Modelling upper stem bark thickness for Eucalypts

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Abstract A non-linear model is used to estimate upper stem bark thickness of different eucalypt species and species groups. The model defines an exponential decay in terms of its shape and scale. The scale parameter is determined by the asymptotic limit of the upper bark thickness. The flexibility of the model (shape and asymptotic stability of the exponential decay) allows for the variation in upper stem bark thickness demonstrated by these eucalypt species and species groups.

1. INTRODUCTION

For most species, the volume of bark represents 10-20% of the total stem volume over bark [Schreuder, Gregoire et al 1993]. Bark thickness is defined as the distance between the cambium and the region of convex closure outside the bark. Bark thickness varies around the stem and is usually recorded as an average of a number of measurements taken equidistant around the bole. Bark thickness can be measured at the base of the tree with a bark gauge, but to estimate sawlog volume under bark in standing trees, estimates of bark thickness up the stem are also needed.

Grosenbaugh [1974] identified three broad patterns in bark thickness trends: bark representing a constant proportion of over bark diameter up the stem, bark proportion decreasing hyperbolically up the stem or bark proportion increasing hyperbolically up the stem. Grosenbaugh developed models for each of these three patterns, predicting diameter inside bark from diameter outside bark and the ratio of inside bark to outside bark diameter at breast height.

There is a wide range in bark characteristics in the eucalypts. In the peppermint and stringybark groups, e.g *E. dives*, the dead fibrous bark is persistent over many years and is lost in small quantities through abrasion and weathering. The gum group of eucalypts, e.g. *E. viminalis*, shed their bark in long strips, usually in hot weather. The ash group, e.g *E. delegatensis*, shows a combination of these patterns, shedding its bark above, but retaining fibrous bark to varying heights in the lower stem. Eucalypts can also lose substantial bark characteristics through fires [Tolhurst, 1992] and survive. This variation in bark thickness means that any general model must have the flexibility to represent variations in the shape and scale of bark thickness trends.

This paper demonstrates the application of a non-linear model which describes upper stem bark thickness as an exponential decay from bark thickness at breast height. This model seems to have the flexibility to represent variations in bark thickness patterns found in the eucalypt species analysed in this data set.

2. DATA

Data was collected from 111 trees of 8 species of eucalypts felled on inventory plots in natural stands in north-east Victoria (see Table 1). Two measurements were made of bark thickness at just 3 points on each bole: breast height (1.3m), near the top of the merchantable bole and at one third of the height to the top of the merchantable bole. The stands in which the trees were felled ranged from maturing regrowth to overmature and the trees covered a wide range of diameters and bark thicknesses and breast height (also shown in Table 1).

The bark thickness data was collected as part of a merchantable volume inventory, and the point for the top bark thickness measurement was determined by the presence of visible defects on the stem. In trees with a clearly unmerchantable section at the top of the stem, the top bark thickness measurement was below this unmerchantable section, and so, in some cases, well below the top of the bole. In trees with a clear bole however, this top measurement was made just below crown break. This leads to a variation in the extent of the bole over which the bark thickness measurements were distributed.

TABLE 1: Summary of characteristics of trees sampled for upper stem bark thickness

Species	**Number of trees**	**Range in DBHOB (cm)**		**Range in double bark thickness at breast height (cm)**	
		min	**max**	**min**	**max**
E. chapmaniana	1	21.1	21.1	5.6	5.6
E. dalrympleana	7	28.4	64.1	4.0	6.0
E. delegatensis	34	36.8	123.9	3.2	12.9
E. dives	7	24.7	67.4	1.4	12.6
E. globulus	9	26.4	110.9	1.2	8.2
E. obliqua	16	43.3	148	4.6	17.0
E. radiata	23	27.5	123.7	1.1	9.5
E. viminalis	14	34.1	118.3	3.6	13.0
TOTAL	111	21.1	123.9	1.1	12.9

3. MODEL IDENTIFICATION

Examination of the bark thickness data shows that all these eucalypts have bark proportions which decrease hyperbolically up the stem. Like stem taper, bark taper can be modelled as an exponential decay trend. The trend is characterised by its asymptotic limit or scale, i.e. the minimum bark thickness in the upper stem and its shape, or the rate at which it approaches that asymptote.

The scale of the bark thickness trend can be estimated, independent of tree size, by representing bark thickness relative to bark thickness at breast height. Using the bark thickness measurement at the top of the merchantable bole as an approximation for the asymptotic limit, variations in the scale of the bark taper between species can be examined. As there were only small numbers of samples for some species, initially the data were grouped into ash, gum, messmate (a heavy fibrous bark) and peppermint groups. These groups show a substantial range in the mean value of this bark thickness ratio, from an average of 0.21 for the gum group to 0.47 for the peppermint group. Later, as a step in model-fitting, residuals were examined by species, to determine whether one or more species within a group showed substantially different trends in either shape or scale.

The non-linear exponential decay model fitted was as follows:

$$dbt(h) = a^i *dbt\_bh - a^i *b*dbt\_bh + b*dbt\_bh \qquad (1)$$

where:

$dbt(h)$ = double bark thickness (cm) at height h (m)
h = height of bark thickness estimate (m)
dbt_bh = double bark thickness at breast height, 1.3m (cm)
a = shape parameter
b = scale parameter
i = number of 0.1 m intervals above breast height = (h-1.3) / 0.1

The flexibility of this model form is shown in Figures 1-2, where the effects of varying the shape and scale parameters are illustrated. Figure 3 shows how model predictions vary for different values of double bark thickness at breast height, while the shape and scale parameter are held constant.

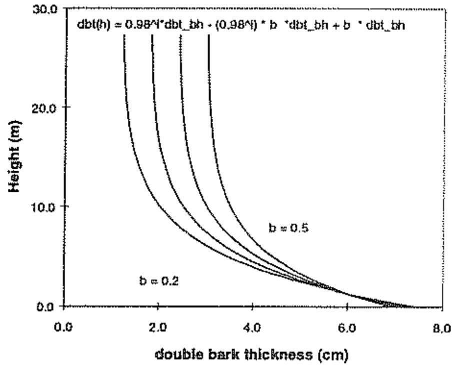

Figure 1: Variation in exponential decay model for upper bark thickness with a range of values of the scale parameter, b

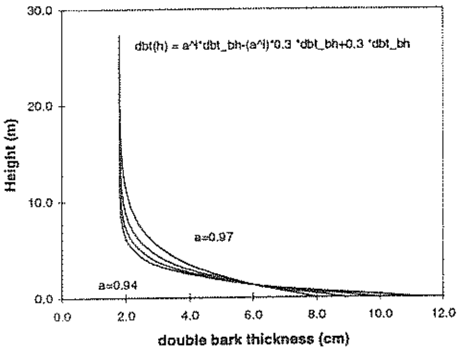

Figure 2: Variation in exponential decay model for upper bark thickness with a range of values of the shape parameter, a

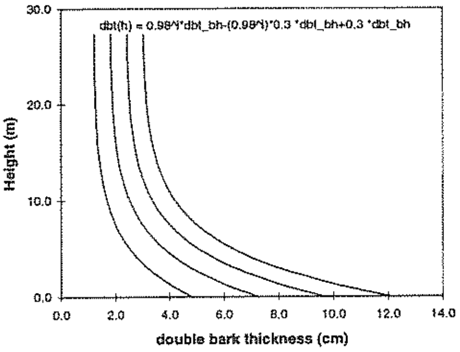

Figure 3: Variation in exponential decay model for upper bark thickness with a range of values of bark thickness at breast height, dbt_bh

For each species group, the average ratio of the bark thickness at the top of the bole to the bark thickness at breast height was used as the initial value for the scale parameter. Experience with the model suggests the shape parameter will be in the range 0.9 to near 1.0, and so 0.9 was used as an initial value for the shape parameter. The model was fitted to the data for each species group using the STATISTICA non-linear estimation package and the Quasi-Newton fitting method [StatSoft, 1994].

Residual errors were calculated for each bark thickness measurement, averaged by species and then examined for each species and height, making comparisons of each species within a species group. This demonstrated that Blue Gum, *E. globulus,* clearly had bark thickness which decreased less rapidly up the stem than the other gums (i.e had a higher a value of the shape parameter), and so it was separated from the remaining gums and separate models were fitted for each group.

Resulting model parameters and asymptotic standard errors for the final models are presented in Table 2, along with root mean squared errors (RMSEs) as indicators of the goodness of fit.

TABLE 2: Summary of parameters and goodness of fit for each species group for the model:
$dbt(h) = a^i * dbt\_bh - a^i * b * dbt\_bh + b*dbt\_bh$

Species	n	a	S.E. (a)	b	S.E.(b)	RMSE
E. chapmaniana, E. dalrympleana, E. viminalis	22	0.965	0.006	0.22	0.03	1.54
E. delegatensis	34	0.9827	0.0017	0.212	0.036	1.51
E. dives, E. radiata	30	0.9486	0.0070	0.418	0.030	0.87
E. globulus	9	0.960	0.000	0.385	0.050	0.90
E. obliqua	16	0.9890	0.0030	0.395	0.085	1.32

4. RESULTS AND DISCUSSION

These models successfully reflect the different bark thickness patterns found in the eucalypts examined here. For example, the peppermints, *E.dives* and *E. radiata* have the highest proportion of bark at breast height retained up the stem, as shown by the high value of the scale parameter, b. Bark thickness declines more rapidly in the gums, *E. chapmaniana, E. dalrympleana, E.viminalis* and *E. globulus* than in the fibrous barked *E. obliqua*, as shown by the gum's lower values of the shape parameter, a.

Average errors in the models vary between species groups, as shown in Table 2 and illustrated in Figures 4 and 5. The peppermint group have an RMSE of 0.87 cm and all errors are less than 3.3 cm. The model estimates and individual measurements are shown in Figure 4 and the errors in Figure 5.

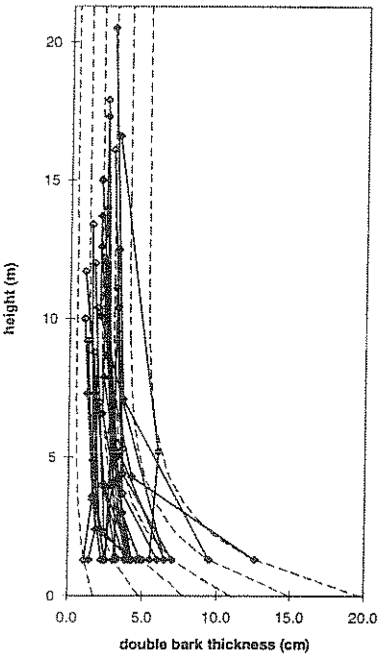

Figure 4: Observed bark thickness trends and predictions from exponential decay model (---) for the peppermint group, *E.dives* and *E. radiata*

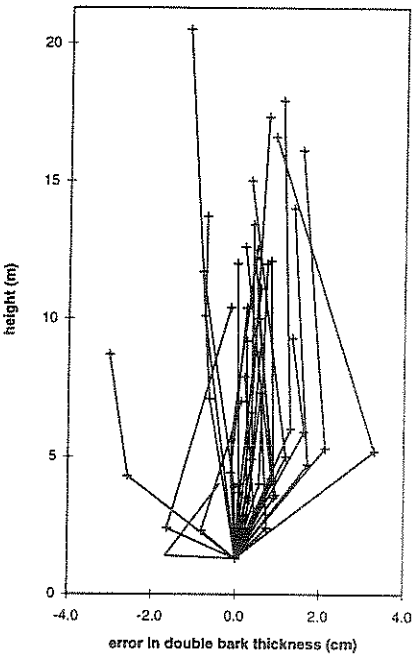

Figure 5: Error in observed bark thickness trends for the exponential decay model for the peppermint group, *E.dives* and *E. radiata*

The ash species, *E.delegatensis*, has the local common name of woolybutt, referring to its retained fibrous bark at the base. As this data set did not provide measurements of bark at regular intervals up the stem, the change from fibrous bark to smooth bark can not be seen clearly (Figure 6), but we know that the height to which this layer of fibrous bark is retained varies substantially from tree to tree. As a result, the largest errors occur for the measurements at 1/3 of merchantable height, (Figure 7), which would be in the vicinity of the transition from fibrous to smooth bark. The errors indicate that the continuous decay modelled here does not provide a good fit for this bark thickness pattern. There are a number of large underestimates of bark thickness where the measurement at 1/3 of merchantable height was at a height below 5m. The RMSE is 1.51cm and errors are as great as 5cm. A more sophisticated model for this species could be developed if records included whether the bark measurement was in the fibrous-barked or smooth-barked zone.

5. ALTERNATIVE MODELS

There are a number of different approaches to modelling bark thickness. The usefulness of this model form was evaluated by comparing the model for the peppermint group with models based on:

(1) Grosenbaugh's multiple regression model for diameter inside bark for trees exhibiting a decline in bark as a proportion of stem up the tree [Grosenbaugh, 1974] and

(2) Johnson and Wood's linear relative bark thickness model used for *P.radiata* [Johnson and Wood, 1987].

Grosenbaugh's model was fitted in the form:

$$DIB = a + b\,DOB + c^{*}DBHIB + d^{*}DBHOB \qquad (2)$$

where:

DIB = diameter inside bark

DOB = diameter outside bark

DBHIB = diameter at breast height inside bark

DBHOB = diameter at breast height outside bark

a, b, c, d = parameters to be estimated

Johnson and Wood evaluated a number of linear and non-linear models for bark thickness in *P.radiata*, and found a simple linear model of relative bark thickness superior to the more complex alternatives. The linear relative bark thickness model was fitted in the form

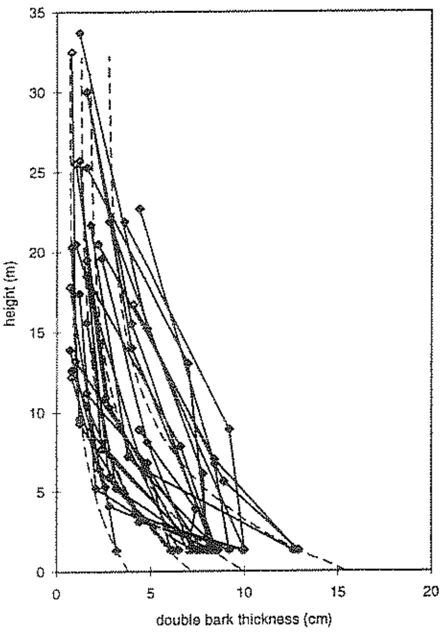

Figure 6: Observed bark thickness trends and predictions from exponential decay model (---) for the ash species, *E.delegatensis*

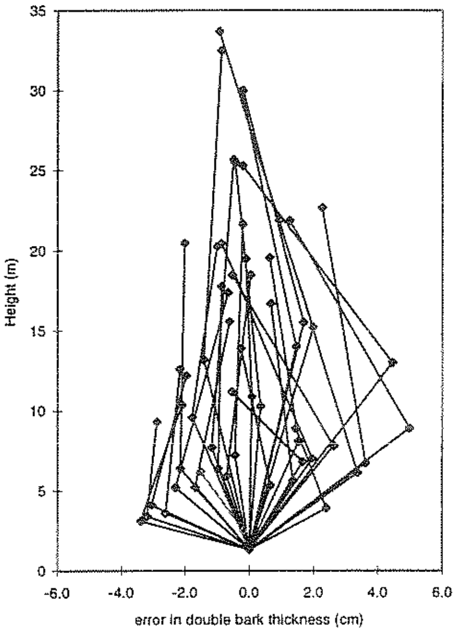

Figure 7: Error in observed bark thickness trends for the exponential decay model for the ash species, *E.delegatensis*

$$RBT = a + b * RD \qquad (3)$$

where:

RBT = bark thickness relative to bark thickness at breast height

=(DOB-DIB) / (DBHOB - DBHIB)

RD = diameter relative to diameter at breast height

= DOB / DBHOB

a, b = parameters to be estimated

A comparison of the 3 models, fitted to the data for the peppermint group, with their parameters and RMSEs is presented in Table 3. None of these models has consistently lower errors, as each uses a different approach to estimating bark thickness, but the non-linear model shows better fit to the data on average.

TABLE 3: Comparison of 3 models for upper bark thickness in peppermints: *E. dives* and *E. radiata*

Model	parameter	parameter estimate	SE	RMSE (cm)
Grosenbaugh:	a	-0.77	0.45	1.31
DIB = a + b * DOB + c * DBHIB + d * DBHOB	b	0.885	0.016	
	c	0.409	0.062	
	d	-0.317	0.062	
Johnson and Wood:	a	-0.45	0.14	1.25
RBT = a + b * RD	b	1.37	0.17	
Exponential decay:	a	0.9486	0.0070	0.87
dbt=a^i * dbt_bh - a^i * b * dbt_bh + b*dbt_bh	b	0.418	0.030	

6. CONCLUSION

The non-linear model presented here has a form that allows bark thickness trends to be defined in terms of the shape and scale of an exponential decay. The model has the flexibility to describe bark thickness trends in a number of major eucalyptus groups with different bark patterns, and provides a better fit than alternative models.

7. REFERENCES

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