2
Forest Genetics for Sustainable Forest Management

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2.1 Introduction

The International Union of Forest Research Organizations (IUFRO) comprises over 700 member institutions in 112 countries, with 15,000 scientists working collaboratively and voluntarily in 280 Divisions, Research Groups and Working Parties. Throughout the twentieth century, the Union stimulated and supported excellent research in a wide range of scientific topics. However, IUFRO has now established Task Forces to encourage the integration of such research and to foster better understanding between researchers and policy makers. At its quinquennial Congress in Malaysia during August 2000, IUFRO scientists produced state-of-knowledge reports on many major issues to indicate both the currently available information and any need for new research. One of IUFRO's Working Parties specifically addresses the potential benefits and risks of molecular technologies in transgenic plantations.

The organizers of the Bio-Refor workshop in Nepal asked me to address particularly the role of forest genetics in sustainable forest management. To some extent I did this in a keynote address to the Queensland Forest Research Institute's conference in Caloundra during November 1996, and some of the points here are repetitions or expansions of issues I raised at that meeting (Burley 1996). At the outset, I should state that I consider forest tree improvement to include enhancements in silviculture, forest management, and product processing; forest genetics must be seen as one component of tree improvement interacting with these elements in the search for sustainable forest management.

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2.2 Sustainable Forest Management

Sustainable forest management is one part of the overall concept of sustainable development. There have been innumerable definitions of this, but a good working definition, provided by the Forestry For Sustainable Development Programme of the University of Minnesota, is: "Development involving changes in the production and/or distribution of desired goods and services which result, for a given target population, in an increase in welfare that can be sustained over time." In order to achieve sustainable development, there has to be a concordance of the three major sets of factors: biological (environmental), economic, and social.

A commonly accepted working definition of sustainable forest management emerged from an Inter-Ministerial Conference on European Forests in Helsinki during 1993: "Sustainable management means the stewardship and use of forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality, and their potential to fulfil now, and in the future, relevant ecological, economic and social functions at local, national and global levels; and that does not cause damage to other ecosystems."

Sustainable forest management is a major concern for a large number of international and national institutions, including: International Tropical Timber Organization; Helsinki Process; Montreal Process; Tarapoto Proposal; African Timber Organization; Lepaterique Process; UNEP/FAO Expert Meeting; FAO/UNEP Expert Meeting; FAO/ITTO Expert Meeting. All of these are seeking to develop for different forest types, or at different levels, some criteria and indicators of sustainable forest management. Although they differ in indicators, there is a high level of agreement in the criteria, and broadly these include biodiversity, productivity, soil conservation, water conservation, forest ecosystem health and vitality, contribution to global ecological cycles, and fulfilment of socio-economic needs.

2.3 Changes in Forestry

In the second half of the last century, there were major changes in the objectives of forestry. Clearly, these differ significantly between regions and countries, but in summary we might consider the 1950s as a period of concern to produce large volumes of industrial wood. During the 1960s, attention began to focus on the quality of industrial wood, particularly from plantations. In the 1970s, intensive research was conducted on the quality of pulp and paper, while during the 1980s and 1990s, globally there was an expansion of interest in the role of trees and forests in supporting agriculture and human welfare. Throughout the half century, there was a growing interest in the use and improvement of non-wood products.

2.4 Changes in Techniques of Tree Breeding

2.4.1 The Traditional or Classical Programme of Tree Breeding

Classical tree breeding has been practised in many countries and organizations, particularly in the 1950s and 1960s. The programme involved several stages, including species and provenance evaluation, establishment of pilot plantations and eventually commercial plantations, creation of seed stands (seed-production areas), mass selection of superior phenotypes, and the establishment of progeny trials to evaluate genotypes (using a range of mating systems and environmental designs that estimated genetic and environmental parameters with varying levels of precision). These stages were accompanied by the creation of clonal or seedling seed orchards.

In the 1970s and 1980s, considerable attention was given to the needs of recurrent selection over multiple generations and the inclusion of multiple traits. Various programmes used tandem selection, independent culling levels, total score, multiple-trait index, and genetic-selection index methods for the selection of parents of subsequent generations.

By the early 1980s, clonal techniques (cuttings and tissue culture) had been developed for many industrial species, and large areas of single or multi-clone plantations were established, accompanied by considerable debate on the number of clones and their management. The Marcus Wallenberg Prize in 1984 was awarded to four members of the Aracruz company in Brazil for their work on integrating selection, breeding, and clonal propagation into a major commercial plantation eucalypt programme for the production of pulp and paper.

By the 1990s, it became clear that the advances made by genetic selection brought with them risks to biodiversity, conservation, and future selection gains; the concept of the multiple-population breeding strategy was developed and refined, for which another Marcus Wallenberg Prize was awarded to Professor Gene Namkoong in 1994 (Namkoong et al. 1984). Multiple population breeding strategies permit us to improve several traits simultaneously: incorporate new material; minimize inbreeding; maintain genetic diversity; respond to changing management, environment or markets; and use genotype-environment interactions. In parallel with this strategy, the concept of breeding seedling orchards was developed to combine both seed production and genetic evaluation (Barnes 1995).

2.4.2 The Specific Case of Molecular Technology

Possibly the techniques with the greatest potential benefits, but also some potential risks, are those based on molecular methods. Almost daily, new methods or refinements of molecular biotechnologies are developed and published. They have different costs and applications, and a broad summary is given in Table 1 (from Rendell 1999); the most immediate applications of molecular methods in ecology, genetics, and tree breeding are listed in Table 2.

Table 1. Comparison of molecular techniques (From: Rendell 1999)

			Genetic diversity	Population structure	Phylogeny	Hybridization	Introgression	Genotype identification	Polyploidization	Mating system
Isozymes			+++	+++	+/– [a]	++	++	+/++ [a]	++	+++
RAPDs			+++	++ [b]	– [c]	++	– [d]	+++	+ [e]	– [d]
Microsatellites			+++	++ [f]	– [g]	–	–	+++	–	? [h]
RFLPs	nDNA	Coding	+	+	+ [i]	++	++	++	++	–
		Non-coding	+++	+++	+++	+++	+++	+++	+++	+++
	cpDNA	Coding	–	–	+	+ [j]	+ [j]	–	+ [j]	+ [j]
		Non-coding	+++	+++	+++	+++	+++	++	+++	– [j]
	mtDNA		+	+	–	–	–	++	–	–
DNA sequencing	nDNA	Coding	++ [k]	++ [k]	+++	+++	+++	+++	+++	+++
		Non-coding	++ [k]	++ [k]	+++	+++	+++	+++	+++	+++
	CpDNA	Coding	++ [k]	++ [k]	+++	+++	+++	+++	+++	+++
		Non-coding	++ [k]	++ [k]	+++	+++	+++	+++	+++	+++
	mtDNA		++ [k]	++ [k]	+++	+++	+++	+++	+++	+++

[a] Depends on study taxa

[b] Less appropriate for within-population structure

[c] Problems with homoplasy due to comigration of non-homologous bands

[d] Problems because pattern of inheritance of bands is poorly understood

[e] Problems with interaction between bands in polyploids

[f] Particularly appropriate for within-population structure

[g] Problems because most microsatellites are specific to single species or genera

[h] Few studies to date

[i] Better for taxonomic groups above the species level

[j] Would need to combine with nDNA data

[k] Would need to consider cost and sample size

Table 2. Application of molecular methods to problems of ecology, genetics, and tree breeding

1. Taxonomy, systematics, evolution, and identification of species and individuals.
2. Genecology and habitat-related genetic variation between populations of a given species.
3. Population genetic structure (for both breeding and conservation).
4. Identification of breeding systems (for artificial breeding, conservation, studies of gene flow, and habitat fragmentation).
5. Evaluation and possibly prediction of genetic differences at the levels of species, population (provenance), individual, and clone.
6. Identification ("finger-printing") of pedigree of clones and progenies in breeding populations and for protection of plant breeders' rights and/or traditional resource rights.
7. Identification of the physiological basis for tree resistance to (or tolerance of) drought, heat, cold, salinity, alkalinity, radiation, pests, and pathogens.
8. Determination of genetic control of wood chemical components, such as lignin, and the enhancement of ligninase enzymes in fungal species, with potential application to pulp and paper manufacture.

In developed countries particularly, but increasingly at a global level, there is great concern about the applications of molecular technologies to human and veterinary medicines, and to agricultural crops and foods. Most recently, the concern has spread to genetic modification of forest trees. In response to public and political concerns, IUFRO Working Party 2.04.06 (coordinated by Professor S. Strauss and Dr. M. C. Campbell), at a meeting in Oxford during 1999, developed a position statement on the benefits and risks of transgenic plantations. This position statement expressed a majority opinion on matters of science and technology policy, based on the perspective of a group of professional experts from 21 countries; its main targets were government regulators, scientists and professionals in biological fields, and citizens with scientific backgrounds in biology and natural resources.

While the position statement summarized the background to the debate and defined various technical terms, the principal component statements included the following:

1. The economic benefits of transgenic crops to society, as well as to industries, can be great.
2. Transgenic crops can provide important environmental benefits.
3. The risks of genetically engineered crops should be considered not only in themselves, but in relation to the risks and benefits of all other candidate systems.
4. Excessive restrictions on the use of transgenic organisms in research, breeding, and in international commerce can obstruct opportunities for new knowledge, improved production systems, and environmental benefits.
5. Scientific claims about the benefits or risks of transgenic organisms should address specific genes, traits, environments, and management systems, not their method of introduction.

In developing this position statement, the Working Party members identified some underlying principles applicable to forest plantations, including the following:

1. Intensification of tree-fibre productivity can reduce pressure on native forests for wood, fibre, chemicals, and energy.
2. Transgenic forest plantations promise a number of significant environmental benefits.
3. While transgenic traits pose some risks for plantations and associated ecosystems, many options exist to mitigate their impacts.
4. Field trials, wisely designed and carefully monitored, are an important part of safety evaluations.
5. For transgenes or species whose sexual spread causes concerns, genetic technology is under development that should render trees unable to produce viable seeds and pollen.

2.5 Challenges for Tree Breeding

Broad changes in the objectives of forestry have been accompanied by changes in policies and institutions that affect forests and forestry. These have offered considerable challenges for genetic conservation and tree breeding.

2.5.1 Changing Policies and Institutions

Throughout the world, there has been a growing trend for governments to hand over the management of production forestry to private organizations. International agencies and governments have sought to reduce the emphasis on industrial forestry in favour of rural development forestry; where industrial forestry has been supported, there has been encouragement for outgrower schemes to support central saw mills or pulp mills. Overall, there has been a growing recognition that forestry and forests are global concerns and resources, even though they are under the sovereign rights of nations.

2.5.2 Changing Natural Environment

Tree breeders, like all forest managers, must be aware of the global concerns for changing natural environments, particularly the climate. The changes in the mean and extreme values of temperature, rainfall, wind, and ultraviolet light are predicted to occur in most parts of the world, with a consequent need to reconsider the optimum species, populations, and genotypes that are suitable for given objectives.

2.5.3 Changing Sites

Throughout the world, the types of land available for forestry are changing, and there is a growing need to develop genotypes for the remediation of degraded sites and the use of extreme sites. Land-tenure systems are also changing, and the likely users of improved genetic material are thus altering.

2.5.4 Changing Management

Throughout the world, often under pressure from environmental groups, there is increasing demand for change from exotic species to indigenous species, and from high-input technology to low-input systems. As new biotechnologies develop, clonal-industrial forestry is expanding and yet there is strong public pressure, particularly in developed countries, for the use of mixed-species plantations. Further, in developing countries and some developed countries, intimate mixtures of crops, animals, and trees in agroforestry systems are required.

2.5.5 Changing Uses and Processes

Wood-using technologies are changing rapidly and there are now many ways of using solid wood from small trees; jointing, gluing, and lamination techniques allow large constructional components and furniture to be made from small pieces of wood. Increasing demands for reconstituted wood have caused refinements of techniques for the manufacture of chipboard, fibreboard, pulp, and paper. Over half the wood that is deliberately cut each year is used for energy, principally for domestic heating and cooking, while in many countries there is an expanding demand for non-wood products.

2.5.6 Changing Ownership and Management of Gene Resources

The Convention on Biological Diversity considers that gene resources should be available to all, but it recognizes that intellectual property rights must be duly recompensed. There is a chain of development of genetic resources from the wild type through to advanced generations of breeding and the resultant propagules. While the intellectual property rights to some of the stages can be recognized and rewarded, the pedigree control and rights tend to become lost when improved material is passed on to farmers and local communities who thenceforward do their own selection and propagation.

All of these environmental, political, and technological changes require different ideotypes of trees to fit different management systems and to provide a range of benefits. The traditional concept of genotype–environment interaction has to be expanded to include these issues.

2.6 Specific Tropical Challenges to Tree Breeding

Many of the principles of forest genetics and tree breeding apply equally to tropical and temperate species and conditions, but there are some practices that are specifically influenced by the species and political/social/environmental conditions of tropical and developing countries.

As forestry becomes more widely privatized, breeders must face more rigorous cost-benefit analysis of their efforts, and at the same time play a significant role in determining breeding economics and the value of forests in national accounts. Breeding strategies must be appropriate to the resources and objectives of the various stakeholders who are dependent on the breeders' efforts. Increasingly, genotypes and ideotypes of trees must be manipulated for mixed plantations, producing multiple benefits and with genotypic stability. Forests and trees are to be established on difficult or degraded sites that will require resistance or tolerance to climatic and edaphic extremes, changing climates, and pests. In common with forest managers, tree breeders must learn to collaborate in participatory research and development efforts.

As tree breeding focuses increasingly on species for rural development, including agroforestry, breeders must be aware of the need for appropriate allocation of intellectual property rights and the loss of pedigree control once farmers and local communities learn to select and propagate their own material. There is increasing concern that forests should be naturally and eugenically regenerated, and equal concern that selective logging may lead to habitat fragmentation and the restriction of population genetic variation.

In many countries, both developed and developing, there are hundreds of examples of species, provenance and progeny trials that have not been recently assessed, analysed, and interpreted. There are great opportunities for gaining new information on genetic structure and change, particularly with appropriate molecular appraisal, while also providing material for future selection in such trials. Without such analyses, all the initial costs of establishing, maintaining and assessing these trials will be wasted, and future generations of researchers and breeders may repeat the experiments in an attempt to "re-discover the wheel."

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