories (see Thompson, 1997). In this paper, we review the categories briefly, then emphasize environmental impact.

The Consequences of Agricultural Biotechnology

Scholarship on agricultural biotechnology rots taken up issues associated with all manner of plant and animal production. Some of the most contentious issues in food biotechnology are entirely or nearly absent in consideration of tree biotechnology. Yet silviculturalists should not be surprised if some of this controversy spills over into their field. With debates on human cloning, contention over food issues has undoubtedly contributed to the general climate of public receptivity (or the lack thereof) toward all forms of genetic engineering. As such, it is useful to review the general debate on agricultural genetic engineering before concentrating on the issues of most relevance to tree biotechnology.

Human Health

Forest trees are used to a very limited degree for food products, but many products of biotechnology are intended for use in medicine or as food. As such it is crucial to assess how these products contribute to health, and to determine the nature and extent of risks. This is also an area in which the moral vocabulary of health benefit and individual rights is most fully developed. One of the most contentious ethical issues concerns whether decision making should be done by a technical elite or by each individual consumer/patient (perhaps under advisement from knowledgeable experts). Experts are in a better position to understand the risks and benefits of using a specific product, yet the public *is* MOM accepting of technology that allows each person to decide whether or not to use it. Empowering the public is consistent with the ethical principle of informed consent, but it may create a situation in which a technology is used less beneficially (or with greater risk) than would be the case if technically informed decision makers were in charge.

Animal Welfare

The application of genetic engineering and cloning to animals has proved to be highly controversial. The issues here are of three kinds. First, does recombinant DNA research expose animal subjects to unreasonable pain or dysfunctional ity, and if so, what is the appropriate response`' Second, do scientists have a responsibility to use genetic (or other) techniques to reduce animal suffering in research or production settings?

Few critics have argued that it would be permissible to genetically engineer animals in order to increase their capacity to endure painful or uncomfortable production techniques. This question leads into the third: Does one commit a wrong by changing an animal's essence, its essential behavioral drives and needs, above and beyond the pain or dissatisfaction experienced by the individual animal? This last question broaches religious views on the moral significance of non-human animals.

Social Consequences

Current social science research on social consequences of agricultural technology emphasizes the "technological treadmill," as analyzed by economist Willard Cochran (1979). Producers adopt technology when it improves the efficiency of their production process, allowing them to lower costs and to reap a price premium while their competitors continue to use outdated production techniques. Since earlyadopting producers have lower production costs, they may undercut their competitors and increase market share. Eventually, all producers must choose between adopting the technology, or face the prospect of being priced out of the market altogether. With each technological advance producers must "run harder" (e.g. produce more) in order to stay in the same place, (e.g. to. maintain a given level of income). Hence the notion of a technological treadmill. The treadmill argument figured heavily in public criticism of recombinant bovine somatotropin, one of the first products of biotechnology to work through the U.S. Food and Drug Administration's regulatory process (see Thompson, 1998).

Forestry has an analogue to the "family farm" issue in that small scale and independent loggers and sawmills may be threatened by technological changes that favor well-capitalized forest products corporations. It is not clear that genetic engineering is a proximate cause of such economic transitions, even in agriculture. It seems reasonable to presume that forest biotechnology's contribution to structural change in the forest industry will be marginal when compared to mechanical and information technologies (such as remote sensing). However, this presumption does not alleviate the more fundamental concern about public participation in decision making. When technology has the potential to alter the goals and character of the community at a fundamental level, the public has a prima facie right to assert an interest

in technology or land use planning. "Survival of the fittest" may be an adequate ethic for competing firms in a capitalist economy, but tile development and adoption of technology can affect the quality of life for many who are not economic competitors to the manufacturers and adopters of the technology. Fairness would appear to imply that affected parties should have some voice in the decisions to research, develop and adopt any technology with such dramatic effects. What is at issue here is whether citizens have a right to representation or recognition in technological decision-making, whatever the likely impact of a given decision might be.

These three types of impact-health, animal welfare and social consequences-have made specific products of agricultural biotechnology politically and ethically contentious. Though one could imagine wood products and production processes that would trigger ethical concerns in these areas, there is no evidence that biotechnology research on trees is moving in that direction. As such, the main lesson to take from this review is that a member of the public may well bring concerns that are framed by this debate to a consideration of tree biotechnology. Spokespersons for tree biotechnology have an ethical responsibility to respect these concerns. At a minimum, respect presumes a responsibility to explain and defend one's science well beyond the professional communities that have the traditional focus of scientific publication and communication.

Forest Biotechnology: Unintended Environmental Consequences

Agricultural biotechnology has also spawned environmentally oriented opposition, beginning with work on ice-nucleating bacteria, one of the first proposals for plant improvement through recombinant techniques (Thompson, 1987). Today, environmental concerns over commercial applications of forest biotechnology reside with use of transgenic trees created by genetic engineering, that is, those created through asexual transfer of synthetic genes, usually from organisms other than plants (James et al, 1998). The widespread and growing uses of cloning in production have raised few significant concerns, as has the use of DNA markers similar to those used in forensic DNA fingerprinting to help breeders make selections. Such practices allow more efficient use of natural (i.e. sexually accessible) genetic variation, rather than importation of genes from unrelated organisms. The kinds of transgenic trees likely to find their way into production within the decade are of four kinds: herbicide resistant trees, insect resistant trees, trees with modified wood chemistry and altered flowering.

Ilerbicide Resistant Trees

Scientists have developed several crop plants tolerant to glyphosate (the active agent of Roundup) which are in large-scale production. It is likely that glyphosate resistant trees will be among the first forest biotechnologies to find their way into production. Herbicide tolerant trees can aid weed control substantially, thus are being developed aggressively by industry and university scientists (Strauss, 1987). Herbicides are already used widely in plantation culture. There will not be gross changes in the status quo for total herbicide use. However, there will be a quantitative shift toward the broad-spectrum herbicides that crop trees have been engineered to tolerate. In the case of glyphosate, which has notably few environmental side effects and little propensity to enter groundwater, this shift should reduce the total environmental impact of herbicide use in the forest products industry.

Resistant trees may also enable reduced cultivation, with its large demands of energy and potentiation of soil erosion on sloped sites. If trees are not reproductively sterile, the other main impact of resistant trees will be the release of feral resistant trees that may be more difficult to control. For example, glyphosate resistant cottonwoods may be a more recalcitrant weed of conifer plantations in some regions. There is, however, little basis for concern that feral trees carrying herbicide resistance genes will affect wild ecosystems. Genetically engineered herbicide resistance affects tree populations only where herbicides are being applied. Only there do the new genes make an appreciable difference. Any environment in which herbicides are applied is, by definition, a human dominated ecosystem. Hence, all significant environmental effects of such trees will be confined to human dominated ecosystems.

Insect Resistant Trees

As food crops are being engineered for resistance to insect pests, so are tree crops. The most likely application is via the BT gene already applied to maize and potatoes. Insect damage is a frequent case of failure in plantation forestry. Broad-spectrum insecticides are used to control defoliating insects in some intensive plantation systems. Trees with high levels of inherent resistance to insect damage are advantageous from both a production and an environmental perspective. The toxin encoding genes from the natural insect pathogen Bacillus thuringiensis (BT) have been inserted in many crops because of BT's specificity and low toxicity to mammals. The primary concern associated with trees with single or oligogenic resistance is that insect pests will develop resistance to BT more rapidly as BT crops (including trees) become widely used. It has also been argued (see James, et al. 1998; Strauss et al. 1991) that resistant pests would impair the use of BT microbial insecticides, which are used widely for community pest control, are accepted as an "organic" pesticide. Hence, if BT trees cause BT resistant insect pests, by implication they cause a reduction in the effectiveness of an organically certified method of pest control.

The durability of insect resistance to BT, and thus its net environmental good or evil, will depend on many ecological and genetic factors that are difficult to predict from laboratory experiments. The experiment of commercialization, in conjunction with scientific research, is the only way we will discover its long-term value. A related concern relates to gene escape. Unlike herbicides, insects are active in both wild and domesticated ecosystems, It has been argued that in the absence of sterility, insect resistant trees will have heightened fitness, thus will be capable of invading native ecosystems and driving down natural biodiversity. Under this scenario, widespread distribution of the BT gene in wild or feral populations could have significant impact on the ecology of insects that remained susceptible to the BT toxin. However, because of the probable limited durability of single gene resistance in the wild, such a scenario is probably more fear provoking than it is realistic. A larger concern is likely to be the heightened opportunity for resistance development on the part of insects. Like herbicide resistance, this issue is confined to human dominated ecosystems where BT pesticides and transgenic plants are employed.

Modified Wood Chemistry

Efforts are underway in many laboratories to use genetic engineering to modify the chemical composition of lignin-the glue that holds the cellulose based wood fibers together-so that it can be extracted ii lore easily during paper production. These approaches may also reduce the total amount of lignin deposited. Because of the high energetic cost of lignin synthesis, this may result in higher rates of cellulose production. This technology would reduce the chemicals used for pulp bleaching, and thus result in less effluent flowing from pulp mills. Large changes in wood chemistry are very likely to reduce the fitness of trees to compete in the wild, and can thus be viewed as a step toward domestication (reduced vigor and strength). Such trees are therefore unlikely to invade natural communities, but could result in some impact on human dominated ecosystems. Nutrient cycles may be affected, and progeny with new genes may be more prone to pest attack or breakage in ice storms. As with insect resistance, basic evolutionary biology and laboratory research on gene properties provide a good basis for predicting which ecosystems are most likely to be affected by wood modification, but the complexity of gene/ecosystem interaction limits prediction of what the affects are likely to be.

Altered Flowering

Release of transgenic seeds is sometimes compared with past experience of the rapid spread of facile vegetative propagation of exotic species. Some have therefore proposed that trees be genetically engineered to male and female sterile (see Strauss et al. 1995). Conditional sterility systems, which allow fertility to be restored in specific circumstances to allow further breeding, are also feasible with current technology. Such applications of genetic engineering might assuage the fears of those who envision genetically engineered trees altering an ecosystem in the manner of zebra mussels, kudzu or killer bees. They can also mitigate the ongoing impact of exotic plantations, which have given rise to invasive feral populations in several parts of the world, (Higgins and Richardson, 1998). Sterility might also improve productivity by lessening the drain of reproductive tissue growth on wood development. Most important, however, is that genetic containment would greatly simplify obtaining both regulatory and public approval for

forest industries. With sterility, the novel genes will stay where they were put-avoiding most questions of their short or long term impact on wild and human. dominated systems.

The Environmental Ethics of Tree Biotechnology

The phrase "environmental impact" is ethically ambiguous. First, it may indicate the collective effects of individual human exposures to health and economic risks from pathways such as air and water pollution, workplace exposure, or food residue. These risks may take on ethical significance either as costs to human welfare or as challenges to human rights. In either case, it is impact on individual human beings that is the focus of attention. Second, environmental impact may call attention to the environment itself, stressing affects on wildlife and habitat, or on the functional integration of both wild and domesticated ecosystems. Thus the U.S. Environmental Protection Agency administers policy under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), which under amendment by the Food Quality Protection Act of 1997 stresses health and economic impact on humans, as well as the Endangered Species Act, which constrains human development that threatens listed species. This duality in environmental ethics and policy is replicated in most industrial countries.

In environmental ethics, the division is generally conceptualized as a distinction between *anthropoocentric,* or human-centered concerns, and *ecocentric* reasoning that attributes moral significance to plants, animals and habitat apart from any value that might be placed upon on them as a result of human interests. The broad distinction between anthropocentrism and ecocentrism has been influential in establishing the terms of debate over many forest issues. Wilderness protection and habitat preservation, for example, are often debated in these terms. However, the anthropocentrism/ecocentrism debate (discussed below) has not proved central to agricultural ethics, and for obvious reasons. Agriculture is a human-dominated ecosystem. As such the ecocentrist has little to say about agriculture, except insofar as it impinges on the quantity and quality of wild nature.

Yet just as one can raise questions about the integrity of wild ecosystems that function as habitat for endangered species, there are questions about the long-term sustainability of human-dominated ecosystems. Many environmental issues in crop biotechnology fall into this third category, where the issue is one of preserving ecosystems that provide habitat for human beings. The emphasis on humanity suggests an anthropocentric focus, but the emphasis on the ecological integrity of food and fiber production demands a systems orientation that departs from traditional ethics' emphasis on harm to or the rights of individual human beings. This *agroecology* approach stands between the philosophical poles of anthropocentrism and ecocentrism because the human species is understood to have ethical significance in virtue of its key role in maintaining ecosystem integrity. The agricultural ecosystem is *tot* understood as existing for the benefit of individual human beings. Agroecology has primarily been applied in environmental ethics as a dimension of *sustainable agriculture.* The issues raised by eminent applications of tree biotechnology appear to be quite relevant to the sustainability of forests as human-dominated ecosystems.

Ecocentric Concerns

Many forest technologies have been developed for an extractive forest products industry. As such, the main themes in environmental ethics are poised to oppose such technologies to the extent that they challenge the overarching goal of protecting wilderness, either for its own sake or for future generations. During the 1970's and 1980's North America, Australia and Scandinavia were the centers for scholarly work on environmental ethics. Each has large tracts of land relatively undisturbed by modern technology but potentially threatened by extractive industries such as mining and forestry. Environmental ethics has tended to ignore human dominated ecosystems, and only recently have any scholars in the field proposed that a farmer's field or a managed forest could be judged better or worse in environmental terms.

Forest biotechnology will be of concern to ecocentrists who see forests in terms of wilderness. Such ecocentrists have traditionally been quite critical of the timber industry, and have opposed clear cutting and forest monoculture, as well as logging of wilderness. Forest biotechnology will become contentious to the extent that it is seen as either a threat to wilderness, or as a "technological fix" to restore lost wilderness. Ecocentric critics fear ecological restoration because they think that restoration techniques fail to create morally authentic

ecosystems. The moral value, that is, of an ecosystem is partly a function of its history. Those ecosystems with histories of human domination and management are less valuable, even if they have been returned to a state that closely matches that of a naturally evolving forest ecosystem (Katz, 1997)

Sustainable Forestry

In addition, forestry is like agriculture in that human management and selection is an essential component of ecosystem regulation. To the extent that forest biotechnology is applied to lands that where trees have been cultivated for many years, the ecocentrist will tend to have as little interest in forestry as in agriculture. However, as agricultural systems can be said to have or lack ecological integrity, so can managed forest ecosystesms. Where sustainability is concerned, human dominated ecosystems can be seen as morally significant habitat for humans *and* wildlife, and as (potentially) having value in themselves. In addition, the sustainability of human management capability and expertise is an additional dimension of sustainability for agriculture and forestry. Understanding the ethical implications of sustainable forestry, thus, requires a sophisticated account of how ecological and human management systems interact, and how to identify the critical threats to either.

It is not clear whether forest biotechnology will be interpreted as improving the ecological integrity of forests, or as a threat to their sustainability. Here we will note three considerations that should be weighed in considering whether a forest ecosystem is sustainable. First, trees have the potential to dominate ecosystems due to their large size and long lifespans. Trees may thus have a more profound impact on an ecosystem than annual crops. This has happened (and is continuing to happen) in several cases of exotic tree species. Second, most forest species in most places have wild or feral relatives with which they can exchange genes. Most agricultural crops by comparison are grown far from their centers of origin. Cultivated forestlands can have direct genetic impact on wild systems. Furthermore, forest trees have undergone very little domestication that would act to preclude or greatly limit gene escape into the wild via pollen (to relatives) or seed (direct escape). The time frame for analysis of risk and ethics issues is much longer than for crops, precluding much empirical research on risk for practical reasons.

Due to trees' large size at maturity and outcrossing (rather than inbreeding) system of mating, the potential for long distance pollen and seed movement is great. The obstacles to genetic containment are Formidable. Much of the evidence on tree genetics indicates extensive rates of gene movement between distant populations. However, because the vegetative body (i.e. the stem) of a tree is the crop product rather than the seed, it is feasible to use genetically sterile trees in production systems where the analogous strategy for containing agricultural biotechnologies is much more complex. Sterile trees are unlikely to cause such concerns. Sterile trees cause only modest economic loss. While the potential for ecological affects from genetically engineered trees is not great, the extensive and delayed spread of genes that is possible creates a high level of uncertainty about their ultimate effects. Vegetatively propagated sterile trees suggests a simplifying measure that should be far more effective than the physical boundaries generally proposed for food crops.

A recent patent referred to as "terminator technology" is a system for rendering recombinant DNA modified plants sterile, precluding gene spread via seed or pollen from transgenic crops. However, despite its value for genetic containment, terminator technology has been criticized because it also would preclude farmers from saving seed, forcing the repurchase of transgenic seeds each year. There is little doubt that in addition to its potential environmental benefits, terminator technology would substantially increase seed producers' ability to control the flow of genetic resources, and in all probability to increase the profitability of recombinant DNA varieties. Thus a social consequence of biotechnology (discussed below) intertwines with environmental risk in a complex way.

Other differences are more obvious, but deserve mention. By convention, the term "forest biotechnology" does not apply to food crops harvested from trees. Genetically engineered woody plants for food uses may be developed one day through horticultural biotechnology, but forest biotechnology does not pose food safety issues. Unlike agricultural cropland, people often perceive forests as wild and natural, even when they are part of a perennial forest cropping system under intensive human management. Forests of all kinds do harbor a greater diversity of living things than do annual crop fields. As a result, there is a tendency to apply quasi-ecocentric rationales to forest ecosystems of all kinds. where such arguments appear ridiculous applied to crop farms Furthermore, environmental critics of the forest industry may be more evenly matched in political and economic power against advocates of production practices than is the case with respect to agriculture.

Intellectual Property

Patents for genes, organisms or gene sequences have sparked ethical controversy ever since the United States Supreme Court awarded the first patent on a living organism in *Diamond vs. Chakrabarty* in 1980 (Svatos, 1997). Arguments for patenting of genes and gene processes have emphasized four claims. First, patent law can be extended to biotechnology in a natural way. Criteria for efficacy, novelty and nonobviousness that serve as the basis for patent claims can be readily
established for chemical or mechanical technologies can also be developed for biotechnology. Second, inventors and backers of genetic research deserve recognition of their work and their willingness to undertake financially risky research. Third, since patents provide the basis for licensing and sale of innovations, they provide a mechanism for private sector investors to fund biotechnology research in the expectation of future profits. Fourth, the patent system itself is thought to be ethically justified in virtue of its contribution to social advancement. Inventions that would otherwise be kept secret (in order to secure a particular manufacturer's economic advantage) are made public. Furthermore, incentives created by patents increase the rate of-technological innovation in response to market demand, traditionally understood to be a public good.

On the other side, the issues in research ethics that have been associated with "patenting life" are extraordinarily complex. Impacts on the research process, on scientific training and on science itself have been of keen interest to scientists. Others see the patent system as a way to hasten the introduction of genetic technologies well before their health, animal, social and environmental impacts have been understood and, where appropriate, mitigated. For many, objection to patents appears to be a proxy for their objections to genetic engineering in all its forms. A third group of critics has objected to gene or organism patents on the ground that they are a crucial step in the commercialization of life processes, a trend they see as inimical to the belief that life is sacred. Finally, some have objected on what must be understood as religious grounds, holding (often obscurely) that genetic engineering or the ownership of genetic resources violates a fundamental religious duty. Each strand of criticism tends to interact with others to one degree or another, producing a public debate in which it is often difficult to determine whether it is patents or genetic engineering itself that is at the heart of the concern. Here, we will consider just two strands that are potentially relevant to forest biotechnology. One is the impact of biotechnology patents on developing countries. The second is the impact on scientific research itself.

Consequences for Developing Countries

Some of the most significant debate has focused on the impact of patenting systems on developing countries. The debate here predates recombinant biotechnology, and grows out of a dispute over the ownership of germplasm collected from developing countries. Traditionally, plant scientists freely collected germplasm from land races, rarely paying even nominal fees for the privilege of doing so. This germplasm would be used to create new crop varieties using conventional plant breeding techniques. The new varieties were protected by Plant Breeders Rights, and were often sold back to the developing countries from which germplasm had been collected. Since new varieties often outperform land races, farmers often felt compelled to purchase (rather than save). seed. During the 1980's Calestous Juma (1984) and Cary Fowler and Pat Roy Mooney (1990) began to argue that the indigenous farmers who created land races through decades and centuries of seedsaving and trial and error cultivation have a property right in germplasm that predates that of the plant breeder. On this view, indigenous farmers are entitled to a share of the income from any plant variety in which land race germplasm has been used. Furthermore, since new varieties displaced land-races in some instances, farmers were said to have `lost' their traditional technology.

This debate was raging when biotechnology entered the scene in the 1980's. Many of those who had argued for indigenous farmers' property rights saw gene patents as a way of further tipping the balance of power between indigenous farmers and First World seed companies in the tatter's favor. Disputes over patenting of genes from the neem tree, common in India, were central to this debate in the early 1990's. Critics claimed that a patent awarded to W.R. Grace deprived Indian subsistence farmers of their right to use neem trees in their traditional farming practice. Defenders of the patent system note that properly administered patents *never* establish proprietary control over uses or procedures that predate the filing for patent protection, hence subsistence farmers *cannot* lose an established use as a result of a patent.

The quality of this debate appears to have stalled at this point. Opponents of patents continue to portray gene or organism patents as the moral equivalent of robbing the poor to benefit the rich. Defenders of patents insist that such a result is not possible under patent law. This argument is technically correct, but it neglects the fact that subsistence farmers are unlikely to be able to mobilize the resources needed to mount a legal defense of their prior claim, hence, there may be a de facto loss of use rights, even when those rights remain legally valid. This is a particularly relevant consideration in countries that have only developed systems of intellectual property in response to biotechnology. In such places, the courts and legal counselors needed to protect a prior use claim may be scarce. In sum, the opponents of patents are committed to shrill claims that are not supported by the legal facts, while the supporters are committed to a legal technicality that may have limited applicability in the setting of subsistence production.

Furthermore, American, European and Japanese companies have used agricultural biotechnology to encourage the creation of patent offices and legal proceedings for the protection of intellectual property in developing countries. Prior to 1990, even such advanced countries as Egypt had no legal code for intellectual property. Without this protection, drugs and other products such as audio recordings could be legally produced in developing countries without licenses or payment of royalties to the individuals or companies who owned relevant patents or copyrights. In the early 90's, the International Service for the Acquisition of Agricultural Applications (ISAAA) was formed to facilitate transfer of propriety agricultural (and potentially forest) biotechnology to developing country scientists at zero licensing cost. Companies contracting with ISSAAA agreed to donate the use of a patented gene for use in a developing country subsistence crop that would not compete with the varieties that the companies were developing for sale in the North. The

Rockefeller Foundation funded several large-scale projects to incorporate donated genes into subsistence crops. However, biotechnology companies are understandably reluctant to donate patented technology if doing so could compromise its proprietary applications. Thus, the "cost" of this gift was that technologies would only be transferred to nations having a functional system of patents consistent with the general pattern of developed country law. Was this an ethically admirable way of donating potentially valuable technology to poor subsistence farmers, or was it an ethically questionable way of gaining protection for developed world property rights in pharmaceuticals and sound recordings? This ethics question remains insufficiently analyzed at the present time.

Consequences for Scientific Practice

Some of the earliest critics of biotechnology predicted that it would tend to close the gap between university research and industry R&D. In part, they argued, this is due to the nature of recombinant DNA science and technology: the basic science of molecular genetics is inherently closer to the development of a specific application than is the case in many other areas of science. They also argued that university scientists who could see the potential for profit were pressing their administrators for policy changes that would significantly alter the conduct of science. Among these changes were to make universities more aggressive in seeking patents, and to share patent revenues with individual faculty members. These moves would have been bootless if no patents in genes and gene sequences were awarded, so critics argued that molecular biologists maintained an economic interest in policies that permitted the patenting of organisms, genes and sequences (Krimsky, 1991: Busch, Lacy, Burkhardt & Lacy 1991). This interest has both public and private dimensions. As a source of funding for future research, patent revenues subsidize basic and applied research in the public interest. Under many of the new arrangements, patent revenues are also a source of income for patent holders. In either case, scientists have a personal interest, either in future support of their research, or in pecuniary rewards.

This concern has been echoed among scientists, though with a different focus. First, scientists have argued that patents being awarded for genes, sequences and products have substantially increased the cost and nuisance of applied research. Second, scientists have worried that conducting proprietary research would introduce tensions into graduate education and postdoctoral research, with young scientists unable to publish or receive proper recognition for work that remains secret prior to a patent filing. Third, scientists have criticized the privatization of public sector research, especially at land grant universities where agricultural and forestry research has traditionally been conducted with the public good as its end in view. None of these arguments implies the corruption of scientists' moral character that has been implicit in non-science-based social criticism. Yet like the argument of the social critics, each claims that the extension of IPR's to genes will alter the incentives that govern science in undesirable ways.

Increased cost affects research in an obvious way. 1n some cases, a. researcher must pay a licensing fee in order to use a gene or process. Such fees can be quite high relative to the balance of research cost. At a minimum, funds that would have gone to support science are diverted to the patent holder, and in some cases, the high cost of a particular research project may persuade a scientist to abandon it altogether, (Sederoff and Meagher, 1995). Yet, the increased cost for research in biotechnology goes along with the possibility of future revenue derived when researchers themselves make patentable discoveries. Defenders of IPR's argue that patent holders will be willing to grant "research exemptions" in virtue of the fact that a successful research application will make their patents more valuable at the point of commercialization. A related concern is that opportunities for commercialization will skew the research agenda. If, for example, it is possible to hold a patent on the sequence of a gene, but not on its function, patent experts predict that research will be skewed away from research on gene function, and toward scientifically less valuable sequencing, (Eisenbach, 1994). In fact, this is the motivation behind the extraordinary spending on genome sequencing and analysis by the biomedical and agricultural biotechnology industries in recent years. However, because patents must show both novelty and usefulness (as well as non-obviousness), and be enabling for these uses, it is unclear whether purely sequence-based patents will ultimately stand up when tested in court.

The second set of arguments, effects on publication, graduate education and postdoctoral research, raise procedural issues that extend beyond their immediate subject. This is first a straightforward concern about the effect of secrecy on young scientists. Will they bear the brunt of proprietary research unfairly? But according to one philosophy of science, its public character is crucial to its epistemic warrant. That is, science can claim to establish truth *because* its norms of full disclosure for data, experimental method and argument provide all scientists with an opportunity to corroborate the result through replication, or to overturn it with a falsifying result.

This is a complex issue that cannot be discussed thoroughly in the present context. On the one hand, an experiment produces a result as surely when it is performed in a proprietary lab as in a public lab. The public character of science seems, on this view, extraneous to its validity. Data and methods will eventually become public as patents are awarded and products move to market. Private sector researchers may not earn the personal recognition that goes along with university science, but many scientists see that as an advantage. On this view, university science is dominated by outsized egos, and it has lost its commitment to science as a collaborative activity, (Rabinow, 1996). On the other hand, science distinguished itself from sectarian knowledge claims and religious revelation by insisting on the public demonstrability and replication of experimental procedures (Shapin and Schaffer, 1985). Individuals within the community of practicing scientists maintain their own views about what makes truth, but strict adherence to the norm of publicity is essential within the larger community of science.

Each of these two competing epistemological positions can be linked with ethical arguments about the procedural responsibilities of scientists. On the one hand, if publicity is inessential to science, and if science establishes the facts, there is little reason why non-scientists should be involved in disputes over the facts. Correlatively, there is little reason why scientists should see themselves as having a responsibility to become involved in public debates. On the other hand, if publicity is essential to the claim that we are warranted in accepting a given scientific result, there is no reason why other scientists, let alone members of the broader public, should accept the validity of any alleged result that has been shielded by proprietary interests. On this view, researchers have a responsibility to support procedures that create general public trust in science.

The "public trust" view of science also ties in with the American land-grant ideal of public science. Based on the Morrill Act of 1864 and tire Hatch Act of 1889, U.S. agricultural universities were commissioned to educate the common citizen and to solve practical problems related to agriculture and the food system. In committing science to the public good, the American land-grant university system made an explicit public commitment that was left implicit in many other nations. The claim that science is done for public benefit, not private reward, may have been crucial to the widespread public acceptance of agricultural and forestry research in America. As research at these universities has moved from public to contractual and proprietary funding, some scientists have questioned whether hard-earned public trust will be compromised. (MacKenzie, 1991).

Consequences of IPR's: Summary and Comment

Potential consequences for developing countries and for the practice of science provide grounds for questioning the extension of IPR's to the products of biotechnology. Yet there are several reasons why these concerns tail to provide decisive arguments against patenting genes and gene processes. First, the possibility that all of these negative consequences may be outweighed by overall social utility of patenting remains. In tact, claims about the relative likelihood and value of these consequences (including social utility) are largely speculative. Critics have failed to spell out the social mechanisms chat would lead to alleged consequences, and defenders of IPR's have never seriously attempted to include the social costs in their assessment of social utility. An external observer would reasonably conclude that the dispute is based on ideology and personal interests, rather than careful weighing of costs and benefits.

Second, the idea that IPR's are justified by their costs and benefits is itself open to question in the broader debate over property. Specific products do nut have to pass a cost-benefit test in order to qualify for patents in both European and United States patent systems. Put another way, it is the system of patents that is alleged to be justified by social utility, not any individual patent. Other philosophical approaches hold that property rights should be recognized whenever labor is invested in a product or only in circumstances where certain natural characteristics of goods are present. The former standard tends to support IPRs for biotechnology, while the latter standard militates against them, (Thompson, 1997). Thus, even if the consequences of biotechnology patents were clearly understood, the debate over IPRs would continue.

Third, the concerns arising from IPR's may be amenable to mitigation and amelioration. That is, it may be possible for professional societies, university administrators, companies and government to develop policies and practices that diminish the unwanted effects of patenting on the developing poor and the scientific enterprise. If so these concerns do not provide adequate grounds for opposing biotechnology patents. They do indicate that scientists have a responsibility to undertake and support the needed reforms.

Finally, the actual public debate over IPRs is considerably less orderly than the above discussion might be taken to imply. Indeed, the literature is filled with comments putatively critical of patents which are in fact aimed at the health, social and environmental consequences of specific products. Western patent law presumes a distinction between recognizing a property claim in a given innovation, and the regulatory approval of that innovation. Hence, one may seek and receive patent protection for an innovative product that will eventually fail to win regulatory approval on health, environmental or social grounds. (The important exception to this is that social grounds never form the basis for a negative regulatory decision in the United States. See Thompson, 1998). One view of the patent debate is that the vast majority of those who participate in it are simply ill informed. They do not appreciate the proper role of argument from expected outcomes. The alternative view is that the IPR debate is only a holding action intended to garner broader public support against specific products of biotechnology.

Conclusion

In conclusion, there are several areas where researchers in tree biotechnology have a clear responsibility to take cognizance of specific environmental risks associated with their work. These risks accrue to the specific nature of a given research program, and not to the fact that genetic engineering is being used to affect plant modification. Forest biotechnology is likely to become embroiled in several ongoing debates about forest policy, especially the contested character of forests as wildlife habitat and as production systems. Contemplated uses of genetic engineering for trees tend toward commercial production systems, but rather than making it non-controversial, this tendency nay link biotechnology to broad forces of commercialization in the mind of wilderness advocates.

Patents for genes and gene processes raise concerns about the course of natural resource development in the Third World, and about the conduct of science. There is no reason why forest biotechnology should be any less susceptible to these concerns than agricultural biotechnology. However, the specific import of these concerns is unclear at present. There appears to be ample opportunity for further discussion and debate to clarify the issues, and to assess which possibilities should be taken seriously, and which are groundless. There is also much room for adjustment of the IPR system to facilitate uses by developing countries and minor crops, as was done for the much publicized virus resistant papaya commercialized in Hawaii.

All of these considerations support the general conclusion that the primary ethical responsibility for researchers in molecular biology is, at present, a procedural one. Biotechnology (and its likely consequences) is not sufficiently understood for an intelligent discussion to take place between its advocates and its critics, much less for the broader public. Improving this situation depends less on educating the public in molecular biology than in engaging critics (and the larger public) with respect to specific issues that are being raised. There are often adequate responses that might be made to critical viewpoints, either in the form of counterarguments or minor reconfigurations of R&D. Of particular importance is the need for scientists to articulate how genetically engineered crops and the genes they contain do or do not present novel biological concerns in light of the natural gene world or conventional agricultural or forest practices. The public is warranted in its suspicion of biotechnology as long as those responses are not made. As a group, scientists must do a better job of encouraging public debate, and must do so by being willing to participate in it.