ADVANCED TREE BREEDING AND PROPAGATION STRATEGIES FOR RADIATA PINE

IAN BAIL

1992 GOTTSTEIN FELLOWSHIP REPORT

JOSEPH WILLIAM GOTTSTEIN MEMORIAL TRUST FUND

The Joseph William Gottstein Memorial Trust Fund was established in 1971 as a national educational Trust for the benefit of Australia's forest products industries. The purpose of the fund is *"to create opportunities for selected persons to acquire knowledge which will promote the interests of Australian industries which use forest products for the production of sawn timber, plywood, composite wood, pulp and paper and similar derived products."*

Bill Gottstein was an outstanding forest products research scientist working with the Division of Forest Products of the Commonwealth Scientific Industrial Research Organization (CSIRO) when tragically he was killed in 1971 photographing a tree-felling operation in New Guinea. He was held in such high esteem by the industry that he had assisted for many years that substantial financial support to establish an Educational Trust Fund to perpetuate his name was promptly forthcoming.

The Trust's major forms of activity are,

1. Fellowships - each year applications are invited from eligible candidates to submit a study programme in an area considered to be of benefit to the Australian forestry and forest industries. Study tours undertaken by Fellows have usually been to overseas countries but several have been within Australia. Fellows are obliged to submit reports on completion of their programme. These are then distributed to industry if appropriate.

2. Seminars - the information gained by Fellows is often best disseminated by seminars as well as through the written reports.

3. Wood Science Courses - at approximately two yearly intervals the Trust organises a week-long intensive course in wood science for executives and consultants in the Australian forest industries.

4. Study Tours - industry group study tours are arranged periodically and have been well supported.

Further information may be obtained by writing to,

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ADVANCED TREE BREEDING AND PROPAGATION STRATEGIES FOR RADIATA PINE

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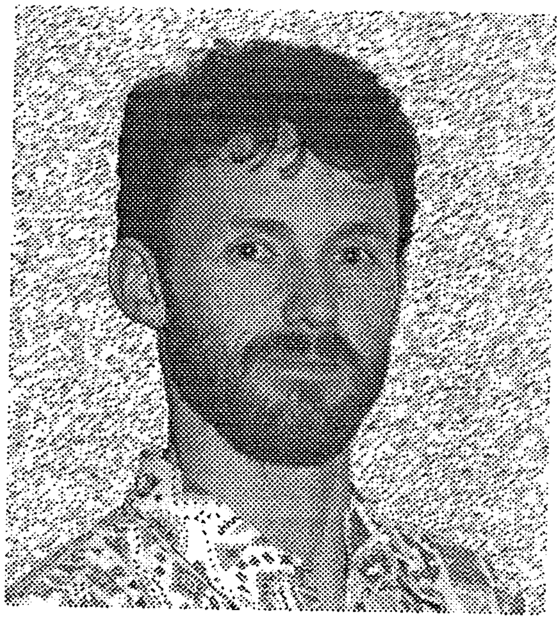
About this Report

Since late 1992 when this report was first drafted, there have been several significant changes which alter the context in which it was originally framed. Of direct consequence to the author was the change in Victoria to a government plantation estate managed as a state-owned enterprise by the Victorian Plantations Corporation. It was felt that a complete review of this document in light of these changes would detract from it as a record of the opinions and activities at the time of the study tour.

GOTTSTEIN MEMORIAL TRUST FUND

Ian Bail is the Principal Scientist responsible for Tree Breeding Research with the Centre for Forest Tree Technology, a business unit within the Department of Conservation and Natural Resources. He specialises in tree breeding and forest genetics, and is responsible for radiata pine breeding, eucalypt progeny testing and selection, and the provision of expert advice on the maintenance of genetic diversity in native forests. Ian holds a Bachelor of Forest Science (Honours) from the University of Melbourne and was a Maxwell Ralph Jacobs Forestry Research award winner for 1991. The combined funding from the Gottstein and Max Jacobs funds enabled him to undertake this study tour of New Zealand during April 1992.



Acknowledgements

The author is particularly grateful to the joint funding provided by the J.W.GOTTSTEIN MEMORIAL TRUST FUND 1992 and the M.R.JACOBS FUND 1991 which enabled this study tour to be undertaken. The co-operation of all the host organisations, in particular the Genetics and Tree Improvement group within the New Zealand Forest Research Institute, is also greatly appreciated.

SUMMARY

Support by the M.R. Jacobs Award (1990) and the J. W. Gottstein Fellowship (1991) provided the opportunity to undertake a four week study tour of New Zealand in April 1992.

The study tour examined advanced tree breeding and propagation strategies for radiata pine being utilised by the major industry and research organisations.

A need to ensure optimum productivity of forest products for specific processes drives the activities in New Zealand.

The Co-operative structure for tree breeding research in New Zealand ensures that Industry has a large input to the process of defining which traits are commercially important for improvement.

Tree Improvement through breeding and propagation is recognised as a vital element of plantation silviculture and management, and significant long term gains are expected from the support of co-operative research programs in these fields.

The technical aspects of tree improvement research and development in New Zealand are largely transportable to the Australian situation, despite large differences in the silvicultural systems and plantation expansion objectives.

Australian radiata pine breeders, growers, and users can benefit from the programs in place in New Zealand, and should explore more fully the opportunity for collaborative research and development projects.

There is the potential for New Zealand tree improvement to progress more rapidly than Australia unless a similar model for combining advanced breeding and propagation is adopted here.

The development of a new series of gain trials in which comparisons of alternative genetic material and propagation strategies can be made, using an approach based on the New Zealand model should be a high priority.

A review of existing prescriptions for stand density should be established by the Department of Conservation and Natural Resources to investigate the interaction between espacement and improved planting stock.

The importance of personal contact such as was made during this study tour cannot be over-emphasised for research staff and practitioners alike.

An increased interaction between staff involved in tree improvement in the two countries can be expected to result from the support given to this project, as can an increased understanding and ability in this field on behalf of the recipient.

AIMS OF THE STUDY TOUR :

Support was obtained to undertake a study tour of New Zealand examining advanced tree breeding and propagation strategies for radiata pine being utilised by the major industry and research organisations. New Zealand researchers have a very successful history in breeding radiata pine, and more recently have made significant progress in increasing the resistance to Pine Needle Blight.

The study tour focussed on the potential for breeding to impact upon three key areas:

i) Improving raw material yield from a limited plantation land base;
ii) Reducing the limits to growth caused by pests and diseases; and
iii) Tailoring raw materials to different client requirements.

Additional to the technical focus of the visit was an intention to help strengthen the links between Australia and New Zealand at both industry and research levels.

The study tour was particularly timely in that the information gained could be used for the critical review of local radiata pine breeding objectives.

INTRODUCTION :

In this report I will use relevant examples from the three key areas of study to illustrate a discussion of the underlying concepts of tree breeding and propagation as they are currently practised in New Zealand. I will not attempt to present much of the technical tree breeding detail which was discussed during the study tour, as this will not be directly relevant to many readers. Readers wishing to discuss a particular point in greater depth are encouraged to do so, and may contact the author using the details given at the beginning of this report.

The New Zealand Tree Improvement Program is only one facet of plantation silviculture in that country. Although this sounds rather obvious, it has been the recognition of this and an emphasis on the 'whole' rather than the 'single' which has had a major influence on all subsequent decision making within the tree improvement program. It is this integration which I believe presents the greatest opportunity for significant long term plantation and resource development and competitiveness. A similar philosophy is not nearly so obvious within plantation forestry in Victoria. Failure to commit ourselves to such a change in thinking and interaction with our many other tree growing and using colleagues will only serve to reduce the effectiveness of any technical detail or research findings which may be introduced into our programs in the future.

The diversity of the plantation resource in terms of current management objectives, history and land base presents a major challenge to tree improvement in New Zealand. The varied and sometimes conflicting factors of site, silviculture and end use are not factors restricted to our eastern neighbour, but the larger scale of plantations has often provided a real commercial incentive to pursue areas of breeding or propagation which could not be justified within a smaller program.

The New Zealand Pine Breeding Co-operative, involving the traditional research provider (the New Zealand Forest Research Institute), Universities and many of the Private plantation growing and processing companies, has been developed to incorporate the diverse requirements from across the forest industry with the economies of scale achievable through such a large group. This ensures that the research program is not only focussed on the long term possibilities, but also on the immediate problems and opportunities facing the industry.

The exposure of each group to the thinking of the other has promoted a particularly healthy atmosphere within the Co-operative. The information generated by the Co-operative is in turn integrated into the plantation activities of the various member organisations. The support offered to an individual representative from a given company by the size and diversity of the Co-operative has helped to maintain the profile of the tree improvement work during difficult times. This has been critical for the continued success of the Co-operative given the long-term nature of progress in tree improvement.

As background to the main thrust of this report, it is important to note the following on the nature of plantation forestry in New Zealand. The radiata pine estate in New Zealand is about to undergo a major expansion. Already in excess of 1.1 million hectares and representing approximately 90% of the total plantation estate, a recent change in the taxation system has seen the way cleared for an annual expansion program of almost 100,000 ha an^{-1} for the next 20 years. Should this program continue to be supported in the long term, New Zealand will have a total radiata pine plantation estate of about 3 million hectares by 2010. This planned trebling of the estate has sharpened the focus of each activity involved in plantation development, and provides an obvious incentive to adopt the most efficient and profitable system available.

Tree Improvement and Propagation are seen as key elements of the total system.

ORGANISATIONS VISITED :

Initial contact was made with staff from the New Zealand Forest Research Institute (NZFRI) during a meeting of the Australian Research Working Group No. 1 (Forest Genetics) early in 1991 to establish their willingness to support a visit. Dr. Mike Carson, Programme Manager of the New Zealand Pine Breeding Co-operative, showed tremendous enthusiasm and subsequently developed a comprehensive itinerary and co-ordinated the study tour during my visit.

The enthusiasm displayed by Dr. Carson, and indeed all those with whom discussions and field visits were made, was very pleasing, and certainly served to develop closer links between our two countries. A perception of 'closed doors' which has been held in Australia of late was certainly dispelled. I believe that personal contact of even a short duration is a tool which should be utilised far more often in specialised research fields.

A list of organisations visited during the study tour is provided in Appendix 1, and an itinerary provided in Appendix 2.

Very special thanks must go to both the M.R.JACOBS FUND 1991 of the Australian Academy of Science and the J.W.GOTTSTEIN MEMORIAL TRUST FUND 1992 of the Australian Forest Industries for recognising the importance of this study tour and actively supporting it. Without their combined support and full funding, this work could not have been undertaken, even though output from the study tour has already proven very beneficial to the Department of Conservation and Natural Resources.

DETAIL OF THE THREE AREAS OF STUDY :

I) IMPROVING RAW MATERIAL YIELD FROM A LIMITED PLANTATION BASE :

The need

The potential for improving raw material yield from a limited plantation base has assumed a high profile in Victoria. The publicly owned softwood plantation estate in Victoria (managed by the Department of Conservation and Natural Resources) has all but reached the target of approximately 120,000 ha set under the Government's Timber Industry Strategy of 1986, and a small annual expansion program should see the target completed by the year 2000. The Government's State Plantation Impact Study of 1990 has now placed the emphasis upon improving the productivity of existing plantations through more intensive management.

An increase in productivity can be achieved from both existing and future plantations, though it is obvious that the potential for tree breeding to have an impact only applies to situations where new trees are being planted which incorporate genetic improvement (i.e. future plantations). The extension of this is that it is an integrated approach which will be required to improve the productivity of our plantations, incorporating, but not relying on, tree improvement.

Quantifying improvements in yield - Genetic Gain Trials

It has been well demonstrated in New Zealand and Australia that the gains resulting from tree breeding can have quite significant impacts upon the profitability of a plantation business. Unfortunately the majority of yield models used in predicting the productivity of plantations are based upon data from stands which were genetically unimproved. There may thus be an artificial 'depression' in the true productivity which will be realised from plantations, due to the under-estimates being provided by such modelling.

Critical to the ability to demonstrate the potential for tree breeding to deliver continuous improvements in plantation productivity therefore, is the ability to generate data which shows the relative performance of a range of different levels of genetic improvement, measured in terms which are transportable to forest planning and yield modelling.

This short-coming has been recognised for some time, and the recent approach to quantifying genetic improvement in New Zealand has been to adopt a multi-disciplinary approach to testing. Staff from tree breeding, mensuration, and management, as well as field practitioners, are now involved in the planning, assessment and outputs from the trials. This has meant a re-evaluation of the experimental designs used, the methods and types of data collected, and the longevity of the trials.

From this have been developed an extensive series of trials across the country in recent years. These 'Genetic Gain' trials are designed to compare a number of seedlots of different genetic quality. The seedlots each are planted in large blocks from which both a measured and a visual comparison of the trees grown as a stand can be obtained. This is quite different from the traditional tree breeding trial which has used small rows or even single tree plots of each type being compared. Different planting densities or other silvicultural operations such as pruning can be also be applied to simulate real options for plantation practice. The trials are replicated across a number of sites so that a broad picture of the performance and relative advantages of the different genetic types can be developed.

These trials, and subsequent ones which are being implemented to assess genetic improvement in traits other than traditional growth and yield under 'normal' forest conditions (*Dothistroma* resistance, for example), are expected to be of critical importance in the longer term.

The Stand Growth Modelling Co-operative, another of the co-operative research programs undertaken through the NZ FRI, details four critical outcomes from genetic gain trials:

i) The provision of data to tree breeders for evaluation of breeding and plant production strategies.
ii) Demonstration of the benefits of investing in tree breeding to managers and representatives of industry and other funding agencies.
iii) Hard information which can be used to assist managers in their choice of the most appropriate breed for their sites and end-uses, and in designing optimal silvicultural regimes for genetically improved plantations.
iv) Accurate growth and yield data on a range of genetic material which forest planners can use in yield prediction and forest estate planning.

These expected outputs from Genetic Gain trials have not previously been available, as discussed above, nor has there been the formalisation of the multi-disciplinary approach which aims to produce this data. These two steps were widely regarded as critical to the long term justification of tree breeding from discussions held with both research and industry groups during the study tour.

The adoption of such an approach should also be seen to have a critical place in Australian plantation research. The shortcomings in the applicability of the data from previous trials is just as valid here, as is the need to involve mensurationists and end-users in the determination of exactly what we quantify from the trials. Tree breeding has the tools to undertake accurate selection and improvement in a range of traits, but the decision on what the important traits are has often been divorced from the groups to whom the traits are commercially important.

There was a tremendous enthusiasm from within the Forest Research Institute to see genetic gain trials established in Australia, because of their importance in justifying the longer term potential of tree breeding as a tool critical to many aspects of the plantation business. The potential for a new series of co-operative trials using the approach outlined above was also discussed, and I believe that a formal comparison of the gains achieved thus far through programs in both Australia and New Zealand would generate vital information for both countries.

As a result of the study tour, two new trials which attempt to measure the genetic gain achieved through the tree breeding program of the Department of Conservation and Natural Resources are proposed for planting in 1993. These trials build upon information provided during the study tour, and will incorporate the Department's mensuration and yield modelling group. The trials are to be sited so that they may be easily accessible to as wide a range of research, regional, management and industry personnel as practicable. These new trials have been planned using currently available seed of different genetic qualities, and it is important that further trials incorporating seed from alternative programs in Australia and New Zealand be planned and established using a true multi-disciplinary approach.

Long-term potential for improved yield through tree improvement

There has been approximately a 10% increase in volume growth in plantations established using seed produced from orchards established after the first cycle of genetic selection in Australia and New Zealand. The expectation is that under a similar system, equivalent gains could also be achieved for each of the next several cycles of breeding, or 'generations' (about 12 years each). There is the potential for tree breeding to deliver greater gains though, and there has been much recent debate and development of improved methods for both selecting the 'best' material from trials at an earlier age, and reducing the amount of time which is necessary to get large quantities of this material into plantations. A large proportion of the time spent in discussion on the study tour was involved with alternative approaches to early selection and mass vegetative propagation.

The Australian equivalent of the New Zealand Pine Breeding Cooperative, the Southern Tree Breeding Association, has recently undertaken a thorough review of their plan for breeding radiata pine. This involved detailed work with the membership, and included a visit to New Zealand by Dr. Tim White (University of Florida). The result of these discussions has been a recognition from both Australia and New Zealand that there is the need to plan for potential exchanges of information or material at some future date to maximise the gains in either program. In practical terms, this has meant an incorporation of greater flexibility in both programs so that avenues for exchange may remain open.

The process of tree breeding on its own is not likely to achieve the maximum potential gain. To achieve this, the gains developed by tree breeding must be 'captured' in commercial plantations. This is largely the role of the propagation phase of plantation silviculture, although establishment, nutritional and stand density regimes will need to be adapted as progressively better genetic material is made available on a large scale. The combination of tree breeding and propagation may be termed tree improvement, as these two elements combine to effect the inherent physical attributes of the trees which can be planted in plantations.

There was no doubt from the discussions and trials visited during the study tour that there are as many alternative propagation strategies being developed and pursued as there were companies visited. Some growers still use a traditional seedling based system, while Tasman Forestry now relies heavily on a highly sophisticated tissue culture laboratory system for a large proportion of their planting stock, turning over nearly 2.5 million plants by this method each year. I believe this degree of differentiation and competition in propagation strategy demonstrates three key points :

i) There are larger genetic gains to be captured in plantations than have been achieved in the past.
ii) There is a strong commercial incentive to develop the best strategy to capture these gains.
iii) There are alternative strategies appropriate for the diversity of plantation growers and processors in the market.

The importance of propagation strategy is such that it will be discussed more fully later in this report as a separate section.

Despite planning for a large increase in the plantation estate in New Zealand, this estate is ultimately limited, and improvements in it's quality and productivity are critical to the ability to remain competitive and maximise returns in the long term. The potential to continuously improve productivity from the plantation base through breeding is the focus of a large investment of industry and research time and effort, and the expectation is that the gains will be forthcoming and worthy of the investment undertaken. There is no reason to expect that the potential for improvement should be any different under Australian plantation growing conditions, but there are a number of technical changes to the structure of Australian breeding programs, and changes to formalise our involvement with other organisations, both breeding and non-breeding, which must be put into place before the potential may be fully realised.

The co-operative nature of research into Tree Improvement, Stand Growth Modelling, and Seed Orchard Research has provided the opportunity to achieve far higher returns on investment for the member organisations in New Zealand than by acting alone. Being involved in Co-operatives is not seen to subtract from the potential for a company to develop a competitive advantage.

Co-operative tree breeding is a reality for many (though not all) of the larger scale radiata pine growers in Australia, through the Southern Tree Breeding Association. This organisation has close though informal links with the New Zealand Co-operatives. There is currently no such funded Co-operative research focus for the development of propagations strategies or stand growth modelling in Australia.

Australian organisations will be able to continuously improve the productivity of their plantation base through improved breeding and propagation strategies, though the pursuit of these gains should be developed as one part of the total plantation growth and processing system.

II) REDUCING THE LIMITS TO GROWTH CAUSED BY PESTS AND DISEASES :

Pine Needle Blight (*Dothistroma septospora*)

The original contribution of funding towards the study tour was provided by the Maxwell Ralph Jacobs Award of the Australian Academy of Science 1990. This funding was provided for the study of Tree Breeding research for Pine Needle Blight in New Zealand. The fungus causing the disease (*Dothistroma septospora*) infects and kills pine needles, resulting in defoliation of all or part of the tree crown, reducing the trees growth rate approximately in proportion to the percentage defoliation. Estimates by the Department of Conservation and Natural Resources suggest that *Dothistroma* is a serious threat to the productivity of approximately 10% of pine plantations in north-eastern Victoria.

Dothistroma has been present in New Zealand since the mid-1960's, and is now distributed throughout plantations across the country. The disease is now so widely spread across the country that quarantine measures aimed at isolating the disease and reducing it's rate of spread have been abandoned.

Control for the disease in New Zealand has largely been based on an annual aerial spraying program with copper oxychloride. Over the past two decades, approximately one million hectares of pine plantation (mainly radiata pine) have been treated for the control of Pine Needle Blight.

The cost of this treatment, and the corresponding impact upon plantation profitability has been substantial. The long term management of the disease obviously requires some system other than the treatment of annual symptoms.

Integrated management incorporating tree improvement

Research undertaken by the Genetics and Tree Improvement group at the NZ FRI demonstrated that there was genetic variation in the degree to which radiata pine trees were defoliated by the disease, and that the variation could be inherited. This opened the way for selection and tree breeding to develop improved lines for planting in areas affected by the disease.

Trials were established to test all the material already being used in the NZ tree improvement program, and from these, rankings for resistance to the disease have been obtained. There is a current project under way at the FRI which is re-evaluating the data used in previous rankings, together with new data for previously untested material, so that a single listing can be obtained which will provide the best available information for improvement in the species. This information will be confidential to the membership of the Pine Breeding Co-operative. Combining this with advances in propagation techniques will provide a tremendous opportunity to make significant progress in producing large numbers of planting stock with improved resistance.

Because of the mode of action of the fungus, and the optimal environmental conditions required for infection, there are a range of other silvicultural operations which can aid in the integrated management of the disease. For many of the plantation growers in NZ, the adoption of an aggressive clearwood regime has meant early pruning, thinning and lower initial stockings are commonplace. These conditions have provided a more ventilated stand condition at early ages (5-15), conditions which are unfavourable for *Dothistroma*, and the disease has been reduced in its significance over the last two or three years.

Other companies, such as NZFP Forests (Carter Holt Harvey) in the central North Island, however, have different management conditions and have not been able to adopt the clearwood regime on a large scale, and still retain a significant area of older forest which is unpruned and at high stocking. These stands continue to be a management problem (for factors other than *Dothistroma* as well), and the company were forced to undertake a spraying program of approximately 20,000 ha in 1991.

The company has been involved in a research program which has developed a correlation between the number of wet days in summer above a given temperature and the expected magnitude of spraying for *Dothistroma* that can be expected in a given year. Areas identified using this system are then verified using aerial checking during the winter to establish the actual spraying program for the spring. The potential usefulness of this system for Australian application should be investigated.

Data now becoming available suggest that a substantial saving in annual expenditure and allocation of resources could be achieved through the planting of more resistant trees. To date, however, there is little information available which accurately quantifies the reduction in infection that can be expected by planting improved breeds. The results which come from tree breeding trials are confounded by the designs used, and most likely under-estimate the exact effect which may be obtained in a plantation of trees with improved resistance.

To overcome this, as for growth and yield, a series of genetic gain trials have been designed and established by the Tree Improvement Co-operative in the last two years which will provide comparisons of several breeds with different levels of improvement for *Dothistroma* resistance under 'stand' conditions. This will then allow modelling of the effect which may be expected from future breeding and propagation of improved genotypes.

Pathology research at the FRI into *Dothistroma* and its interaction with radiata pine has been wound back over recent years. This is largely because of the tremendous emphasis which was placed on the disease in the early years, and the recommendations resulting from this work which have been successfully adopted for the integrated management of Pine Needle Blight. Trials still under way are investigating the effect of <u>not</u> spraying for the disease across a range of sites. The objective is to determine parameters of site, location etc., which might justify 'not spraying' as a valid management strategy. Often, although a problem may be identified, a complex solution is sought, ignoring the potential and economic effects of the simpler approach.

The applicability of the New Zealand research to the Australian situation has been questioned, but there are two significant factors which suggest that it should be readily transportable. Firstly, the most likely source of the fungus which entered Australia was New Zealand. Secondly, the sexual stage of the fungus which would allow differentiation between the pathogen in the two countries has not been found in New Zealand, and we can thus regard the population of the disease here as identical to that in New Zealand. Testing of the stability of resistance will be possible from a range of material which is common to trials in the two countries.

Other harmful agents - simultaneous improvement

Another pathogen which has a very high profile in New Zealand, far more so than in Australia, is *Cyclaneusma* needle cast. This disease behaves somewhat differently to *Dothistroma*, and there is apparently no significant correlation between resistance for the two. Assessment of the degree of attack by *Cyclaneusma* is a standard trait which is assessed in all tree breeding trials, and this information is so critical that selection of trees from within a trial will not be made until there has been an attack of the disease, and an assessment made of its effect.

The process of screening for *Cyclaneusma* resistance is not as advanced as that for *Dothistroma*, although there is probably a higher emphasis placed upon the data for the former. This is a reflection of the reduced options available for integrated control, and tree breeding is seen to be critical to the long term management of *Cyclaneusma* in New Zealand.

It must be recognised that although genetic improvement is often be seen as a tool useful for solving a number of problems facing the forest manager, there are also difficulties with this approach which must be understood. Firstly, there is always a trade off in improvement of other traits to be made when an extra trait is introduced into the program. Secondly, the lead time between testing for genetic variation and the large scale propagation of significantly improved planting stock can be at least a third to half a rotation. This in turn means that the existing estate will remain open to effects of the pest or disease which is of importance, and that a number of years will pass when re-establishment or plantation expansion must be undertaken with plants unimproved for the particular resistance.

Despite these limitations, data from existing research suggests that for diseases such as *Dothistroma* and *Cyclaneusma*, long term management and improvement in productivity can best be achieved through integrated programs based upon genetic improvement.

The importance of integrated management strategies

Sirex wasp has been a significant problem for forest managers in both Australia and New Zealand. Trials in Australia using seed from natural stands of radiata pine have shown there to be variation at the genetic level in the degree of attack.

The use of tree improvement to combat *Sirex* is not being pursued in New Zealand or Australia, despite these results. This is because of the recognition that the conditions favouring the outbreak of Sirex are symptomatic of generally poor forest health. It is far more important to take other silvicultural action to raise the level of health, rather than plant material which will suffer less attack from the wasp when in poor health conditions.

A thorough understanding of the agent and the problem through multi-disciplinary research in this case has enabled a clear and effective management strategy to be developed without a reliance on tree improvement.

III) TAILORING RAW MATERIALS TO DIFFERENT CLIENT REQUIREMENTS.

As I have discussed above, the ability to make gains in a single characteristic of radiata pine through tree breeding is reduced with the addition and emphasis on each subsequent character. Also, the interaction between two such traits which we may wish to improve is not always favourable. These 'genetic correlations' may work against us such that selecting a tree which has a good growth rate, for instance, will mean that the wood density will most likely be reduced, an undesirable result for many uses. As a result, the tree breeder must select and breed between a large amount of material to make improvements in the traits to a specific set of customer requirements.

The potential to improve a range of traits simultaneously obviously then depends on the traits which we are aiming to improve. The nature of the membership of the New Zealand Radiata Pine Breeding Co-operative is such that there is a tremendous range of sites being planted, and an equally large range of end uses to which the timber is being directed after harvesting.

Two questions then were put to my hosts at the organisations visited ;
What is the ideal tree for your sites and processes?, and
How successfully can that tree be delivered through selection and breeding as part of a large and diverse Co-operative?

The ideal tree varied principally with the sites. Growers such as Carter Holt Harvey working on sands in the north of the North Island had little concern for branch size, but placed tremendous emphasis on growth rate and wind firmness. City Forests, at Dunedin in the south of the South Island related all their problems of management and processing to the branch characteristics of the trees : size, angle, frequency and so on. NZFP Forests, as has already been mentioned, carry a large number of sites and stands particularly favourable for *Dothistroma*, and they place emphasis on increasing the resistance of radiata pine to this disease. Other traits such as reduced branch size and increased branch frequency are favoured, as these will enable more efficient pruning regimes to be implemented.

Some growers, such as Juken Nissho, a recent Japanese entrant to plantation forestry in New Zealand, have very clearly defined processing requirements, and are able to define their ideal tree in terms of these. A minimum knot-free piece size of 0.9 m for furniture componentry has prompted them to invest in research for a long-internode breed, whereby there will be a greatly reduced need to prune. This was one of few examples of clear directions for tree improvement based on processing requirements. The interest in the long-internode breed has increased among other members of the Co-operative now though, and the research will be absorbed into the annual works program rather than as a parallel program being separately funded. This type of clear direction based on processing needs of the industry, particularly for sawn timber, is less developed in Australia. Indeed, despite there being well developed breeding theory which can incorporate economic weightings for different traits (such as wood density, stem straightness), very few true economic weights have been defined.

The ability to satisfy the needs of the different members in breeding for their 'ideal tree' seems to be being met by the Co-operative. In general, the traits being pursued work either favourably together, or without significant negative correlations, and can be progressively improved within a single breeding program. The exception is the long-internode breed which has been established using a population of trees selected principally for this characteristic.

It is worth noting that a great deal of the emphasis on particular traits, and the overall intention to have these reflect the requirements of the end-use of the timber has come about with the advent of the New Zealand Pine Breeding Co-operative. A similar situation can be expected to develop in Australia amongst the membership of the Southern Tree Breeding Co-operative.

In New Zealand, as in Australia, staff involved in tree breeding research have recognised for some time the importance of having economic weightings that can be used to set the priorities for the tree improvement progress. The New Zealand situation, with a well established Co-operative, a series of particularly striking trials demonstrating the potential differences that can be achieved through breeding, and close links to both industry and research wood processing groups has raised the profile of this need to a high level.

The improvement in productivity which we achieve through breeding will best be measured in terms of the increased output of forests products in the long term. Certainly, an increased volume production of unmerchantable wood, such as was the situation on pasture sites in North-east Victoria, can hardly be regarded as increased productivity.

It is obvious that each plantation owner must end up with plants of the most suitable type for their needs each planting season. In a Co-operative where there is such a range of requirements, it has become critical to have a system in place which can produce 'made-to-order' seedlots which combine the appropriate combination of traits for each grower. This is being achieved through Proseed, the seed orchard production member, and the adoption of large scale control pollinated seed orchards.

Additional Item I

THE INTERACTION BETWEEN TREE BREEDING AND PROPAGATION STRATEGIES:

Propagation, which captures the results of genetic improvement and transfers this into plantations, underpins a tree improvement program, and is the vital link between breeding and improved plantations.

Some definitions

A brief definition of the alternative methods of propagation for radiata pine is useful for those who have not had to deal with this field in the past.

Seedlings : Seed may be collected from trees in either unimproved plantations, or specially designed orchards which can yield different levels of genetic improvement. The seed is then sown into large production nurseries, and seedling plants transplanted from there to the plantation 9 months later. One plant is produced from each seed.

Cuttings : Short lengths (5-15cm) of material from the tips of suitable stems or branches may be cut off and carefully stuck directly into soil in carefully prepared nurseries. This material will form roots, and develop into a plant which can be transplanted into the plantation after 9-12 months. A number of cuttings can be produced from one original tree.

Tissue culture : Very small pieces of plant material, such as sterile seed or buds from the end of branches, may be taken from suitable trees and placed 'in culture' in specialised laboratories. This material is made to multiply and develop roots and shoots. The small plantlets are then transferred to greenhouses, and then into nursery beds for further development and eventual planting in new forests. The multiplication from one seed to planted trees can be in the order of 1000 fold over twelve months.

Somatic Embryogenesis : The embryo within a seed may be excised and placed in a specialised liquid suspension. The embryos are made to duplicate every 48 hours, and very large multiplication rates can be achieved in a relatively short time. These new embryos are removed from solution and given an artificial seed coat so that they can be sown into a nursery and grown like seedlings. Current research aims to improve the efficiency of each step so that a greater percentage of the potential multiplication may be realised.

Current status of research and commercial propagation programs

The process of propagation for radiata pine has traditionally been from seed or cuttings taken from young plants managed for the purpose. The propagation and early growth group at the NZ FRI have been responsible for a large amount of the research leading to improved practices in these traditional methods. They have also been at the fore in fundamental research and the development of applied systems in micropropagation, tissue culture, rejuvenation and somatic embryogenesis for radiata pine at an international level. Although these terms may be unfamiliar to many at present, it is expected that these systems will assume a higher and higher profile in commercial forestry over a very short time. The laboratory scale process for tissue culture and mass propagation from juvenile plant material which was developed at the FRI has been built upon and is now operated at a commercial scale by Tasman Forestry.

The best material which can be recommended from any tree breeding program has always been in short supply due to the time lag of using a seed or cuttings based propagation system to multiply this material. Results from gain trials have reinforced the economic advantages to be gained from using the best available material, and the focus of propagation now is on the ability to quickly mass propagate the 'best' to the point that it is not limiting.

With the current status of the research and commercial propagation systems in New Zealand, it is likely that the best material will continue to be in short supply for a number of years, especially given the huge expansion program which is planned. Already, all plants for 1993 planting have been sold before they are sown or set in nurseries. The impact of this has been two-fold.

Firstly, there has been a forced 'backwards' step to collect seed from seed orchards which were thought to be beyond their commercial life, and a tightening of export conditions for improved seed. This will mean that plantations are being established with tremendous variation in the level of genetic improvement, including material previously regarded as superseded. It will also mean that the purchase of improved seed from New Zealand will be more difficult for some time.

Secondly, and because of this, there has been a willingness on behalf of the major companies to invest in research programs for controlled pollinated seed orchards (producing seed of the best genetic combinations), tissue culture and rejuvenation (such as Tasman Forestry's facility) and more extreme processes such as embryogenesis, which offers the potential for virtually unlimited multiplication from a very small amount of the best material.

The current research can be categorised into two streams: that which aims to make existing processes far more cost-efficient through improving specific aspects of existing practices, and that which is attempting to make laboratory scale processes a commercial possibility. The Seed Orchard Research Program, developed in association with Proseed and the University of Canterbury falls into the first group, whilst NZFP Forests (Carter Holt Harvey) funding of the embryogenesis research at the NZ FRI fits the second.

Propagation as a tree improvement process

There are differences in the physical attributes of the plants produced under each of the alternative systems available, and this variation represents both a challenge and an opportunity for the forest manager .

There have been several detailed studies of the differences between seedlings and cuttings both in Australia and New Zealand, and these have shown significant differences in the degree of stem straightness, the size and frequency of branching, bark thickness and so on. These have been translated into definite economic advantages for cuttings material. However, there have also been studies showing that cuttings taken from older trees have a slower growth rate. Material which is propagated by tissue culture may also behave less like a seedling and more like an older tree when planted. These effects are being demonstrated to managers, and are now seen as alternatives which can be used to advantage.

Tree Improvement : Tree Breeding + Propagation

It is apparent that the changes in the behaviour of planting stock can work either for or against the gains developed from tree breeding, and that the two systems must be closely aligned to deliver the most appropriate material for a given forest owner.

Improvements in windfirmness through the use of cuttings with well developed root systems and more rigid stems has enabled the successful establishment of plantations on the South Island Canterbury Plains. The ability to improve these characters of the plant through propagation has also meant that emphasis in tree breeding and selection can be placed upon fewer other valuable traits, increasing the gain which can be expected in each. The use of a cuttings based system also means that large quantities of expensive control pollinated seed need not be purchased, as multiplication in the nursery can yield many plants from few seeds.

Plantations established on the sand dunes of the far North Island are not as productive as the majority of the New Zealand estate. Branch size and tree straightness are less of an issue than growth rate on these sites, and seedling material with rapid early growth is favoured. Genetic improvement in growth rate works in conjunction with this, and the overall effect is high gain in growth rate with the use of a relatively cheap propagation method.

Australian plantation growers have been aware of some of these effects in the past, and APM have relied on a cuttings based system for a number of years. The advances being pursued in New Zealand for the full range of propagation systems should be watched with great interest, and attempts made here to remain at the forefront of such work, either through collaborative or original research and development programs.

Additional Item II

GENETIC VARIATION - IMPACTS FOR FUTURE PLANTATIONS

The use of tree breeding and selection as a tool for plantation development has raised concerns on the impact of reduced genetic variability and the ability of plantations to resist devastation from some new agent.

This issue has become especially relevant with the advent of propagation systems that can produce huge numbers of plants from a small number of individuals. This could result from any of the systems based on vegetative multiplication, such as cuttings, tissue culture or embryogenesis. In the extreme situation, a single embryo could be multiplied using highly sophisticated bio-reactors to produce enough plants for the entire plantation establishment program in New Zealand. Such an extreme, and the commercial reality of clonal forestry systems approaching this, has raised the priority of genetic diversity dramatically within plantation forestry in New Zealand, as elsewhere.

At present, it is uncertain which way the resolution of the issue may lead. It is certain not to be clear cut, and two very well framed arguments can be developed supporting extremes of maximum or minimum diversity in plantations.

Types of diversity

It is important to recognise what is meant when discussing diversity, as it occurs at two very different levels.

Diversity in plantations

The first is the diversity which we require in our plantation estate. This estate is continuously re-established, and any individual tree will exist for the length of one rotation, say 30 years. The perfect estate may be where every tree behaves exactly the same, so that our management may be greatly streamlined. However, there may be an unknown event to which our trees are not resistant (insect plague, disease, wind storm, drought etc.), and the total estate is lost.

The question then becomes, at what level of diversity in our plantation do we regard the impact of such an event to be acceptable? If we have ten different types of tree, is this enough to have an economically acceptable loss, or is it one thousand? The scope of this question is far too broad to be covered here, but a resolution of an exact number is unlikely.

The practical reality of plantations is that a range of the currently available material will be used in each year, and that over years, this will vary. As a consequence, our plantations will probably contain far more variability than may be necessary.

A very important management consequence then should be to have an information system which can describe the genetic variation which has been established in our forests, so that this variation can be managed, planned for, and utilised should it be important in future. There has recently been some pulp recovery research which has shown trees of a certain genetic type to have 40% lower energy consumption. Unfortunately, the records of where this material may have been established in plantations are not sufficient to allow managers to make the best advantage of the research information.

Diversity in breeding populations

The second level of variation, and the level which was regarded as far more important and requiring a greater diversity, is that which is maintained in the population of trees which is used in tree breeding.

I have already stressed the need to have a large amount of material amongst which selection and breeding can be undertaken to develop improved genetic types. The long term effect of too few types in our breeding work would be to introduce an increasing level of inbreeding which would have a major negative effect.

The development of tree breeding for radiata pine in both Australia and New Zealand was initially based on selections from plantations already established in the two countries. Subsequent research has shown that the material present in those plantations did not represent the full range of variation in the species, and a number of seed collection trips from the native stands have been undertaken. This material has been less advanced than that in the existing breeding programs, and has required some developments in theory to develop plans for infusing it into the breeding programs.

The breeding co-operative in New Zealand has recently gone back to plantations established from unimproved seed and made an additional round of selections. Selections are also being made from seedlots collected from Guadalupe Island, off Mexico, as this population has a naturally higher wood density which can be introduced into current advanced populations. Both these groups of selections will be used to provide even more material which can be tested and used for obtaining gain in the longer term.

The development of theoretical aspects and modelling of the necessary level of genetic diversity at this level is a function of the Pine Breeding Co-operative, and is critical to its long term success. As has already been mentioned, these aspects are also critical to Australian tree breeding programs, and have been an important part of the research undertaken by the Southern Tree Breeding Association.

The management of diversity at both the levels discussed above will most likely continue to be based upon recommendations from a range of specialists including tree breeding staff, and it is therefore the responsibility of these staff in Australia to keep a watchful eye on developments occurring as part of the tree breeding and propagation programs in New Zealand.

CONCLUDING COMMENT ON SILVICULTURAL DIFFERENCES

The pursuit of a clear wood regime involving high pruning, early thinning and reduced stockings is in obvious contrast to Australian radiata pine plantation forestry.

This is obviously effected by many aspects of the commercial and physical environment in which each country operates.

One aspect of our silviculture, though, which is worthy of review, is stand density. A major part of the need to plant at high densities during original plantation development in Australia, as in New Zealand, was the very low number of acceptable stems of sawlog quality which could be expected to develop from the unimproved seed used. These conditions no longer prevail, and a very high proportion of the stems which we currently plant have the potential to develop into acceptable final crop trees.

One significant outcome of existing Genetic Gain trials in New Zealand has been the clear demonstration of this difference to forest managers, and the provision of data to allow modelling of these effects.

The availability of the best genetic material has already been described as limiting, above, and we should be endeavouring to maximise the area of plantation established with this best material in any given year. Planting at high densities on the basis of thinning unacceptable stems to produce a commercial forest could be seen to be unnecessary and wasteful of potential gain when using advanced material.

It is important to explore the interaction between all aspects of our plantation process, and I feel that a review of the reasoning for our current stand density prescriptions would be timely.

CONCLUSIONS AND RECOMMENDATIONS :

The four week study tour to New Zealand supported by the M.R. Jacobs Award (1990) and the J. W. Gottstein Fellowship (1991) provided the opportunity to discuss the latest New Zealand thinking on tree breeding and propagation strategies for radiata pine.

This information is being generated in an environment with tremendous commercial incentive to introduce the maximum amount of relevant gains in the most economically efficient manner.

The technical aspects of research and development activities in New Zealand are largely transportable to the Australian situation, despite large differences in the silvicultural systems and plantation expansion objectives.

A need to ensure the maximum productivity from the plantation estate drives the activities in both countries. The co-operative nature of tree improvement, stand growth modelling and propagation research and development have had a significant effect on the viability of the plantation business in New Zealand, and are expected to continue to do so in future.

Tree Improvement is recognised as an important though single aspect of plantation silviculture and management, and the emphasis on multi-disciplinary program development will ensure that the maximum return can be expected from the programs collectively.

Australian radiata pine breeders, growers, and users can benefit from the programs in place in New Zealand, and should explore more fully the opportunity for collaborative research and development projects. There is the potential for New Zealand tree improvement to progress more rapidly than Australia unless a similar model for combining advanced breeding and propagation is adopted here.

Recommendations specific to Conservation and Natural Resources :

The development of a new series of gain trials in which comparisons of alternative genetic material and propagation strategies can be made, using an approach based on the New Zealand model should be a high priority. The planning and design of these trials should incorporate contacts made during the study tour.

A review of existing prescriptions for stand density should be established by the Department of Conservation and Natural Resources to investigate the interaction between espacement and improved planting stock.

The integrated *Dothistroma* control program being pursued by the Department of Conservation and Natural Resources is based upon the New Zealand model. The local program is on track, and should continue to be actively supported. Increased interaction with the New Zealand program would be possible following this study tour.

Propagation research in New Zealand is progressing rapidly under strong commercial pressure. A process for information exchange and adaptation of the research and development results to the Australian situation should be initiated.

The combination of a seedling and cuttings based system adopted by the Department of Conservation and Natural Resources seems most appropriate given our current access to advanced genetic material and requirements for multiplication.

The Department of Conservation and Natural Resources should become a member of the Southern Tree Breeding Co-operative to maximise the potential for our breeding effort to be translated into improved plantations.

APPENDIX ONE :

LIST OF ORGANISATIONS VISITED

The study tour was co-ordinated in New Zealand by Dr. Mike Carson of the Forest Research Institute.

Discussions were held with representatives from the following organisations :

New Zealand Forest Research Institute; Genetics and Tree Improvement (Radiata Pine Breeding, Stand Growth and Eucalypt Breeding Co-operatives), Propagation and Early Growth, Pathology, Economics, Wood Quality groups.

Carter Holt Harvey (NZFP Forests Kinleith Forest Region and CHH Woodhill Forest Region sub-groups)

Tasman Forestry, Te Teko Tree Breeding and Nursery Complex.

University of Canterbury, School of Forestry

Seed Orchard Research Group / Proseed

Selwin Plantation Board, Darfield

City Forests, Dunedin

Juken Nissho, Masterton

Delegation from Fujian Forestry Department, China

APPENDIX TWO :

ITINERARY

Date	Location - Activity
April 5	Travel to Rotorua
6	Forest Research Institute, Rotorua. Genetics & Tree Improvement Group
7	FRI - Field trip : Progeny trials and seed orchards
8	FRI - GTI
9	FRI - Field trip : Gain Trials
10	FRI - Propagation & Early Growth
13	NZFP Forests inc. field trip
14	Tasman Forestry - Te Teko Facility inc. field trip
15	FRI - GTI
16	FRI - Wood Properties Group, Eucalypt Co-operative
17	Travel to Christchurch
27	University of Canterbury Forestry School, Christchurch
28	Field trip : Proseed seed orchards, Amberley
29	U. of C., Selwin Plantation Board
30	City Forests, Dunedin inc. field trip
May 1	Travel to North Island
4	FRI - GTI, Seed Certification, Summary
5	FRI - field trip. Juken Nissho
6	FRI - Pathology Group, PEG
7	Carter Holt Harvey, Auckland Region inc. field trip
8	Spare : Report preparation
9	Return to Melbourne from Auckland