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COMMERCIAL AND ENVIRONMENTAL
VALUES OF FARM FORESTRY IN THE
MURRAY-DARLING BASIN IRRIGATION AREAS

PROCEEDINGS OF WORKSHOP
HELD AT DENILIQUIN, NEW SOUTH WALES
JULY 1999

Edited by

B. H. George
COMMERCIAL AND ENVIRONMENTAL
VALUES OF FARM FORESTRY
IN THE MURRAY-DARLING BASIN
IRRIGATION AREAS

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RESEARCH AND DEVELOPMENT DIVISION
STATE FORESTS OF NEW SOUTH WALES
SYDNEY
2000
In-kind and financial support for the Workshop from -

Natural Heritage Trust
CSIRO
Centre for Forest Tree Technology (CFTT)
Murray Riverina Farm Forestry (MRFF)
and
State Forests of New South Wales

is appreciated and acknowledged.
INTRODUCTION TO THE WORKSHOP
LIST OF ATTENDEES
SUMMARY OF WORKSHOP OUTCOMES
WORKSHOP AGENDA

Species Performance, Genetic Variation and Salt Tolerance
Baker, Arnold and Marcar

INTRODUCTION
SPECIES PERFORMANCE
GENETIC VARIATION AND TREE IMPROVEMENT
HYBRIDS
SALT TOLERANCE
CONCLUSIONS
IMPLICATIONS AND IMPEDIMENTS
ACKNOWLEDGEMENTS
REFERENCES

Summary and Conclusions from Discussion of Species Performance, Genetic Variation and Salt Tolerance
Booth

Site Selection and Silviculture
Stackpole and Booth

INTRODUCTION
SITE SELECTION
SILVICULTURE
1. ESTABLISHMENT
2. MANAGEMENT
3. SAWLOG AND VENEER LOG SILVICULTURE
4. POST, POLES, PULP AND BIOFUELS SILVICULTURE
PROTECTION
1. PATHOGENS
2. ENTOMOLOGY
CONCLUSIONS
REFERENCES

Summary and Conclusions from Discussion of Site Selection and Silviculture
Eldridge and George
INTRODUCTION TO THE WORKSHOP

A substantial body of research into the growing of trees in irrigated areas of the Murray-Darling Basin has been conducted during the past ten years. Much of this research was initiated and subsequently encouraged and supported by the members of the Trees for Profit organisation. This group, comprising the major bodies represented here today, was formed to promote and coordinate research into the establishment and growing of native trees species on farms within the irrigation areas of north-east Victoria and southern New South Wales. A number of valuable trial sites were established and monitored throughout the past decade. In June 1998, after the decision was taken to dissolve the Trees for Profit group, the board wished to maintain, at an informal level, the links between research and development providers and other bodies involved in promoting farm forestry in the irrigation areas of the Murray-Darling Basin. A workshop was proposed to review developments in research findings in this field, with particular emphasis on the commercial and environmental aspects of farm forestry, as these apply to degraded or salinised land in the Murray-Darling Basin. Today's program reflects the efforts of the organisers of the workshop: State Forests of NSW, CSIRO Forestry and Forest Products, the Centre for Tree Technology and Murray-Riverina Farm Forestry.

Our intention in running the Workshop is to provide a forum for the exchange of current research information and ideas, viewed against a background of implications for management and expansion of farm forestry. In order to ensure a useful outcome, we have asked a number of people to firstly review current findings and later to facilitate discussion of these findings to establish the need/priorities for future research in the field. We would particularly like all participants to be prepared to think critically but constructively about the role of research and development in removing impediments to further adoption of farm forestry. It is anticipated that research priorities identified by the workshop may be of assistance to agencies and other research and development funding bodies.

On behalf of the organisers, I would like to welcome everyone to what I believe will be a productive workshop.

Dr A M Grieve
General Manager
Research and Development Division
State Forests of New South Wales
LIST OF ATTENDEES

Tim Ada
Roger Arnold
Richard Benyon
Trevor Booth
Michelle Boyle
Leon Bren
Karen Cody
Saul Cunningham
Kaye Dalton
Steve Dobson
Martin Driver
Mark Edwards
Robert Eldridge
Randall Falkiner
David Flinn
Brendan George
Alastair Grieve
Geoff Heagney
Alfred Heuperman
John Ive
Rob Kuiper
Brad Law
Peter Lyon
Nico Marcar
Fiona McDonald
Geoff McLeod
Stephen Midgley
Jim Morris
Brian Myers
Michael Pisasale
Philip Polglase
Jo Sasse
Nick Saunders
John Scott
John Shaw
Richard Silberstein
Stuart Sizer
Des Stackpole
Martin Steinbauer
Tivi Theiveyanathan
John Thompson
Mark Tunningley
Tim Vercoe
Glen Walker
Russell Washusen
Karen Williamson

Department of Natural Resources and Environment
CSIRO Forestry and Forest Products
CSIRO Forestry and Forest Products
CSIRO Forestry and Forest Products
State Forests of New South Wales
University of Melbourne
Bureau of Rural Sciences
CSIRO Entomology
Department of Land and Water Conservation
State Forests of New South Wales
Greening Australia
Bureau of Rural Sciences
State Forests of New South Wales
State Forests of New South Wales
State Forests of New South Wales
Agriculture Victoria
CSIRO Wildlife and Ecology
Murray Riverina Farm Forestry
State Forests of New South Wales
Environment Australia
CSIRO Forestry and Forest Products
Murray Riverina Farm Forestry
Murray Irrigation
CSIRO Forestry and Forest Products
Centre for Forest Tree Technology
CSIRO Forestry and Forest Products
Murray Riverina Farm Forestry
CSIRO Forestry and Forest Products
Centre for Forest Tree Technology
CSIRO Forestry and Forest Products
Murray Riverina Farm Forestry
CSIRO Forestry and Forest Products
State Forests of New South Wales
CSIRO Forestry and Forest Products
CSIRO Land and Water
Riverina Trees
Centre for Forest Tree Technology
CSIRO Entomology
CSIRO Forestry and Forest Products
NSW Agriculture
CSIRO Forestry and Forest Products
CSIRO Forestry and Forest Products
CSIRO Land and Water
CSIRO Forestry and Forest Products
Department of Natural Resources and Environment
SUMMARY OF WORKSHOP OUTCOMES

The presentations and discussions of the past two days have demonstrated clearly the value of well-planned research as a basis for new industry development. Much valuable information has been obtained from the substantial investment in forestry and product research over the last 10 years. This knowledge is helping those landowners who have decided to plant trees on farms in the irrigation areas, with choices of species, silvicultural and irrigation management strategies.

Yet the question remains: Is commercial tree-growing under irrigation truly profitable or even sustainable in the longer term? Clearly there is a hurdle to overcome in creating an industry of sufficient size to warrant development of infrastructure such as processing facilities and transport systems. Given the distance to ports and other existing timber industry centres, this is likely to remain a significant obstacle.

The more vexing questions centre on identifying non-commercial drivers such as benefits through lowering watertables or enhancing biodiversity or, perhaps, creating carbon “sinks” which would warrant application of scarce irrigation water to the growth of trees. Speakers referred to the need for adequate irrigation applications to generate acceptable growth rates and to the importance of managing irrigation (especially flood irrigation) to avoid generating excessive drainage. Native tree species were shown to be sensitive to salinity in soil or water at similar levels to agricultural crops, although one trial had produced acceptable growth without irrigation through reliance on rainfall and groundwater. Nevertheless, the result of lack of irrigation was substantial increases in soil salinity, raising concerns about subsequent rotations.

The meeting concluded with the resolution that the previous commitment to long-term species trials across a range of sites and conditions should be maintained, if possible, in order to realise the value of this investment. Current irrigation management research is expected to yield valuable guidelines in the short to medium term and, as more experience is gained with the properties of irrigation-grown timber, there may be a need to define these properties more precisely. It was also resolved that a brief summary of research priorities and recommendations for provision of further funding of long-term projects should be forwarded to the Federal Government for consideration.
WORKSHOP AGENDA

Venue: Deniliquin RSL Club
Date: July 28th and 29th 1999
Theme: Commercial and environmental values of farm forestry in MDB irrigation areas
Format: Day 1 - Research reviews and workshop
        Day 2 - Open forum and field day
Objectives: 1. Review research findings on the commercial and environmental values of farm forestry and its application in rehabilitating degraded/salinised land in the Murray-Darling Basin.
            2. Identify impediments to investment in farm forestry.
            3. Evaluate future research needs and explore opportunities for collaboration.
            4. Communicate significant findings to key stakeholders.

*   *   *
Chair: Dr Alastair Grieve

Role of reviewers is to consult with other researchers in the field and present technical information to stimulate a lively discussion relevant to:

a) summarising the current knowledge in the field;
b) implications for management of plantations;
c) impediments to expansion of farm forestry.

Role of the facilitators is to consider relevant information in the context of impediments to farm forestry, summarising and refining identified issues from the reviewers presentation and the following discussion. This information will then be presented in the second session.

Reviewers will present for 20 minutes followed by 20 minutes of discussion.

<table>
<thead>
<tr>
<th>Time</th>
<th>Reviewer</th>
<th>Facilitator</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30</td>
<td>Alastair Grieve SFNSW</td>
<td></td>
<td>Welcome and introductory remarks</td>
</tr>
<tr>
<td>8:45</td>
<td>Tom Baker, CFFT; Nico Marcar and Roger Arnold, CSIRO</td>
<td>Trevor Booth, CSIRO</td>
<td>1. Species performance - species/provenance/hybrids, salt tolerance results of pilot trials of selected hardwood species</td>
</tr>
<tr>
<td>9:25</td>
<td>Des Stackpole, CFFT; Trevor Booth, CSIRO</td>
<td>Robert Eldridge, SFNSW</td>
<td>2. Silviculture, protection and site selection - site selection and preparation, pruning, thinning, nutrition, and species interactions</td>
</tr>
<tr>
<td>10:00</td>
<td></td>
<td></td>
<td>Morning tea</td>
</tr>
<tr>
<td>10:30</td>
<td>Phil Polglase, CSIRO; Brendan George, SFNSW</td>
<td>Jim Morris, CFFT</td>
<td>3. Water management of irrigated plantations</td>
</tr>
<tr>
<td>11:10</td>
<td>Russell Washusen, CSIRO</td>
<td>John Shaw, CSIRO</td>
<td>4. Wood products and economics</td>
</tr>
<tr>
<td>11:50</td>
<td>Richard Silberstein, CRC for Catchment Hydrology</td>
<td>Leon Bren, University of Melbourne</td>
<td>5. Catchment-scale impacts</td>
</tr>
<tr>
<td>12:30</td>
<td>Brad Law, SFNSW</td>
<td>John Ive, CSIRO</td>
<td>6. Biodiversity issues in farm forestry</td>
</tr>
<tr>
<td>1:10 - 2:00</td>
<td></td>
<td></td>
<td>Lunch</td>
</tr>
</tbody>
</table>

COMMERCIAL AND ENVIRONMENTAL VALUES OF FARM FORESTRY IN THE MDB IRRIGATION AREAS

STATE FORESTS OF NEW SOUTH WALES TECHNICAL PAPER NO. 65
Session 2

Breaking Down the Barriers
Identifying biophysical and economic impediments
to expansion of farm forestry, and future R&D needed for their removal

Chair: David Flinn, CFTT

The objective is to identify impediments to investment farm forestry and the R&D required for their removal.

- Review recent R&D priorities (eg 1995 TFP workshop, RIRDC/AACM, RWG11) as a starting point
- Reviewers and facilitators from Session 1 to provide one page list of suggested priorities prior to workshop
- Impediments and R&D needs from each topic to be discussed in turn (followed by a plenary forum)

<table>
<thead>
<tr>
<th>Time</th>
<th>Reviewer</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>2:00</td>
<td>David Flinn, CFTT</td>
<td>Introduction • Overview, objectives, process</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Review of 1995 TFP priorities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Review of other priorities (RIRDC/AACM, RWG11, etc)</td>
</tr>
<tr>
<td>2:20</td>
<td>Trevor Booth, CSIRO</td>
<td>Species performance – species/ provenance/hybrids, salt tolerance results of pilot trials of selected hardwood species</td>
</tr>
<tr>
<td>2:40</td>
<td>Robert Eldridge, SFNSW</td>
<td>Silviculture and site selection – site selection and preparation, pruning, thinning, nutrition</td>
</tr>
<tr>
<td>3:00</td>
<td>Jim Morris, CFTT</td>
<td>Water management of irrigated and dryland plantations</td>
</tr>
<tr>
<td>3:20</td>
<td>John Shaw, CSIRO</td>
<td>Wood products and economics</td>
</tr>
<tr>
<td>3:40 – 4:00</td>
<td></td>
<td>Afternoon tea</td>
</tr>
<tr>
<td>4:00</td>
<td>Leon Bren, University of Melbourne</td>
<td>Catchment-scale impacts</td>
</tr>
<tr>
<td>4:20</td>
<td>John Ive, CSIRO</td>
<td>Biodiversity issues in farm forestry</td>
</tr>
<tr>
<td>4:30</td>
<td>David Flinn, CFTT</td>
<td>Overview and conclusions</td>
</tr>
<tr>
<td>5:15</td>
<td>Close</td>
<td></td>
</tr>
</tbody>
</table>
Day 2
Field Day Open Forum:
Environmental benefits and commercial returns from farm forestry

Session 3
Presentations

Chair: Alastair Grieve, SFNSW

Time   Speaker                      Topic
8:30-8:40 Alastair Grieve, SFNSW   Opening remarks
8:40-9:00 David Cromarty, SFNSW    Growing softwood plantations for commercial and environmental gain
9:00    Des Stackpole, CFTT        Matching species to sites
9:15    Russell Washusen, CSIRO   The potential for timber products in the Murray-Darling Basin
9:30    John Scott, MRFF          New strategic initiatives by MRFF
10:00   Alastair Grieve, SFNSW    Close of indoor session and summary comments

Morning tea and depart to first field site

Session 4
Field Tour

Time   Location                                      Topic
10:45   Landale’s (Brendan George, SFNSW)           Species performance
              Stuart Sizer (Riverina Trees) and Michael Pisasale (MRFF) - on buses between sites
              Regional planting and silvicultural experiences
11:40   Barklay’s (Roger Arnold, CSIRO)             Seed orchard
12:35   Norwood Park (Phil Polglase, CSIRO)        Irrigation management
              Lunch
1:45    Karawatha (Polglase et al., CSIRO)         High performing *Eucalyptus grandis*
3:00    Crossley’s (Roger Arnold, CSIRO)           · Seed orchard, species performance
              · Variation in growth with soil type
3:30    Wron Wron (Nico Marcar)                    Trees for salted land, saline seed orchard
4:30    Close of Workshop
Species Performance, Genetic Variation and Salt Tolerance

Thomas G. Baker\(^1\), Roger J. Arnold\(^2\) and Nico E. Marcar\(^2\)

\(^1\) NRE Centre for Forest Tree Technology
PO Box 137, Heidelberg, Victoria 3084

\(^2\) CSIRO Forestry and Forest Products
PO Box E4008, Kingston, ACT 2604
INTRODUCTION

Interest in the establishment of forest tree plantations on irrigated and non-irrigated sites in the southern Murray-Darling Basin (MDB) for commercial and other objectives has increased in recent years. This has resulted from a wider recognition that integration of trees into farming systems is an essential component of sustainable agricultural production (Vercoe and Clarke 1997), and also from commercial prospects perceived for farm forestry plantations.

In identifying the best species to plant, landowners first need to clearly define their objectives for growing trees. Species differ in their potential to provide alternate products such as sawn timber, pulpwood, shelter, fodder and/or ground water control.

SPECIES PERFORMANCE

Absolute performance (survival, growth and yield) of species varies greatly between sites, and the relative performance or ranking of different species across sites may also vary. The latter is not surprising where site factors such as radiation, temperature, rainfall and soils are markedly different. Much of the early species performance data for irrigated plantations in the southern MDB comes from wastewater irrigated trials established during 1975-1980, including those trials at Werribee, Mildura, Robinvale, Merbein, Horsham, Dutson Downs, Wangaratta and Wodonga. However, few of these trials have been maintained and monitored over long (>10 years) periods.

Results for *Eucalyptus grandis* from the Wodonga study (irrigated with municipal effluent) and from a trial at Kyabram (irrigated with channel water during the first few years, and then tapping groundwater to some extent) illustrate a three-fold range of growth potential between sites (MAI = 15 to 45 m³/ha at age 10 years (Baker 1998, unpubl.)) where irrigation water salinity and initial soil salinity were not significant problems. At Wodonga, species ranking for growth (volume index, m³/ha) to age 10 years was: *E. grandis* (416), *E. saligna* (350), *Pinus radiata* (248), *Casuarina cunninghamiana* (212), *Populus deltoides x nigra* (177) and *E. camaldulensis* (< 100). At Kyabram species ranking (volume index, m³/ha) at age eight years was: *E. grandis* (99), *E. globulus* (79), *E. saligna* (66) and *E. camaldulensis* (49). However, at age 18 years the species were ranked: *E. grandis* (255), *E. camaldulensis* (179), *E. globulus* (169) and *E. saligna* (80). Changes in species ranking were attributed to significant changes in site factors (cessation of irrigation and an increase in soil salinity in the root zone) resulting in significant mortality in *E. globulus* and particularly in *E. saligna*. In contrast, there was little or no mortality in *E. grandis* and *E. camaldulensis* between age eight and 18 years.

A second wave of wastewater irrigated plantation studies from 1988-93, included trials at Albury, Shepparton, Werribee, Bolivar and Wagga Wagga. The oldest of these is drip- and flood-irrigated *E. grandis* at Shepparton where MAIs (age 10 years) of approximately 25 m³/ha and 30 m³/ha respectively are being realised. While the earlier trials (eg Horsham, Mildura) indicated that effluent-irrigated *E. grandis* and *E. globulus* have similar initial growth rates, the studies at Werribee (Delbridge *et al.* 1998, unpubl.²), Bolivar (Shaw *et al.* 1996) and Shepparton (Duncan *et al.* 1998, unpubl.³) show that up to age four to six years, growth of *E. globulus* can exceed that of *E. grandis* by 30 to 100%. At Bolivar, the species studied in the high effluent rate application treatment were ranked at age six years (volume over bark, m³/ha): *E. globulus* (276), *C. glauca* (226), *E. grandis* (165), *E. occidentalis* (153) and *E. camaldulensis* (145). However, the growth rate of *E. globulus* at age six years was declining, probably because of increasing soil salinity, whereas that of *C. glauca* was increasing.

Under the Trees for Profit (TFP) program, which investigated commercial tree growing for land and water care benefits, trials were established during the period 1992-1996 at pilot sites and related sites in Victoria, including Undera, Mangalore, Cobram, Nathalia, Tatura, Timmering, Appin South, Yarrawalla South and Swan Hill (Bren *et al.* 1993, Baker *et al.* 1994, Stackpole *et al.* 1995). Most of the initial TFP pilot sites (1990-94) were used primarily to investigate tree growth under a range of irrigation water salinities (0.5 to 10 dS/m), whereas the more recent trials investigated growth on saline sites irrigated with fresh water.

The primary species studied by TFP included *E. camaldulensis*, *E. globulus*, *E. grandis* and *E. saligna*. Growth to age four years generally ranks these species *E. globulus > E. grandis > E. saligna > E. camaldulensis* (Duncan *et al.* 1999, unpubl.⁴). However, while growth of *E. globulus* was approximately 50 to 100% greater than that of *E. camaldulensis* the irrigation water salinity was less than 1.5 dS/m, the difference was less than 50% for salinities greater than 2.5 dS/m. Moreover, the average growth across all species on the latter group of sites was 25-50% of that at the former sites.

Most irrigated plantation studies have focussed on native species, particularly *Eucalyptus* spp. While the earliest trials did not have success with pines, more recent work has demonstrated that *P. radiata* can be highly productive under effluent irrigation (Wodonga, Albury, Wagga Wagga). Also, on nutritionally poor sites, this latter species has responded significantly to effluent application at later ages (Dutson Downs, Canberra). Over shorter rotations though, *P. radiata* has significantly less volume production than the faster growing eucalypts. For example, age 10 year volume index of *P. radiata* at Wodonga was 248 m³/ha compared to *E. grandis* having 416 m³/ha. However, *P. radiata* has not been tested over longer rotations under effluent irrigation.

In addition to preferred species identified by TFP work, spotted gums (*Corymbia maculata* - formerly known as *Eucalyptus maculata*) and the closely related species *C. variegata* and *C. henryi*, have also been identified as candidate plantation species for irrigated and non-irrigated sites where the total annual precipitation plus irrigation is equivalent to 600 mm or more per annum, and/or where there is a possibility of exploiting high watertables. However, these species cannot withstand heavy frosts (lower than around -5°C screen temperature) or poorly drained soils.

Other good candidate species for non-irrigated sites of the southern MDB with intermediate rainfall (600-800 mm annual rainfall) include *E. cladocalyx* and *E. sideroxylon*. Both have shown reasonable growth, good stem form and produce good quality sawn timber (Washusen *et al.* 1998). Both these species also perform relatively well on some sites in lower rainfall areas (400-600 mm annual rainfall) (Bird 1997, Bird *et al.* 1996). *E. occidentalis* is considered a good option for drier sites (350+ mm annual rainfall) and/or those with heavier, poorer drained soils of moderate to high salinity.

**GENETIC VARIATION AND TREE IMPROVEMENT**

There can be substantial genetic variation in growth between provenances\(^5\) of any one eucalypt species, as illustrated in Table 1. Similarly, variation between families\(^6\) within provenances can far exceed the variation between provenances in many eucalypt species (Moran 1992). Good families can often be identified from within poorer provenances. Consequently, it is inappropriate to judge species on the basis of just one, or few provenances. Also, provenance merit cannot be judged on seedlots obtained from only limited numbers of parent trees; accurate representation of provenance potential requires a sample of at least 10 widely separated parent trees (Eldridge *et al.* 1993).

Of the preferred species identified above for irrigated plantings in the southern MDB, *E. grandis,* *E. camaldulensis,* *E. globulus* and the *Corymbia* species are well represented in provenance and provenance-family trials. In addition, provenance-family trials have also been established for a range of other candidate species for irrigated and/or non-irrigated sites including *E. cladocalyx,* *E. dunnii,* *E. benthamii* and *E. occidentalis.* Such trials have for some species enabled identification of the better natural stand provenances (with respect to adaptation, growth and form) for use on southern MDB sites:

- *E. globulus* - provenances from the Strzelecki Ranges and the eastern Otway Ranges in Victoria have shown both good growth and higher wood densities in a range of trials (Dutkowski and Potts 1999), making them more desirable for pulpwod production. Seed orchard seedlots, where available, should have superior growth to such natural stand provenances.

- *E. grandis* - of the natural stand provenances, those from lower altitudes in the southern part of the species range have generally shown the better growth in irrigated trials in the southern MDB (Arnold *et al.* 1996). However, all natural stand provenances have generally been inferior in irrigated trials to seedlots from the *E. grandis* Coffs Harbour seed orchard (belonging to State Forests of NSW), and some other improved Australian seedlots (Arnold *et al.* 1999, unpubl.).

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\(^5\) Provenance is a term used in discussion and specification of tree seed sources. It is defined as the original geographic source of seed (being a population of a tree species growing at a particular geographic location) (Eldridge *et al.* 1993).

\(^6\) A family refers to the progeny raised from the seed collected from a single tree.

Table 1. Variation in height growth between and within selected eucalypt species in a number of trials in the southern Murray Darling Basin (Source: CSIRO Forestry and Forest Products and CSIRO Entomology, unpubl. data).

<table>
<thead>
<tr>
<th>Site</th>
<th>Mean annual rainfall/irrigation (mm yr⁻¹/ML ha⁻¹ yr⁻¹)</th>
<th>Species</th>
<th>Age (years)</th>
<th>Species mean height</th>
<th>Number of provenances represented</th>
<th>Range in provenance mean heights</th>
<th>Max. range in family mean heights within one provenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deniliquin, NSW</td>
<td>410/6</td>
<td><em>C. henryi</em></td>
<td>3</td>
<td>5.9 m</td>
<td>1</td>
<td>n.a.*</td>
<td>5.1 - 6.6 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>C. maculata</em></td>
<td>3</td>
<td>5.3 m</td>
<td>7</td>
<td>4.4 - 5.9 m</td>
<td>3.5 - 6.0 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>C. variegata</em></td>
<td>3</td>
<td>5.4 m</td>
<td>7</td>
<td>4.7 - 5.8 m</td>
<td>3.8 - 6.6 m</td>
</tr>
<tr>
<td>Deniliquin, NSW</td>
<td>410/6</td>
<td><em>E. benthamii</em></td>
<td>3</td>
<td>5.9 m</td>
<td>3</td>
<td>5.3 - 6.1 m</td>
<td>4.5 - 7.5 m</td>
</tr>
<tr>
<td>Deniliquin, NSW</td>
<td>410/6</td>
<td><em>E. dunnii</em></td>
<td>3</td>
<td>5.6 m</td>
<td>14</td>
<td>5.3 - 5.9 m</td>
<td>4.7 - 7.0 m</td>
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<tr>
<td>Koorlong, Vic.</td>
<td>280/10</td>
<td><em>E. grandis</em></td>
<td>4½</td>
<td>6.5 m</td>
<td>10</td>
<td>5.8 - 7.7 m</td>
<td>5.9 - 8.2 m</td>
</tr>
<tr>
<td>(Mildura)</td>
<td></td>
<td><em>E. saligna</em></td>
<td>4½</td>
<td>4.9 m</td>
<td>1</td>
<td>n.a.</td>
<td>4.5 - 5.8 m</td>
</tr>
<tr>
<td>Wellington, NSW</td>
<td>620/0</td>
<td><em>E. camaldulensis</em></td>
<td>2</td>
<td>2.7 m</td>
<td>28</td>
<td>2.0 - 3.5 m</td>
<td>2.3 - 3.4 m</td>
</tr>
<tr>
<td>Holbrook, NSW</td>
<td>625/0</td>
<td><em>C. maculata</em></td>
<td>2½</td>
<td>3.1 m</td>
<td>3</td>
<td>3.0 - 3.3 m</td>
<td>1.3 - 3.5 m</td>
</tr>
</tbody>
</table>

* n.a.: not applicable
• *E. camaldulensis* - provenances from Lake Albacutya, Lake Hindmarsh and selected locations nearby in north-west Victoria, have shown superior growth across a range of sites in the southern MDB, as well as higher survivals under more adverse conditions on sites with moderate to high soil salinities (Marcar and Benyon 1999, unpubl.

• *Corymbia* species - at the species level, *C. variegata* displays significantly greater frost tolerance than *C. maculata* and *C. henryi*, with provenances from inland high altitude locations (650 m to 1100 m asl) on the Great Dividing Range generally showing the best frost tolerance (Lamour *et al.* 2000, in press). In trials on irrigated sites near Deniliquin and on one non-irrigated site near Holbrook, provenances with better early growth (up to age three years) have come from geographically disparate locations. More importantly, the variation between families within provenances is often substantially greater than the variation between provenances (see Table 1).

The substantial genetic variation that exists within most eucalypt species provides good potential for ongoing genetic improvement. However, the existence of such variation within a species does not alone justify intensive breeding. The intensity of breeding must be appropriate to both a species' potential total establishment area and its end use or product value. The continuum of intensity for tree improvement ranges from simple selection and use of the best wild provenance(s), through the establishment of first-generation seed production areas and seedling seed orchards, to intensive breeding strategies which may incorporate controlled pollination, sub-lines and clonal testing and deployment.

Some of the provenance-family trials already established in the southern MDB have been designed to enable their conversion at later ages into first generation seedling seed orchards. This will involve selection of the superior trees and heavy thinning to remove poorer-performing families and individuals. Seed from well designed eucalypt seedling seed orchards should result in superior growth and form relative to that from the best natural provenances, with gains in log volume production of up to 15% or more.

For a limited number of species, including *E. globulus, E. grandis, E. camaldulensis* and the *Corymbia* species, more intensive tree breeding programs are also being pursued by a range of organisations to advance their improvement beyond that achievable from the current provenance-family trials/seedling seed orchards.

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HYBRIDS

Some growers have considerable enthusiasm about the prospects for eucalypt hybrids in the southern MDB. In South Africa, Brazil and some other countries, the growth and survival of hybrids has, in some cases, been superior to the pure species on marginal sites. Some hybrids have also been consistently more resistant to diseases, pests, cold, heat and drought (Denison and Kietzka 1993), while their wood density has normally been intermediate between that of the parent species (Malan 1993).

Several Australian organisations are involved in testing and/or developing interspecific eucalypt hybrids likely to be well adapted to target environments in southern Australia. For example, work is in progress to try to combine the salt-tolerance of E. camaldulensis with the pulping/timber qualities of E. globulus and E. grandis through hybridisation. Of particular importance in field testing such hybrids will be their susceptibility to defoliating insect pests, since most of the parent eucalypt species are susceptible with potential major impacts on growth and form. It is essential that all candidate hybrid clones for establishment in the southern MDB be rigorously field tested in the target environments prior to broad scale deployment.

SALT TOLERANCE

A limited number of species and species-provenance field trials have been undertaken for evaluating survival and growth under saline conditions in the southern MDB. These trials included sites with varying drainage, water table depths and salinity and were irrigated with saline water or unirrigated. Results from some of these trials are highlighted below. However, it is difficult to determine responses to in situ or imposed salinity because of limited site characterisation or absence of control plots in most of these trials.

As a general rule, commercially valuable species such as E. globulus and E. grandis have been shown to be only moderately salt-tolerant at best, with yield reductions often beginning at root-zone EC_e 2-4 dS/m but with generally good survival at EC_e 5-10 dS/m, depending on site conditions (eg incidence of waterlogging) (Marcar et al. 1995). Tree growth on saline sites is relatively slow, regardless of whether the irrigation water is saline or fresh, or whether salt tolerant species (eg E. occidentalis, E. spathulata, E. camaldulensis) are used. Nonetheless, with correct species selection, growth rates of up to 10 m^3/ha/year on saline sites may be achievable (eg C. glauca, C. cunninghamiana and E. camaldulensis at Girgarree (J. Morris pers. comm.)). In addition to the use of conventional tree improvement (eg Arnold et al. 1999, Marcar and Benyon 1999), there are opportunities to use clonal (Bell et al. 1994, Morris 1995) and hybrid (Odie and McComb 1996, J. Sasse, pers. comm.) technologies to improve salt tolerance.
Limited information is available on the ability of some species to use groundwater of varying salinity and depth. At a dryland site near Wellington, NSW, substantial use of shallow saline (up to 20 dS/m) groundwater was found for individual trees of seven year-old *E. camaldulensis* (Marcar and Benyon 1999). A few studies have shown that water use per unit leaf area or sapwood area is generally similar between species under similar growing conditions, including saline sites (Morris and Collopy 1998, Benyon *et al.* 1999, Marcar and Benyon 1999).

Glasshouse experiments with eucalypt seedlings have provided some useful information on (i) species, provenance and family level variation with respect to tolerance to salt and waterlogging and (ii) relationships between leaf Cl concentrations and growth (J. Morris, pers. comm.). Modelled (using 3PG) values of *E. grandis* growth in response to salinity within the Deniliquen area are also available (J. Morris, pers. comm).

Some relevant studies:

- **Mildura, Vic:** re-use of irrigation drainage water (EC 1.5-2.5 dS/m) on 16 species (25 seedlots) on sandy loam/loam soil, using drippers. Dale (1992) provides 14 and 21 month data; best performing eucalypts were *E. camaldulensis* (especially Lake Hindmarsh provenance), *E. occidentalis*, *E. spathulata* and *E. sargentii* with height growth rates of around 1-1.5 m/year whilst *E. grandis* had <1 m/year. Study on sustainability (with and without sub-surface drainage) of irrigating established *E. camaldulensis* with saline water (EC ca. 4 dS/m) to begin soon.

- **Loxton, SA:** re-use of saline water (EC 2 dS/m) on 22 species (36 seedlots) planted in 1990 on sandy soil using drippers (Stevens *et al.* 1999) indicated height growth rates of 1.2-1.6 m/yr for *E. grandis*/E. *saligna*.

- **Kerang, Vic:** drip/sprinkler irrigation of 22 species with saline water (EC 6.5-13.3 dS/m) on highly saline-sodic clay soil underlain by highly saline (EC 40-50 dS/m), shallow groundwater (Morris *et al.* (1994) unpubl. provides data up to age nine years); growth was relatively slow, even for salt tolerant species used (*eg* *E. occidentalis*, *E. spathulata*, *E. camaldulensis*); good early survival of *E. camaldulensis* did not continue to age nine years.

- **Deniliquen, NSW:** *E. camaldulensis* provenance-family trial planted on saline (EC <2-12 dS/m) sandy loam, with a shallow water table, no irrigation; highly significant survival and growth differences were observed between provenances and families, but relative growth decline to increasing salinity was similar among provenances and families at age two years (Marcar and Benyon 1999).

- **Coleambally, NSW:** a trial planted in 1992 on a highly saline, waterlogged, clay soil with several species. Many recent deaths. Some species (*eg* *C. glauca*) showed good survival.

- **Shepparton, Vic:** three TFP sites (Nathalia, Tatura and Timmering), established 1993, irrigated with saline water (EC nominally 2.5, 5 and 10 dS/m, respectively) (Hamlet and Morris 1996). Effects of salinity on growth were greatest in *E. globulus* (> 50% volume reduction) and least in *E. grandis* and *E. camaldulensis*. An additional trial with six families of *E. globulus* and *E. grandis* was established in 1994 at Tatura.

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• Undera, Vic: 16 species were flood irrigated with saline water (EC about 9 dS/m) on clay soil with subsurface drainage (SBC system); Greenslade et al. (1999) provided tree height data for 10 and 17 months. *E. occidentalis* and *E. trabouti* showed the best height growth (1.5-2 m/yr) while that of *E. grandis* was less (ca. 1 m/yr).

• Mt Barker and Beverley, WA: dryland sites; hybrid populations of *E. camaldulensis* x *globulus* tested on saline soils; preliminary data has been reported by Odie and McComb (1996).

• Wellington, NSW: dryland, saline site; partitioning of ground water and soil water use by seven year-old *E. camaldulensis*; growth responses for several species to salinity; species differences in water use have been observed (R.G. Benyon pers. comm.).

**CONCLUSIONS**

Plantations on non-saline sites and those irrigated with good quality water can be highly productive and therefore may offer promise of commercially viable returns. The species presently identified as most suitable in these situations are *E. grandis* and possibly *P. radiata* for sawlogs and veneer logs, and *E. globulus* for pulpwood or biofuels. On saline sites, or those irrigated with highly saline water, growth rates are likely to be too poor to justify irrigation costs, and the identified best species (*E. camaldulensis*, *E. occidentalis* and *C. glauca*) do not currently offer strong commercial prospects.

For sites with reasonable soils where there is a possibility of exploiting high watertables or, in higher rainfall (>750 mm) areas, a range of species, including *P. radiata*, *E. globulus* and some *Corymbia* species, can offer prospects for productive, if not commercially viable, plantations. In all cases, genetically improved trees offer growers advantages of superior growth and stem form in amenity, land-care and commercial timber plantings.
IMPLICATIONS AND IMPEDIMENTS

- Identification of the better performing species and provenances requires many years. Ideally, judgement on the best species and provenances should not occur until trials are at least 1/2 to 2/3 rotation age.

- Eucalypt species can be sensitive to even minor site variations. Performance in a specific environment with a particular management regime may be quite different to performance given a different set of conditions. Consequently, care needs to be taken in extrapolating trial results to different environments.

- The extent and nature of genotype-by-environment interactions - these can result in marked changes in the relative performance of provenances and of families across sites. These interactions have not, as yet, been examined for most of the preferred species.

- Poor availability, to date, of improved or quality seed for most of the preferred species.

- Limited availability of resources for tree improvement efforts for key species.

ACKNOWLEDGMENTS

Information in the section on species performance draws largely and selectively on published and unpublished data from studies by CFTT scientists including T. Baker, M. Duncan, P. Hopmans, J. Morris and D. Stackpole.

Information presented in Table 1 is based on unpublished data from collaborative field trials of CSIRO Forestry and Forest Products and CSIRO Entomology, which involve a range of other parties.
REFERENCES


Summary and Conclusions from Discussion of
Species Performance, Genetic Variation and Salt Tolerance

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The priorities outlined by Baker et al. (this proceedings) and discussed at the workshop include:

- Increase tree improvement effort for core species eg *Eucalyptus grandis*, *E. globulus*, *E. camaldulensis*, *Corymbia maculata* and *Pinus radiata*
- Increase breeding and field testing of hybrids
- Improve site characterisation of salt tolerance, including further assessments of likely use of saline groundwater by different species
- Improve methods to extrapolate trial results to different environments, including development of decision support systems
- Increase efforts to explain genotype x environment interactions
- Maximize use of information from existing trials eg use in models
- Continue selection and breeding for pest and disease resistance
- Evaluate use of diverse stands (species and ages) to minimise pest and disease problems
- Investigate systems for new uses eg oil mallee and bioenergy
- Improve collaboration by setting up groups such as ALRTIG (Australian Low Rainfall Tree Improvement Group)
- Further evaluate species for dryland sites eg *E. sideroxylon*, *E. cladocalyx*, *E. occidentalis*, *E. camaldulensis*, *P. pinaster* and *P. brutia*. 
Site Selection and Silviculture

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INTRODUCTION

Growing eucalypts under irrigation presents many challenges. Issues such as selection of appropriate sites and management practices have been addressed by a number of programs. Much of our early knowledge of irrigated eucalypt silviculture has come from studies of waste water and effluent reuse plantations as in Stewart et al. (1980). There has been renewed interest in the 1990s, at sites in South Australia (Shaw et al. 1996), New South Wales (Myers et al. 1999) and Victoria (Baker et al. 1997, unpubl'). The Trees for Profit program of the 1990s aimed to intensively examine the effect of irrigation on wood production plantations and the land used for this purpose. This paper summarises key studies and outcomes from this period, highlighting areas for further research.

SITE SELECTION

The broad scale suitability of the Deniliquin area for irrigated farm forestry was evaluated in a series of four publications for the Denimein, Berriquin, Cadell and Wakool irrigation districts (Deller-Smith and Ashton 1996). Sites were ranked 1 to 9 for plantation suitability, rated according to ground water salinity (<2500, 2500-5000, 5000-10000, >10000 EC), depth to watertable (0-2 m, 2-4 m, >4 m) and soil drainage (well drained, not so well drained). The assessments provided a useful overview, but no validation was attempted.

A Rural Industries Research and Development Corporation (RIRDC) funded project on “Forecasting tree growth and yield”, building on an earlier project, began in 1996 (Baker et al. 1996). It has collated a large database comprising species, growth rates, and site characteristics. The database has enabled development of growth curves (relating age to height and volume) for major farm forestry species in Victoria and South Australia. These growth curves allow comparisons to be made between stands of different ages, and are therefore helpful in developing relationships between site features and tree growth. Currently, the data base does not include irrigated sites.

A CSIRO-led project gathered tree growth and environmental data from trials of five eucalypt species (Eucalyptus grandis, E. globulus, E. camaldulensis, E. saligna and Corymbia maculata) from 82 plots at 43 sites in south-eastern Australia (Jovanovic et al., unpubl). Twenty-three of the 82 plots were from irrigated sites.


Regression relationships were developed relating growth to environmental conditions. The work is continuing using the ProMod model (Battaglia and Sands 1997).

The use of simulation models has become much more common in recent years and further improvements are likely to continue as a major research theme. Both ProMod and 3-PG (Landsberg and Waring 1997) have been used to assist analyses of site suitability. For example, 3-PG has been used to estimate the productivity of *E. grandis* plantations in irrigation districts of southern New South Wales under varying site conditions and management. The original model was extended to include the effects of saline soil, groundwater and irrigation on growth, to also allow for both selective and systematic multiple thinnings and to estimate product volumes (ie vineyard trellis logs) from an assumed tree diameter distribution. Funding for this development came from Xylonova, with private clients funding the product application studies. The Victorian Department of Natural Resources and Environment’s Private Forestry Unit funded further model development work in 1998-99. This includes validation, improvement of parameter selection and extension of scope to additional species. The development is based on growth and biomass data collected by Victoria’s Centre for Forest Tree Technology (CFTT). Further application and development is planned for tropical eucalypt plantations in southern China within Australian Centre for International Agricultural Research project FST 9777.

Whilst models are particularly useful for broad-scale evaluations, paddock-level site assessments can sometimes be inferred from the relative performance of various species on known soil and site types, if existing plantations are nearby. The Shepparton and surrounding regions were intensively mapped as part of the irrigation development planning process in the early 1960s (Skene and Poutsma 1962, Skene 1963). These maps describe texture, irrigability, drainage and salinity risk. Soils are classed into a five scale suitability ranking, which holds true for stonefruit, dairying, and forestry applications. Soil type and texture determines species choice and suitability for irrigation. Position in the landscape will dictate whether flood irrigation is possible, or whether piped delivery systems will be required. In the Shepparton districts, the best textured soils (the fine sandy loams) are positioned too high in the landscape to be considered for flood irrigation. Lower in the landscape, heavy clay soils with grey mottled subsoils are unsuited to productive plantation development. There is a range of potential site classes between these extremes. However, the occupation of the most suitable soils by existing agricultural enterprises is probably the major impediment to expansion of irrigated farm forestry in both the Shepparton and Deniliquin areas. Soils not occupied by intensive agriculture do not appear to be suited to tree crops either. Industrial plantation development in these areas has not been possible because of the difference in expectations between plantation companies (seeking broad areas) and resident farmers, desiring a patch of forest on their farm as a ‘sideline’. Forestry must be considered in frameworks other than the industrial model.

The recently established trials and plantations are now providing an indication of potential in Shepparton and Deniliquin and are improving the basis for assessing the potential of other areas.
1. **ESTABLISHMENT**

CFTT managed studies and plantation operations have resulted in a good understanding of the principles in the establishment of flood irrigated plantations. These comprise deep ripping to increase soil rooting volume, mounding to elevate young seedlings and improve soil friability (Stackpole 1998, unpubl.3), and to direct irrigation flows. Weed control was found to have the dominant influence in plantation getaway in a weed control by fertiliser trial at Undera in 1990. Fertiliser had only a small additive effect (R. Borschmann pers. comm). Without weed control, all treatments grew poorly in the first growing season, and did not appear to recover from their initial set back. Survivors were both stunted and moribund five years after establishment.

The success of weed control can be variable for any given method, due to the range in site types and management histories. The basic operational objective is to maximise crop tree growth by reducing competition, particularly during the plantation establishment phase. Actions include minimising live weed and seed load, the use of residual herbicides to destroy germinating weeds, and timely control of any weeds surviving these initial treatments. Contractors deal with particular weed issues within this framework. Few herbicides are, as yet, certified for irrigated tree crops. This is unlikely to change in the short term as crop areas are small and, thus, there is insufficient demand for certification of key chemicals.

Sites that are intended to be flood irrigated, whether by border check or contour systems, usually require laser grading to facilitate water flow. The A horizon is removed prior to setting the subsurface layers to a consistent slope. The A horizon is relaid over the site. This process rarely results in even redistribution, and areas can grow variably depending cut and filled areas. The use of dripper or spray irrigation does not require laser grading and can hence be used on undisturbed ground. This may result in more even crops. However, ripping and at least small mounds are still recommended for irrigation areas.

Containerised seedling production systems which emphasise root training, appropriate nutrition and generous root:shoot ratio, such as Lannen®, appear to be entirely satisfactory for use in irrigation areas.

2. **MANAGEMENT**

Effective weed control in the first year, and complete, timely irrigation can produce a vigorous stand within 12 months, and may negate any need for second season weed control. Regular irrigation is required in the establishment year to ensure rapid site occupation. This requires a specific commitment from the landholder. Landholders frequently express the desire to reduce irrigation volumes in the years after the establishment phase. This is understandable due to water costs, but such economy invariably results in tree growth loss.

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3 Stackpole, D.J. (1998). Effects of mounding and weed control on growth to four years of age on irrigated *E. grandis* and *E. globulus* at Nathalia, Victoria. Centre for Forest Tree Technology (unpubl.).
Stand nutrition research by CFTT on irrigated and other sites is contributing to the development of a database which will allow diagnosis of nutrient status using foliar analysis. Aspects of fertiliser application rate and timing, efficiency and cost-effectiveness remain. Effective systems for monitoring and managing stand nutrition are required.

3. **SAWLOG AND VENEER LOG SILVICULTURE**

Given the present trend of relatively small, landowner-managed forested areas on individual farms, silvicultural management has been diverted towards production of higher value logs, where possible, rather than pulp wood crops. This is because there is a view that quality sawlogs can be sold more profitably than pulpwood to existing or potential local hardwood millers.

Methods for managing eucalypts for sawlogs have been adapted from those used in *Pinus radiata*. CFTT established three sawlog regime trials in north-central and north-east Victoria in 1992-93 (Stackpole et al. 1995). These have shown that volume growth of selected crop *E. globulus* and *E. grandis* responds well to heavy thinning at three years of age, at which stage stand height was 10 to 12 metres. An older and less vigorous stand did not display such strong reaction to heavy thinning at age seven (Baker and Stokes, unpubl.). Pruning of branches to 7 cm stem diameter at pruned height over bark (DPHOB), commencing at age three, reduced growth of *E. globulus* and *E. grandis* in comparison to pruning to 12 or 17 cm DPHOB. However, the 7 cm treatment, which removes branches from a greater length of stem early in the rotation, results in fewer pruning visits being required. This results in a saving of pruning costs, and may compensate for the loss of growth (Stackpole et al. 1999).

Conventional specifications for pruning silviculture rely on simultaneous removal of non-crop trees at the time of pruning. This is because the unpruned non-crop trees may have a competitive advantage relative to the pruned crop trees. However, this may not hold for eucalypts. A concurrent trial in Tasmania showed that when half the length of green crown was pruned from dominant *E. nitens* trees, growth did not diminish relative to unpruned neighbours (Pinkard and Beadle 1998). The current thinning trials include treatments to test if *E. globulus* and *E. grandis* behave in the same manner; if so, regimes growing both pruned sawlog and a mid-rotation pulp crop might be possible. The trials are too young as yet to confirm this possibility.

Prescriptions for sawlog production have been produced from this work. These include the need to select and prune (to 10-12 cm DPHOB) a selection of the best trees (400 tph proposed at present) at the first stage that potential crop trees can be identified (at 10-12 metres height). Whether pruning may continue on all 400 trees, or a smaller subset of these, is likely to depend on the productive capabilities of the site. A second thinning of the smaller selected trees is considered likely especially on low productivity sites.

Pruning of branches while still green and of relatively small diameter (<2 cm) produces a pruning wound that appears to be less susceptible to degrade due to infection than larger wounds in Tasmania (Gerrand et al. 1997). At the establishment stockings in the CFTT trials (1250-1333 tph) branch diameter at stem diameters of 12 and 17 cm are usually well above 2 cm. Hence the prescription of pruning to stem diameter of between 10-12 cm DPHOB was selected, allowing for the lower size to be used if branch thickness was excessive.

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4. POST, POLES, PULP AND BIOFUELS SILVICULTURE

Silvicultural methods for fuel, post or pulp crops usually assume no pruning or thinning. They can be managed as coppice regrowth. Management of effluent irrigated coppice at Shepparton gave several responses after two years (Duncan et al. 1999, unpubl.5). The first was that coppice growth is 1.2 to 1.7 times faster than equivalently aged seedlings, and the second was that unthinned coppice stumps produced 1.8 to 3.6 times the volume produced where coppice was thinned to one stout stem. However, the singled coppice produced excellent stem form compared to clumps or seedlings, with very fine branching. As coppice or seedlings, denser stockings can initially accumulate biomass at a faster rate than lower stockings, however within two years the gap is closing swiftly, and no productivity benefit is expected by radically high stockings.

Biomass or coppice plantation layout and design is dependent upon the objectives of site management; and the proposed dimensions of feedstock, which might be dictated by handling systems.

PROTECTION

1. PATHOGENS

Old (1990) reviewed diseases of plantation trees and found known species causing occasional problems in irrigated plantations. A new (tentatively assigned to Selenophoma sp.) variety was observed in 1994 at effluent-irrigated plantations at Wagga, Bolivar and Dubbo. It defoliated on certain provenances of E. camaldulensis, leaving other species and provenances alone (M. Dudzinski, pers. comm.). These sites used spray irrigation that may have increased the risk of foliar diseases. Irrigated plantations are probably more susceptible to root pathogens than rain-fed plantations because of their frequently moist soil conditions. All monocalypt species planted in a species trial at Undera in 1990 had failed to survive to three years (Borschmann, pers. comm.). This is in strong contrast to most Symphomyrtus species, which display excellent survival and growth. As those monocalypts tested have a preference for well drained soils, it appears likely that the soil texture at the Undera site, combined perhaps with enhanced soil pathogen behaviour, contributed to their downfall.

CFTT studies in Victorian irrigated plantations, seeking wood decay and leaf diseases, have found virtually nothing of concern, despite the high volume of irrigants applied at times.

2. **ENTOMOLOGY**

Insects can partly or completely defoliate stands, with significant effects on productivity. The autumn gum moth *Mnesampela privata* is a typical defoliator, which is mainly active in autumn months on *E. globulus* and *E. benthamii*. Populations of the steelblue sawfly *Perga affinis* can build over several eplet seasons to numbers that can completely defoliate stands. Neumann and Collett (1997a,b) have reported results of insecticide treatments for autumn gum moth and steelblue sawfly in young irrigated plantations near Kyabram and Nathalia in north-central Victoria. Both species typically hatch *en masse* in early autumn and, at this stage, can be controlled with low concentration insecticide dosages. An aerial application trial proved successful against *Perga affinis*.

The leaf blister sawfly *Phylactaeophaga froggatii* is typical of insects that are difficult to control economically with insecticide due to an extended adult emergence cycle and the inaccessibility of its larvae to contact insecticide. *P. froggatii* has proliferated on *E. grandis* and *E. saligna*, particularly in the Deniliquin area, and effective means of control are unavailable. Psyllids such as *Cardiaspina* and *Glycaspid* species may not defoliate stands to the same degree, however the impact on growth of heavy infestations of these may be significant. Control of these is possible using stem injected systemic insecticides, but this is impractical on plantations. Some success in controlling leaf blister sawfly and psyllids (in *E. camaldulensis*) has been achieved using contact herbicides in trials (Floyd *et al.* 1994).

While some natural insect predators exist for all the species indicated above, little is known of their actual or potential role in controlling insect pests.

The major insect pests of eucalypts in south-eastern Australia have been described in a series of four page colour leaflets prepared by Farrow (1996). Farrow (1997) reported on insect threats to the main eucalypts grown in irrigated plantations in the Shepparton-Deniliquin area, and also briefly describes a range of management options. Farrow *et al.* (1994) described possible genetic differences in resistance to grazing by *Mnesampela privata*, of *E. globulus*. A King Island provenance was determined to be resistant in a trial at Undera. However, under heavy grazing cycles, as foliage was consumed, this too was eventually grazed.

CSIRO Entomology currently has two projects funded by Joint Venture Agroforestry Program. One is examining the impact of insect pests on eucalypts in the Murray Valley. The other is identifying pest-resistant eucalypts using near infrared spectroscopy on an aerial platoform. The intention is to locate candidate trees for inclusion into breeding programs.
CONCLUSIONS

Site selection by models is still in development. Strategic planning models have the potential to give rapid assessments of the amount of land suited to certain tree crops within a given district or catchment. However, the models are not so good at processing the real situation which comprises hundreds of small growers with greatly varying objectives, management and land characteristics. At this stage, site selection is still largely at the paddock level, where principles such as soil drainage and texture, ease of irrigation, and the landowner’s commitment still rank highly in achieving success on a given site.

Model validation depends on whether existing stands can provide growth data of sufficient period to validate early curve predictions. If they are too young, their management ought to be funded to continue through to the age at which they can, rather than start new sites again.

Silvicultural practices have proven not to be too far removed from established norms of cultivation, establishment and management. Presently there are many areas which could be refined to improve cost effectiveness, however the industry is as yet too small to warrant extensive research and development until a particular growing option, if any, is taken to the next level by a group of growers.

Perhaps of most interest in the irrigation areas and further afield are:

1. The eucalypt sawlog silviculture projects.
2. The development of foliar analysis for nutrient deficiency and amelioration.
3. Protection from insect pests is an area of great concern given the erratic and occasionally heavy outbreaks, the public’s concern with insecticide spraying, and uncertainty of insect dynamics in the event of establishment of much larger areas in close proximity.
4. The losses of growth resulting from attempting to ration irrigation water supply.
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Summary and Conclusions from Discussion of
Site Selection and Silviculture

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In determining the current issues and impediments for site selection criteria and silvicultural concerns in irrigated areas, the general priority remains the concentration on species productivity in relation to site capability with consideration of the end-use product. Assuming the end-use products could be traditional wood produce (ideally high value products such as saw logs), or non-wood products (such as increasing the opportunity for biological diversity, or optimisation of saline water), several key site selection and silvicultural issues have been identified in the preceding review paper by Stackpole and Booth. Here we summarise the conclusions from further discussion at the workshop.

Priorities

Site selection

• Site and species suitability leading to estimation of potential productivity. We need to concentrate on developing a good understanding of likely growth characteristics of current species across a range of sites. Some work has already been done (eg TFP sites, individual organisations research), and further coordination of existing projects is essential. There is a need to maximise use of existing trials and improve the soil information available from these and new trials (especially for model development).

Establishment

• Fertiliser at establishment. Development of better understanding of the benefits of establishment fertiliser to young trees.

• Weed control. Acknowledged as essential in the first season (six to twelve months), there is still scope to develop a more integrated approach for weed management.

Nutrition

• Fertiliser and nutrition. General fertiliser requirements concerning macro- and micro-nutrients must be related to species and site characteristics. Thus site specific management for continued long-term survival, growth rates and potentially wood quality can be achieved.

• Modelling requirements. To model long-term nutritional requirements for different species across sites, continued data is required for development (including parameterisation) and application of suitable nutritional models.

• Diagnostic tools. The development of diagnostic tools that will allow for comprehensive and consistent measurement at different sites will improve general knowledge for managers whilst feeding into the model development. These models will allow for better management of existing trials.
Pruning

- **Stem conditions.** There is a need to determine improvement of wood product via optimal pruning timing and operations (considering reduction of stem damage with improved form).

- **Stem degrade.** A better understanding of the processes involved in stem degrade in short and long-term rotations is required.

Pests and diseases

- **Monitoring and control.** Employment of successful monitoring and control program for new plantings. There are concerns over long-term impact of disease and pests in single species plantations, especially in low rainfall areas.

- **Development of resistance.** Use of monitoring to identify and capture insect resistant phenotypes for subsequent tree improvement programs.

Irrigation

- **Scheduling.** Optimised irrigation scheduling from suitably applied water is required for long-term viability of plantations. For example, aspects of root development (minimising wind-throw, accessing ground water, reducing potential water stress) will be determined by irrigation applications.

Existing trials

- **Value.** There are considerable resources and value in existing trials. Further consideration of (limited) resources should consider ongoing monitoring, especially considering longer term issues such as pruning and disease. Also, to understand wood properties via measured growth rates and characteristics, the established trials are an essential source of advanced information.

Impediments

Several impediments exist in achieving the identified priorities for site selection and silvicultural research in irrigated areas of the southern Murray-Darling Basin:

1. The most pressing impediment is a lack of standardisation across trials in these areas. The inclusion of a small block of two or three key species, in a standard design in each trial, will provide some benchmark information for comparisons between trials.

2. Associated with this is an incomplete geographic coverage in these regions and indeed nationally.

3. Many trials are young (< five years of age) and extrapolation of data for long growth periods is difficult and risky.

4. We need to identify a minimum data set from ongoing and establishing trials to allow for an integration of the research. In addition we must allow for increased species and geographical understanding, and modeled output capabilities. The idea of minimum data sets of growth and environment measurements needs to be furthered through the existing Regional Plantations Committees and their planting activities.
Irrigation Management of Plantations in the Southern Murray-Darling Basin

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INTRODUCTION

Water is the factor most limiting establishment and growth of plants in the low rainfall (< 600 mm) areas of the southern Murray-Darling Basin (MDB). In agricultural systems, water stress suppresses crop yields up to 70% of potential levels (Boyer 1982). Efficient use of water is a major requirement for managing the long-term economic viability of plantations in the southern Murray-Darling Basin (MDB). For (irrigated) plantations to succeed ‘...planting must be driven by profitability’ (Anonymous 1997). In much of the MDB irrigation will be required to achieve commercial rates of growth for conventional wood product markets (for example wood chips for pulp production, or sawn timber).

A primary consideration for irrigated plantations is the availability and cost of water. In the Coleambally, Murrumbidgee, and Murray Irrigation Areas, water for temporary licenses costs about $10 to $20/ML (Bratby 1997). The cost of water for a temporary transfer varies significantly and is season dependent, but can exceed $70/ML during peak demand.

Sources of saline water include bore water pumped from shallow aquifers (Bratby 1997), and diverted drainage water. Irrigation with sewage effluent presents a specialised set of conditions requiring careful management of water, nutrients, and salt to maximise plantation productivity without causing environmental harm. Its use and a discussion of issues has been covered elsewhere and is not dealt with here. This review considers the use of fresh or saline water to irrigate plantations with the primary purpose of growing a commercial tree crop.

WATER DEMAND AND GROWTH

The water balance of a plantation can be calculated as:

\[ I = RO + E + D + \Delta S \]  

(1)

where \( I \) is total water input (irrigation + rainfall), \( RO \) is surface water run-off (collected in the tail drain), \( E \) is evapotranspiration, \( D \) is deep drainage below the root zone, and \( \Delta S \) is change in soil water storage, all units in mm or ML/ha.

The combined evaporation from soil (\( E_s \)) and through plants (transpiration, \( E_p \)) gives total evaporation (\( E_t \)), also termed evapotranspiration (E). A few days after irrigation when deep drainage and runoff have subsided, the daily-change in moisture (\( \Delta S \)) approximates total evaporation (\( E_t \)) and effectively becomes the daily water use rate. Measurement of change in soil water content can then be used as the basis for irrigation scheduling.
In the Deniliquin region, net irrigation demand under flood irrigation is predicted from the WATLOAD2 model of water balance (Theiveyanathan and Myers, unpubl.) to be 14.4 ML/ha/year (1440 mm/yr). This volume far exceeds expected operational rates of irrigation, generally in the range 4 to 8 ML/ha/year. The question then becomes - how can this sub-optimal volume of water be used to maximise growth responses?

A key issue is the relationship between growth and volume of irrigation, particularly when sub-optimal irrigation may induce stress at some times of the year. Different hardwood species will react differently to water stress through adapted phenology (Honeysett et al. 1992, Myers and Landsberg 1989). Whereas species may avoid drought through stomatal closure (Wang et al. 1988), or by root development to maximise available water in soil (Pereira and Koslowski 1976), in low-rainfall areas the response to increased water availability is marked.

Near Deniliquin, growth of three-year-old Eucalyptus grandis increased linearly as the volume of flood irrigation applied increased from 0.5 and 7 ML/ha/year, there being about a three-fold difference in growth. With about 7 ML/ha applied, current annual increment between three and four years was 19 m³/ha/year. At the Wagga effluent-irrigated plantation (Myers et al. 1996), E. grandis was spray-irrigated either weekly or twice per week with micro-jet sprinklers. Mean annual increment after four years was 23 m³/ha/year for an average annual application of 8.9 ML/ha/year, this being the rate of water use less rainfall. When this rate was lowered to 5.3 ML/ha/year (a 40% reduction in water application), growth decreased to 18 m³/ha/year (a 22% reduction). Thus, decreasing irrigation made more efficient use of the irrigation water while still achieving respectable growth rates.

WATER CONSERVATION STRATEGIES

1. IRRIGATION SYSTEMS

Water can be supplied to the plant in various forms. The type of delivery mechanism depends on site geography, type and availability of the water source, cost of infrastructure establishment and maintenance, and historic attachment to a particular kind of system. In Australia, plantations have been irrigated successfully using flood, drip, and micro-jet spray systems. Generally drip irrigation has been favoured because most soils lack the properties that will allow flood irrigation, and spray irrigation can incur high maintenance costs, and is less compatible with forestry operations than are drip systems.

Surface irrigation is often favoured on heavy, slowly permeable soils. This can entail broad-scale flood irrigation whereby several hectares of plantations are fed from a single outlet, to furrow and siphon irrigation systems where water flow is confined to small channels running along the planting line. This reduces runoff, evaporative loss, and enables smaller volumes to be applied per irrigation. For flood irrigation, water flow across bays can be controlled in irrigation design by determining the grade and furrow (bay) length. Lyall and Macoun (1995) indicate typical grades for furrow irrigation depend upon soil type - changing from 0.05 to 0.25% for clay soil, to 0.15 to 0.6% for
clay loam, to 0.3 to 1.0% for a sandy loam soil. In operation, the supply head (height of water supplied from the channel) will influence the flow rate across the bay (or down the furrow). Surge irrigation (Bishop et al. 1981), where the water is released at intermittent rates into the furrow, can increase uniformity in the rate of movement along the furrow to the end of the bay. This will improve the efficiency of application, delivering water in a more even fashion along the bay.

Flood irrigation generally operates on land with a fall between 1:2000 and 1:500, and is recognised as the least efficient method. Water can be lost as runoff, evaporation from ponded water during irrigation and subsequently from soil, and deep drainage.

2. **EFFICIENCY - THE KEY TO SUCCESSFUL IRRIGATED PLANTATIONS?**

To maximise conservative use of water, two types of efficiency need to be considered.

1. **Irrigation efficiency (IE)** — the proportion of water applied that remains in soil, viz:
   \[
   IE = \frac{\Delta S}{I},
   \]
   where \(\Delta S\) and \(I\) are as defined before.

2. **Water use (transpiration) efficiency (WUE)** - volume increment or net primary production produced per unit of water transpired, viz:
   \[
   WUE = \frac{G}{T}
   \]
   where \(G\) is plantation growth (m³/ha or t/ha) and \(T\) is plantation transpiration (mm or ML/ha).

The two efficiencies are not independent from each other. Growth is dependent upon transpiration, which in turn depends upon changes in soil water content - related to the term \(\Delta S\). The magnitude of IE is determined by: (i) type of irrigation system used, (ii) irrigation strategies, and (iii) season. WUE is primarily determined by (i) species selection, and (ii) season. Having selected the type of irrigation system to be used and species to be planted, manipulating the irrigation strategy among seasons offers the best opportunity for maximising conservative use of water.

Data from near Deniliquin (Theiveyanathan et al. unpubl.) indicates for a range of sites that IE is only about 0.3 (30%) under flood, a large proportion of the applied water being lost to runoff and drainage. Broad-scale irrigation generally adds about 1.5 to 3 ML/ha in a single application, a gross excess for shallow soils with limited water storage capacity. If we assume water costs $20/ML, efficiency of the flood system determines the cost of irrigation. Most cost savings are realised when irrigation efficiency increases from 0.2 to 0.6. Thereafter increases in efficiency become less important. It should be noted that, if drainage water is captured and recycled, this effectively increases irrigation efficiency, as much of the runoff is counted as a loss.

Alternative irrigation systems being investigated to increase the available water include furrow irrigation with siphons and a hybrid system of a laser-graded furrow. Drip irrigation conserves the most water but its use is not widespread in regions where flood irrigation is traditionally used. However, with the higher efficiency of drip irrigation compared with flood and probable increasing water prices, drip-based irrigation systems can be expected to gain wider acceptance.

A potential reduction of root development in agricultural crops is a limitation of the drip system (Bresler 1977). Root development is an important consideration in irrigated plantations and photographic evidence of the limited root development of irrigated *E. camaldulensis* and *Casuarina*
cunninghamiana suffering from wind throw as height increased with age indicates this is a significant issue (Stewart et al. 1988). Baldwin and Stewart (1987) found that in effluent-irrigated E. grandis, roots were most concentrated in the top 0.3 m of soil, declining rapidly with soil depth.

3. SCHEDULING — HOW MUCH, WHEN, AND HOW OFTEN

Regardless of the type of irrigation system chosen, optimising timing and frequency of application is essential for conservative and economic use of water. Irrigation scheduling involves an estimation of future short-term climatic conditions and an understanding of current plant water requirements (Heermann et al. 1990). The particular method chosen to schedule irrigation will be determined by management objectives that might include maximising growth, utilising all available water, leaching salts from the root zone, and promoting root growth. Scheduling of irrigation can allow for induced crop stress to yield specific results. Such ‘deficit irrigation’ is used in viticultural production (Goodwin and Jerie 1992).

There are three main methods to determine when to irrigate a crop/plantation (Gregory 1988):

1. Measurement of soil water content or potential
2. Assessment of the plant’s condition/stress indicator
3. Climate-based models.

Methods to measure soil water range from those taken with simple tools (for example a soil auger), to more complex tools that record volumetric soil water (neutron moderation meters, capacitance probes or other dielectric methods) or soil water potential (tensiometers or gypsum blocks). Two systems particularly suited for down-profile measurement of soil water content in plantations are: (i) the neutron moderation method, and (ii) frequency-domain systems. Much more is known of the neutron moderation systems and their use in periodic measurement. However, the frequency-domain systems as described by Paltineanu and Starr (1997) are well suited for temporal measurement of soil water content. It is important that regular measurements are recorded to allow improvement in irrigation scheduling and soil/plant management decisions.

Climate-based scheduling methods take account of the relationship between climate and potential evaporative demand. The Penman-Monteith (P-M) equation (Monteith 1965) provides a mechanistic assessment of water use, and hence irrigation demand, but the input variables required for its calculation are not always available. For this reason, more widely-available data from pan evaporation is often used as a surrogate. However the relationship between evaporation measured from a pan and that calculated from the P-M equation varies across climatic gradients because stomatal response to a changing climate is not reproduced by pan evaporation processes (Myers et al. 1996). To overcome this complication, Theiveyanathan et al. (1998) developed the WATSKED2 model by calibrating the P-M equation to measured water use at the Wagga effluent-irrigated plantation. This relationship was then used to calculate monthly pan coefficients (the ratio of water use to pan evaporation, otherwise termed the crop factor) for a range of sites around Australia where long-term climatic data was available. The pan coefficient, unique for 10 biogeoclimatic zones in Australia, can then be used in conjunction with measured pan evaporation to schedule irrigation.

WATSKED2 (Myers et al. 1999) was developed for irrigation with effluent where the primary purpose usually is to maximise application of water. In commercial plantations irrigated with fresh water, the main aim is to conserve water, maximising its efficient use for optimum growth. Scheduling irrigation to achieve this then becomes a more difficult proposition. Methods need to be developed that allow flexibility in the timing, volume, and frequency of application. Moreover, some knowledge of variation in WUE among seasons is needed. For example, suppose that a
planted owner/manager uses 6 ML/ha/yr for irrigation. When should this be applied (timing of application), in what amounts, and how often (frequency of application)? There is some evidence from trials at Deniliquin and Wagga Wagga that irrigation in the autumn and spring will maximise efficient use of water, and that WUE will be least in summer.

Tree species respond to water stress with different strategies. Water stress effects on Eucalyptus seedlings include increasing the root/shoot ratio, increasing water use efficiency, decreasing stomatal conductance, decreasing growth rates of stems and foliage, and decreasing transpiration rates (Blake 1977, Bachelard 1986, Myers and Landsberg 1989). Some species may be more efficient in their water use compared to other species, for example, E. globulus is more water efficient than E. nitens and with a better growth rate if soil water conditions are similar (Honeysett et al. 1996). Both species control water loss by reducing transpiration when water is limiting. E. nitens is more conservative than E. globulus and therefore grows at a slower rate in comparable conditions (Cromer 1996). However E. globulus is more prone during severe drought (White et al. 1996). Further consideration of differences between provenances (eg E. microtheca (Tuomela and Kanninen 1995)) in response to water stress also needs consideration. The difference between WUE among species and provenances has been observed in initial growth rates (to 24 months) of irrigated eucalypts in the Deniliquin region indicating growth of E. globulus > E. grandis > E. camaldulensis > C. maculata (George and Johnson, State Forests of New South Wales, unpubl. data). Optimum growth (between and within species) will be more readily achieved by reducing the duration and severity of water stress.

Soil type and depth is a primary determinant of the irrigation strategy. In the Deniliquin region many of the sub-soils are alkaline, saline, sodic, massive clays (R. Falkiner, CSIRO, unpubl. data), unfavourable for penetration by roots. Measurement of a wide range of soil hydraulic dynamics indicate that soil water is not being extracted below about 1 m. Under these circumstances, soil has a limited capacity to store plant available water. Flood irrigation can easily exceed soil water holding capacity, increasing groundwater recharge and wasting a limited resource. For example, when a site with run-off (RO in equation 1.) excluded was irrigated twice per year (once every three months during the irrigation season), 25% of the applied water was lost to drainage. When the irrigation frequency was increased to once per month (seven irrigations/year), the proportion of water lost to drainage increased to 50%. This was due to soil remaining relatively wet between monthly irrigations, but plant available water decreasing to growth-limiting levels.

For these shallow soils, irrigation needs to be frequent (every seven to 10 days) and in small volumes (0.3 to 0.5 ML/ha for example), in order to maximise growth while minimising drainage. On deeper, sandier soils, trees are able to utilise water from deep in the soil profile for some time, and irrigation needs to be less frequent (eg every 30 days).

This generalised result is supported by the modelling analysis of Sands et al. (1999) who used the Promod model to describe relationships between growth and irrigation for E. globulus growing in the Deniliquin region. Maximum growth (and profitability) was achieved when irrigation was applied every two weeks during the irrigation season. Excellent (qualitative) growth rates have been observed in a plantation established near Narrandera in September 1997 that has received about 10 to 14 applications of water during the spring-autumn period (F. McDonald, MRFF, pers. comm.). Irrigation was applied by siphons down furrows to supply a total of about 4 ML/ha (qualitative assessment by landholder).
SALINE WATER

Two types of saline water are available for irrigation - bore water and drainage water. The primary advantage of both these sources is that they are essentially free. Use of drainage water has the added advantage that it reduces the salt load into rivers, and pumping of groundwater can lower shallow watertables.

Irrigation with saline water presents the problem of accumulation of salt in the root zone, particularly with under-irrigation. Under most circumstances salt will have to be occasionally leached (White 1987). The amount of over-irrigation required is termed the 'leaching requirement' (LR) or 'leaching fraction'. LR depends upon: (i) salinity of the irrigation water, (ii) the threshold soil salinity — a species-related property that determines the soil salinity above which the reduction in growth becomes unacceptable, and (iii) rainfall. As the threshold soil salinity decreases and irrigant salinity increases, LR is increased, sometimes to very high values at low threshold salinities. Under these circumstances over-irrigation must be substantial, increasing groundwater recharge. Management considerations include choice of an appropriate species, knowledge of the relationship between growth of that species and soil salinity, and irrigation with water of appropriate salinity (mixing with fresh water if necessary).

CONCLUSIONS

1. In the low rainfall regions of the southern Murray-Darling Basin (< 600 mm), plantations will need to be irrigated to achieve commercial rates of growth for conventional forest products, unless tree roots can access groundwater.

2. The potential demand for water is high in these regions (10 to 14 ML/ha/year), greater than the 'acceptable' volume of water that would be expected to be applied. Consequently trees will be water limited during certain periods of the year, especially during summer.

3. When sub-optimal volumes of water are to be applied, irrigation needs to be scheduled to maximise growth/ML applied while minimising groundwater recharge.

4. As the cost of water rises and supply becomes less certain, broad-scale flood irrigation may find it difficult to compete with other methods, having a low irrigation efficiency and not being amenable to the application of small quantities of water in a single event. Surface irrigation remains a viable method, providing the irrigation infrastructure and application strategy can utilise water efficiently. Furrow irrigation using siphons is a good example of an efficient method. The rate of application can be adjusted by manipulation of the supply water potential (head) and the siphon size and number in furrows. Soil hydraulic properties need to be taken into consideration when designing fall across the field.
5. Under flood irrigation, growth is linearly related to irrigation between about 0.5 to 7 ML/ha/year of water applied. But as the frequency of irrigation increases, so too does the proportion of water lost to deep drainage. Under the more efficient spray irrigation, the growth response to irrigation flattens by about 5 ML/ha/year applied, and good rates of plantation growth are still achieved.

6. Irrigation scheduling needs to consider how much water to apply, when to apply it, and how frequently. Indications are that, for shallow soils or where subsoil properties are not conducive for root penetration, frequent irrigation in small volumes, concentrated in spring and autumn, will maximise growth per ML of water applied. This will also minimise losses to deep drainage and, for flood irrigation, losses to runoff.

7. Most scheduling methods have been designed to maximise use of water, such as for disposal of effluent, and not for sub-optimal application of water. A significant challenge remains to describe the relationship between irrigation strategy and plantation growth, and to develop appropriate scheduling tools.

8. Saline water pumped from shallow aquifers, or diverted from runoff, are two cheap sources for irrigation, and their use might be expected to increase. Careful consideration needs to be given to potential accumulation of salt in the root zone, the consequent need for leaching, and implications for groundwater recharge.

REFERENCES


Summary and Conclusions from Discussion of
_Irrigation Management of Plantations in the Southern Murray-Darling Basin_

Jim Morris
NRE Centre for Forest Tree Technology
PO Box 137, Heidelberg, Victoria 3084

Issues discussed at the workshop from paper of Polglase et al. included:

**Water and growth**

- Increasing water application increases growth rate in the water-limited environment of the southern Murray-Darling Basin, but the increase tends to flatten off at high application rates. Hence for a given volume of water it may be more productive to irrigate a larger area of plantation at a sub-optimal rate, than a smaller area at a luxury rate.

- There are practical limitations on the amount of water that can be applied, due to both limited infiltration rate on heavy soils and excessive drainage on sandy soils.

- Micro-irrigation appears to offer the most efficient means of application, but there are unresolved doubts as to root system configuration, tree stability and ability to leach accumulated salt from the upper profile.

**Salinity and growth**

- Saline drainage water or pumped groundwater may be a low cost source of water not subject to competition with agricultural crops.

- Saline root zone conditions will reduce tree growth rates, and the reduction may become substantial as salt accumulates in the soil over one or more irrigation seasons.

- Accumulated salt can usually be removed by leaching, as a result of either rainfall or heavy irrigation, but this implies an addition of water and salt to the groundwater.

**Irrigation scheduling**

- Timing of irrigation through spring, summer and autumn will affect both the proportion of water lost through drainage, evaporation and runoff, and the ability of trees to use the remaining portion for growth.

- Frequent irrigation using small volumes minimises drainage and runoff losses, but may lead to shallow root systems and surface salt accumulation, and makes unrealistic management demands unless an automated irrigation system is in place.

- The “trigger” for scheduling irrigation to avoid excessive moisture stress may be based on observations of climate, leaf or soil factors.
**Groundwater effects**

- Shallow groundwater provides a supply of water in addition to irrigation, if it is not too saline for tree uptake, and may strongly affect growth rates on favourable sites.

- Excessively shallow groundwater may lead to waterlogging during winter or after each irrigation, with detrimental consequences for tree survival and growth. This is particularly a problem if the groundwater is saline.

- Soil texture has a major effect on accessibility of groundwater, height of the capillary fringe and optimum watertable depth.

**Leaching prescription**

- Leaching provides a means of limiting the extent to which root zone salinity increases as trees use saline irrigation water or groundwater.

- Rainfall may sometimes be sufficient to provide an annual leaching of the root zone; irrigation applications can be designed to do the same thing, or to ensure leaching during each irrigation event.

- Irrigators will not usually have precise information on the relation between volume applied and effective leaching rate.

**Modelling**

- All of the above are amenable to examination by modelling if appropriately detailed, process-based models of tree growth, groundwater and soil conditions in relation to plantation management are available.

- Current models such as 3PG go much of the way towards meeting this need, but can be improved with additional data collection, validation and elaboration.

**Impediments and research priorities**

**Cost of water and limitations on available supply**

- More clearly define the irrigation strategies – volume, timing and frequency – which maximise irrigation efficiency and water use efficiency in different site conditions.

- Assess use of low quality water – effect on growth rate and soil salinity relative to scheduling/leaching rate, soil and groundwater conditions.

**Salt accumulation in the root zone of plants using saline water**

- Quantify dynamics of watertable and salinity changes beneath plantations, and effects on growth.

- Investigate leaching strategies for maintaining acceptable salinity in different soil and groundwater conditions without excessive recharge.
Installation cost of drip irrigation, familiarity with flood system

- Investigate institutional strategies for promoting adoption of more efficient methods, eg low cost loans, tax incentives, advisory/support services.

Competitive disadvantage against plantations on more favourable sites in Victoria and Tasmania

- Investigate marketing requirements and local processing possibilities; opportunities for new product development.

Uncertain plantation growth rates, yields and economic outcomes

- Further development, validation and application of modelling tools to quantify effects of environmental factors on growth, and point to limiting factors/potential for increasing productivity.
Solid Wood Product Quality from Plantation Hardwoods for Irrigation and Associated Dryland Areas of the Murray-Darling Basin

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INTRODUCTION

Over the past 15 to 20 years the timber industry in south-eastern Australia has become more reliant on resource from regrowth forests. With this change, technological changes have taken place in the industry to cater for a resource of logs with smaller diameter, higher growth stresses and increased drying difficulties. During this time the industry also changed from one dominated by the production of structural products to one increasingly focussed on value-adding for high-value appearance products. This change has steadily seen an increase in the resource value.

The improved processing techniques for small logs that accompanied these changes has provided the knowledge to seriously investigate plantation grown native hardwoods for high quality solid wood products in the cleared areas of Australia. CSIRO Forestry and Forest Products has used these techniques in past evaluation, and for ongoing research of a number of plantation species, particularly in the Murray-Darling Basin. High quality, high value products, which have potential to give growers good returns have been a key focus of this research because of the high transport costs likely in large areas of inland Australia.

This paper briefly discusses the findings of research in utilisation of plantation grown eucalypts from irrigation areas, the high-rainfall slopes and the medium to lower-rainfall areas of southern Australia. We introduce and discuss current and future research that is needed to answer a number of outstanding questions. While the paper considers high quality, solid wood products as the primary objective, the production of posts and poles, as a high-value thinning option, and reconstituted products are briefly discussed.
RESULTS

The results of several investigations are shown in Table 1. This shows recovery of dried, high quality appearance products which are graded as select or better according to CSIRO Appearance Grading Criteria (Waugh and Rozsa 1991). This category includes polishing and moulding grades as well as select grade which is the lowest quality grade traditionally accepted for high quality appearance products. The select grade is graded on one face and two edges and, while it allows small knots, tight kino and some surface checking, the grade is largely defect free. Table 1 also compares the current regrowth ash resource used by industry in Victoria using quarter-sawing as opposed to back-sawing of the plantation species. However, the grading and drying methods are similar to those used on the younger plantation resources. All native forest logs are equivalent to Victorian B and C grade, whereas the plantation logs are generally of lower quality with the best equivalent to B grade but with most lower than D.

Table 1. High-quality sawn product potential from different natural forest and plantation-grown eucalypts from CSIRO research studies.

<table>
<thead>
<tr>
<th>Resource</th>
<th>Age</th>
<th>Final dried total product recovery (%)</th>
<th>% of product of select quality or better</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural based forest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plantation-grown</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High rainfall, SE Aust.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E. regnans</td>
<td>31</td>
<td>26</td>
<td>7</td>
<td>Waugh and Yang (1993)</td>
</tr>
<tr>
<td>E. globulus</td>
<td>34</td>
<td>28</td>
<td>6</td>
<td>Waugh and Yang (1993)</td>
</tr>
<tr>
<td>Irrigation area, Nth Vic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E. saligna</td>
<td>25</td>
<td>35</td>
<td>55</td>
<td>Waugh et al. (1997)</td>
</tr>
<tr>
<td>E. grandis</td>
<td>18</td>
<td>33</td>
<td>42</td>
<td>Waugh et al. (1997)</td>
</tr>
<tr>
<td>E. camaldulensis</td>
<td>18</td>
<td>30</td>
<td>24</td>
<td>Waugh et al. (1997)</td>
</tr>
<tr>
<td>Medium/low rainfall MDB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. maculata</td>
<td>40</td>
<td>36</td>
<td>72</td>
<td>Washusen et al. (1998)</td>
</tr>
<tr>
<td>E. cladocalyx</td>
<td>36</td>
<td>28</td>
<td>63</td>
<td>Washusen et al. (1998)</td>
</tr>
<tr>
<td>E. sideroxylon</td>
<td>40</td>
<td>28</td>
<td>48</td>
<td>Washusen et al. (1998)</td>
</tr>
</tbody>
</table>

The results show relatively lower values for the regrowth native forest Eucalyptus regnans than some of the plantation resources. However, the recovery for industry is currently higher than given here because of further processing that upgrades lower quality boards through defect docking and lamination into larger-section products. This value-adding, to give recoveries that are similar to the plantation trees, comes at a cost estimated at around $500 per cubic metre of final product. The results show that some plantation species have considerable potential to have standing values much higher than the native forest regrowth resource, increasing optimism for viable farm forestry. Given better access and potentially lower harvesting costs on cleared areas than is possible in native forests, many species could be economically competitive with other land uses when integrated with agriculture.
1. THE IRRIGATION AREAS

In the irrigation areas and on sites with effluent irrigation, E. grandis and E. saligna have the greatest prospect of the species studied (Waugh et al. 1997). Both species have moderate to good branch shedding, although pruning would increase green recoveries. Drying degrade is also low and recent drying trials by Northway (1996) have been successful in kiln-drying E. grandis from green with little degrade. Other species studied include E. globulus, which is discussed in greater detail below. Further work is needed to evaluate E. dunnii.

2. THE MEDIUM TO LOW RAINFALL AREAS

In the medium to lower rainfall areas (580-750 mm) of the southern Murray-Darling Basin, Corymbia maculata, E. cladocalyx and E. sideroxylon have produced good results. All display good branch shedding in block plantations and very little drying degrade and light pruning is likely to produce good results with modest improvements in recovery of high quality products. C. maculata and, to a lesser extent, E. sideroxylon has also been kiln-dried rapidly from green, with very low levels of degrade. E. cladocalyx, which has very high density, needs careful, slow drying to prevent surface checking and distortion associated with changes in grain direction. All of these species are good prospects for ‘break of slope’ forestry and can thrive in recharge areas, although as soil depth declines growth rates drop off. The species have an added advantage in being able to survive fire. In comparison, E. globulus grown in the same areas has problems with drought and there is considerable doubt about wood quality, as serious drying degrade is common (Northway and Blakemore 1996, Washusen et al. 1998).

The most outstanding problem with both C. maculata and E. cladocalyx is frost damage in seedlings and, for E. cladocalyx and E. sideroxylon, tree form needs to be improved. The problem with frost may be overcome with good site selection as, even in areas with high frost risk, good stands can be found, particularly in mid to upper slopes where cold air drainage is good.

In the lower rainfall areas (400-600 mm), further research is about to commence to examine a number of other potential species. The combined area in the medium to low rainfall zone is estimated at 30,000,000 hectares in eastern Australia alone, primarily in the Murray-Darling Basin. If just 1% of this region were established with plantation forests, the resource area would amount to 300,000 hectares.

3. A SPECIAL CASE FOR THE SOUTH-EASTERN AUSTRALIAN HIGH-RAINFALL SPECIES

Not all the results have been good. Table 1 shows that the high rainfall species have presented a considerable problem, with low dried recovery of high quality products. Much of this can be attributed to branching defects such as green and dead knots, kino and decay. This may be reduced with pruning. However, drying degrade is a major problem, particularly for plantation grown E. globulus in southern Australia. Tension wood has been suspected as a problem in this species (Northway and Blakemore 1996, Washusen 1998) and was recently found to be very common in well grown straight trees in Mt. Gambier (Washusen and Ilic 1999, unpubl.). Research is essential to understand what factors contribute to tension wood formation, particularly in straight, vertical plantation trees. Growth stress and end splitting are related characteristics.

4. **UTILISATION**

(a) *Sawn products*

The wood characteristics and utilisation potential of the nine plantation species shown in Table 1, are summarised in Table 2. The wood density values given are lower than is expected for mature trees in all cases except for *E. cladocalyx* (Ozarska and Ashley 1998). This species density and MOE (Modulus of Elasticity) is around mature tree values. The MOE in all other species is lower than mature values, but still higher than many used for furniture.

Unit shrinkage values are high by comparison with mature trees. This would require special design features to allow for greater shrinkage in use with changes in humidity. The gluability of the high density *C. maculata, E. cladocalyx* and *E. sideroxylon* using conventional glues is poor. Further research is needed in this area.

(b) *Thinning and residues*

At this stage very little work has been conducted on the utilisation of thinnings for posts and poles. A Forest and Wood Products Research and Development Corporation (FWPRDC) project has commenced on *E. grandis, E. globulus* and *E. camaldulensis*. Long term, in-ground testing is essential to assess the effectiveness of a number of preservative treatments. Six-year-old *E. grandis* has already been treated successfully with three preservatives and it has shown potential for MDF and particle-board.

Table 2. Some critical attributes of plantation grown solid wood products.

<table>
<thead>
<tr>
<th>Species</th>
<th>Ref*</th>
<th>Age (Years)</th>
<th>MOE (Gpa)</th>
<th>Unit Shrinkage</th>
<th>Density (kg/m³ at 12% MC)</th>
<th>Gluability</th>
<th>Preservation of posts and poles</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>E. regnans</em></td>
<td>1</td>
<td>15-20</td>
<td>10.3</td>
<td>0.43</td>
<td>728</td>
<td>Very good</td>
<td>**</td>
</tr>
<tr>
<td><em>E. globulus</em></td>
<td>2</td>
<td>15</td>
<td>13.3</td>
<td>0.43</td>
<td>728</td>
<td>Very good</td>
<td>**</td>
</tr>
<tr>
<td><em>E. nitens</em></td>
<td>1</td>
<td>15-20</td>
<td>8.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>E. saligna</em></td>
<td>2</td>
<td>25</td>
<td>14.4</td>
<td>0.52</td>
<td>779</td>
<td>Very good</td>
<td></td>
</tr>
<tr>
<td><em>E. grandis</em></td>
<td>2 &amp; 3</td>
<td>22</td>
<td>12.3</td>
<td>0.47</td>
<td>720</td>
<td>Very good</td>
<td>**</td>
</tr>
<tr>
<td><em>E. camaldulensis</em></td>
<td>2</td>
<td>17</td>
<td>11.4</td>
<td>0.45</td>
<td>778</td>
<td>Very good</td>
<td>**</td>
</tr>
<tr>
<td><em>C. maculata</em></td>
<td>2</td>
<td>40</td>
<td>15.2</td>
<td>0.50</td>
<td>871</td>
<td>Poor</td>
<td></td>
</tr>
<tr>
<td><em>E. cladocalyx</em></td>
<td>2</td>
<td>40</td>
<td>17.4</td>
<td>0.48</td>
<td>1032</td>
<td>Poor</td>
<td></td>
</tr>
<tr>
<td><em>E. sideroxylon</em></td>
<td>2</td>
<td>40</td>
<td>10.4</td>
<td>0.44</td>
<td>934</td>
<td>Poor</td>
<td></td>
</tr>
</tbody>
</table>

*References:
1 Waugh and Yang (1993)
2 Ozarska and Ashley (1998)

** Research underway
CONCLUSIONS

Research into plantation grown hardwoods in the Murray-Darling Basin is far from complete. A number of outstanding issues need to be resolved and research will continue for several years to address these. However, from past research, a number of species have shown considerable potential to produce high-quality solid wood products in the irrigation areas and associated low-medium rainfall areas. They have shown an inherent capacity to produce high-quality solid wood products with good natural branch shedding, low levels of drying degrade and good strength properties even at young ages. These characteristics suggest good potential for development of solid-wood product resources that can be effectively used and marketed by industry.

ACKNOWLEDGMENTS

Much of this research has been supported by the FWPRDC and RIRDC. We acknowledge the many tree owners who have contributed to this work by allowing access to plantations and sampling.
REFERENCES


Discussion of the properties of wood products from irrigated plantations, after the paper “Solid wood product quality from plantation hardwoods for irrigation and associated dryland areas of the Murray-Darling Basin” by Washusen and Waugh, concentrated on the following issues:

1. Major species for consideration include *Eucalyptus grandis*, *E. saligna*, *E. globulus* and *E. camaldulensis* in irrigation areas. In lower rainfall areas (rain fed sites) *E. cladoalyx*, *Corymbia maculata* and *E. sideroxylon*. Of these species, *E. grandis* and *E. saligna* are currently proving the highest recovery of select grade material from irrigated plantations. In non-irrigated plantations *E. cladoalyx*, *C. maculata* and *E. sideroxylon* are currently providing the best select grade recoveries in southern New South Wales and northern Victoria. *E. globulus*, in both rainfed and irrigated plantations, has produced very poor recoveries due to knot defect and significant degrade during drying. Recent research has associated the drying problems of *E. globulus* with tension wood and that also significant differences have been found in drying performance between provenances.

2. Further consideration of the expected “end-products” for the planted forests is required. Are wood products the main output? If so, then concentrate on high value and increasing yield recovery processes.

3. Residues are currently considered with an emphasis on their use as pulp chip. We need to consider other markets for residue products, such as biomass energy, charcoal and medium density fibre.

4. Though beneficial associated values (eg biodiversity) may be obtained from plantings in medium to low-rainfall areas, wood products will still compete with products from existing markets and cost-benefits must be favourable for investment.

5. To develop long-term industry investment we still need to quantify the useable outputs (and their respective economical returns) and compare them to the input costs.

6. From 5. above, research therefore needs to quantify the cost effectiveness of silvicultural operations and their impact on end applications.

**Research Priorities**

Given the discussion of the above points, two key questions need to be addressed in focussing further research:

1. Who is the customer for products in medium to low-rainfall areas? What does the customer want? How do we consider the (financial) importance of the environment, biodiversity, wood products and other non-wood products?

2. We need to concentrate research in the 580 to 760 mm rainfall zone with more work required in the low rainfall areas (400 to 600 mm). In these mid- to low-rainfall areas it is imperative that research concentrate on high-value wood products, not wood chip.
Efficacy of Non-Irrigated Plantations for Salinity Control in the Riverine Plains of the Murray-Darling Basin

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BACKGROUND

Irrigation and clearing of native vegetation for dryland agriculture in southern Australia has led to widespread land and stream salinisation. An area of particular concern is the Riverine Plains Region of the Murray Basin. Watertables under some irrigation areas have risen about 20 m resulting in shallow watertables. Drainage and groundwater pumping to control groundwater levels, and hence salinisation, forms an important component of most irrigation areas. However, the cost of maintaining such schemes and difficulties of handling disposal of drainage water have led to the search for alternatives.

Plantations and agroforestry have been suggested as possible solutions for controlling groundwater levels and hence salinity (Greenwood 1986, Schofield 1992, Kapoor 1997). Undoubtedly, revegetation in dryland areas can lead to reduced recharge, which will eventually control salinity (Greenwood et al. 1985, George 1990, George 1991, Bari and Schofield 1992). However, their effectiveness is reduced when the groundwater systems are regional as they are under the Riverine Plains. Also, the continued use of irrigation, and the need for a leaching fraction of the area under irrigation, means that significant recharge will be occurring in any case. Hence, the only way in which plantations and trees as part of agroforestry can control salinity in these areas is through direct use of groundwater.

This can happen in two ways (Westcott 1988). The first is by tree roots extracting water from the watertable. The second is through groundwater pumping and the use of that pumped water for irrigation of plantations. Such plantations not only provide the benefits of timber and other wood products, hence diversifying the income base, but also provide public benefits of partial salinity control, as well as aesthetics and biodiversity. Should the level of salinity control and other public benefits be large enough, there may be the potential of sharing the costs of plantations between the landowner and the broader community, thus making plantations more economically attractive.

There are standard methods for estimating the benefits of salinity control in the irrigation areas of the MDB. Effectively, this equates to the level of groundwater control. In the case where tree roots are extracting water from the watertable, this partly offsets the need for groundwater pumping and hence the benefit is through being a biological groundwater pump. The amount of benefit is proportional to the level of groundwater use by the trees. In the case of groundwater pumping, there is the benefit of timber production and other wood products, ie trees as an irrigated crop. For this, the trees need to be compared to other irrigated crops. There is also the benefit of not needing to export the salt, generally back to the River Murray, but concentrating the salt within the root zone of the trees. In this context, the plantation can be considered as a green disposal basin. The benefit is proportional to the amount of salt retained within the local area. For this paper, we shall only consider the non-irrigated case, and hence, are interested in the amount of groundwater used by the plantations.

The efficacy of trees as biological pumps is dependent on a number of site factors. For this paper, we will restrict our attention to the Riverine Plains. Thus, the aim of this paper is to provide some discussion on the applicability of using plantations for groundwater control within the Riverine Plains of the MDB. A detailed case study at Kyabram will be described.
In the absence of other sources of water, the water use by vegetation in sub-humid and semi-arid environments is limited by the rainfall. Over the Riverine Plains, annual rainfall is in the order of 480 mm, much less than the potential evaporation of \(~1400\) mm. Where shallow water is available, it is possible for trees and other vegetation to supplement their water supply from shallow water tables. If water is freely available, the water use is then limited by the available energy. Thus, the water use of vegetation can vary from nearly rainfall to being close to potential evaporation as groundwater use varies from being close to zero to being constrained by energy availability. The growth of the vegetation is closely related to the total water use and hence can substantially increase should significant amounts of groundwater be used. Conversely, water use by trees is almost proportional to the leaf area (Hatton et al. 1998).

There are two important constraints in groundwater being freely used for transpiration. The first is the ability of the soils and groundwater to be able to deliver sufficient quantities of water to the tree. Over much of the Riverine Plains, the soils and shallow aquifers have low permeability and hence this is an important constraint. Where permeability is an important constraint, the trees will use the available soil moisture and lower watertables within the close vicinity of the plantation. However, the impact will not extend more than tens of metres. Such local drawdowns have been found to be common (George et al. 1999, Heuperman 1999, Stirzaker et al. 1999).

The second key constraint is salt accumulation. As groundwater is used, salt that is contained within the groundwater is concentrated in the soil zone. This causes roots to die back and increases the osmotic potentials against which the plant needs to extract water. Both lead to decreased transpiration and plant growth.

There have been several studies on groundwater use, salt accumulation and reduction in tree growth over recent years (Jolly et al. 1993, Thorburn et al. 1993, Heuperman 1995, Thorburn et al. 1995, Mensforth 1996, Mensforth and Walker 1996a, 1996b, Thorburn 1996, Thorburn et al. 1997, Benyon et al. 1998, Cramer et al. 1999, Heupermann, 1999, Khanzada et al. 1999, Morris and Collopy, 1999, Silberstein et al. 1999, Slavich et al. 1999a, 1999b and Zhang et al. 1999). The spate of recent studies have been due not only to the increased interest in plantings in areas of shallow watertables and risk of native ecosystems to salinity and water logging but also to the improvement in technology eg our ability to log changes in soil moisture and transpiration, use of isotopes to partition sources of plant water and better models to simulate water balance and plant response in presence of shallow watertables.

It is clear from these studies that the ability of eucalypts to use substantial amounts of groundwater decreases for total dissolved solids TDS greater than 5000 mg/L (eg George et al. 1999, Stirzaker et al. 1999). Such salinities are common across the Riverine Plains. The degree to which groundwater can be transpired is strongly related to the frequency of major leaching events (eg annual winter rainfall, floods) as these enable sustainability of greater water use.

The studies of plant water use in shallow watertable areas can be roughly divided into two categories; those with a regular annual leaching event (eg Mensforth and Walker, 1996a, Benyon et al. 1999) and those with a presence of a more or less permanent dry zone (eg Jolly et al. 1993, Heuperman 1995, 1999). The division into these two categories is dependent on a number of factors including permeability of soils and aquifers, salinity of the groundwater, movement of groundwater to surface water systems and salt tolerance of the vegetation.
Where the soil zone is regularly leached, the groundwater system is also regularly recharged. Whether there is a long-term nett groundwater, use is dependent on there being a salt export mechanism such as wash-off, drains, streams, etc. In the absence of a salt export mechanism, the shallow groundwater system becomes progressively more saline and direct groundwater use diminishes. Vegetation can transpire more water between leaching events and hence have increased growth. This can be compromised by the need for a dynamic root system which dies back as watertables rise to the surface and grow in response to salinisation of surface soils (eg Mensforth and Walker 1996b). There is a need for vegetation to be salt-tolerant, particularly to survive through extended dry periods.

Where there is a more or less permanent dry zone, watertables are generally deeper and hence the rate of salt accumulation slower. The time for the soil zone to be salinised can be decades (eg Jolly et al 1993, Thorburn et al. 1995, Stirzaker et al. 1999) ie on the same time-scale as plantation growth. Thus, in the initial stages, groundwater use may be higher and then decreases over time. This may also lead to a decrease in leaf area and growth. Early measurements and growth may lead to over optimistic estimates of the water use of trees in shallow watertable areas and hence their ability as biological groundwater pumps.

Thorburn (1996) reviewed all studies that measured groundwater use by vegetation, most of which included plants adapted to saline environments. He found that the groundwater use was generally not significantly greater than what would have occurred through bare soil surfaces. For most vegetation, transpiration rates were much lower than potential, even when water was available.

KYABRAM - CASE STUDY

More detailed descriptions of the case study may be found in Heuperman (1995), Connell et al. (2000) in press1, Heuperman (1999) and Silberstein et al. (1999).

In 1976, a 2.4 ha plantation of five Eucalyptus species (E. camaldulensis, E. botryoides, E. grandis, E. globulus, E. saligna) was established near Kyabram as a density trial and species and provenance trial. The plantation was irrigated for the first six years, and subsequently received rainfall, with occasional overflow from irrigation channels. It is estimated that the watertable was about 2 m below the surface at the time of planting (Heuperman 1995). In 1982 a network of piezometers was installed within the plantation and in the surrounding paddocks, revealing that the plantation had drawn down the watertable to around 4 m. Groundwater beneath the site now has a salinity ranging from 1000 to 10,000 mg/L within the top 10 m, but is mostly in the range 2000-3000 mg/L.

In 1994, an intensive two year field programme was commenced to quantify the effects the trees were having on the watertable, the water use and growth of the trees, and the effect the salt was having on the trees. Tree water use was intensively monitored at several locations throughout the plantation using the heat pulse method. Groundwater gradients were monitored in several piezometer transects and unsaturated zone water and salt movement was monitored using electrical conductivity sensors and capacitance instruments. These data allowed testing each of the components of the simulation model developed in the project.

Figure 1. Topog Dynamic simulates water and salt movement over the land surface, into the soil, through the soil and groundwater system, and back to the atmosphere via evaporation and transpiration. At the same time, it also predicts the growth of plants (trees, crops and grasses) and the effect that plants have on mediating water and salt movement. The growth of plants is, in turn, affected by the site water and salt balance, so feedbacks between vegetation growth and hydrology are represented.

Figure 1 illustrates the processes modelled for each element in a network. The model was shown to simulate well the water movement, solute transport, tree transpiration and growth at the Kyabram field site. The model was then used in prediction scenarios where a range of different properties and conditions were investigated.

The main conclusions from the case study are:

**Groundwater impact:**

- Watertable has been lowered significantly by the trees when compared to surrounding watertable levels.

- The spatial extent of this watertable control is limited to 40 m from the plantation boundary. This is primarily due to low soil hydraulic conductivities at the site.

- Watertable levels under the trees show a seasonal pattern, rising during winter and falling during summer; a trend more marked under the trees than in surrounding irrigated land;

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STATE FORESTS OF NEW SOUTH WALES
TECHNICAL PAPER NO. 65

COMMERCIAL AND ENVIRONMENTAL VALUES OF FARM FORESTRY IN THE MDB IRRIGATION AREAS 53
• The watertable is gradually rising underneath the plantation, due to trees using progressively less groundwater.

• There is an inward lateral and an upward vertical hydraulic gradient around and under the plantation respectively.

• Plantations can effectively control groundwater recharge. Plantation density could be determined for different sites to ensure that net recharge to groundwater is minimised.

Salt accumulation in the unsaturated zone:

• Salt has accumulated in the root zone. Zones of salt accumulation appear to be dynamic, the magnitudes increasing and decreasing on a seasonal basis in response to watertable levels, tree water extraction patterns, and influx of rainfall during heavier events.

• There is a dry zone within the root zone of the trees that is subject to little or no net leaching by infiltrating rain.

Tree water use and tree growth:

• Tree growth rates are relatively low for 20 year old trees (mean annual increments MAI=19 m³/ha/yr; best plots had MAI=22m³/ha/yr).

• Tree water use is relatively low (approximately 300 mm/yr). Trees are using more water than is provided by rainfall, indicating that they are using groundwater to meet their requirements.

• Salt balance and groundwater levels suggest that groundwater use may have been higher previously, so that total water use is about half the potential ET.

• Trees may be moisture-limited (indicated by low tree water use and leaf area).

• Limitations to growth at the Kyabram site are primarily a result of low soil permeability and high planting density. It is probable that the salt accumulation is decreasing the ‘availability’ of groundwater to the trees.

Conclusions from the modelling:

Simulations were carried out for a range of watertable depths and salinities, and for trees with different salt sensitivities. Conclusions include the following:

• Groundwater use is very sensitive to groundwater salinities.

• Tree growth and dieback is also sensitive to groundwater salinities.

• Trees used in a rotation with pasture may lead to salinity impacts on subsequent pasture periods.

• Simulations of the likely future of the plantation suggest that the site appears to have a time scale of about 20 years before the effects of salt accumulation and water limitation (caused by the low soil permeability) become apparent. This corresponds to the current age of the plantation at Kyabram, and indicates that the plantation growth is declining, albeit gradually.
Figure 2 shows results of simulations conducted on two plantation rotations. In the Figure, I indicates the first rotation, replaced by pasture in 1998 (indicated by the vertical dashed line), II the second plantation planted in 1998 in a neighbouring paddock, and III a site between the two which had irrigated pasture throughout. Figure 2(a) shows that when the first plantation (I) was removed and replaced by irrigated pasture, the salt which had accumulated within the root zone of the first plantation severely impacted on the growth of irrigated pasture which replaced it. The growth was substantially less than the site between them which had permanent irrigated pasture. Note also the watertable trace in Figure 2(c) which indicates the rise in the watertable under the replacement pasture, due to its much lower water use, and death. This result has severe implications for management of plantations in these areas.

![Graph of plantation response and groundwater dynamics at Kyabram.](image)

Figure 2. Plantation response and groundwater dynamics at Kyabram. The data are plotted for three domain elements, with I indicating the first plantation, II the site with the second plantation and III indicating permanent irrigated pasture. The vertical dashed line indicates the timing of the harvest and second planting.

Of the two categories of behaviour described above, the Kyabram site clearly falls under the more or less permanently dry zone. Salt accumulation rates are slow and correspond to previous estimates. This behaviour results from the relatively low salinity at the site, the salt-tolerance of the eucalypts, the low permeability of the aquifers and the lack of any sinks for salt in the area.
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

- The main public benefit of salinity control in non-irrigated plantations is through trees decreasing the amount of groundwater pumping or drainage that may need to otherwise occur for salinity control (trees as biological pumps).

- For the Riverine Plains, the key constraints to groundwater use by plantations is the ability for the soils and shallow groundwater systems to deliver sufficient water and salinity impacts.

- The balance between these two constraints is dependent on the permeability of the shallow soils and aquifer material, the salinity of the groundwater, the salt-tolerance of the systems and any other sinks for groundwater in the vicinity.

- The balance between these two will change in time as salt accumulates. It would appear that a time scale of one to three decades is required for salt accumulation in the Riverine Plains, roughly corresponding to the lifetime of a plantation.

- The lateral extent of any groundwater control will be limited to tens of metres.

- Groundwater use and leaf area will gradually decline over time.

Taken as a whole, the use of dryland plantations to control groundwater tables in shallow watertable areas will be limited to some favourable areas. Heuperman (1999) suggests that for sustainability, plantations will need to be rotated to different paddocks or placed at the periphery of a groundwater pumping scheme. However, the preliminary modelling results of Silberstein et al. (1999) suggest that there may be adverse salinity impacts on any pasture following a tree rotation. It may be that plantations irrigated with groundwater provide a better benefit, varying from its value as an irrigated crop where groundwater quality is good to its value as a green disposal basin where groundwater quality is poor. This is unclear at this stage.
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Summary and Conclusions from Discussion of
Efficacy of Non-Irrigated Plantations for Salinity Control
in the Riverine Plains of the Murray-Darling Basin

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The workshop highlighted both the negative and positive aspects of large-scale plantation development on local and regional streamflows. In general these can be summarised as:

(i) Trees have the potential of providing an alternative “standby” crop which can use excess irrigation water when it becomes available. Although hardly a “minimal care” crop, the relative robustness of trees is such that much tending could be undertaken in otherwise quiet times.

(ii) Trees offer a positive means of removing and evaporating excess water produced as a result of irrigation. This excess water may have salinity problems or be in a difficult topographic position. By irrigating plantations of trees the water can be used and an economic yield gained. The alternative would be dumping of the water into the regional rivers and drainage systems.

(iii) Trees have a more or less continuing demand for water, and this characteristic can give difficulties in periods when water is not always available. In severe cases it could mean that irrigated eucalypt plantations could suffer dieback and death.

(iv) Given the large number of alternative crops in many of the Murray-Darling Basin irrigation areas, it is unlikely that tree density in a catchment could ever be enough to have a regional impact on the catchment hydrology; rather the trees could be used to provide local amelioration.

The more detailed studies reported at the workshop indicate that trees can have a definite impact at the catchment scale, but that it is easy to over-estimate the magnitude of this. Thus although development of waste-water fed plantations may offer a useful method of waste reduction and help to allow infiltration of this water, it is unrealistic to expect that trees, by themselves, can solve all the hydrologic problems of the Murray-Darling irrigation area. Rather, they can be regarded as useful tools in what should be an extensive collection of tools. The paper by Walker, Silberstein, and Trewheila is an interesting combination of field research and modelling, and suggests that a long time span may be involved to obtain easily detected field results, and that heavy tree water use may also lead to an accumulation of salinity in the soil. The question of just how much water trees can extract from local groundwater is still not answered, but the results in the forum do set limits on these numbers.

Research Priorities

The workshop highlighted important areas for research. In particular:

(i) Our ability to program impressive, excellent, and sophisticated computer models is exceeding our ability to be sure that they provide reasonably reliable results, or to even set error limits. This will be particularly marked for periods which particularly deviate from “average” years. Development of methods of verification of complex regional models will be difficult and time-consuming, but must be done before such models can be accepted for routine planning use.
(ii) The question of salt accumulation under growing trees is an area that requires major work both at the theoretical and the field level. There is a concurrence amongst scientists that because trees usually exclude sodium and chloride ions from the transpiration stream, that these become concentrated in the soil. Limited evidence supports the contentions that the resulting salt accumulation then acts to inhibit growth of the trees. Future work can and should concentrate on quantifying this effect and determining the site requirements to either avoid this or to somehow “leach” the material from the soil.

(iii) As always there is a need for more knowledge on local and regional groundwater behaviour, the linkages between shallow and deep aquifers, and the pollution of fresh water aquifers by saline water aquifers.

(iv) Definitive work on the extent, duration, and ferocity of droughts in this environment needs to be carried out. Although “drought” has been a feature of the last few years over the Murray-Darling irrigation areas, there are questions as to how serious these dry periods are compared to historic drought periods. Of particular interest was the question of how irrigated eucalypts might fare in extreme dry periods when water is not available.

(v) Much discussion centred around the “ultimate wood yield” of these areas and the related questions of water yield. Many scientists felt that the habit of eucalypts of closing stomata at periods of high transpiration stress (presumably an adaptation to water conservation) limited both the growth and water use of trees in such periods. There was a consensus that quantifying what was achievable in volumetric tree growth, and the corresponding tree water use, would provide a very useful bench-mark for evaluation of existing plantations.

It is hoped that many of these questions will be resolved by good forestry research in the coming years.
Biodiversity Issues in Farm Forestry

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INTRODUCTION

Biodiversity refers to the variety of life and includes the diversity of ecosystems, species and genes. It is most often measured as the richness of species (the number of species) occurring at a particular spatial scale. High biodiversity itself is not necessarily the desired outcome for land repair. Instead, the restoration of a functioning ecological community that approaches the "original" community would be the ideal (Recher 1993). Because functioning ecological communities are difficult to measure, documenting biodiversity can offer a useful surrogate.

It is well known that cleared pasture generally supports few native species (Green and Catteral 1998) and that these are typically habitat generalists or open country species, many of which benefit from their association with humans. Because forest-dwelling species are absent or occur in greatly reduced numbers on cleared land, there is considerable potential to increase regional biodiversity through farm forestry.

The contribution of farm forestry to biodiversity conservation has received little direct study, particularly among plantations of *Eucalyptus* and in irrigated regions. This can be overcome somewhat by applying knowledge derived from studies of forests to plantations. As a general principle, the more complex the forest vegetation, both in terms of floristics and structural diversity, the greater number of animal species it can sustain (e.g., Recher 1993). In most cases plantations fall within the simple end of this complexity gradient. However, their establishment on land cleared for agricultural purposes (e.g., cropping and/or grazing), mining or land degraded by rising salt levels increases regional heterogeneity (assuming that cleared land is usually extensive), and provides greater structural complexity and floristic diversity. At a landscape scale, environmental heterogeneity (Lambeck and Saunders 1993, Hansson et al. 1995) and habitat mosaics (Law and Dickman 1998) increase opportunities for species that require multiple resources throughout their lives.

Plantations will generally never support all forest species without supplementation of key missing resources. For example, many forest-dependent species have specialised requirements for decorticating bark, dead wood, hollow logs and tree hollows that occur only in old trees (Kavanagh 1987, Dickman 1991, Scotts 1991, Law 1996). A range of techniques will be required to encourage this specialized suite of biodiversity to recolonize plantations.

The few actual studies on biodiversity in established plantations (NB none have been undertaken in irrigated plantations) helps us to document expected levels of biodiversity on farm forestry sites, to identify the species that will benefit from planting trees and to make suggestions about how to increase biodiversity.
Pine plantations are established for commercial purposes and being exotic they provide the greatest contrast with native forest. They are generally depauperate in their populations of birds and mammals compared to nearby native forest and to eucalypt plantations (e.g., Disney and Stokes 1976, Driscoll 1977). Besides the expected loss of hollow-nesting species, pine forests have fewer species that normally feed in the canopy of eucalypt trees. The presence of most fauna in pine plantations is attributed to the retention of native forest remnants within the plantations, including native remnant vegetation found near creeklines and the occurrence of grassy patches along road edges and during the open stages of plantation development (Lindenmayer et al. 1999). Among ground-dwelling mammals, introduced species are more likely to be found in pine plantations than in native forest (Barnett et al. 1977).

Fewer studies have compared the fauna in eucalypt plantations with those in nearby native forests. These studies included work on birds (Woinarski 1979, Nichols and Watkins 1984, Collins et al. 1985, Curry and Nichols 1986, Kavanagh and Turner 1994), reptiles and frogs (Nichols and Bamford 1985) and some invertebrate groups (Nichols and Burrows 1985). Species richness and abundance were generally lower in eucalypt plantations compared to native forest. For example, Woinarski (1979) recorded a total of 44 bird species in native forest compared to 33 species in eucalypt plantation. Greater biodiversity was related to the presence of a wide range of understorey plant species (planted or natural regrowth) and special micro-habitat features, such as logs and a moist litter layer.

Plantations are also likely to support a considerable diversity of invertebrates, although few studies have documented this directly. Chilcott et al. (1997) found that windbreaks supported more species of microarthropods, a group important for their role in nutrient processing, than open pastures. The diversity of understorey plants will vary greatly depending on the type of plantation established and where it is geographically located. One study in north Queensland found 250 species of understorey plants in rainforest plantations (Keenan et al. 1997).

The studies outlined above compared the number of species found in plantations with nearby native forest. Only one study could be found that compared species in cleared pasture with both wooded vegetation (mostly undisturbed) and 50 year-old regenerating woodland (Green and Caterall 1998). Although this southeastern Queensland study concluded that many decades of regeneration were necessary for most forest dependent species to be maintained, regenerating vegetation supported considerably more species of native birds and mammals than cleared pasture. This positive influence of regenerating vegetation was less apparent for frogs, reptiles and invertebrates (Green and Caterall 1998). It is important to note that this study documented fauna in naturally regenerating forest, not a carefully managed plantation. However, it does illustrate the expected gap in biodiversity levels between different land-use practices.
In addition to the favourable environmental image that biodiversity adds to farm forestry, a number of tangible benefits can be expected. Enhancing biodiversity within plantations (and the associated region) could have direct economic benefits by playing a positive role in the functioning of production systems as well as natural ecosystems. An example is the effect of natural predators on pests. Remnant native vegetation provides a refuge for natural predators that can biologically control insect pests in pastures (Reid et al. 1997, Campbell and Brown 1998). This may also apply to plantations with the potential for increased tree growth via pest control by natural predators. At present few studies have quantified the effect of biodiversity on such functions or processes (see Beck 1998). One relevant example from pine plantations (*Pinus pinaster*) found a lower number of species of litter and soil invertebrates in plantations compared to adjacent native vegetation (Springett 1976). Rates of litter decomposition in this study were significantly correlated with species diversity, providing evidence for enhanced nutrient recycling by diverse communities of soil microorganisms. Thus, interspersing remnant vegetation and their associated biological communities could be beneficial.

Corridor connections may be one of the more important factors likely to influence biodiversity on irrigated farm forestry sites in western New South Wales. Although few studies have attempted to demonstrate the effectiveness of corridors (Hobbs 1992), they are more likely to be important in irrigated landscapes because extensive clearing effectively isolates new tree plantings from forests and source populations of animals and plants. Without vegetated corridors, colonising biodiversity is likely to be dominated by highly mobile species such as birds, bats, flying invertebrates and wind dispersed seeds. Small-scale farm forestry itself can supplement resources for fauna and act as corridors/stepping stones between remnants of native vegetation still existing in the landscape. The conservation status of some species now rare or vulnerable, and that require forest cover, are predicted to improve as cleared land is replaced by eucalypt plantation. A second method of improving biodiversity values involves retaining paddock trees. Recent research by State Forests’ Research and Development Division has demonstrated the importance of paddock trees to some threatened vertebrates (Law et al. in press¹). Retaining these trees and their abundant hollows increases the number of bird species (Kavanagh and Turner 1994) and probably many other groups in future growing plantations.


COMMERCIAL AND ENVIRONMENTAL VALUES OF FARM FORESTRY IN THE MDB IRRIGATION AREAS STATE FORESTS OF NEW SOUTH WALES TECHNICAL PAPER NO. 65
Additional methods for enhancing biological diversity in plantation forests have been summarized by Spellerberg and Sawyer (1997) as:

- Diversify age structure of plantation
- Provide open space habitat
- Provide dying and dead wood
- Increase tree species richness
- Maintain stands of mature trees beyond normal economic maturity
- Sensitive management of riparian zones, woodland set-asides and remnants of indigenous vegetation
- Increase resources for wildlife eg nest boxes
- Landscape design
- Sensitive management of understorey vegetation

**CONCLUSIONS**

It is clear that farm forestry has the potential to increase the levels of biodiversity on cleared land requiring rehabilitation by providing habitat for forest-dependent species. Plantations of exotic pines support less biodiversity than native eucalypt species, but various options exist to enhance the biodiversity potential of both plantings. Factors that will enhance biodiversity include the retention of adjoining native vegetation along plantation edges and internally, the development of an understorey, the enhancement of missing elements (eg hollows), mixed species plantings, the use of locally native species and corridor connections to other forests.

There is a notable lack of studies that document directly the biodiversity levels in eucalypt plantations. Further research on eucalypt plantations is required to investigate the number of years it takes for different components of biodiversity to establish in eucalypt plantations, the influence of different plantation species and the effectiveness of various methods for enhancing biodiversity (eg retention of paddock trees). In addition to enhancing biodiversity in general, farm forestry may benefit certain threatened species. If so, research into how these species are managed, in the context of a final timber harvest, will need to be considered. Such studies would assist the production of management guidelines for maximizing biodiversity levels in plantations. Studies into the economic and ecosystem benefits of retaining biodiversity would also be valuable.
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Summary and Conclusions from Discussion of
Biodiversity Issues in Farm Forestry

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The State of the Environment Report (1996) noted that “two of the six major environmental problems affecting Australia are loss of biodiversity and land degradation resulting from over clearing of native vegetation”. It further claimed that “the loss of biological diversity is perhaps our most serious environmental problem. In many cases, the destruction of habitat, the major cause of biodiversity loss is continuing at an alarming rate.” With interest in farm forestry emerging in traditional agricultural areas, the scene of most clearing, it is not surprising that farm forestry has been quickly claimed as having potential to curb, if not reverse, further loss of biodiversity. For instance, Joint Venture Agroforestry Program strategic plan identified that it was a key priority to “determine how best agroforestry can increase biodiversity and nature conservation. This will particularly focus on a quantified understanding of changes in biodiversity between cleared agricultural land and agroforestry systems”. As this statement suggests, farm forestry can realistically regain only part of the biodiversity lost as a result of past clearing.

Surveys of rural tree planting activity following the establishment of LandCare indicate that ‘native vegetation and wildlife conservation’ (the category most akin to biodiversity) has been a minor (2%) reason for undertaking rural tree planting. ‘Shade and shelter’ on the other hand has been responsible for 68% of planting activity. Follow-up monitoring is now indicating that these plantings ostensibly undertaken for non-biodiversity purposes are delivering some biodiversity benefits. Compared to LandCare plantings, the highly commercial focus of farm forestry operations poses an additional impediment to even by-product regain of biodiversity. It remains an important challenge to establish that not only is biodiversity a value in itself but that it can have substantial indirect benefits for farm forestry production objectives (eg basis for integrated pest management).

There is limited documented evidence from the fledging Australian farm forestry industry of the potential biodiversity opportunities available, however a recent literature review of forestry issues concluded that:

- Biodiversity of plantations is considerably less than that of native forests.
- Biodiversity of plantations on just-cleared native vegetation areas is a misleading indicator to that of plantations on long-cleared agricultural land.
- Biodiversity response to plantations established on long-cleared agricultural land is largely unknown.
- Farm forestry plantation practice is mimicking that of agricultural cropping - single provenance in single age class stands receiving fertiliser, herbicides, pesticides, baits etc.
- The challenge is whether commercially viable farm forestry can deliver ecological benefits to our ailing agricultural systems.
- Farm forestry design and management practices are urgently required that are more sympathetic to, and encourage biodiversity.

With farm forestry in its infancy and the importance of biodiversity as an integral component of production systems only now gaining acceptance, the relevant research questions for farm forestry are very fundamental. The preceding review paper by Law canvasses the limited evidence for biodiversity in plantations and uses this evidence to suggest some issues that should be addressed.
if biodiversity values of plantations are to be improved. From this review and subsequent discussion research priorities emerged.

**Research priorities**

The high priority research questions identified were:

- What increase in biodiversity can farm forestry plantations offer?
- How can this increase in biodiversity be most efficiently achieved without jeopardising production objectives?
- What is the biodiversity value of eucalypt plantations relative to native forest and cleared agricultural land?
- Do retained isolated native trees and small remnants have a role in fostering higher biodiversity in farm forestry plantations?
- How can the final harvest of farm forestry plantations be managed to ensure maximum retention of the biodiversity gained during the plantation's life cycle?

**Background discussion**

In discussion on these questions the following points emerged:

The extent of clearing in many agricultural areas has been so complete that to propose quantitatively the pre-cleared biodiversity profile of these long-cleared areas would be purely speculation. As a consequence it is difficult to establish appropriate biodiversity targets as a step to managing biodiversity regain. Ideally the biodiversity values of plantations should be considered in the wider regional context where all land use activities and settings are evaluated and managed to collectively maximise the multiple production and conservation goals of individuals and the broader community.

Farm forestry invariably involves the planting of selected non-endemic species and establishment of artificial constructs, therefore it is unrealistic to expect to regain the original pre-clearing biodiversity, in fact biodiversity regain may be quite limited. Therefore, for these long and highly modified areas, it is more appropriate to establish the extent that farm forestry can contribute to the re-establishment of the original complement of ecological functions (e.g. nutrient cycling, hydrological balance etc.) that these areas performed in the landscape prior to clearing.

It is indicative of the lack of knowledge that some of the basic farm forestry design and management principles remain the subject of on-going debate. For instance, there is debate on the role of plantation size upon biodiversity prospects and likewise upon value of connectivity to remaining remnants and nearby plantations. This uncertainty arises because of a lack of study and understanding of the tradeoff between the benefits conveyed by size and connectivity such as increased heterogeneity and the dis-benefits, for instance increased risk of pests, pathogens and weeds.

Biodiversity studies run the risk of concentrating attention on the number of species which is only one of the three arms of biodiversity, thereby overlooking the genetic and landscape components of biodiversity. Concentration on species is even more constraining when only particular taxa are selected for study. Birds are often targeted because of easy of observation and identification - unfortunately convenience is unlikely to be related to functional importance.

On a note of caution, biodiversity expectations from farm forestry need to be kept in context, as farm forestry plantations are an anthropocentric construction with production objectives. It would...
be counterproductive to the continued expansion of farm forestry plantations if biodiversity considerations unduly prevent the realisation of the productive objectives and monetary expectations from established and future plantations.

The following quote from Greening Australia (1996) encapsulates in a very practical way the collective sentiment of the above discussion: “a key challenge is to nurture a balanced landscape ethic, where the range of stakeholders work co-operatively, embracing both conservation and profit dimensions to vegetation protection and establishment”.

References


Greening Australia Ltd. (1996). Farm forestry in Australia: integrating commercial and conservation benefits.

Copies and further information are available from:

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