



Pulpwood quality of 13 eucalypt species with potential for farm forestry

**A report for the RIRDC/Land & Water
Australia/FWPRDC
Joint Venture Agroforestry Program**

by C. C. Hicks and N. B. Clark

November 2001

RIRDC Publication No 01/164
RIRDC Project No CSF-56A

© 2001 Rural Industries Research and Development Corporation.
All rights reserved.

ISBN 0 642 58383 8
ISSN 1440-6845

Pulpwood quality of 13 eucalypt species with potential for farm forestry
Publication No. 00/164
Project No. CSF-56A

The views expressed and the conclusions reached in this publication are those of the author and not necessarily those of persons consulted. RIRDC shall not be responsible in any way whatsoever to any person who relies in whole or in part on the contents of this report.

This publication is copyright. However, RIRDC encourages wide dissemination of its research, providing the Corporation is clearly acknowledged. For any other enquiries concerning reproduction, contact the Publications Manager on phone 02 6272 3186.

Researcher Contact Details

Mrs Christina Hicks
CSIRO Forestry and Forest Products
Private Bag 10,
Clayton South MDC,
Victoria 3169

Phone: (03) 9545 8111
Fax: (03) 9545 2448
Email: Christina.Hicks@ffp.csiro.au

Dr Noel Clark
CSIRO Forestry and Forest Products
Private Bag 10,
Clayton South MDC,
Victoria 3169

Phone: (03) 9545 2259
Fax: (03) 9545 2448
Email: Noel.Clark@ffp.csiro.au

RIRDC Contact Details
Rural Industries Research and Development Corporation
Level 1, AMA House
42 Macquarie Street
BARTON ACT 2600
PO Box 4776
KINGSTON ACT 2604

Phone: 02 6272 4539
Fax: 02 6272 5877
Email: rirdc@rirdc.gov.au
Website: <http://www.rirdc.gov.au>

Published in November 2001
Printed on environmentally friendly paper by Canprint

Foreword

Farm forestry is seen as an increasingly feasible business option for rural land in many parts of Australia. However, a key impediment to the implementation of farm forestry on a wider scale in the Australian landscape is lack of access by farmers to relevant information.

Of particular concern is the shortage of information about the market opportunities that exist for residual wood that may be generated by farm forestry plantations. The information is vital because thinnings, toplogs and sawmill residues make up more than 50% of the wood volume produced over a rotation, even in a plantation managed for sawlogs.

This publication reports the results of laboratory tests on the pulpwood properties of 13 eucalypt species with potential for use in farm forestry plantations. The data are used to develop an index of the suitability of each species for pulpwood production, compared with existing commercial pulpwood resources. The information should assist farmers in selecting species with the potential to produce an optimum mix of products for the markets in their region.

This project was funded by the Joint Venture Agroforestry Program (JVAP). The JVAP is supported by three R&D Corporations — Rural Industries, Land & Water Australia and Forest and Wood Products. These Corporations are funded principally by the Federal Government.

This report, a new addition to RIRDC's diverse range of over 700 research publications, forms part of our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australian farming systems.

Most of our publications are available for viewing, downloading or purchasing online through our website:

- downloads at www.rirdc.gov.au/reports/Index.htm
- purchases at www.rirdc.gov.au/eshop

Peter Core

Managing Director

Rural Industries Research and Development Corporation

Acknowledgements

The samples at Uriarra and Kowen were obtained with assistance from Mr P. R. Coble, Mr R. A. Gobim and Mr C. M. Costelloe from the Stromlo office of ACT Forests. The samples from Coffs Harbour were obtained with the assistance of Mr Warren Taylor, Ms Lyn Corrigan and Dr Ross Dixon of NSW State Forests. Dr Allie Muneri of QFRI provided the samples from Gympie in Queensland. The samples from Timmering in Victoria were obtained with the assistance of Mr Des Stackpole of the Centre for Forest Tree Technology. The authors would like to thank all of these people for their kind assistance, often provided under trying conditions and to strict time constraints.

The authors would also like to thank the following CSIRO staff: Ms Karen Hands and Mr Goran Langfors for their help in the preparation of woodchip samples, and Mrs Maureen McHenry for the preparation and testing of the handsheets made from the kraft pulps.

Abbreviations

AA	active alkali
BD	basic density
BDU	bone dry unit
CSF	Canadian Standard Freeness
EA	effective alkali
FOB	free on board
OSB	oriented strand board
MAI	mean annual increment
MDF	medium density fibreboard
mm	millimetres
g/L	grams per litre
kg/m³	kilograms per cubic metre
m³	cubic metres

Contents

FOREWORD	III
ACKNOWLEDGEMENTS.....	IV
ABBREVIATIONS.....	IV
CONTENTS	V
EXECUTIVE SUMMARY	VI
1. INTRODUCTION	1
2. METHODOLOGY.....	2
2.1 Sampling.....	2
2.2 Sample Preparation	8
2.3 Moisture Content	8
2.4 Basic density.....	8
2.5 Kraft Pulping	8
2.6 Papermaking Properties	8
2.7 Pulpwood Values.....	9
3. DETAILED RESULTS	10
3.1 Basic Density	10
3.2 Pulping Properties.....	13
3.3 Unbleached Papermaking Properties	15
3.4 Pulpwood Values.....	22
4. DISCUSSION OF RESULTS	24
4.1 Basic Density	24
4.2 Pulping Properties.....	24
4.3 Unbleached Papermaking Properties	25
4.4 Pulpwood Values.....	26
5. IMPLICATIONS.....	27
6. RECOMMENDATIONS.....	27
7. APPENDICES	28
7.1 Appendix 1 - Unbleached Papermaking Properties	28
7.2 Appendix 2 - Glossary	33
8. REFERENCES.....	37

Executive Summary

The objective of this project was to assess the potential of eucalypt species proposed for use in farm forestry production systems for kraft pulping and papermaking, relative to existing commercial pulpwood resources.

A total of 23 samples, representing 13 eucalypt species aged from 6 to 14 years, were collected across five sites in the eastern States of Australia. Wood basic density, kraft pulping properties and unbleached papermaking properties were measured and selected parameters used to calculate an index of the suitability of different wood resources for export woodchips.

Two of the sites in the ACT differed particularly in terms of rainfall, and by sampling the same species at both sites, the effects of differences in growing conditions on wood quality were assessed. The slow-growing trees from the low-rainfall (450-500 mm) Kowen site had generally lower wood densities, lower pulp yields and poorer papermaking properties than samples of corresponding species from Uriarra, where mean annual rainfall was about 200 mm higher.

The species indicated by the pulpwood quality index as most suitable for chemical pulping were *Corymbia maculata* (Spotted Gum) from Gympie, followed by *E. occidentalis* (Swamp Yate) from Timmering and *E. dunnii* (Dunn's White Gum) from Coffs Harbour. *E. smithii* (Gully Gum) may also have promise as pulpwood, ranking above *E. nitens* (Shining Gum, a commercially important species) at both Uriarra and Kowen. The two species least suitable for chemical pulping were *E. benthamii* (Camden White Gum) and *E. kartzoffiana* (Araluen gum), which both produced lower quality wood than that available from the native forests of Tasmania.

The strong association found between low rainfall and poor pulpwood quality suggests that farmers planning to grow trees in dryland regions (<600 mm) may suffer more than reduced growth rates. The trees may also produce poorer quality and hence less marketable pulpwood.

Most of the trees tested in this project came from species suited to high rainfall conditions, with only three, *E. occidentalis*, *E. kartzoffiana* and *C. maculata*, having any potential for low rainfall sites. Even these trees were mainly sampled from high rainfall or irrigated stands (primarily due to availability) so that questions remain about the likely wood quality of low rainfall species grown on dryland sites. Future work should address this uncertainty. Research on the wood properties of several genotypes of dryland pine is presently underway. Complementary work will also be required for hardwoods.

1. Introduction

In June 1999, a 3-year project, entitled "Farm Forestry Seed and Information Support" commenced. The project was funded by the RIRDC-LWRRDC-FWPRDC Joint Venture Agroforestry Program (JVAP) and the Natural Heritage Trust (NHT), and was managed by CSIRO Forestry and Forest Products. The overall aim of the project was to provide high quality planting material and information to enhance the economic and environmental benefits of commercial farm forestry.

Farm forestry is seen as an increasingly feasible business option for rural land in many parts of Australia. The economic benefits of farm forestry include the diversification of farm incomes from the commercial returns from wood, fibre, fodder and energy. Environmental benefits may accrue from increased shelter for stock and crops, the lowering of water tables, the control of salinity and the sequestration of carbon.

As indicated above, improving the information available to landholders was a primary aim of the project. This included extending the existing knowledge base where it was considered deficient. While earlier work by CSIRO had provided information about the suitability of eucalypts for timber production (1), less was known about the commercial potential of residual wood from the range of tree species likely be used in farm forestry.

In the future, significant areas of inland Australia may be planted with trees to address environmental problems, and residual wood from thinnings, toplogs and sawmill residues will make up at least 50% of the volume produced, even for plantations grown for sawlogs. A commercial outlet must be found for this residual material. While the production of wood composites such as oriented strand board, medium density fibreboard and particleboard may consume some of these residues, the markets for these products are smaller than those for pulpwood.

Information on the suitability of residual wood from farm forestry species for pulping is essential before the feasibility of these plantations can be properly assessed. This report outlines results of a sampling and testing program aimed at supplementing the information presently available for a range of eucalypt species with potential for use in farm forestry systems.

2. Methodology

2.1 Sampling

Following consultation with the project steering committee and other stakeholders, a list of species with potential for farm forestry plantations was proposed (Table 1). From this list, species with priority for pulpwood testing were chosen. Important commercial species such as *E. grandis* and *E. nitens* were not included, simply because previous studies had already provided useful information concerning the pulpwood properties of these trees.

Table 1
Species selected for farm forestry project

Species	Rainfall Zone	Climatic Zone	Pulping study
<i>Eucalyptus grandis</i>	w	T, Tr	
<i>E. globulus ssp globulus</i>	w	T	•
<i>E. globulus ssp bicostata</i>	w	T	•
<i>E. globulus ssp maidenii</i>	w	T	•
<i>E. globulus ssp pseudoglobulus</i>	w	T	•
<i>E. nitens</i>	w	T	
<i>E. saligna</i>	w	T	
<i>C. maculata/citriodora</i>	wd	T, Tr	•
<i>E. camaldulensis</i> (north & south provenances)	wd	T, Tr	
<i>E. benthamii</i>	w	T	
<i>E. dunnii</i>	w	sTr	•
<i>E. viminalis</i>	w	T	•
<i>E. cladocalyx</i>	d	T	
<i>E. occidentalis</i>	d	T	•
<i>Acacia mearnsii</i>	w	T	
<i>E. tereticornis</i>	wd	T, Tr	
<i>E. cloeziana</i>	w	Tr	•
<i>E. sideroxylon</i>	d	T	
<i>E. fraxinoides</i>	w	T	•
<i>Grevellia robusta</i>	w	T, Tr	
<i>E. pilularis</i>	w	sTr	•
<i>E. smithii</i>	w	T	•
<i>Araucaria cunninghamii</i>	w	sTr	
<i>E. pellita</i>	w	Tr	
<i>A. melanoxylon</i>	w	T, Tr	
<i>Casuarina cunninghamiana</i>	wd	T, Tr	
<i>C. glauca</i>	d	T	
<i>Toona ciliata</i>	w	T, Tr	
<i>Acacia mangium</i>	w	Tr	
<i>E. argophloia</i>	d	sTr	
<i>E. kartzoffiana</i>	wd	T	
<i>E. botryoides</i>	w	T	•
<i>oil mallee eucalypts</i>	d	T	
<i>E. macarturii</i>	w	T	
* <i>Pinus radiata</i>	wd	T	
* <i>P. pinaster</i>	d	T	
* <i>P. caribaea</i>	w	Tr	
* <i>P. eliotii</i> x <i>caribaea</i>	w	sTr	
<i>E. grandis</i> x <i>camaldulensis</i>	wd	T, Tr	
<i>E. globulus</i> x <i>camaldulensis</i>	wd	T	
<i>E. grandis</i> x <i>nitens</i>	w	T	
<i>Acacia stenophylla</i>	d	T	

With the resources available, not all of the proposed species could be tested for pulpwood quality. In fact, within the projected life of the pulping subproject, less than 25 samples could be tested. Further, for some species, suitable forestry trials were not available. The trees had to be at least six years old, with known genetic make up (provenance), and had to be grown in properly managed stands (i.e. with adequate silviculture). The planned laboratory tests required quantities of wood that could only be

obtained by the use of destructive sampling, so the trees felled would not be available for any other future use. Taking account of these prerequisites, five sites across four States/Territories were identified as suitable and were sampled for the project (Table 2, Figure 1).

Table 2
Sites sampled for the project

Site	State or Territory	Species sampled	Age years	Trees Sampled
Uriarra	ACT	8	13	45
Kowen	ACT	8	13	45
Coffs Harbour	NSW	1	9	6
Gympie	QLD	4	12	20
Timmering	VIC	1	6	12

Figure 1
Locations of sites sampled



Uriarra and Kowen

In 1984, CSIRO and ACT Forests established trials at Uriarra, Kowen and two other sites to assess the potential of plantations to supply fuelwood to Canberra and surrounding districts of the ACT. The sites were selected to represent the range of environmental conditions likely to be encountered in future plantings in the region. Kowen is a dry shaly site, representative of much of the ACT and neighbouring parts of NSW. Uriarra was chosen to provide contrast; it is a moist, high-quality site similar to those in the area planted with radiata pine. Details of the sites are given in Table 3. The preparation and establishment of the two trials have been described elsewhere (2-4).

Table 3
Details of Uriarra and Kowen sites

Parameter	Kowen	Uriarra
Latitude	35° 19' S	35° 17' S
Longitude	149° 19' E	148° 53' E
Altitude	700 m	680 m
Mean annual rainfall	450-500 mm	700+ mm
Mean minimum temperature - coldest month	-0.2°C	0.12°C
Absolute minimum temperature	-9°C	-9°C
Mean maximum temperature - hottest month	26.5°C	27.2°C
Soil	Sedimentary shale	Red podsolic to silty clay
Planting date	6-9 November 1984	12-15 November 1984

The provenances of each of the eight species sampled at Uriarra and Kowen for the pulping subproject (Table 4) were chosen on the basis of their survival and growth rates across the two sites. Although *E. nitens* was not a high priority species in the pulping study, it was sampled at the both sites for two reasons. First, it was one of the best-performing species in the ACT fuelwood trials; and second, it had the potential to provide a valuable benchmark for comparison with the lesser-known eucalypts.

Table 4
Species and provenances sampled at Uriarra and Kowen

Species	Provenance	Seedlot	State	Latitude	Longitude	Altitude m
<i>E. badjensis</i>	Nimmitabel	CS13286	NSW	36°32' S	148° 15' E	900
<i>E. benthamii</i>	Wentworth Falls	CS14214	NSW	33° 48' S	150° 24' E	150
<i>E. globulus</i> ssp <i>bicostata</i>	Wee Jasper	CS09246	NSW	35° 28' S	148° 10' E	910
<i>E. kartzofiana</i>	Majors Ck, Araluen	CS14231	NSW	n/a	n/a	n/a
<i>E. macarthurii</i>	Marulan	CS12023	NSW	34° 39' S	150° 07' E	600
<i>E. nitens</i>	Big Badja Mtn	CS12114	NSW	36° 01' S	149° 34' E	1250
<i>E. smithii</i>	Mitagong	CS10163	NSW	34° 27' S	150° 27' E	1070
<i>E. viminalis</i>	Traralgon	CS12652	VIC	38° 22' S	146° 31' E	325

Six trees from each provenance were selected at random from the available replicate plots. After felling, 20-mm thick disks were cut at 1-m intervals of stem height, from the stump (0.3 m above ground level) to the green crown. A chainsaw fitted with a guide-bar (Figure 2) was used to cut disks of constant thickness, automatically providing samples proportional to the volume of the original tree. Billets were also collected at Uriarra for the composite subproject. These billets were taken from the first metre of the stem above the stump, so that the top of each billet was at breast height (1.3 m).

Figure 2
Cutting disks from trees at Uriarra



Photograph: Bronwyn Clarke, CSIRO FFP

Figure 3
Kowen site



Photograph: Bronwyn Clarke, CSIRO FFP

Coffs Harbour

The project steering committee endorsed *Eucalyptus dunnii* as a species with potential for farm forestry plantations. This species is utilized overseas for pulping and is already commercially planted in NSW for a range of end products. State Forests NSW was asked to help obtain wood samples of this species. Fortunately, plantations near Coffs Harbour were to be sampled in September 1999 for a sawing trial and it was considered feasible to sample one 9-year-old *E. dunnii* plot for pulpwood at the same time. The plantation (Figure 4) is located off Ballards Road, outside Coffs Harbour, at latitude 30° 31' S, longitude 153° 12' E. Altitude is 5m and mean annual rainfall 1703 mm.

Figure 4
9-year-old *E. dunnii* near Coffs Harbour



Photograph: Dr Ross Dixon, SFNSW

With assistance from Mr. Warren Taylor of State Forests NSW, six *E. dunnii* trees were selected and felled. Disks (Figure 5) were taken at 1-metre intervals of stem height using a chainsaw fitted with a guide bar. Unfortunately, against all expectations, the identity of the provenance planted at the site could not be determined from the records of State Forests NSW. However, according to oral history (Mr Spencer Bruskin, personal communication 2000) the seed source for the *E. dunnii* trees was probably Moleton at Dorrigo (about 45 km inland from Coffs Harbour). Moleton was a popular place for seed collection for the species at the time the trees were planted. Most of the seed used for the current *E. dunnii* plantings comes from Wallaby Creek at Urbenville.

Figure 5
Disk cut from 9-year-old *E. dunnii*



Photograph: Dr Ross Dixon, SFNSW

Gympie

Four species with potential for farm forestry in tropical or subtropical areas (*C. maculata*, *E. cloeziana*, *E. dunnii* and *E. pilularis*) were planted in the Shell Trial Experiments 352 & 355 HWD, in the Toolara State Forest. This site is located about 40 km east of Gympie, at latitude 26° 01' S and longitude 152° 47' E, and has an altitude of 60 m. The site receives a mean annual rainfall of 1300 mm per year and the soils are prairie alluvium. At the time of sampling (November 9-10, 1999) the trees were 12 years old. The provenances sampled are listed in Table 5.

Table 5
Species and provenances sampled Gympie

Species	Provenance	State	Latitude	Longitude	Altitude m
<i>E. cloeziana</i>	Gympie	QLD	26° 18' S	152° 48' E	75-100
<i>C. maculata</i>	Gympie	QLD	26° 18' S	152° 48' E	75-100
<i>E. pilularis</i>	Rifle Range	QLD	17° 16' S	145° 28' E	780
<i>E. dunnii</i>	Kyogle	NSW	28° 24' S	152° 41' E	400

It is probable that the trees planted as *C. maculata* may not in fact have been this species. Recent work has found that the natural range of *C. maculata* does not extend into Queensland and that trees identified as *C. maculata* are more likely to be a closely related species, *C. variegata* (5). However, to maintain conformity with previously published reports on the site, in this report the trees will continue to be designated *C. maculata*. Four trees were sampled to represent *C. maculata* and *E. dunnii*, with 20-mm thick disks taken at 1-m intervals from 0.3 m. Six trees were sampled to represent *E. cloeziana* and *E. pilularis*, with 20-mm thick disks taken at 2-m intervals from 0.3 m. The sampling was undertaken on behalf of the pulping project by Dr Allie Muneri of QFRI.

Timmering

E. occidentalis shows some promise as an alternative to *E. camaldulensis* for poor sites, as the former species has a reputation for high salinity tolerance, high basic density at an early age and acceptable tree form. Further, a study on a 6-year-old irrigated site at Bolivar in South Australia found that although fibre length was shorter than desirable, one provenance of *E. occidentalis* had a higher pulp yield than is typical of *E. globulus* at the same age (6). It was therefore considered advantageous to widen the knowledge base by sampling and testing provenances of *E. occidentalis* from other sites.

One of the better performing provenances of *E. occidentalis* (Bremer Bay, 34° 23' S, 119° 23' E) was represented at a 6-year-old site at Timmering in Victoria. Timmering (36° 18' S, 144° 95' E) has an altitude of 100 m and receives a mean annual rainfall of 425 mm per year. The district is characterised by high watertables, generally within 1 to 2 metres of the surface, coupled with electrical conductivity (EC) levels of around 10,000 $\mu\text{S cm}^{-1}$. Although there are some better patches, soils are generally heavy clays known locally as Alta clay loam, which are subject to seasonal waterlogging. This site was a semi-commercial trial managed by a local farmer, and flood-irrigated. Alternate blocks received fresh (200 EC) and salty (10,000 EC) water, respectively, sourced from the routine irrigation supply. Site preparation and establishment have been previously described by Stackpole *et al.*(7).

Six trees were each selected at random from the available replicates irrigated with fresh and salt water, making 12 trees in all. Disks were cut at 1-m intervals of stem height from 0.3 m to the green crown. Several trees were forked or had multiple leaders and where this occurred the disks were taken from the dominant leader.

2.2 Sample Preparation

The disks cut from the trees at each site were transported to the Forest Products Laboratory in Clayton, where each disk was debarked and then chipped. Fines were removed using a rotating cylindrical screen. The wood chips representing each species at each site were mixed to obtain a composite sample, and stored under refrigeration at 2°C until required for the pulping tests.

2.3 Moisture Content

Moistures were determined in triplicate by drying 100g of chips in an oven at 105°C for 3 days.

2.4 Basic density

Basic density is defined as the oven-dry weight per unit volume of green wood. The basic density of the woodchips was measured according to the draft Australian Standard AS/NZS 1301.001s, using the alternative boiling method.

2.5 Kraft Pulping

The kraft cooks were carried out in 3-litre pressure vessels, held horizontally and rotated in an electrically heated air bath (Figure 6). All the cooks used the same mass of woodchips and the same temperature profile, but the active alkali charges were varied to obtain a Kappa number (a measure of the degree of delignification) of 18. The cooking conditions were as follows:

- 600g o.d. wood charge
- 4:1 liquor to wood ratio
- 25% sulfidity
- Time to temperature 75 minutes
- Cooking temperature 165°C
- H-Factor 1300

After each cook, the chips were rinsed with 20L of water to remove spent cooking liquor (black liquor) then disintegrated at about 5% concentration at 2850 rpm for 5 minutes. The pulps were then further rinsed with cold water and shives were removed using a packer screen with 0.2-mm wide slots. After dewatering in a press and crumbling, the pulps were analyzed for residual lignin content, determined as Kappa number according to Australian /New Zealand Standard AS NZS 1301.P201m-86. The moisture contents of the pulps were determined in triplicate by drying 10-g lots in an oven at 105°C overnight. The pulp yield and shive content, as percentages on an oven dry basis, were calculated.

2.6 Papermaking Properties

Handsheets were prepared according to AS/NZS 1301.P203s:1993 from unbleached pulp beaten in a PFI mill using 24 g (o.d.) pulp charge, 10% stock concentration and 1.77 N/mm beating load (AS/NZS 1301.209rp-89) and tested according to AS/NZS 1301.208s-1997.

Figure 6
Air bath used for kraft pulping trials with pressure vessels in foreground



Photograph: Dr Noel Clark, CSIRO FFP

2.7 Pulpwood Values

The basic density, active alkali requirement and pulp yield data obtained from the laboratory tests were used to calculate an index of the suitability of different wood resources for export woodchips. The cost of producing pulp from each species in a Japanese mill was compared with that of a resource whose commercial value was known (northern Tasmanian export woodchips), and the differential between the two used to obtain the index value. The pulp production costs are a function of several factors:

$$\text{Pulp production cost} = f(\text{wood cost, freight cost, processing cost}) \dots \text{Equation 1}$$

The wood cost is calculated from pulp yield and the price of the northern Tasmanian woodchips. The sea freight costs are estimated from basic density, because of the difficulty of accurately measuring woodchip packing factors in the laboratory. The processing cost is aggregated from components corresponding with the parts of a kraft pulp mill (digester, chemicals, evaporation, recovery, recausticizing, etc). These calculations are based on theoretical proportionality statements linking each part of the kraft process (8).

Differences in papermaking properties are not considered because no universally acceptable means exists for quantifying the effect of pulp quality on pulpwood price; a wide range of different paper products can be produced from eucalypt kraft pulp, each requiring a different combination of pulp properties.

The calculations can be structured in several ways, according to the assumptions made about the state of the market for pulp and the constraints on the rate of production in the pulp mill. In this report, the most conservative assumptions were used (i.e. that higher pulp yield is only used to reduce wood costs). Note that these results are not comparable with market prices because the effects of supply and demand have not been taken into consideration.

3. Detailed Results

3.1 Basic Density

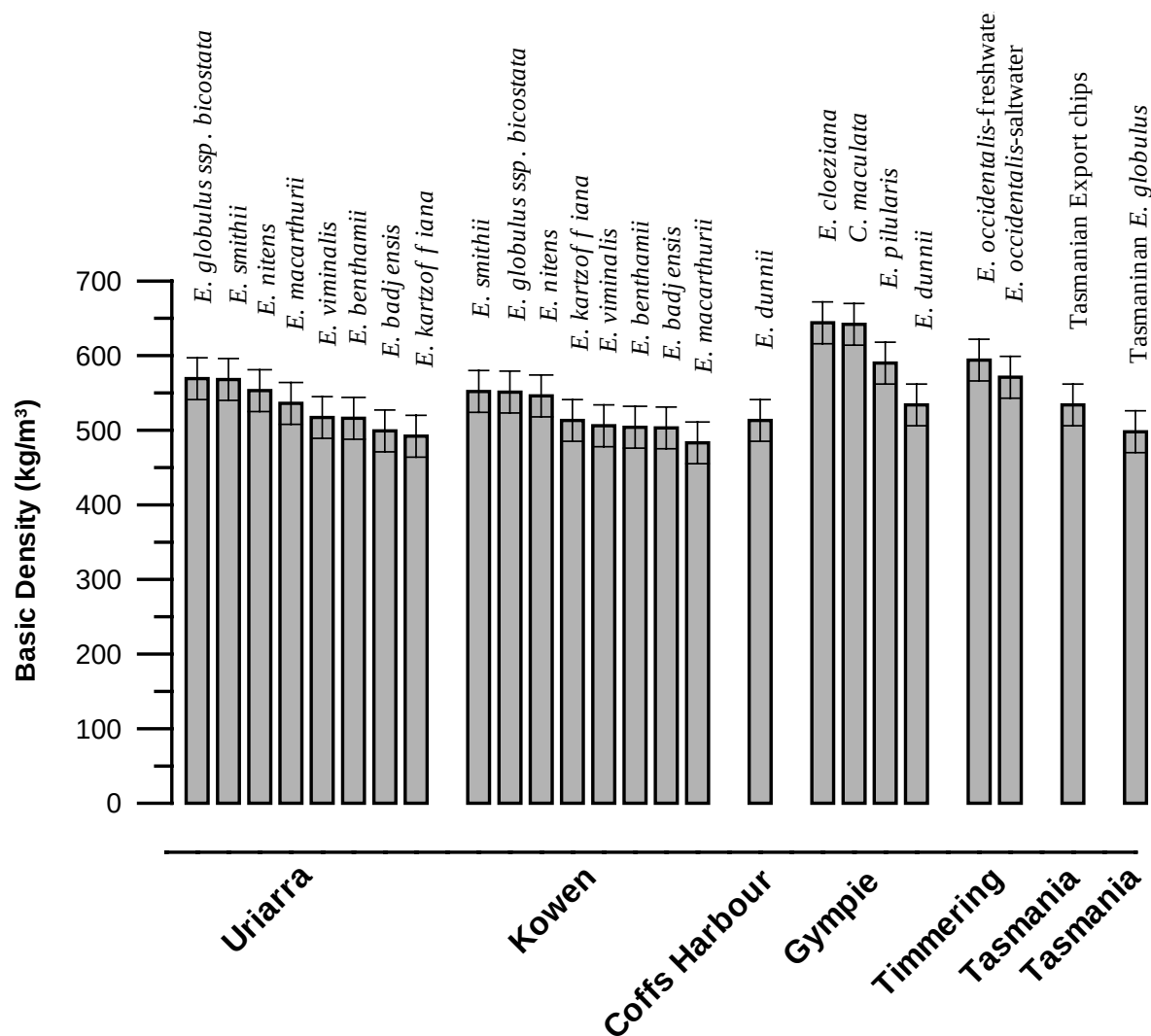
The mean basic densities of the woodchip composites representing the species sampled for the present project are given in Table 6 and illustrated in Figure 7. Results for two commercial wood resources, 10-year-old plantation grown *E. globulus* and northern Tasmanian export woodchips, are included for comparison.

Most of the samples tested were within the 400-600 kg.m⁻³ range. *E. cloeziana* and *C. maculata* from Gympie were denser at 644 kg.m⁻³ and 642 kg.m⁻³ respectively.

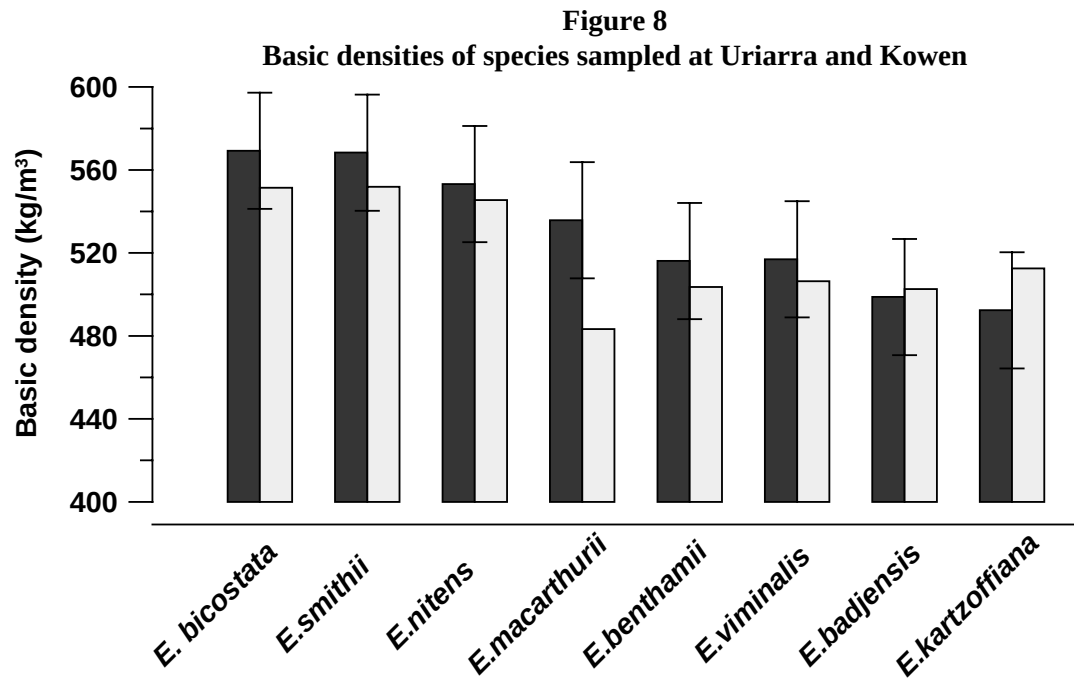
Table 6
Basic densities of wood samples

Site	Species	Tree age years	Basic density kg/m ³
Uriarra (ACT)	<i>E. badjensis</i>	14	499
	<i>E. benthamii</i>	14	516
	<i>E. globulus ssp. bicostata</i>	14	569
	<i>E. kartzoffiana</i>	14	492
	<i>E. macarthurii</i>	14	536
	<i>E. nitens</i>	14	553
	<i>E. smithii</i>	14	568
	<i>E. viminalis</i>	14	517
Kowen (NSW)	<i>E. badjensis</i>	14	503
	<i>E. benthamii</i>	14	504
	<i>E. globulus ssp. bicostata</i>	14	551
	<i>E. kartzoffiana</i>	14	513
	<i>E. macarthurii</i>	14	483
	<i>E. nitens</i>	14	546
	<i>E. smithii</i>	14	552
	<i>E. viminalis</i>	14	506
Coffs Harbour (NSW)	<i>E. dunnii</i>	9	513
Gympie (QLD)	<i>E. cloeziana</i>	12	644
	<i>E. dunnii</i>	12	534
	<i>E. pilularis</i>	12	590
	<i>C. maculata</i>	12	642
Timmering (VIC)	<i>E. occidentalis</i> – fresh	6	594
	<i>E. occidentalis</i> – salt	6	571
Tasmania	<i>E. globulus</i>	10	498
	Export chips	n/a	534

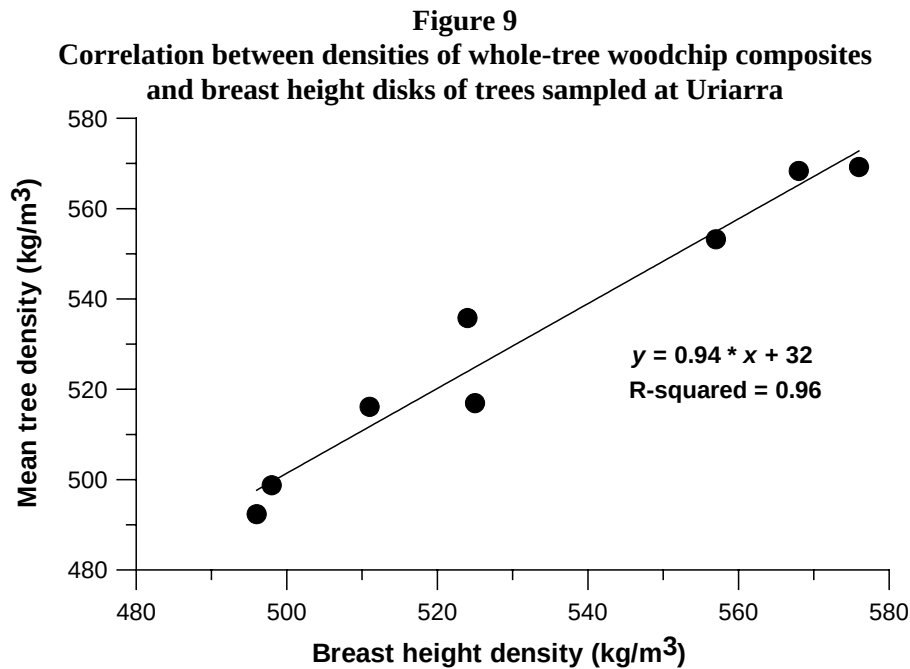
Figure 7
Basic densities of wood samples
Compared with commercial Tasmanian wood resources



With the exception of *E. kartzoffiana* and *E. badjensis*, the basic densities of the Uriarra trees were generally higher than those from Kowen (Figure 8). However, based on the variation found between trees in other stands (8), the differences between the two sites were less than would be considered statistically significant for composites of six trees (i.e. less than $\pm 28 \text{ kg.m}^{-3}$ at 500 kg.m^{-3} , error bars in Figures 7 and 8).



The density results obtained for the whole-tree woodchip composites representing the Uriarra species were compared with the mean breast height densities of the same trees. These breast height densities were measured by a parallel sub-project, whose aim was to assess the potential of the Uriarra species for the production wood composite products. The results are shown in Figure 9. Remarkable correlation is evident, suggesting that breast height samples were an accurate predictor of whole-tree density.



3.2 Pulping Properties

The full pulping results are presented in Table 7 and the screened yields are illustrated in Figure 10. Results for the two commercial wood resources are included for comparison.

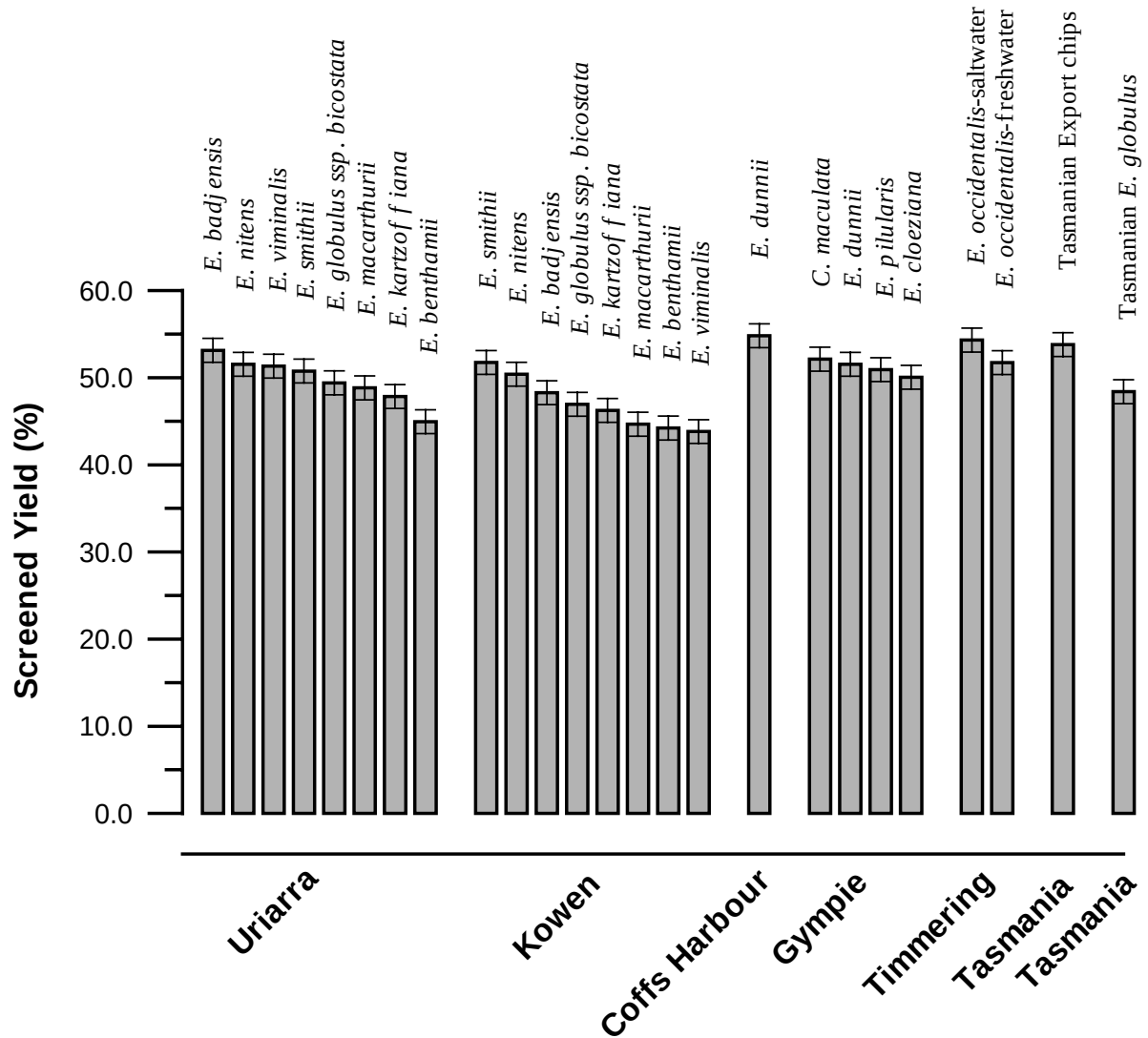
The samples with the highest pulp yields were the 9-year-old *E. dunnii* from Coffs Harbour, the 6-year-old *E. occidentalis* (salt-water irrigation) from Timmering and the 14-year-old *E. badjensis* from Uriarra. These three samples had pulp yields comparable with, or better than, 10-year-old plantation-grown *E. globulus* from Tasmania.

Table 7
Kraft pulping properties

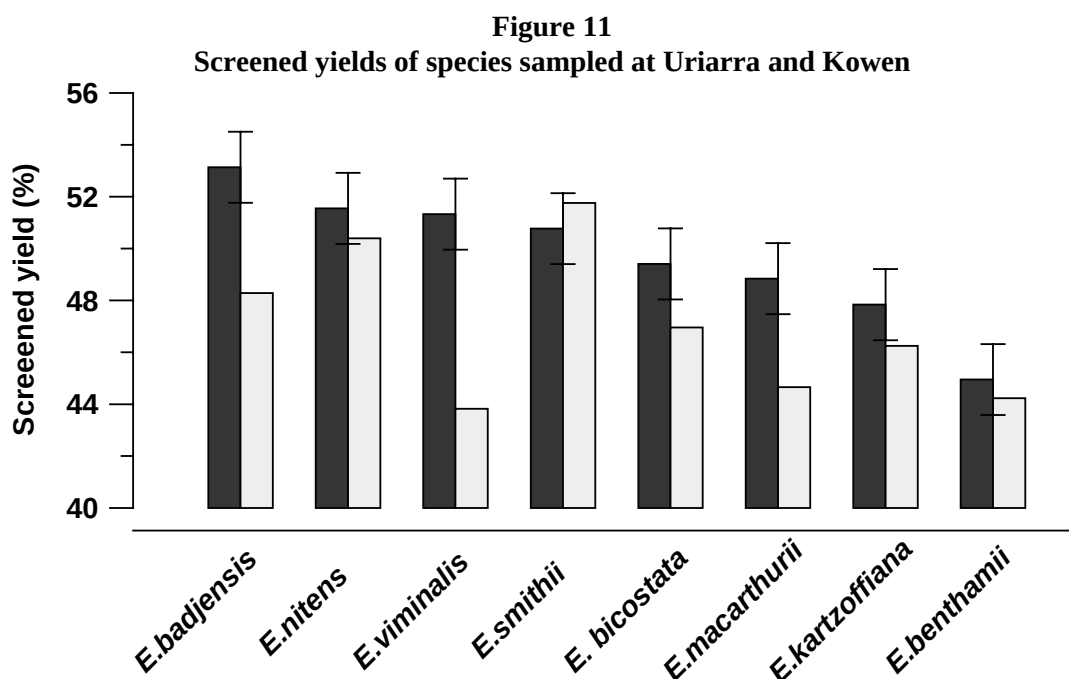
Site	Species	Active Alkali % Na ₂ O	Screened yield %	Screen rejects %	Total yield %	Kappa number
Uriarra (ACT)	<i>E. badjensis</i>	13.0	53.1	0.2	53.3	17.4
	<i>E. benthamii</i>	15.0	45.0	0.0	45.0	17.5
	<i>E. globulus ssp. bicostata</i>	13.6	49.4	0.1	49.6	18.1
	<i>E. kartzoffiana</i>	14.5	47.8	0.0	47.9	17.3
	<i>E. macarthurii</i>	14.1	48.5	0.1	48.6	17.2
	<i>E. nitens</i>	14.0	51.6	0.4	52.0	18.9
	<i>E. smithii</i>	13.3	50.8	0.4	51.2	18.6
	<i>E. viminalis</i>	13.5	51.3	0.2	51.5	17.7
Kowen (ACT)	<i>E. badjensis</i>	14.0	48.3	0.1	48.4	18.0
	<i>E. benthamii</i>	15.0	44.2	0.1	44.3	19.0
	<i>E. globulus ssp. bicostata</i>	15.0	47.0	0.2	47.1	18.1
	<i>E. kartzoffiana</i>	15.0	46.3	0.0	46.3	17.6
	<i>E. macarthurii</i>	15.6	44.7	0.1	44.7	18.4
	<i>E. nitens</i>	14.5	50.4	0.2	50.6	18.0
	<i>E. smithii</i>	12.5	51.8	0.4	52.2	18.8
	<i>E. viminalis</i>	14.5	43.8	0.0	43.9	17.5
Coffs Harbour (NSW)	<i>E. dunnii</i>	12.3	54.8	0.1	54.9	17.4
Gympie (QLD)	<i>E. cloeziana</i>	15.4	50.1	0.0	50.1	17.6
	<i>E. dunnii</i>	13.9	51.6	0.2	51.7	17.5
	<i>E. pilularis</i>	14.5	50.9	0.1	51.0	17.5
	<i>C. maculata</i>	14.2	52.1	0.0	52.1	17.2
Timmering (VIC)	<i>E. occidentalis</i> -salt	13.2	54.3	0.3	54.6	17.6
	<i>E. occidentalis</i> -fresh	12.9	51.7	0.3	52.0	17.0
Tasmania	<i>E. globulus</i> *	11.5	53.8	1.5	55.3	18.0
Tasmania	Export chips*	16.0	48.4	0.6	49.0	18.0

* Source: Clark and Rawlins (1999)

Figure 10
Screened kraft pulp yields of wood samples
compared with commercial Tasmanian wood resources



The pulp yields of the trees sampled at Uriarra were generally higher than those sampled at Kowen (Figure 11). In five out of the eight species, the differences would be considered statistically significant for composites representing six trees, (i.e. more than $\pm 1.4\%$ at 50% yield, error bars in Figures 10 and 11).



3.3 Unbleached Papermaking Properties

Appendix 2 gives the results of the papermaking tests on the unbleached kraft pulps, carried out after beating the pulps with a PFI mill to four levels. Such a mass of figures can make it difficult to distinguish and comprehend the extent of differences between pulps. A common solution to this difficulty is to extract a single figure to represent each variable by interpolating at a nominated level of another variable such as freeness, handsheet bulk, handsheet density or even tensile strength. Unfortunately, none of these variables is always ideal as a basis for comparing papermaking results and papermaking companies often have their own standards in this respect. In this project, the results are reported at two freeness levels, 250 mL and 350 mL CSF, with the former being used as the basis for statistical comparisons of pulp properties because it is more commonly employed in the literature.

Tables 8 and 9 present values for handsheet bulk, tearing resistance and tensile strength, interpolated at 250 mL and 350 mL CSF, respectively. Figures 12, 13 and 14 illustrate the data at 250 mL CSF for each papermaking parameter in turn. In each of the charts presenting papermaking properties at 250 mL CSF, the repeatability of the test is shown as error bars. Repeatability is useful in judging the significance of differences between samples where repeated test results are not available. It is defined as the limit within which agreement may be expected 95% of the time between two test results obtained under essentially the same conditions (9).

Table 8
Unbleached papermaking properties interpolated at 250 mL CSF

Species	Location	Age years	Bulk cm ³ /g	Tear index mN.m ² /g	Tensile index N.m/g	Fibre length* mm
<i>E. badjensis</i>	Uriarra	14	1.13	8.1	109	0.64
<i>E. benthamii</i>	Uriarra	14	1.25	9.7	96	0.58
<i>E. globulus</i> ssp <i>bicostata</i>	Uriarra	14	1.20	8.2	101	0.70
<i>E. kartzoffiana</i>	Uriarra	14	1.15	8.1	101	0.54
<i>E. macarthurii</i>	Uriarra	14	1.25	9.5	103	0.58
<i>E. nitens</i>	Uriarra	14	1.18	8.9	111	0.63
<i>E. smithii</i>	Uriarra	14	1.18	9.3	111	0.74
<i>E. viminalis</i>	Uriarra	14	1.18	9.1	111	0.68
<i>E. badjensis</i>	Kowen	14	1.11	7.3	102	0.52
<i>E. benthamii</i>	Kowen	14	1.24	7.8	88	0.52
<i>E. globulus</i> ssp <i>bicostata</i>	Kowen	14	1.15	7.4	94	0.57
<i>E. kartzoffiana</i>	Kowen	14	1.13	8.2	96	0.53
<i>E. macarthurii</i>	Kowen	14	1.14	7.5	91	0.50
<i>E. nitens</i>	Kowen	14	1.14	8.7	104	0.62
<i>E. smithii</i>	Kowen	14	1.20	8.7	103	0.67
<i>E. viminalis</i>	Kowen	14	1.12	7.2	97	0.51
<i>E. dunnii</i>	Coffs Harbour	9	1.25	10.1	106	0.73
<i>C. maculata</i>	Gympie	12	1.25	9.9	107	0.84
<i>E. cloeziana</i>	Gympie	12	1.36	10.6	87	0.90
<i>E. dunnii</i>	Gympie	12	1.25	9.9	102	0.86
<i>E. pilularis</i>	Gympie	12	1.27	10.6	99	0.88
<i>E. occidentalis-salt</i>	Timmering	6	1.24	7.3	92	0.64
<i>E. occidentalis-Fresh</i>	Timmering	6	1.21	7.2	91	0.62
Export Chips	Tasmania	>110	1.25	7.8	95	0.64
<i>E. globulus</i>	Tasmania	10	1.19	8.3	109	0.59

*Length-weighted average measured on pulps after 1000 PFI revs

Table 9
Unbleached papermaking properties interpolated at 350 mL CSF

Species	Location	Age Years	Bulk cm ³ /g	Tear index mN.m ² /g	Tensile index N.m/g
<i>E. badjensis</i>	Uriarra	14	1.22	7.5	94
<i>E. benthamii</i>	Uriarra	14	1.36	8.9	80
<i>E. globulus</i> ssp <i>bicostata</i>	Uriarra	14	1.28	8.0	88
<i>E. kartzoffiana</i>	Uriarra	14	1.26	7.5	81
<i>E. macarthurii</i>	Uriarra	14	1.37	8.5	83
<i>E. nitens</i>	Uriarra	14	1.25	8.8	100
<i>E. smithii</i>	Uriarra	14	1.25	9.0	100
<i>E. viminalis</i>	Uriarra	14	1.28	8.5	95
<i>E. badjensis</i>	Kowen	14	1.24	6.8	80
<i>E. benthamii</i>	Kowen	14	1.35	6.6	69
<i>E. globulus</i> ssp <i>bicostata</i>	Kowen	14	1.25	6.8	76
<i>E. kartzoffiana</i>	Kowen	14	1.23	7.3	71
<i>E. macarthurii</i>	Kowen	14	1.27	6.0	61
<i>E. nitens</i>	Kowen	14	1.22	8.5	91
<i>E. smithii</i>	Kowen	14	1.28	8.5	89
<i>E. viminalis</i>	Kowen	14	1.22	6.8	78
<i>E. dunnii</i>	Coffs Harbour	9	1.34	10.0	94
<i>C. maculata</i>	Gympie	12	1.31	9.5	95
<i>E. cloeziana</i>	Gympie	12	1.42	9.8	78
<i>E. dunnii</i>	Gympie	12	1.34	10.0	93
<i>E. pilularis</i>	Gympie	12	1.34	10.2	87
<i>E. occidentalis-salt</i>	Timmering	6	1.34	6.6	77
<i>E.occidentalis-Fresh</i>	Timmering	6	1.30	6.6	77
<i>E. globulus</i>	Tasmania	10	1.24	8.8	102
Export Chips	Tasmania	110	1.29	8.1	86

Figure 12
Handsheet bulk at 250 ml Canadian Standard Freeness
compared with commercial Tasmanian wood resources

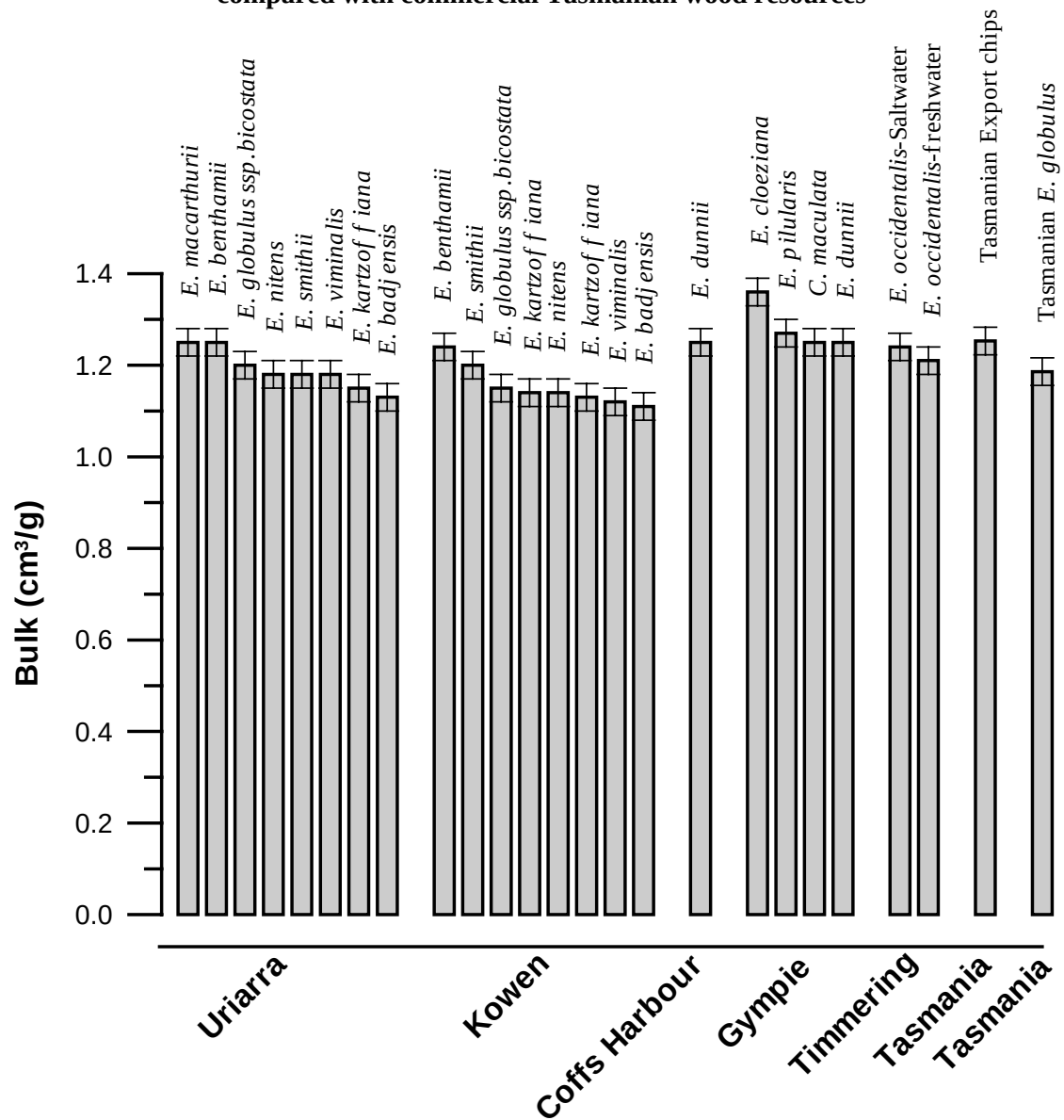


Figure 13
Tearing resistance at 250 ml Canadian Standard Freeness
compared with commercial Tasmanian wood resources

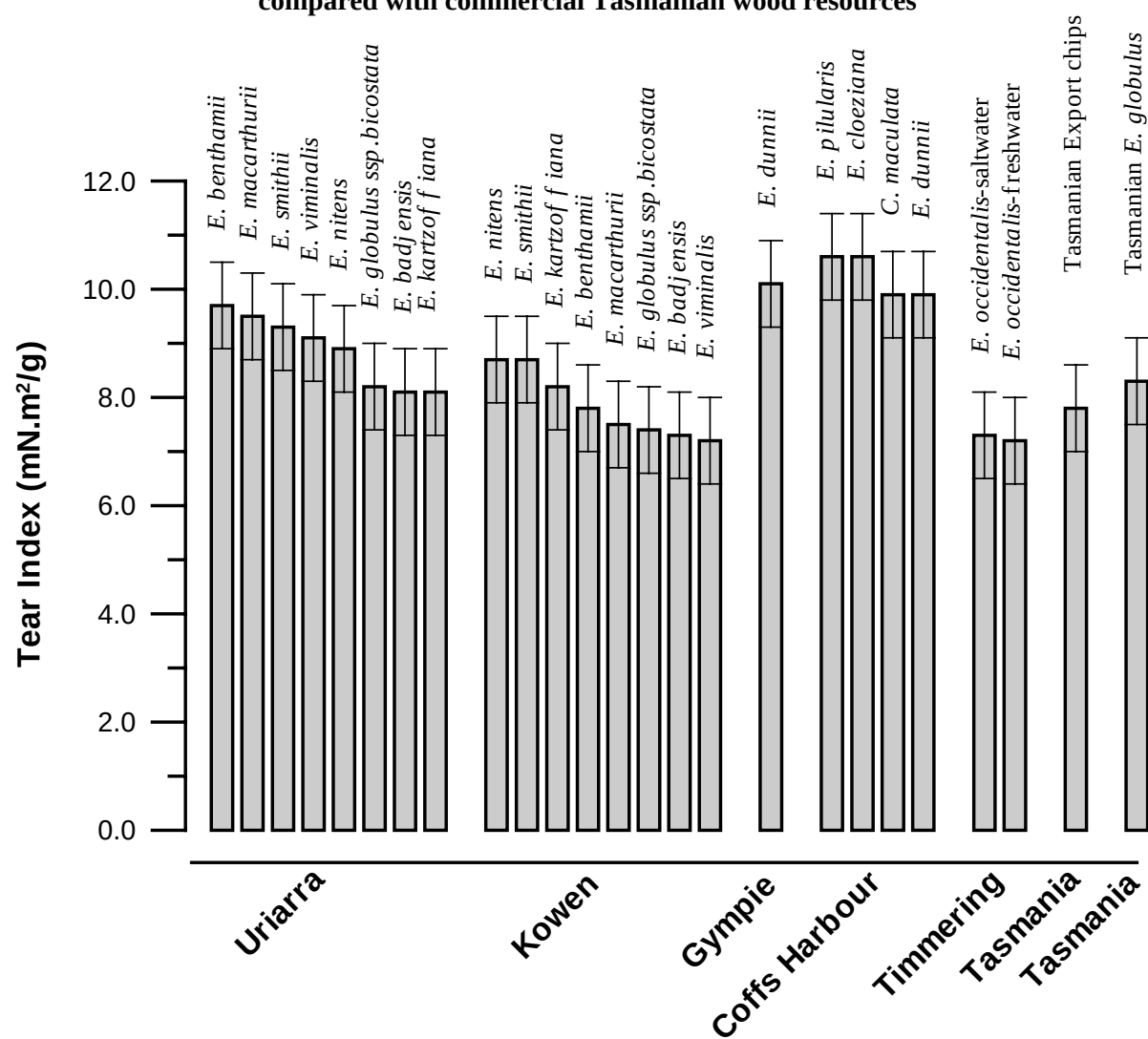


Figure 14
Tensile strength at 250 ml Canadian Standard Freeness
compared with commercial Tasmanian wood resources

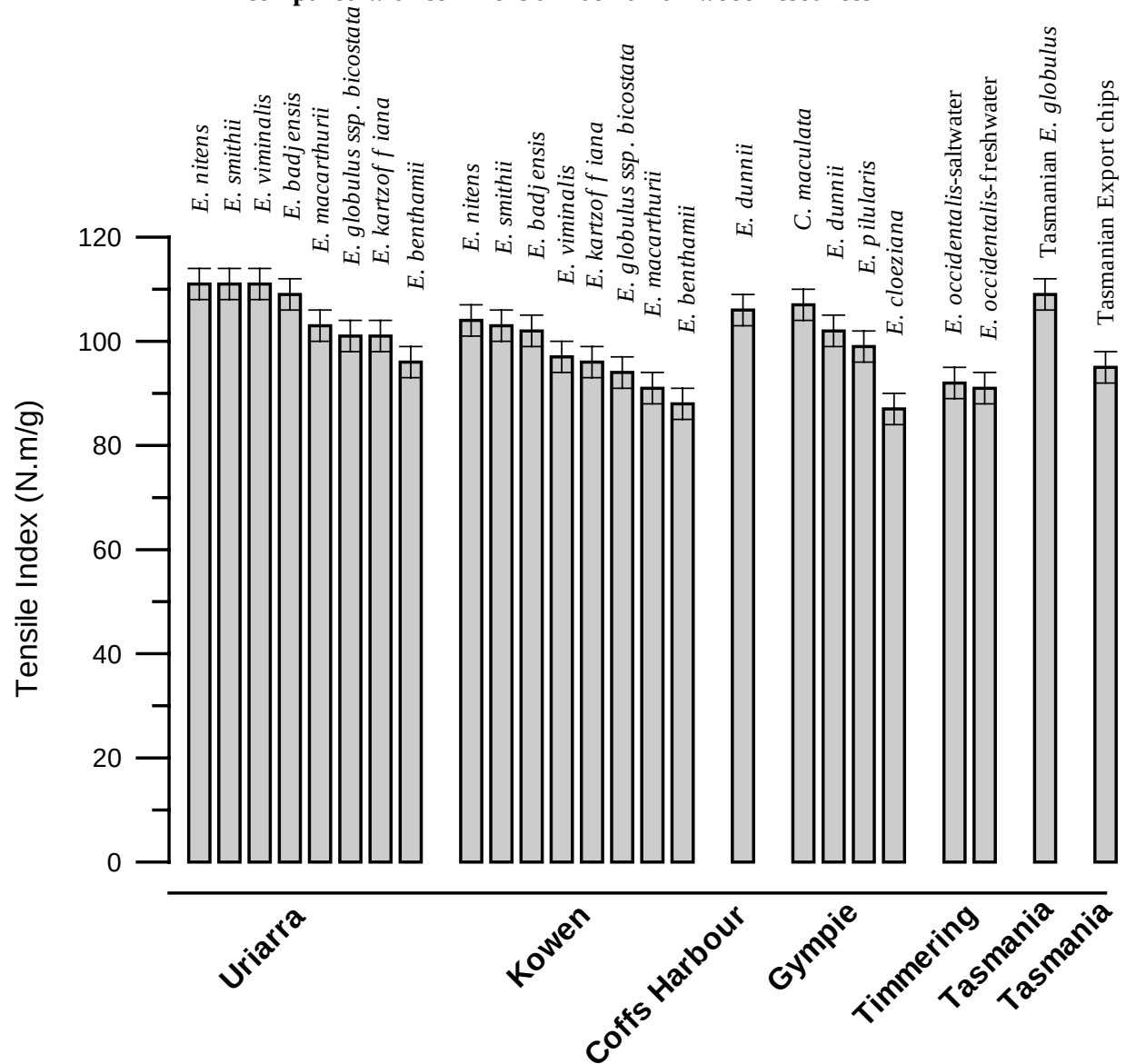


Figure 15
Handsheet bulk at 250 mL CSF
Species sampled at Uriarra and Kowen

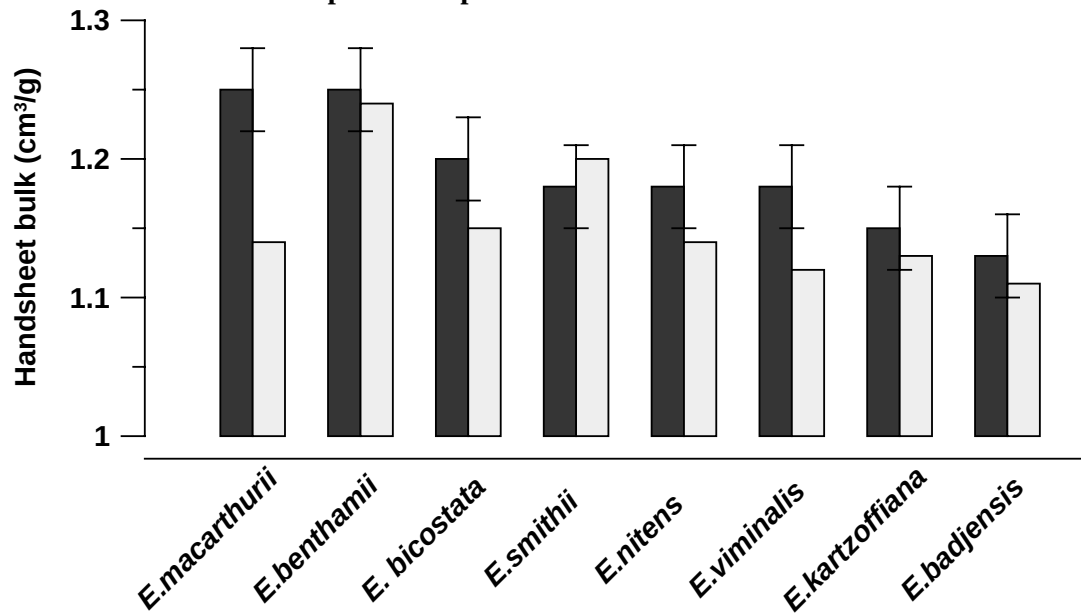


Figure 16
Pulp fibre lengths of species sampled at Uriarra and Kowen

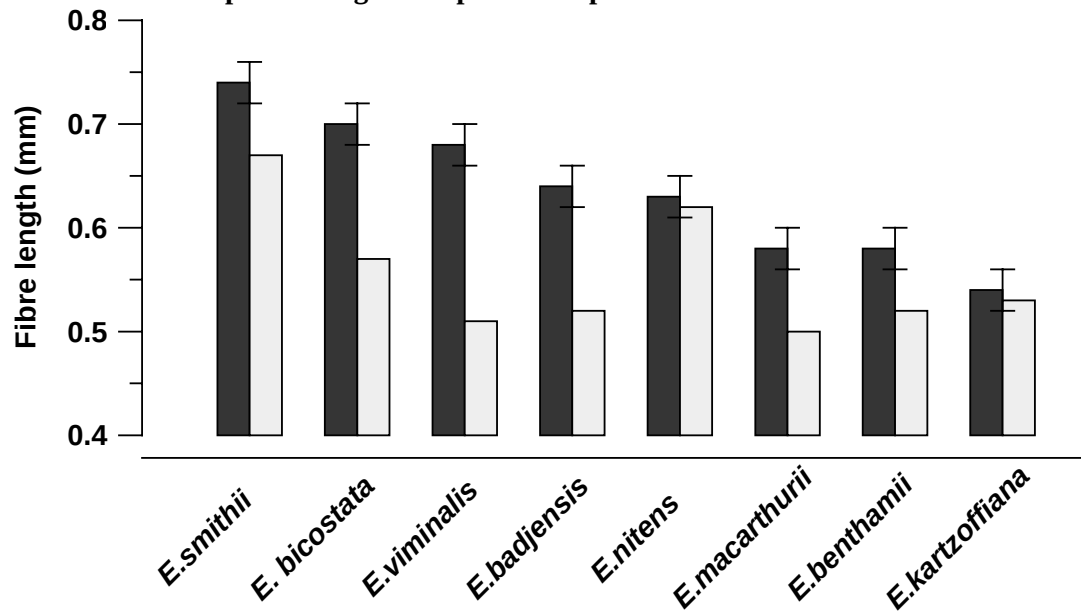


Figure 17
Tearing resistance at 250 mL CSF
Species sampled at Uriarra and Kowen

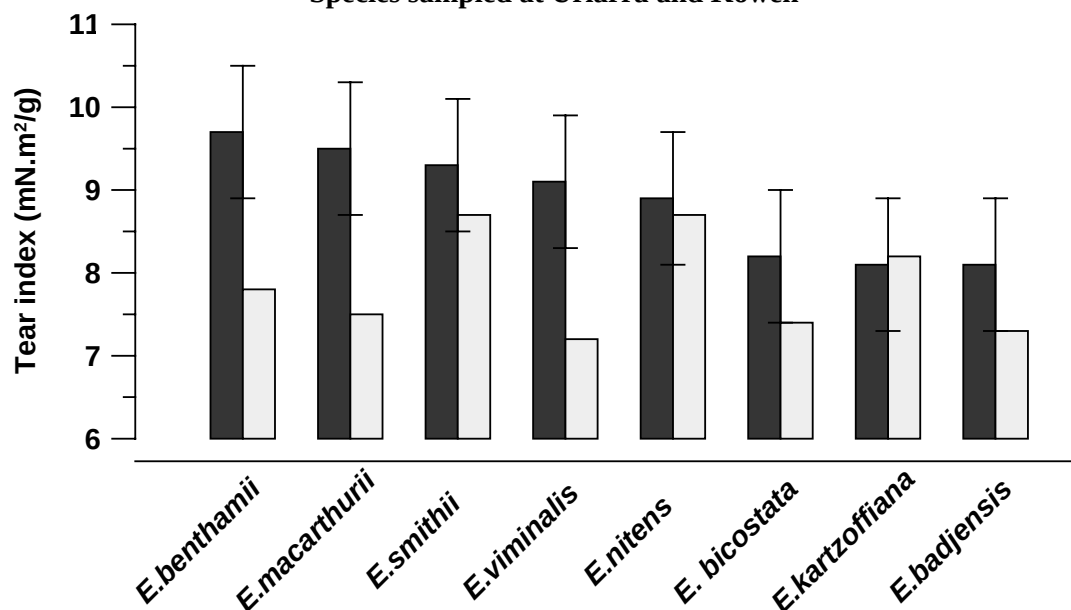
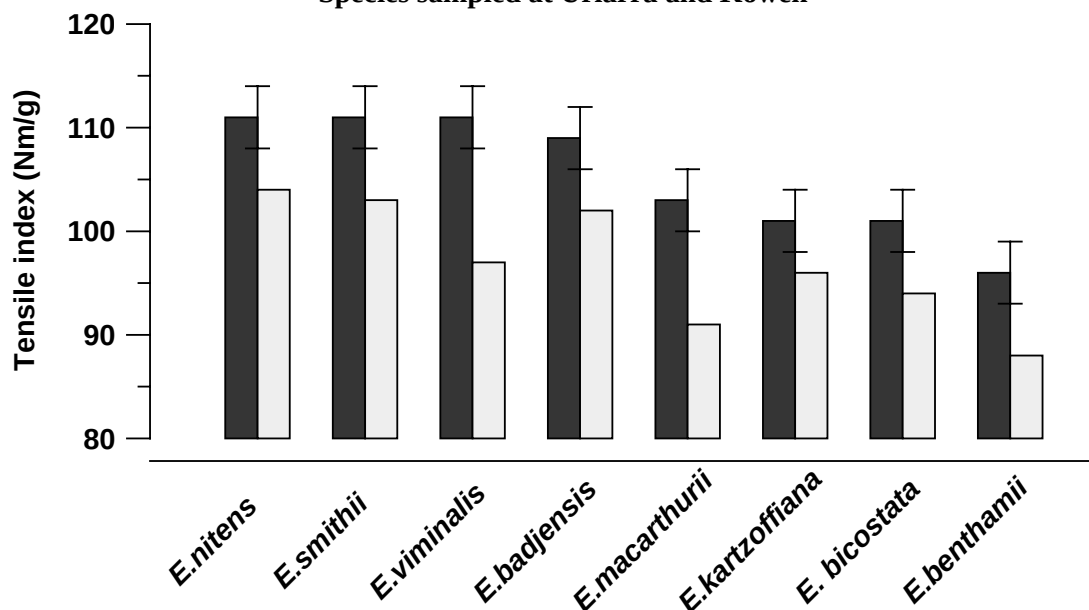


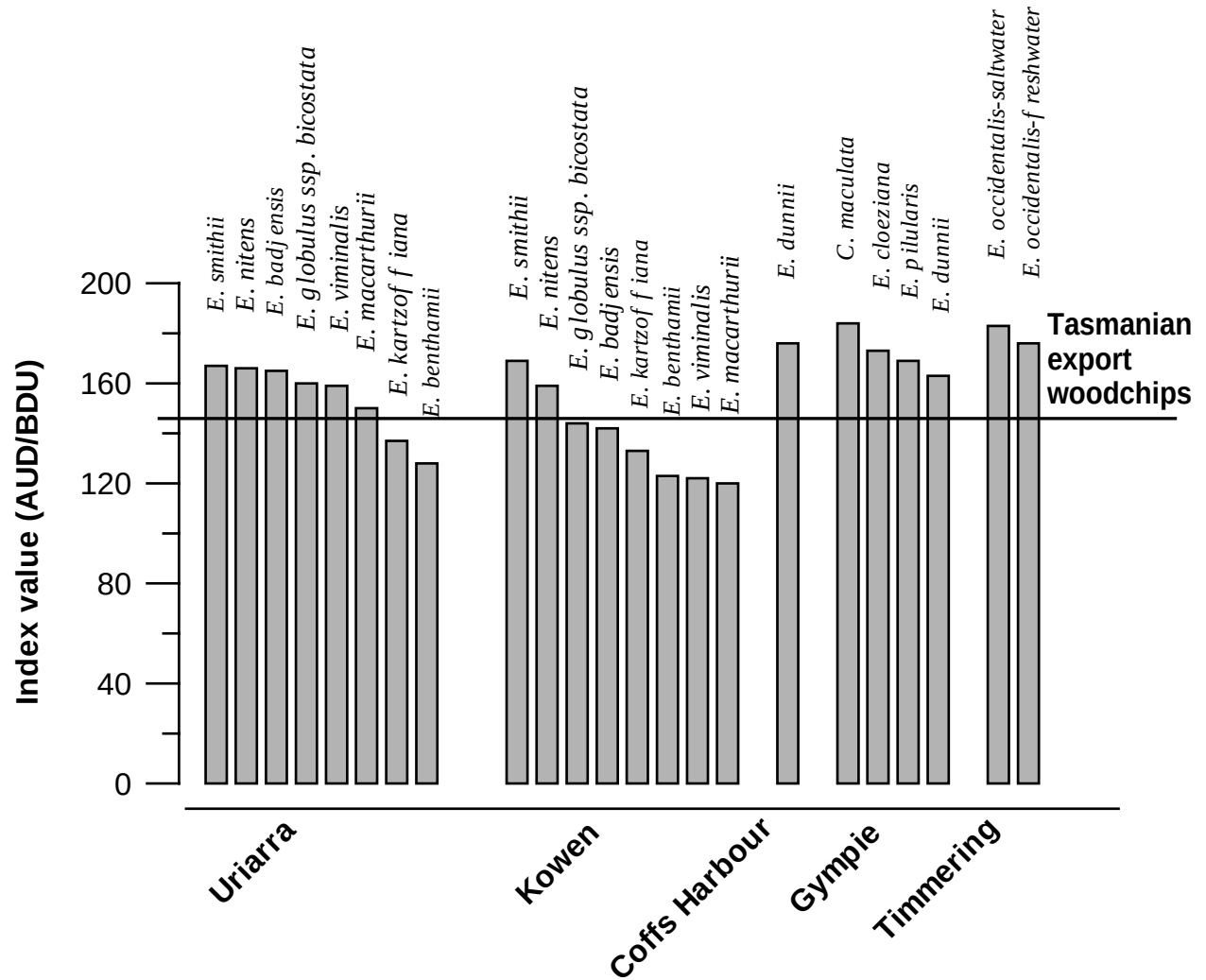
Figure 18
Tensile strength at 250 mL CSF
Species sampled at Uriarra and Kowen



3.4 Pulpwood Values

Using the basic densities, alkali requirements and pulps yields obtained from the laboratory tests, an estimate of the relative of each sample as export chips was calculated (Figure 19). The three species with the highest values as export woodchips were *C. maculata* from Gympie, followed by *E. occidentalis* from Timmering and *E. dunnii* from Coffs Harbour. Eight of the wood samples had values lower than that of the export woodchips from Tasmania but six of these samples came from the Kowen site where adverse growing conditions reduced yield and density. Only the *E. benthamii* and *E. kartzoiffiana* trees had low index values at both the Kowen and Uriarra sites.

Figure 19
Suitability of eucalypt species for chemical pulping
Compared with commercial wood resources



4. Discussion of Results

4.1 Basic Density

Basic density is defined as the oven dry mass of wood per unit green volume and is a key indicator of pulpwood quality. Among eucalypts, basic density has been correlated with paper properties (10, 11), so that different density ranges are suited to different paper products. Eucalypts at the high end of the density range of commercial pulpwoods (12), up to 600 kg.m^{-3} , have fibres with thick walls relative to their diameter and are stiff and resistant to collapse. A bulky, open sheet results, which is porous and more compressible, giving better printability (13, 14). Lower bonding results in increased sheet softness, so that medium density eucalypts (according to Zobel *et al.* (15), up to 540 kg.m^{-3} for *E. grandis*) are considered superior raw materials for tissues (16). Woods at the low end of the commercial density range (as low as 400 kg.m^{-3}) collapse more readily, forming ribbon-like shapes that have greater surface area and therefore bond well together. Papers made from these fibres have high tensile and bursting strengths but low opacity, and are best suited to packaging grades of paper.

Density also has direct effects on the economics of wood chip transport, and on pulping in mills in which the capacity of the digester is a limiting factor (17). Basic density is inversely related to moisture content (18), although the exactness of this relationship varies (19). Moisture content can influence road transport costs, since state laws usually limit the weight a truck can carry.

Most of the samples tested were within the $400\text{--}600 \text{ kg.m}^{-3}$ range nominated by Higgins (12) for commercial pulpwoods, but from Gympie were denser, at 644 kg.m^{-3} and 642 kg.m^{-3} respectively. High-density woods can be more difficult to impregnate with cooking liquors, leading to uneven delignification of woodchips, but paper companies now accept wood with higher densities for fine paper production, up to 650 kg.m^{-3} in Australia (20) and up to 700 kg.m^{-3} in Japan. Accordingly, even *E. cloeziana* and *C. maculata* would be considered acceptable for the production of fine papers.

The trend towards higher wood density at the higher rainfall site (Urriara) compared with the lower rainfall site (Kowen) is in marked contrast to previous studies where faster growing trees (associated with higher irrigation rates) had lower wood density (21). Differences in growth rate associated with increased water availability appear to have variable effects on wood density, because incremental growth may be composed of either earlywood (thin-walled fibres = low density wood) or latewood (thick-walled fibres = high density wood), perhaps depending on when the water becomes available in the growing season (18). In addition, there may be significant differences in the size and number of other wood structural components such as vessels.

4.2 Pulping Properties

In the current study, the aim was not to model particular kraft pulp mill configurations, but rather to assess the suitability of different eucalypt species for pulping. Accordingly, a conventional batch-type kraft pulping process was used in the laboratory tests. The results of such tests can give only a relative estimate of pulping quality, as industrial-scale installations may give widely different results according to the details of their particular design and operation. Despite these limitations, much useful information is obtained from laboratory pulping studies. The most important parameter is pulp yield. Wood costs are the single largest variable cost of producing chemical pulp for papermaking, whereas chemicals comprise a much smaller proportion of total costs.

The pulping results may therefore appear to suggest that the 9-year-old *E. dunnii* from Coffs Harbour, the 6-year-old *E. occidentalis* (salt-water irrigation) from Timmering and the 14-year-old *E. badjensis* from Uriarra have the most potential for pulping, since these had the highest pulp yields. However, for export woodchips, sea freight costs are also important. The latter are strongly influenced by basic density, so the species ranking changes when export chips are the intended end product rather than domestic utilisation.

The good results obtained for the Timmering *E. occidentalis* trees is in agreement with those reported for a 6-year-old irrigated site at Bolivar in South Australia (6). In this study, one provenance of *E. occidentalis* (Pallerup Rock, WA) had a higher pulp yield than that typical of *E. globulus* at the same age. However, this earlier work also found consistent evidence of a reduction in pulp yield with increased irrigation water salinity, at least in *E. camaldulensis*. The higher pulp yield obtained for the *E. occidentalis* trees irrigated with saline water is therefore unexpected and raises questions about the uniformity and effectiveness of the flood irrigation used at the Timmering site, or the generality of the conclusions drawn from the *E. camaldulensis* study. At the time the samples were collected from the site, some low-lying areas were under water whereas higher areas were dry. Lower water availability can reduce pulp yield (see, for example, the results for Uriarra and Kowen), in a manner analogous to differences in salinity (21).

The lowest pulp yields were produced by *E. benthamii* and *E. kartzoffiana*. These two species gave lower yields than the Tasmanian export chips and consequently residual wood from these two species is unlikely to be economic as a resource for chemical pulping.

4.3 Unbleached Papermaking Properties

Eucalypt kraft pulps are mostly utilized in printing and writing grades of papers, where the particular balance of strength and optical properties of these pulps have an advantage (23). French, quoted by Dean (24) identified bulk, opacity (or scattering coefficient), surface roughness, porosity (or air resistance), stiffness and formation as important properties for these papers. Sidaway (25) suggested that refiner energy requirement was an important attribute, and Colley (26) determined that the size and number of vessel elements could be a significant quality factor. Vessel elements often lie flat on the surface of a paper sheet and can be lifted out during offset printing, leaving white areas that degrade print quality to an extent that is partly related to the size and concentration of the vessels.

In a recent survey of the Japanese pulp and paper industry (27), low vessel picking tendency and high sheet bulk were identified as the most desirable attributes for eucalypt kraft pulps used in fine papers. Smoothness, opacity, tear and tensile strengths, beatability, porosity and freeness were ranked progressively lower. As noted above, vessel picking tendency influences printing quality, whereas high sheet bulk improves paper properties such as stiffness and opacity, and allows an increase in sheet thickness (and sometimes smoothness) at a given basis weight. Where sheet bulk is low, more fillers like calcium carbonate may be added during papermaking to improve opacity. The amount of filler that may be added is limited by dust generation, and pulp strength may also be a consideration, even in printing and writing papers.

In this project, the optical properties of the pulps (brightness and opacity) were not measured because the pulps were not bleached. Vessel picking tendency was not tested for two reasons. First, all the trees were less than 20 years old. Vessel diameter has been found to be smaller in younger woods than in older woods (28) and if the vessels are small enough in diameter they may not present a significant picking problem (26). Second, laboratory measurements are often inaccurate or may bear little relation to the results obtained on an industrial scale.

At 250 mL CSF, only two of the plantation grown eucalypts (12-year-old *E. cloeziana* and *E. pilularis* from Gympie) had a handsheet bulk higher than that of the pulp from the export woodchips. However, seven other samples had handsheet bulks within the repeatability limit of the test (i.e. $\geq 1.22 \text{ cm}^3/\text{g}$). These samples were: *E. dunnii* and *C. maculata* from Gympie, *E. dunnii* from Coffs Harbour, *E. benthamii* and *E. macarthurii* from Uriarra, *E. benthamii* from Kowen and *E. occidentalis* from Timmering (saltwater treatment).

Only eight samples had handsheet bulks significantly lower than that of Tasmanian *E. globulus*. Three-quarters of these came from the Kowen site. As noted above, the densities of the trees at

Kowen were generally lower than the corresponding species at Uriarra, and a relationship often exists between wood density and handsheet bulk (10). Low bulks would therefore be expected for the pulps produced from the Kowen trees (Figure 15) as a result of adverse growing conditions rather than genetic differences between species.

Linear regression across the entire data set indicated that a low but statistically significant correlation exists between handsheet bulk and wood density ($r^2 = 0.34$, $p = 0.002$). However, a somewhat stronger correlation was found between bulk and fibre length ($r^2 = 0.45$, $p < 0.001$). Fibre length may be expected to contribute to handsheet bulk, since longer fibres do not pack together as closely (22), but fibre length would not be expected to overshadow the effects of wood density. When both wood density and fibre length were used in the regression against handsheet bulk, no great improvement in the fit was evident ($r^2 = 0.47$, $p = 0.001$) over the use of either parameter alone. It was concluded that the high correlation with fibre length was probably spurious. Both density and fibre length were higher in trees grown at Uriarra than at Kowen (Figures 8 & 16) leading to a significant overall correlation between fibre length and basic density ($r^2 = 0.53$, $p < 0.001$).

In brief, the wood and paper properties of the trees grown at Kowen were adversely affected by the growing conditions at the site. If these results are discounted, all the species tested had handsheet bulks comparable with the range of commercial pulp wood resources, with the possible exception of *E. badjensis* and *E. kartzoffiana*.

For tearing resistance at 250 mL CSF, 12 of the samples were stronger than the Tasmanian *E. globulus* pulp, and 16 were stronger than the pulp from the export woodchips. However, all 23 samples had tearing resistances above the lower repeatability limit of the pulp from the export woodchips (i.e. above $7.0 \text{ mN.m}^2.\text{g}^{-1}$), meaning that all the samples were comparable with or better than this commercial wood resource. Again, as may be predicted from the fibre length results, the pulps from the Kowen trees were generally lower in tearing resistance than those from corresponding species from Uriarra (Figure 17).

For tensile strength at 250 mL CSF, only one pulp sample (*E. badjensis* from Uriarra) was as strong as the Tasmanian *E. globulus* pulp. However, only four were significantly weaker than the pulp from the export woodchips (*E. benthamii* and *E. macarthurii* from Kowen, *E. cloeziana* from Gympie and *E. occidentalis* (freshwater treatment) from Timmering). As in the other paper properties, the tensile strength of the pulps from the Kowen trees were generally inferior to those of pulps from corresponding species from Uriarra (Figure 18).

4.4 Pulpwood Values

The three species with the highest values as export woodchips were *C. maculata* from Gympie, followed by *E. occidentalis* from Timmering (both saltwater and freshwater irrigation treatments) and *E. dunnii* from Coffs Harbour. For *C. maculata* and the freshwater irrigated *E. occidentalis*, higher densities compensated for slightly lower pulp yields. The high index values calculated for *C. maculata* are in accord with results for trees from more southerly provenances (or species, if the genotype planted at Gympie was actually *C. variegata*), where *C. maculata* ranked only third behind *E. globulus* and *E. viminalis* (6). The high values obtained for the *E. occidentalis* samples are also in agreement with previous work but it must be emphasized that the short fibres of the species may limit its application in paper products where strength is critical.

Another notable result was that of *E. smithii*, which ranked above *E. nitens* (a commercially important pulpwood species) at both Uriarra and Kowen. *E. smithii* appears to have considerable potential as a pulpwood species and is already extensively planted for this purpose in South Africa (29). However, further tree breeding work may be necessary to improve the form of trees from some provenances.

5. Implications

Survival and growth rate are usually the primary criteria for selecting tree species for planting. This project shows that wood quality, as defined in relation to the intended end product, should not be ignored. Several eucalypt species, such as *C. maculata*, *E. dunnii*, *E. smithii* and *E. occidentalis*, have potential for farm forestry production systems and may find a market as a component of the woodchips exported from Australia. However, two species, *E. benthamii* and *E. kartzoffiana*, may be impossible to market unless their prices are significantly discounted for their poorer pulpwood quality.

The strong association found between low rainfall and poor pulpwood quality suggests that farmers planning to grow trees in dryland regions (<600 mm) may suffer more than reduced growth rates. The trees may also produce poorer quality and hence less marketable pulpwood.

6. Recommendations

Most of the trees tested in this project came from species suited to high rainfall conditions, with only three, *E. occidentalis*, *E. kartzoffiana* and *C. maculata*, having any potential for low rainfall sites. Even these trees were mainly sampled from high rainfall or irrigated stands (primarily due to availability) so that questions remain about the likely wood quality of low rainfall species grown on dryland sites. Future work should address this uncertainty. Research on the wood properties of several genotypes of dryland pine is presently underway. Complimentary work will also be required for hardwoods.

7. Appendices

7.1 Appendix 1 - Unbleached Papermaking Properties

Beating Revs	Freeness CSF	Drainage s	Bulk cm ³ .g ⁻¹	Tear index mN.m ² .g ⁻¹	Tensile index N.m.g ⁻¹	Stretch %	Burst index kPa.m ² .g ⁻¹	Air res. s	Zero span index N.m.g ⁻¹	Fibre Length mm
<i>E. badjensis</i> Uriarra										
0	484	4.8	1.4	5.9	51	2.6	2.9	7	152	0.64#
1000	384	5.7	1.3	7.9	86	3.9	5.7	22		
2000	312	7.0	1.2	7.9	102	4.3	7.0	74		
4000	185	11.9	1.1	7.9	110	4.6	8.1	578		
<i>E. benthamii</i> Uriarra										
0	450	4.9	1.5	6.8	57	2.5	3.1	7	153	0.58
1000	317	6.1	1.3	9.4	86	3.7	5.6	25		
2000	253	7.5	1.2	9.7	96	4.5	6.7	74		
4000	154	12.4	1.2	9.1	104	4.5	7.5	320		
<i>E. globulus ssp. Bicostata</i> Uriarra										
0	509	4.6	1.4	6.3	55	2.2	3.0	6	151	0.70#
1000	388	5.1	1.3	8.1	84	3.6	5.6	16		
2000	280	6.5	1.2	8.0	95	4.0	6.8	56		
4000	153	12.3	1.1	7.8	109	4.4	7.9	599		
<i>E. kartzoffiana</i> Uriarra										
0	418	5.0	1.4	6.6	59	2.8	3.5	14	142	0.54
1000	299	6.2	1.2	7.9	92	4.2	6.2	53		
2000	269	7.2	1.2	8.0	100	4.6	7.3	129		
4000	167	11.7	1.1	8.1	107	4.8	8.2	882		
<i>E. macarthurii</i> Uriarra										
0	442	4.7	1.5	6.4	57	2.2	3.0	6	156	0.58
1000	335	5.7	1.4	8.7	87	3.8	5.7	19		
2000	264	7.0	1.3	9.4	102	4.4	6.9	45		
4000	156	11.6	1.2	9.3	111	4.7	7.8	258		
<i>E. nitens</i> Uriarra										
0	493	4.6	1.4	6.9	56	2.2	3.1	6	153	0.63
1000	424	5.1	1.3	8.9	89	3.8	6.0	15		
2000	349	5.9	1.2	8.9	100	4.1	7.0	39		
3000	209	9.8	1.1	8.4	110	4.3	7.9	326		
<i>E. smithii</i> Uriarra										
0	517	4.5	1.6	6.1	50	1.9	2.4	3	156	0.74#
1000	414	5.3	1.4	8.9	83	3.3	5.0	9		
2000	366	6.0	1.3	9.0	98	3.9	6.5	27		
4000	198	9.3	1.2	8.8	112	4.4	7.8	177		
<i>E. viminalis</i> Uriarra										
0	457	4.7	1.4	6.6	62	2.2	3.2	6	156	0.68#
1000	364	5.6	1.3	8.7	93	3.6	5.9	21		
2000	268	7.2	1.2	8.8	108	3.8	7.7	76		
4000	152	12.7	1.1	8.6	111	4.2	8.8	587		
<i>E. badjensis</i> Kowen										
0	396	5.1	1.3	6.0	65	2.8	3.6	19	135	0.52
1000	335	6.3	1.2	7.0	87	4.0	3.7	45		
2000	255	7.9	1.1	7.3	99	4.5	7.1	182		
4000	185	14.1	1.1	6.9	106	4.9	7.8	1200		
<i>E. benthamii</i> Kowen										
0	395	5.2	1.4	5.7	58	2.3	3.0	11	147	0.52
1000	255	7.2	1.3	7.9	85	3.7	5.6	51		
2000	223	9.3	1.2	7.7	95	4.2	6.7	153		
4000	137	14.5	1.1	7.7	103	4.8	7.4	549		
<i>E. globulus ssp. bicostata</i> Kowen										
0	428	4.9	1.4	5.6	55	2.7	3.1	11	122	0.57
1000	321	6.1	1.2	7.0	81	4.0	5.5	38		
2000	260	7.4	1.2	7.5	93	4.5	6.7	109		
4000	172	13.9	1.1	7.3	102	4.9	7.7	1200		

Beating revs	Freeness CSF	Drainage s	Bulk cm ³ .g ⁻¹	Tear index mN.m ² .g ⁻¹	Tensile index N.m.g ⁻¹	Stretch %	Burst index kPa.m ² .g ⁻¹	Air res. s	Zero span index N.m.g ⁻¹	Fibre Length mm
<i>E. kartzoffiana</i> Kowen										
0	387	5.0	1.5	5.5	57	2.4	3.2	14	132	0.53
1000	319	6.3	1.3	7.8	83	3.9	5.4	30		
2000	237	8.5	1.2	7.9	96	4.6	7.0	130		
4000	168	14.9	1.1	8.1	105	5.1	7.5	1200		
<i>E. macarthurii</i> Kowen										
0	361	5.4	1.3	5.7	58	2.6	3.2	25	127	0.50
1000	286	7.7	1.2	7.2	81	4.1	5.6	85		
2000	241	10.7	1.1	7.5	93	4.5	6.9	251		
4000	177	19.2	1.1	7.1	102	5.1	7.0	1200		
<i>E. nitens</i> Kowen										
0	478	4.7	1.4	5.9	53	2.5	2.9	6	143	0.62
1000	388	5.7	1.3	8.9	85	3.9	5.8	20		
2000	314	6.6	1.2	8.4	94	4.4	7.0	55		
4000	196	10.9	1.1	8.0	107	4.8	8.1	350		
<i>E. smithii</i> Kowen										
0	502	4.7	1.5	6.2	55	2.0	2.8	6	148	0.67
1000	373	5.5	1.3	8.6	86	3.3	5.4	17		
2000	294	6.6	1.2	8.5	97	3.8	7.0	50		
4000	150	12.8	1.2	8.0	111	4.2	7.9	508		
<i>E. viminalis</i> Kowen										
0	420	5.1	1.3	5.5	54	2.8	3.0	16	118	0.51
1000	323	7.3	1.2	7.1	87	4.2	5.6	90		
2000	251	9.6	1.1	7.1	95	4.5	6.4	237		
4000	181	20.0	1.1	6.6	102	4.6	7.2	1200		
<i>E. dunnii</i> Coffs Harbour										
0	524	4.5	1.6	7.1	56	1.9	2.8	3	180	0.73
1000	407	5.0	1.4	9.6	83	2.7	5.2	11		
2000	329	5.9	1.3	9.9	99	3.5	6.3	30		
4000	188	9.6	1.2	9.8	110	4.0	7.8	217		
<i>E. cloeziana</i> Gympie										
0	577	4.4	1.7	5.3	39	1.5	1.9	1	161	0.90#
1000	470	4.8	1.5	8.0	59	2.3	3.5	3		
2000	363	5.3	1.4	9.6	78	3.2	4.7	9		
4000	191	8.2	1.3	10.7	89	3.6	6.2	51		
<i>E. dunnii</i> Gympie										
0	553	4.5	1.6	6.0	49	1.8	2.3	3	174	0.86#
1000	448	5.2	1.4	9.2	76	2.8	4.7	8		
2000	359	6.1	1.4	9.6	92	3.4	5.8	20		
4000	205	10.2	1.2	9.5	104	3.8	7.6	148		
<i>E. pilularis</i> Gympie										
0	540	4.5	1.6	6.5	49	1.5	2.4	2	172	0.88
1000	439	5.1	1.4	8.8	75	2.7	4.5	7		
2000	337	6.1	1.3	10.4	87	3.1	5.9	26		
4000	167	10.4	1.2	10.0	104	3.9	6.8	228		
<i>C. maculata</i> Gympie										
0	539	4.5	1.6	5.9	49	1.7	2.4	3	173	0.84
1000	454	5.3	1.4	9.4	79	2.9	4.7	10		
2000	352	6.2	1.3	9.4	92	3.4	5.8	26		
4000	211	10.7	1.2	9.6	109	4.1	7.1	176		
<i>E. occidentalis</i> (freshwater irrigation) Timmering										
0	486	4.6	1.5	4.2	44	1.6	2.2	3	145	0.62#
1000	354	5.7	1.3	6.7	77	3.2	4.6	13		
2000	259	7.2	1.2	7.0	88	3.6	5.8	45		
4000	144	14.1	1.1	7.1	100	4.2	7.0	516		

Beating	Freeness	Drainage	Bulk	Tear	Tensile	Stretch	Burst	Air	Zero span	Fibre
---------	----------	----------	------	------	---------	---------	-------	-----	-----------	-------

revs	CSF	s	cm ³ .g ⁻¹	index mN.m ² .g ⁻¹	index N.m.g ⁻¹	%	index kPa.m ² .g ⁻¹	res. s	index N.m.g ⁻¹	Length mm
<i>E. occidentalis</i> (saltwater irrigation) Timmering										
0	469	4.8	1.5	4.3	49	1.6	2.2	3		
1000	353	5.8	1.3	6.6	77	2.8	4.6	11	148	0.64#
2000	262	7.6	1.3	7.0	90	3.5	5.8	38		
4000	139	17.0	1.2	7.3	101	4.0	6.5	786		
<i>E. globulus</i> 10-year-old Tasmania										
1000	455	5.2	1.31	8.5	91	3.3	5.7	9	144	0.59
2000	370	5.9	1.25	8.8	100	3.7	6.9	25		
4000	239	8.4	1.18	8.3	110	4.0	8.0	123		
6000	128	14.1	1.13	7.8	112	4.3	8.4	633		
Export Chips Tasmania										
1000	591	4.4	1.59	5.0	38	1.4	1.7	1	n/a	0.64
2000	401	5.6	1.32	8.1	79	3.1	4.4	12		
4000	240	7.8	1.25	7.9	96	3.8	6.1	81		
6000	140	12.4	1.20	7.9	100	3.9	6.9	422		
# Amcor Kajaani FS200 used										

Figure 20
Eucalypt unbleached pulps tear and tensile indexes

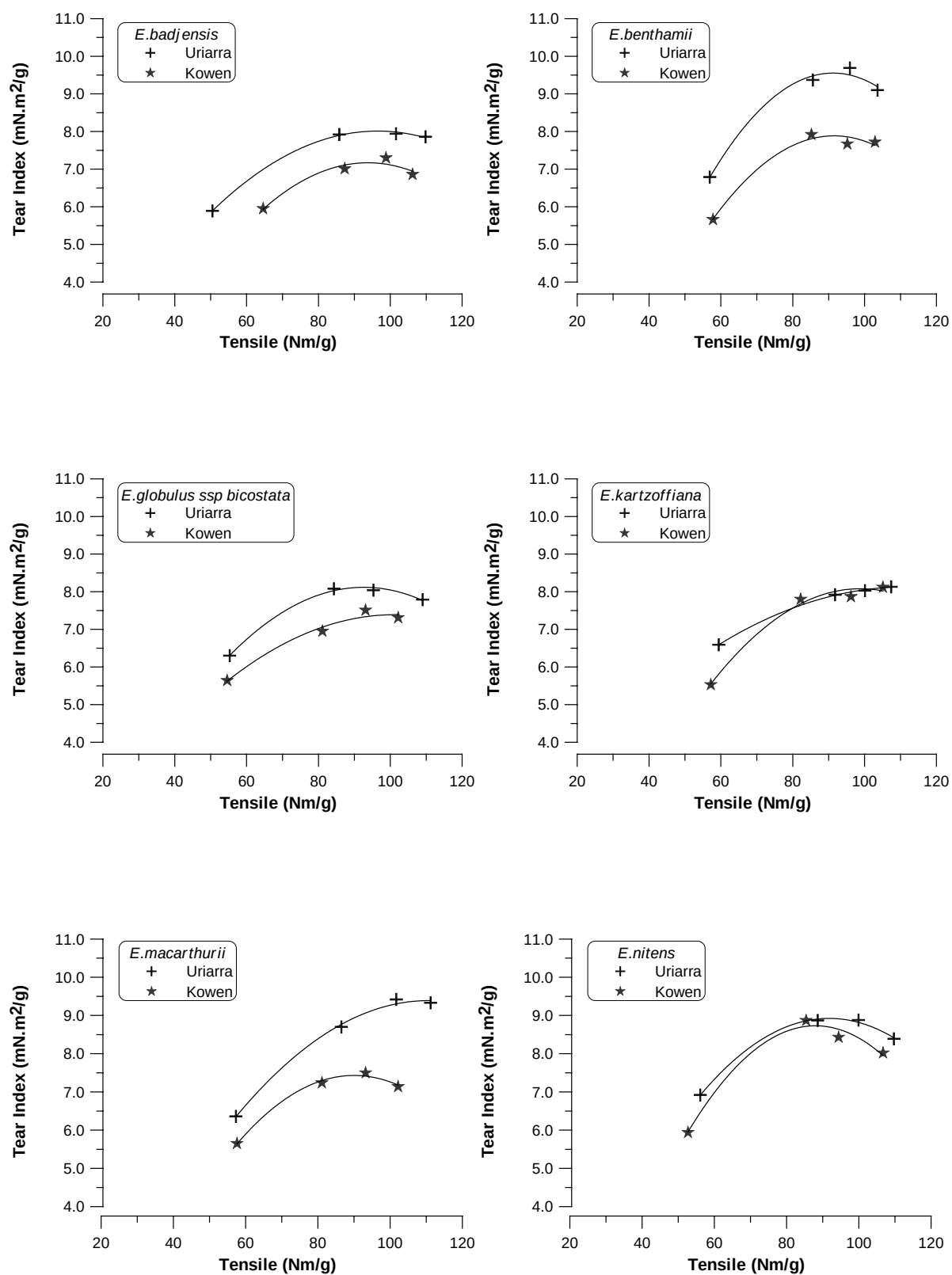
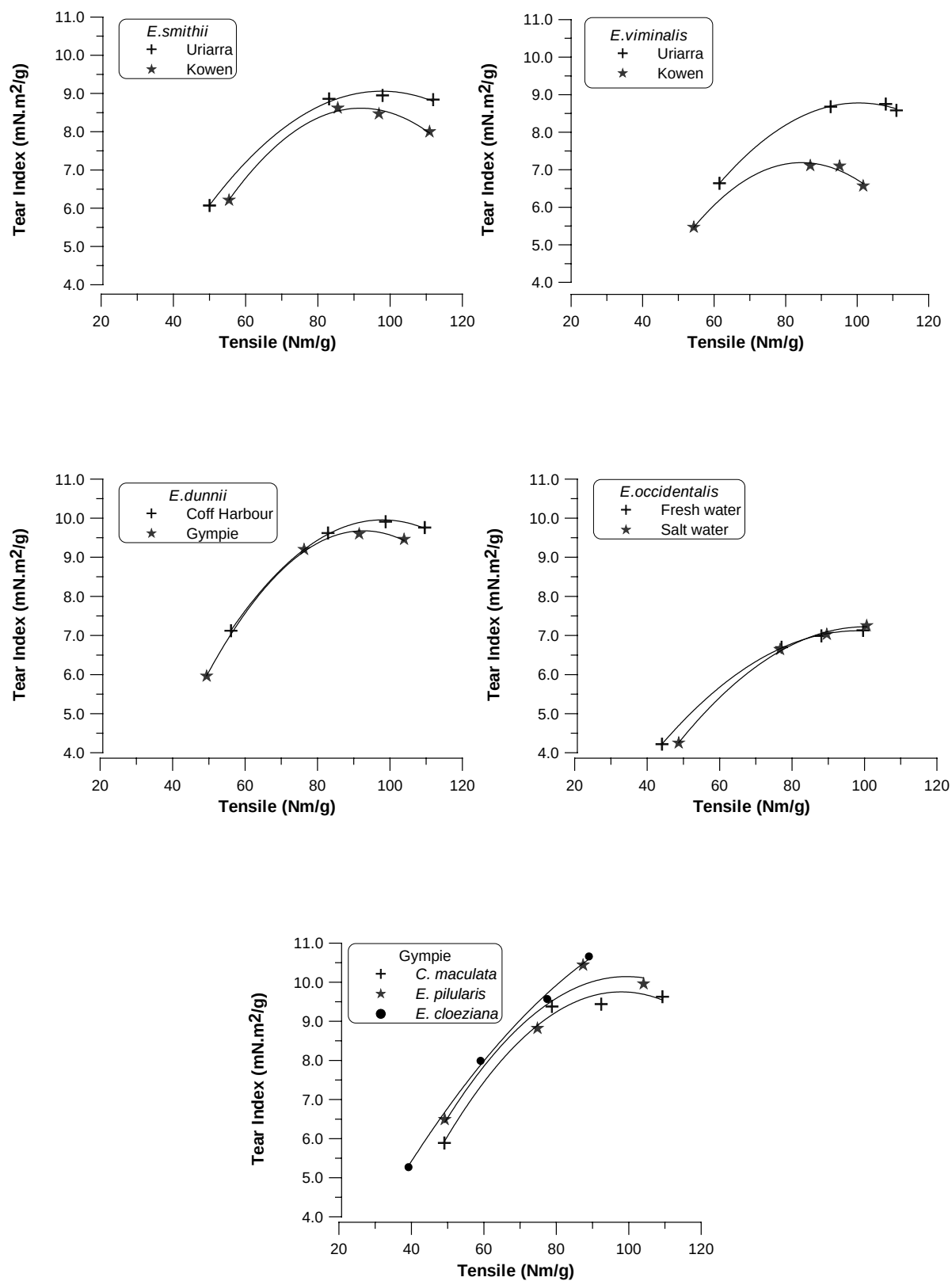


Figure 20 (cont.)
Eucalypt unbleached pulps tear and tensile indexes



7.2 Appendix 2 - Glossary

Active Alkali (AA). On an industrial scale, kraft-pulping liquor is composed of an aqueous solution of two active alkaline constituents, NaOH and Na₂S, plus a greater or lesser amount of relatively inert carbonates. Active alkali is usually described as NaOH + Na₂S, expressed Na₂O, and usually as a percentage of the initial mass of oven dry wood. In practice only half of the Na₂S present is actually available for the pulping reaction (see **effective alkali**).

Air dry pulp. Technically, pulp dried in equilibrium with the surrounding air. Commercially, usually defined as pulp with 10 or 12% moisture content according to country and the particular commercial agreement. In Australia and the USA, 90% dry fibre content is the commonly accepted level.

Air resistance. Related to the porosity of paper, in this study measured as air permeance according to *AS/NZS 1301.420s-89 - Gurley air permeance of paper*.

Australian/New Zealand Standard (AS/NZS) 1301. The joint Standards Australia / Standards New Zealand series of Methods of Test for Pulp and Paper.

Basic density (BD). The density of wood in terms of oven dry mass per unit green volume. In this study the basic density of wood chips was measured according to the draft Australian standard *AS/NZS 1301.001s:199? - Basic density of wood chips*. Solid wood samples were tested to *TAPPI T258 om-89 - Basic density and moisture content of pulpwood*.

Black liquor. The spent cooking liquor from a chemical pulping process. It is usually dark coloured owing to the content of suspended and dissolved degradation products of wood.

Bleaching. A process, usually achieved over a sequence of discrete stages, in which a dark coloured pulp is converted into one which is much lighter in colour, primarily by the removal of lignin by a sequence of chemical treatments.

Bone Dry Unit (BDU). The units in which woodchips for export are traditionally sold. Based on a cord of Douglas fir, the BDU is equivalent to 1.0886 metric tonnes of dry wood.

Brightness. The intrinsic reflectance factor measured at an effective wavelength of 457 nm with a reflectometer conforming to the requirements described in *AS/NZS 1301.436s-91 - Measurement of diffuse reflectance factor*, and calibrated against ISO reference standards. Units of brightness are a ratio, expressed as a percentage, of the radiation reflected by a body to that reflected by a standard reflecting diffuser under the same conditions.

Bulk / bulking thickness. Bulking thickness is the thickness of a single sheet of paper, calculated from the thickness of several superimposed sheets, measured under an applied static load, under the standard method of test detailed in *AS/NZS 1301.426s:1994 - Determination of thickness and apparent bulk density or apparent sheet density*. Bulk, in cm³/g, is derived from bulking thickness by dividing by grammage. For eucalypt kraft pulps that are mainly used in **fine papers**, high bulk is an advantage.

Bursting strength / Bursting index. Bursting strength is a measure of the strength of paper when tested in a burst tester, and relates to the true peak pressure developed by the hydraulic fluid in forcing a rubber diaphragm through a circular area of the paper under test. The procedure is regulated by *AS/NZS 1301.403s:1997 - Bursting strength of paper*. Bursting index is the bursting strength divided by the grammage (units kPa.m²/g). Bursting strength strongly correlates with tensile strength and high levels of both properties are an advantage for pulps used in packaging grades of paper. In fine papers, high bursting strength beyond a certain minimum threshold level is not critical to product performance, but in commercial negotiations any deficit may be used to discount market pulp price.

Canadian Standard Freeness (CSF). See Freeness.

Delignification. The process of removing lignin from wood. Most lignin is removed during pulping, using chemicals like sodium hydroxide (soda process) or a mixture of sodium hydroxide and sodium sulfide (kraft process). Delignification can be continued after the pulping stage by some bleaching chemicals such as oxygen and chlorine dioxide.

Effective Alkali (EA). The effective alkali of a kraft pulping liquor is the total amount of alkaline constituents, excepting carbonates, actually available for pulping reactions. It is commonly described as $\text{NaOH} + \frac{1}{2}\text{Na}_2\text{S}$. The first term (NaOH) refers to free alkali initially present in the liquor. The second term ($\frac{1}{2}\text{Na}_2\text{S}$) refers to alkali derivable from the Na_2S on hydrolysis.

Extractives. Substances present in wood that can be extracted by water, alkaline solutions, or organic solvents. In eucalypts the nature of the extractives varies from one group of species to another. They include ellagitannins, proanthocyanidins, stilbenes, and steroid compounds. Alkali soluble material in mature eucalypt samples may constitute over 40% by mass.

Fine paper. Printing and writing papers comprised principally of chemical pulp rather than mechanical pulp. Usually considered a synonym for wood-free papers, although the term is sometimes used to mean the high quality end of such papers.

Free On Board (FOB). A point in the supply and shipping of goods at which a price is calculated without charge to the purchaser for delivery on board or into a carrier at a specified point or location.

Freeness. The freeness test measures the drainage properties of a pulp. In this study, freeness tests were performed using a Canadian Standard Freeness tester and specific conditions of temperature and stock concentration detailed in *AS/NZS 1301.206s-88 - Freeness of pulp*. Typically, freeness results for hardwood kraft pulps vary from about 500 ml CSF for a rapid draining unbeaten pulp, to less than 200 ml CSF for a highly beaten pulp. Low pulp freeness may reduce the rate of production on older fourdrinier paper machines, but on modern twin wire machines its effect is minimal.

Grammage. The grammage of paper is the mass per unit area (units g/m^2). For all pulps prepared and tested in this project, the mass is the air-dry, or conditioned mass, *ie.* the mass of the sheet when dried in air at standard conditions of temperature and humidity (23 ± 1 °C and 50 ± 2 per cent). Grammage is determined according to *AS/NZS 1301.208s-89 - Physical testing of handsheets*.

H-factor. A means of expressing the times and temperatures of any cooking cycle as a single numerical value, first developed by Vroom (1957). The H-factor represents the area under a curve of relative reaction rate *versus* time, and correlates with the degree of pulping achieved.

Kappa number. The Kappa number of a pulp is derived from a procedure in which a measured quantity of pulp is reacted with acidified potassium permanganate solution. Since the permanganate reacts rapidly with lignin but slowly with carbohydrates, this procedure provides an indirect measure of the residual lignin content of the pulp, and so its relative bleachability. Conventional kraft pulping of hardwoods is generally carried out to a Kappa number of 18 to 20. Kappa number measurements are carried out in accordance with *AS/NZS 1301.201m-86 - Kappa number of pulp*.

Kraft process. A chemical pulping process in which the primary aim is removal of lignin from woodchips. Wood is heated to about 170°C in a pressure vessel called a digester with a mixture of sodium hydroxide and sodium sulfide in aqueous solution, which reacts with and eventually dissolves most of the lignin in the wood.

Lignin. The amorphous polymeric material that cements the cellulosic fibres together in solid wood. Its removal from between and within the fibres is the prime objective of chemical pulping and bleaching.

Liquor:wood ratio. The ratio of the volume of liquor in a digester to the mass of wood charged. For example, at a liquor:wood ratio of 3.5:1, 500 g of chips are treated with 1.75 litres of liquor.

Mean Annual Increment (MAI). A figure representing the rate of growth of a stand of trees, usually expressed as the increase in wood volume per unit area per unit time. Units are typically cubic metres per hectare per year.

Mechanical pulp. Papermaking pulp made by separating the fibres in wood or other raw material principally by mechanical rather than chemical means.

Opacity. The property of paper that governs the extent to which one sheet of paper visually obscures printed matter on underlying sheets of paper. Printing opacity (ISO paper backing opacity) is the ratio of the diffuse reflectance of light, when the paper is backed by a very black material, to the diffuse reflectance when it is backed by sufficient layers of the same paper for the number of layers not to affect the reading. The opacity of industrial papers is influenced principally by grammage, type of furnish (eg. mechanical pulp or chemical pulp), extent of refining, and the amount and type of filler added.

PFI mill. A laboratory beater used to modify the structure and properties of pulp fibres before they are made into handsheets for testing. Beating the fibres improves their ability to form inter-fibre bonds, and this improves tensile strength and related properties. Excessive beating may damage fibres to some extent. The procedure followed is regulated by *AS 1301.209 - Laboratory processing of pulp - PFI method*.

Replicate test. In papermaking tests, a replicate test is defined as a single performance of the procedure of the test on a single test piece. The mean of several replicates (as recommended in the relevant standard) may be required to obtain a test result.

Scattering coefficient. Light is scattered at interfaces between fibres, since the fibre wall is essentially transparent. Scattering coefficient is calculated from the diffuse reflectance of light from paper with a black backing, the diffuse reflectance from paper when it is backed by an opaque pad, and the grammage. Measurements of scattering coefficient are usually made according to *SCAN-C 27:76 (1976) - Pulp light scattering coefficient*, because no Australian standard currently exists.

Screened yield. The pulp yield after uncooked fibre bundles, dirt and bark have been removed by screening the pulp through a plate with narrow (0.2 mm) slots. It is usually expressed as a percentage, in terms of the oven dry mass of pulp per unit oven dry mass of the original wood.

Sulfidity. The proportion of sodium sulfide (Na_2S) relative to active alkali, expressed as a percentage.

TAPPI. The technical association of the pulp and paper industry of the United States of America.

Tearing resistance / tear index. The (internal) tearing resistance of paper (units mN) is the force required to continue the tearing of a single sheet of paper, under conditions specified in *AS/NZS 1301.400s:1998 - Tearing resistance of paper*. Tear index is the tearing resistance divided by the grammage (units $\text{mN.m}^2/\text{g}$). The tearing resistance of paper is a compound measure of fibre strength, fibre length and the bonding between the fibres. For a well-bonded sheet of hardwood fibres of a given length, the maximum value attained is an indirect measure of the strength of the fibres. High tearing resistance is an advantage for pulps used in packaging grades of paper. In fine papers, high

tearing resistance beyond a certain minimum threshold level is not critical to product performance, but in commercial negotiations any deficit may be used to discount market pulp price.

Tensile strength / tensile index. Tensile strength (units N/m) is the maximum tensile force per unit width that paper will withstand before it breaks under conditions specified in *AS/NZS 1301.448s-91 - Tensile strength of paper and paperboard (constant rate of elongation method)*. The test span for handsheets (the distance between the clamps holding the test piece) is 100 mm. Tensile index is the tensile strength divided by the grammage (units N.m/g). The tensile strength of paper is largely a function of the bonding between the fibres, modified by the strength of the individual fibres. High tensile strength is an advantage for pulps used in packaging grades paper. In fine papers, high tensile strength beyond a certain minimum threshold level is not critical to product performance, but in commercial negotiations any deficit may be used to discount market pulp price.

Test result. For papermaking tests, a test result is defined as mean of the results of the required number of replicate tests performed in accordance with the relevant standard.

Vessel picking tendency. The tendency of vessels to be pulled out of the surface of a sheet of paper during printing when the applied external tensile force exceeds the cohesion of the vessels and fibres on the surface of the sheet.

Woodfree paper. Paper comprised principally of chemical pulp rather than mechanical pulp. Often considered a synonym for fine papers.

Zero-span tensile strength / zero-span tensile index. The zero-span tensile strength of paper (units N/m) is the maximum tensile force per unit width that paper will withstand when the test span is zero (*ie.* the clamps of the tester are in contact at the start of the test) under conditions specified in *AS/NZS 1301.459rp:1998 - Zero span wet tensile strength of pulp*. Zero-span tensile index is the zero-span tensile strength divided by the grammage (units N.m/g).

8. References

1. Waugh, G., Ozarska, B. and Yang, J. L. (1996) – Properties of plantation-grown eucalypts. Proceedings, 25th Forest Products Conference, Clayton, November 18-21.
2. Clarke, B., Whitfeld, S. and Vercoe, T. (1997) – The growth of eucalypt and acacia provenances in the ACT and at Tallaganda NSW. Report 12-15, August.
3. Clarke, B. (1998) – *Choosing trees for the NSW southern tablelands*. CSIRO Forestry and Forest Products, Canberra.
4. Spencer, D. J. and Matheson, A. C. (1987) – Eucalyptus species testing for large-scale fuelwood planting in the ACT: a summary of the age 2 and 3 year height and survival measures. Interim report to the ACT Forests Branch Department of Capital Territories. Canberra: CSIRO Forestry and Forest Products.
5. McDonald, M. W., Butcher P. A., Bell J. C. and Larmour J. S. (2000) – Intra- and interspecific allozyme variation in eucalypts from the spotted gum group, *Corymbia*, section 'Politaria' (Myrtaceae). *Australian Systematic Botany* **13**, 491-507.
6. Clark, N. B. and Rawlins, W. H. M (1999) – The prospects for pulpwood from the Murray-Darling Basin. *Appita J.* **52**(3): 203-212.
7. Stackpole, D., Borschmann, R. and Baker, T. (1995) – Trees for Profit Program, Report 19-21, June.
8. Clark, N. B. (1998) – The pulpwood quality of trees grown in the Murray-Darling Basin. Ph.D. Thesis, University of Melbourne.
9. Tappi T1206 rp-86
10. Higgins, H. G. (1970) – Technical assessment of eucalypt pulps in the papermaking economy. *Appita J.*, **23**(6): 417-426.
11. Higgins, H. G. and Phillips, F. H. (1970) – Effect of wood density on the properties of eucalypt sulfate pulps. Proc. 24th Appita Annual General Conference, Surfers Paradise, April 9, Session A, Paper no. 1.
12. Higgins, H. G. (1978) – Pulp and Paper. In: Hillis, W. E. and Brown, A. G., (Eds.) *Eucalypts for wood production*. CSIRO/Academic Press, Chapter 13: 290-316.
13. Dillner, B. (1979) – A classification of hardwood pulps for paper. In: Hass, L. E. (ed.), *New Pulps for the Paper Industry*. Symp. 'New Pulps for the Paper Industry', Brussels, May.
14. Arbuthnot, A. L. (1991) – The influence of basic wood density of eucalypts on pulp and paper properties. Proc. Symposium on Intensive Forestry: the role of eucalypts. Durban, South Africa. September 2-6: 966-975.
15. Zobel, B. J., Campinhos, E. and Ikemori, Y. (1983) – Selecting and breeding for desirable wood. *Tappi J.*, **66**(1): 70-74.
16. Paavilainen, L. (1998) – Quality - competitiveness of Asian short-fibre raw materials in different paper grades. *Jaakko Pöyry Magazine*, 1/98: 4-8.

17. Higgins, H. G. and Phillips, F. H. (1973) – Technical and economic factors in the export of woodchips from Australia and Papua New Guinea, *Aust. For. Ind. J.*, **39**(1) February: 47-53; (2) March: 31-43; (3) April: 33-40.
18. Zobel B. J. and van Buijtenen, J. P. (1989) – *Wood variation: Its causes and control*. Springer-Verlag, Berlin.
19. Clark, N. B. (1991) – Pulpwood quality and value. In: Kerruish, C. M. and Rawlins, W. H. M., (Eds.) *The young eucalypt report*. CSIRO Aust., 210-244.
20. Farrington, A. and Dench, I. D. - Pulping of improved plantation-grown eucalypt wood and subsequent use in various papermaking applications. Proc. Joint Japanese/Australian workshop on Environmental management: the role of eucalypts and other fast-growing species. Tsukuba, Japan, March 3-8 (1997).
21. Clark, N. B., Read, S. M. and Vinden, P. (1999) – The effects of drought and salinity on wood and kraft pulps from young plantation eucalypts. *Appita J.* **52**(2): 93-97, 113.
22. Kibblewhite, R. P., Riddell, M. J. and Shelbourne, C. J. A. (1997) – Kraft fibre and pulp qualities of 29 trees of 15-year old New Zealand grown *Eucalyptus nitens*. Proc. 51st Appita Annual General Conference, May. Paper 1C23: 149-157.
23. Rydholm, S. A. and Gedda, L. F. (1967) – Quality and economy of pulps in fine paper production. *Paper Technol.*, **8**(3): 217-227.
24. Dean, G. H. (1995) – Objectives for wood fibre quality and uniformity. In: Eucalypt plantations: Improving fibre yield and quality. Potts, B. M., Borralho, N. M. G., Reid, J. B., Cromer, R. N., Tibbits, W. N. and Raymond, C. A. (Eds.) Proc. CRC-IUFRO Conf., Hobart, 19-24 Feb. CRC for Temperate Hardwood Forestry.
25. Sidaway, S. (1988) – The availability and use of eucalyptus pulps. *Tappi J.*, **71**(12): 47-51
26. Colley, J. (1973) – Influence of vessel elements on the picking tendency of eucalypt pulps. *Pap. Technol.*, **14**(5): 293-296.
27. Clark, N. B. and Trajstman, A. C. (1997) – Pulpwood quality of trees grown in degraded environments. Environmentally friendly tree products and their processing technology. Proc. Joint Japanese/Australian workshop on Environmental management: the role of eucalypts and other fast-growing species. Tsukuba, Japan, March 3-8.
28. Hillis, W. E. (1978) – Wood quality and utilization. In: Eucalypts for wood production. Hillis, W. E. and Brown, A. G. (eds.) CSIRO/Academic Press, Chapter 12: 259-289.
29. Clarke, C. R. E. (1995) – Variation in growth, wood, pulp and paper properties of nine eucalypt species with commercial potential in South Africa. Ph.D thesis, University College of North Wales, Bangor, United Kingdom.