Review of STANDSIM model for yield projection of natural ash eucalypt forests

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Summary

Data from the permanent plots in natural regrowth forests of mountain ash (*Eucalyptus regnans* F. Muell.) and alpine ash (*E. delegatensis* R.T. Bak.) in Victoria were used to evaluate the accuracy of projection by the growth model, STANDSIM. In general, where the stand ages used to initiate STANDSIM's projection were 15 yr or more, the errors (biases) for one-year projections would be expected to be within ±1% of the observed values for the projected future stand densities, ±0.5% of the observed values for the projected stand basal areas, and within ±1% of the observed values for the projected total product volumes. These resultant error estimates indicated that the accuracy of the future yields projected from STANDSIM model was generally in an acceptable range, if the projection intervals were less than 50 yr and projections were initiated at a stand age of 15 yr or older. However, the projected yields from this model would have a lower precision if the projections were initiated at stand ages of less than 15 yr. As indicated by a previous researcher, the small-diameter trees were under-represented in the projected diameter distributions. This problem may indicate that the STANDSIM model overestimates the competition-induced mortality of natural ash eucalypt forests. However, our investigation did not indicate that this would result in a direct underestimation of pulpwood and overestimation of sawlog yield.

Keywords: yield; increment; simulation models; STANDSIM; *Eucalyptus regnans; Eucalyptus delegatensis*

Introduction

STANDSIM is a computer-based forest growth model for predicting the growth, yield and treatment responses of naturally regenerated, even-aged ash-type eucalypt forest stands in Victoria, dominated by *Eucalyptus regnans* F. Muell. (mountain ash), *E. delegatensis* R.T. Baker (alpine ash), or *E. sieberi* L.A.S. Johnson (silvertop). The model was originally developed by Opie (1972). Campbell *et al.* (1979) and Incoll (1983) reported successive developments. Ritchie and Hann (1997) classified STANDSIM as a whole stand disaggregative growth model.

The growth functions in STANDSIM were estimated from data with a limited range of stand ages and some were established using 'graphical analysis' rather than conventional statistical analyses (Campbell *et al.* 1979). Simulations conducted by the original researchers suggested that the model appeared to be reliable for yield projection in the age range of 20–50 yr with initial ages from 20 to 40 yr (Opie 1972; Incoll 1983). No validation was performed, however, to verify the accuracy of yield estimates for the full age range of application, which is commonly from current stand ages to about 120 yr in Victoria, due to lack of long-term measurements from permanent growth plots (PGPs).

West (1991) explored the use of STANDSIM to analyse the thinning response of eucalypt plantations using data from experimental plots established in *E. regnans* plantations in Victoria. He found that a proportion of very small trees was always missing from the predicted diameter distributions when compared to observed diameter distributions. He considered that this problem resulted from the STANDSIM model overestimating the intensity of competition-induced mortality. This led West to conclude that the yield projections from STANDSIM for a given stand would underestimate pulpwood yield, and overestimate sawlog yield, when the model is extended to project future yields of plantations. Because he did not have suitable data for performing similar simulations for naturally regenerated eucalypt forests, West (1991) formulated two indirect tests for the yield projections of STANDSIM for this application. The predicted mortality from STANDSIM was compared with a mortality function developed previously, and with an empirical stocking function derived from the concept of the density-management diagram. Based on the results of these comparisons, West indicated that STANDSIM would also overestimate the intensity of competition-induced mortality in natural eucalypt forests.

Yield projection in STANDSIM is a two-phase process. For stand ages of less than 15 yr, only stand total density and mean dominant height are predicted in a one-year growth cycle up to the age 15. At age 15, the maximum tree diameter and stand total basal area are predicted. A tree diameter distribution that satisfies the projected stand density, basal area and maximum diameter is derived by reference to the binominal probability distribution. A list (array) of tree diameters is then generated to match the diameter distribution. If yield projection is initiated at a stand age greater than 15 yr, the initial stand basal area must be specified, along with a site index estimate and the stand age. A frequency distribution of tree diameters may be either specified or generated using the binomial distribution. Yield projection for stands over 15 yr involves predicting the annual increments of gross basal area per unit area and mean dominant height, and distributing the gross basal area increment predicted among the individual trees in the diameter list. In each projection cycle, stand total and product volume is estimated by firstly predicting the total height for each tree in the diameter list using a height–diameter model, and then estimating its total volume from the diameter and estimated tree height using a species-specific volume equation. Product (sawlog and pulpwood) volume of the simulated tree is determined using a taper equation according to the user-supplied specification (e.g. log length, small end diameter etc.). Stand total or product volumes are obtained by the summation of individual tree estimates.

Projection of stand density in STANDSIM for stands over 15 yr old involves two independent processes for simulating tree mortality. The first process simulates the competition-induced mortality (i.e. the deaths of suppressed trees), and is estimated by two functions, which predict maximum possible density (stems per unit area). One of these functions uses an estimate derived from age and site index; the other uses mean dominant height only as predictor. If the stand density is larger than the densities predicted from either function, the smallest trees are removed progressively from the diameter list. Additional competition-induced mortality is simulated by assuming that any tree in the diameter array will die if its diameter is less than one-seventh of the predicted maximum diameter at a given age. The second process simulates the deaths of trees due to exogenous causes, such as disease, insect attack and lightning. This mortality is simulated by removing a few trees systematically (i.e. every 150th tree) from the diameter list.

This study was initiated because STANDSIM has been used to provide the essential input to Victoria's sustainable yield forecasting system (DNRE 1997), and the Department of Natural Resources and Environment (DNRE) has collected data from the PGP system for at least 25 yr since the model was first developed. The specific objectives of the study were to:

1. Test the accuracy of STANDSIM's yield projections over the age range of the currently available PGP data;
2. Verify the problem of overestimation of competition-induced mortality; and
3. Investigate the effect of overestimating competition-induced mortality on product yields for naturally regenerated ash-type eucalypt forests in Victoria.

Since previous work has suggested that this model is reliable for periods of 20–50 yr and STANDSIM has two phases of yield projection, three age ranges were chosen for the evaluation. These were:

1. From 1 to 15 yr;
2. From 15 to 50 yr; and
3. From 15 yr to the maximum age of available data.

The two species, *E. regnans* and *E. delegatensis,* share a number of growth functions in the STANDSIM model (Opie 1972) and the growth functions for *E. sieberi* were developed later by Incoll (1983). This study was limited to evaluating the yield projections for *E. regnans* and *E. delegatensis* only. Also, because the mean dominant height functions used in the STANDSIM model had been evaluated in a previous study (Chikumbo *et al.* 1998), these prediction functions were not addressed in this study.

Table 1. Frequency distribution of validation plots by site index and age classes at the first measurement

Species	Age class (yr)	Site index class (m)				Total
		< 26	26–30	31–35	> 35	
E. delegatensis	< 11	2	1	1	1	5
	11–20	1				1
	21–30		3			3
	31–40	2				2
	> 40	1				1
Sub-total		6	4	1	1	12
E. regnans	< 11			4	2	6
	11–20		1	1		2
	21–30	1	1	3		5
	31–40	1	2	7	2	12
	> 40		1	2		3
Sub-total		2	5	17	4	28
Total						40

Permanent growth plot data

Repeated measurements from 40 validation plots (PGPs) were used in this study. These PGPs were established at 24 different localities across Victoria in the stands dominated by *E. regnans* (28 plots) or *E. delegatensis* (12 plots). These data were selected from a large PGP database for native eucalypt forests maintained by the Victorian DNRE. The criteria used to select these PGPs from the database were that a plot had to be predominantly mono-specific (i.e. at least 90% of the trees on the plot had to be the dominant species), and that the plot was in naturally regenerated even-aged stands, and had not been treated or commercially thinned. Each of the PGPs had been measured at least five times with a measurement interval ranging from 1 to 5 yr, and total measurement periods ranging from 15 to 63 yr. Some of the PGPs used may have been used for the original development of STANDSIM model; but the measurement periods of these PGPs are now at least 25 yr greater than at the time when STANDSIM was developed.

Parameters were compiled for each plot and each measurement, including plot density (stems ha^{-1}), basal area (m^2 ha^{-1}), a site index estimate that is defined as the mean height of 62 largest diameter trees per hectare at the reference age of 20 yr, and the frequency distribution of tree diameters by 4-cm diameter classes. The distributions of the selected PGPs by 10-yr age classes and 5-m site index classes are shown in Table 1 and the descriptive statistics for the first measurement of the plots are in Table 2.

Methods

Many procedures have been suggested for evaluating the performance of forest growth models for projecting future yields (e.g. Reynolds *et al.* 1981; Vanclay and Skovsgaard 1997). The procedures suggested include verifying the growth or yield relationships (functions) used in a growth model or validating the predictions derived from the model. In this study, the closeness (accuracy) of projected yields and stand structure (i.e. diameter distributions) to their actual observations in the permanent plots

Table 2. Descriptive statistics for the first measurement of the validation plots

Species	Number of plots	Age (yr)	Site index (m)	QMD (cm)	Density (stems ha^{-1})	Basal area (m^2 ha^{-1})
E. delegatensis	12	4-22-59	20-26-35	7-20-50	218-1867-4222	8-34-57
E. regnans	28	2-25-44	24-32-37	4-29-52	221-1406-9605	6-42-63

QMD is quadratic mean diameter, and the tabulated values are in the minimum-mean-maximum format

Table 3. Numbers of permanent growth plots used for validating the projection accuracy of the STANDSIM model

Age (yr)		Number of plots	
Starting	Ending	*E. regnans*	*E. delegatensis*
< 15	= 15	7	5
≥ 15	≤ 50	28	11
≥ 15	> 50	22	7

was primarily addressed. More specifically, the projected and observed stand densities, basal areas and total merchantable volumes per hectare of the validation plots were graphically compared, error statistics were computed, and then statistical procedures were applied to draw conclusions on the projection accuracy of the model.

The procedures used to derive the projected yields for each of the objectives studied, and the statistical procedures used for accuracy evaluation, are as follows.

Yield simulation procedures

To determine the accuracy of STANDSIM, simulation runs for yield projection were performed over the three stand age ranges, defined earlier. These simulations were first used to evaluate the accuracy of projected stand densities and basal areas. The numbers of plots used in each age range are summarised in Table 3. The validation plots used in the third age range were a sub-set of the plots used in the second age range. For the ages less than 15 yr, the initial stand parameters were stand density per hectare and a site index estimate. For the ages greater than 15 yr, the actual diameter distribution was also input to STANDSIM. Yield projections were made in one-year cycles to the age of last measurement within the age range. The projected stand density or basal area values were then compared to their calculated values at the same age. Because felled tree data were not available for determining the actual product volumes of the validation plots for comparison, the accuracy of projected product volumes was evaluated using a different simulation approach that is described below.

To verify whether STANDSIM overestimates competition-induced mortality, three localities were arbitrarily selected for each species, all with stand ages greater than 15 yr at the first measurement. Each locality selected included 2 or 3 plots. STANDSIM was used to project yield for each plot in a selected locality. The average projected and observed diameter distributions of all plots in a selected locality were then compared. The average diameter distributions were used to reduce the variation of individual diameter distributions in small sample plots.

To investigate the effect of overestimating the intensity of competition-induced mortality on merchantable yield projection, 10 plots were selected for each of the two species. These plots had relatively small errors in their projected stand densities based on some preliminary projections. For each plot, two types of simulations were performed. The first simulation projected yields from the first to the last measurement, using the calculated stand parameters at the first measurement to initiate the projection. This simulation was to derive the projected sawlog and pulpwood volumes from the usual yield projection of STANDSIM. The second simulation simply used the observed stand parameters and diameter distribution at each measurement to obtain the equivalent estimates of the actual product volumes from STANDSIM without involving a yield projection.

In all simulations, the parameters specified for estimating pulpwood volumes were a minimum small-end diameter of 10 cm, 10% defect deduction and 12 m maximum piece length. To estimate sawlog volumes, a minimum small-end diameter of 25 cm, 20% defect deduction and 25 m maximum piece length were used. Also, a length increment of 0.3 m and a minimum piece length of 4.8 m were used for calculating both sawlog and pulpwood volumes. West (1991) used similar parameters in his testing of the STANDSIM model. To provide a graphical comparison of projected yields, the observed and projected values of stand density, basal area and total product volume per hectare were plotted against stand ages.

Statistical procedures

Prediction errors of a model may be divided into systematic (bias) and random (variance or precision) components, and the accuracy of a model is then affected by both bias and precision of the predictions (Freese 1960; Reynolds 1984). To measure the errors of individual projected yields, per cent error (*PE*) or relative error, defined as $PE = (y - \hat{y})/y \times 100$, rather than the absolute error, $e = y - \hat{y}$, was used in this study, where y and $\hat{y}$ are the observed and projected stand density, basal area or product volumes per hectare for a given plot. Also, to give a basis for comparison between plots with different measurement intervals, the periodic mean annual per cent errors (i.e. *PE* divided by the associated interval (years) of projection) was used in all accuracy evaluation procedures.

To estimate the projection accuracy of STANDSIM, statistical procedures for evaluating model predictions, suggested in the literature (e.g. Freese 1960; Rennie and Wiant 1978; Reynolds 1984), were used as described next.

Maximum anticipated error, E*

This statistical accuracy measure was derived from Freese's (1960) chi-squared test and defined as:

$$E^* = \left[\frac{\sum_{i=1}^{n} e_i^2 \chi_{1-\gamma}^2(1)}{\chi_{1-\gamma}^2(n)} \right]^{1/2} , \quad (1)$$

where e_i is the difference between the ith pair of observed and predicted values, $\chi^2_{1-\gamma}(1)$ and $\chi^2_{1-\gamma}(n)$ are $100(1-\gamma)$ percentiles of the chi-squared distribution with 1 and n degrees freedom, respectively, and n is sample size. When applying this statistical procedure for accuracy evaluation, E^* represents the borderline of the critical region of Freese's (1960) chi-squared test for accuracy. According to Reynolds (1984), the E^* value can be used to make the following accuracy statement:

$$\Pr(|e| < E^*) \geq 1 - \gamma . \quad (2)$$

This statement can be interpreted as follows. The probability that the prediction error e is less than E^* will be greater than $1-\gamma$ if the model is repeatedly used for making predictions of the response variable in a given population. To make such an accuracy statement, the assumption is required that the errors of a model are independent and identically distributed normal variables with a zero mean and constant variance. Since a zero mean of model errors implies that the predictions of the model are unbiased, the resulting value of E^* indicates the precision of predictions when the model is assumed to be unbiased.

Confidence interval for the expected value of errors

The $100(1-\alpha)$ per cent confidence interval for the expected value of errors is defined as (Reynolds 1984):

$$\bar{e} \pm t_{1-\alpha/2}(n-1)\frac{S_e}{\sqrt{n}} , \quad (3)$$

where $t_{1-\alpha/2}(n-1)$ is the $100(1-\alpha/2)$ percentile of t distribution with $n-1$ degrees of freedom, and S_e is standard deviation of errors. The confidence interval constructed indicates the possible range of bias that may be present, if the model is used to make predictions repeatedly.

Prediction interval for a future value of errors

The prediction interval for a future value of errors is defined as (Reynolds 1984):

$$\bar{e} \pm t_{1-\alpha/2}(n-1)S_e\sqrt{1+\frac{1}{n}} . \quad (4)$$

The interpretation of this statistic is that the probability is $1-\alpha$ that the future value of prediction errors will fall in this random interval (range). In a similar application, Neter *et al.* (1990, p.79) indicated that a prediction interval is useful where the model is to be used to make prediction for a new observation from a new trial. The new trial should be independent of the trials from which the model was developed.

Prediction interval for k future values of errors

In some situations, the average values of stand parameters for some groups of forest stands are of interest, rather than the parameters of individual stands. Reynolds (1984) indicated that under these situations, a $100(1-\alpha)$% prediction interval for k future values of errors would be useful. The procedure is defined as:

$$\bar{e} \pm t_{1-\alpha/2}(n-1)S_e\sqrt{\frac{1}{n}+\frac{1}{k}} . \quad (5)$$

This procedure is similar to that for the prediction interval above; but instead of a future error this procedure is concerned with the mean of k future values of errors (e.g. the mean error for the projected yields of k new plots). In this study, the k value was arbitrarily set as 5.

In this study, the absolute error e in all testing procedures above was replaced by the periodic mean annual per cent error defined earlier. A 5% probability level was used for calculating all statistical accuracy measures.

Results

Comparisons between projected and observed yield trajectories

The projected trajectories of stand density were generally consistent with the observed trajectories over the projection period from 10 to 78 yr of age (Figs 1 and 2). The average per cent errors (bias) were within ±15% of actual stand densities. This indicates that the functional forms and mechanism in STANDSIM are basically appropriate for predicting the mortality of natural ash-type eucalypt stands for ages greater than 15 yr. For ages less than 15 yr, projection errors were relatively larger for individual stands.

No serious bias was identified for the projected stand basal areas based on the graphical comparison between projected and observed stand basal area per hectare in most validation plots. Mean per cent errors were generally less than 5% of observed stand basal areas per hectare across all age classes. However, for those validation plots with an initial basal area greater than 40 m^2 ha^{-1}, the projected values underestimated observed stand basal area (Fig. 1). This result may indicate that insufficient data was used in the development of the original prediction function of stand basal area. Similarly, the projected total merchantable volumes generally agreed with the estimated total merchantable volumes. Mean per cent errors of projected total merchantable volumes per hectare were less than 9% of the estimated total merchantable volumes per hectare for all age classes (Fig. 2).

Accuracy of projected stand density and basal area

Before the statistical accuracy procedures suggested were applied, the normality assumption was checked for the individual annual per cent errors of the projected stand densities, basal areas and total merchantable volumes per hectare using the normal probability plots. No obvious departure from the assumption was found. All statistics calculated for accuracy evaluation are presented in Tables 4 and 5.

Mean annual per cent errors

In general, the mean annual per cent errors of stand densities can be expected to be within ±1.0% of the actual observed values if

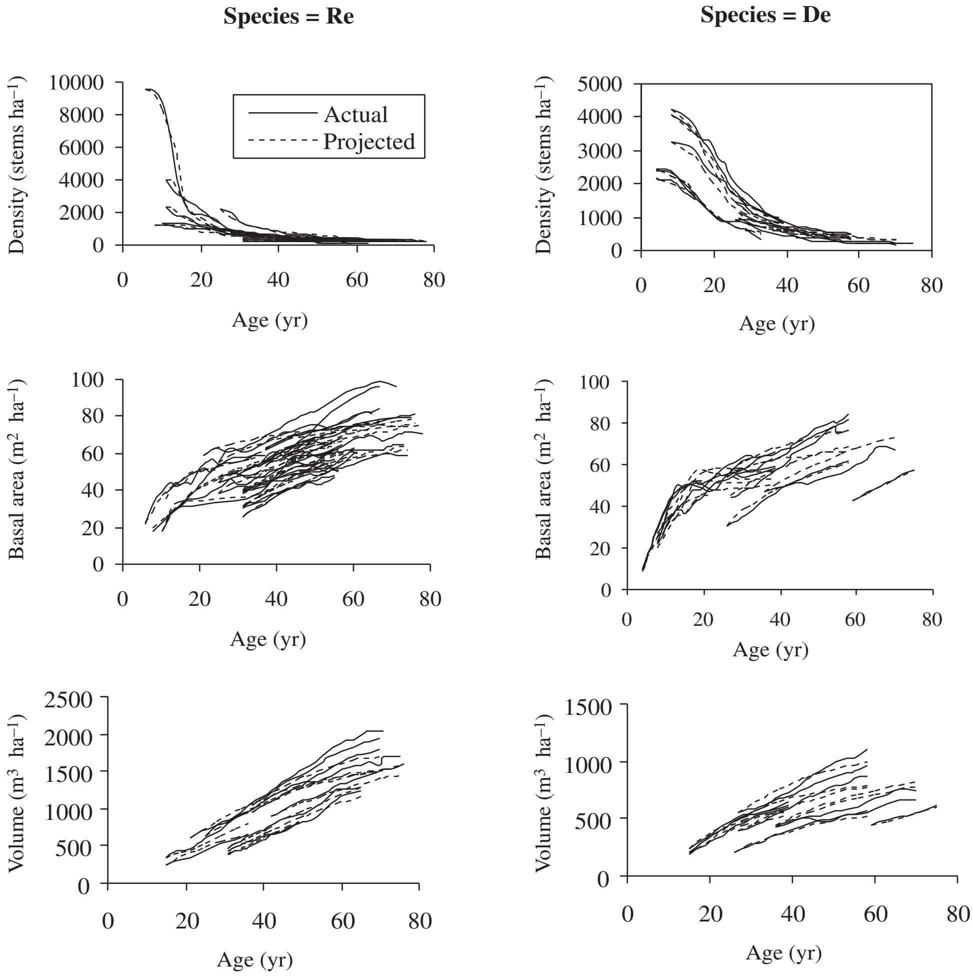

Figure 1. Plotting the projected (dashed lines) against observed (solid lines) trajectories of density, basal area and total merchantable volume of validation plots of *E. regnans* (Re) and *E. delegatensis* (De)

the simulation is initiated at 15 yr or older. However, if the simulation is initiated at an age of less than 15 yr, the mean annual per cent error can be as large as ±2.0% of the observed values. For the projected stand basal area per hectare, the mean annual per cent errors are generally within ±0.35% of the values observed when the simulation is initiated at a stand age of 15 yr or older; if the simulation is initiated at a stand age of less than 15 yr the mean annual per cent errors in stand basal area can be as large as ±3.6% of the observed values.

Confidence intervals for mean annual per cent errors

The wider ranges of the 95% confidence intervals for the stand age range evaluated from 1 to 15 yr showed that the projected stand density and basal area values would have a very low precision for this projection period. For the other two ranges of stand ages evaluated, the narrower 95% confidence intervals for the expected values of the mean annual per cent errors indicated a relatively high precision of the projected yields. The resultant 95% confidence intervals of mean annual per cent errors indicate the possible ranges of projection errors when the STANDSIM model is used to make large numbers of yield projections for a given forest population and a one-year projection interval. Because the ranges of all 95% confidence intervals obtained included the value of zero, the null hypothesis that the expected errors of stand densities and basal areas per hectare projected for a one-year period are equal to zero would be accepted at the 5% probability level, if *t*-tests were performed. This result showed that the projected stand densities and basal areas per hectare from the STANDSIM model are generally unbiased for a one-year projection period.

Maximum anticipated errors

For one-year projection intervals, the maximum anticipated per cent errors (E^*) at 95% accuracy level for the projected stand densities and basal areas per hectare ranged from ±3.41% to ±5.23% of the observed values where the initial ages were less than 15 yr, and from ±0.64 to ±2.1% of the observed values, where the projections are initiated at a stand age of 15 yr or older. Based on the statistical interpretation of E^* discussed earlier, and for any given application, if ±2% of the actual values is considered to be the maximum error limit for a one-year projection, yield estimates from STANDSIM are acceptable where the yield projection is initiated at a stand age of 15 yr or older, but will not be acceptable where the projection is initiated at stand ages of less than 15 yr.

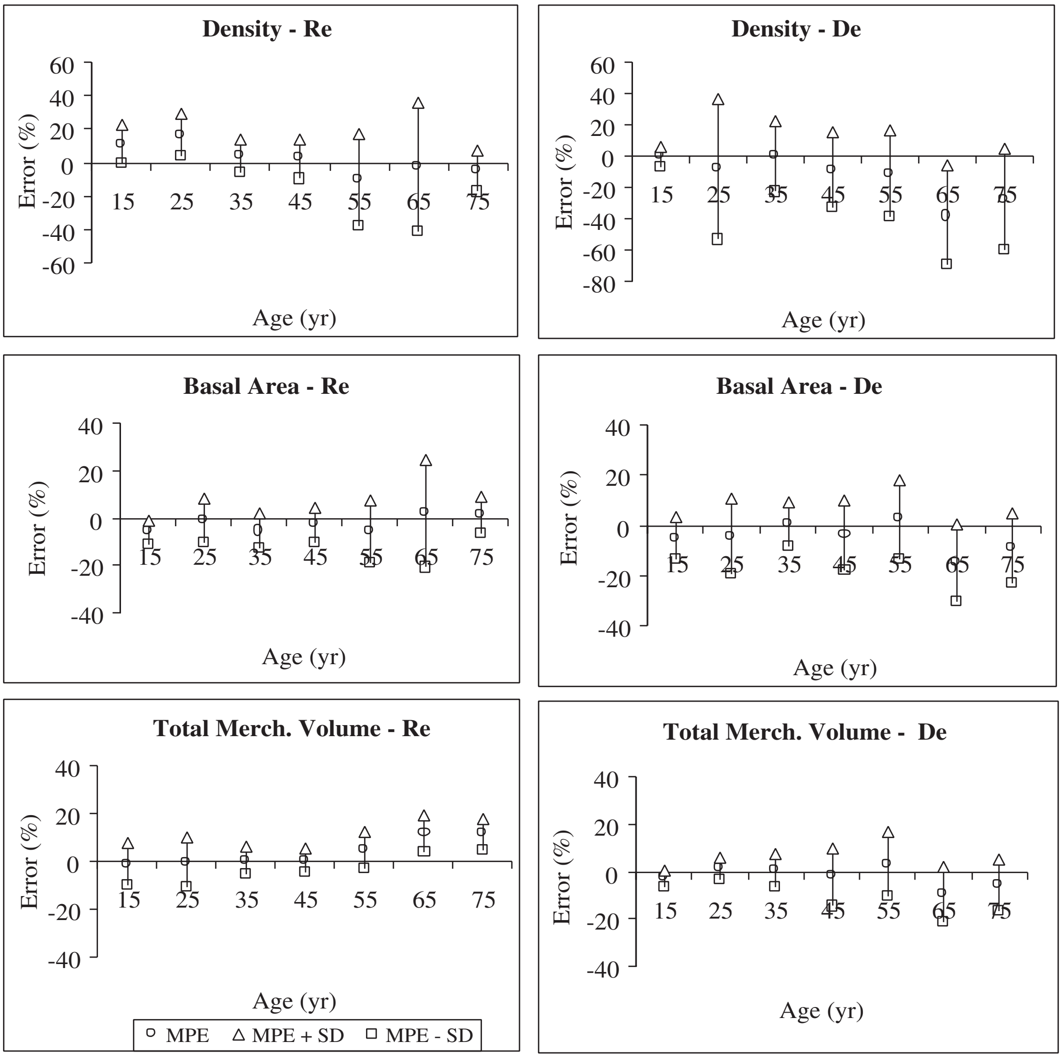

Figure 2. Mean per cent errors (MPE) and associated standard deviations (SD) by 10-yr age classes for projected densities, basal areas and total merchantable volumes per hectare of *E. regnans* (Re) and *E. delegatensis* (De)

Table 4. Estimated mean annual per cent errors (*PE*) of projected stand stocking and basal area for three tested periods of yield projection for *E. regnans* (Re) and *E. delegatensis* (De)

Projection period (yr)	Species	Number of plots (n)	Average projection period (yr)	Density (stems ha^{-1})		Basal area (m^2 ha^{-1})	
				Mean annual PE ($\bar{e}$) (%)	Standard deviation (S_e)	Mean annual PE ($\bar{e}$) (%)	Standard deviation (S_e)
1 to 15	Re	7	7.3	–2.12	3.61	0.34	3.11
	De	5	9.0	0.98	2.68	3.64	1.58
15 to 50	Re	28	19.4	–0.14	0.96	–0.33	0.48
	De	11	22.3	–0.79	1.67	–0.14	0.99
15 to > 50	Re	22	31.3	–0.78	1.49	–0.34	0.77
	De	7	30.0	–0.52	0.87	0.02	0.48

Per cent error is defined as $(y - \hat{y}) / y \times 100$, where y and $\hat{y}$ are the observed and projected values.
Periodic mean annual per cent errors are estimated mean per cent errors divided by the projection periods (yr).

Prediction intervals for future projection errors

Compared with the resultant confidence intervals, the corresponding 95% prediction intervals were generally wider. These resultant prediction intervals for a one-year projection period indicate the ranges of potential bias in projected stand density and basal area per hectare when STANDSIM is used to project yields for stand conditions other than those represented by the current validation plots (Table 2).

Projected diameter distributions

The comparisons between the average observed and projected diameter distributions for the three selected localities (Fig. 3) verified the problem that small-diameter trees were under-represented by the projected diameter distributions, as found by West (1991). In general, the projected diameter distributions were more centralised than the observed diameter distributions. That is, the projected diameter distributions appear to underestimate

Table 5. Estimated maximum anticipated errors (E^*), 95% confidence intervals and 95% prediction intervals for k new observations for mean annual per cent errors of projected stand stocking and basal areas for three tested projection periods and for *E. regnans* (Re) and *E. delegatensis* (De)

Projection period (yr)	Species	E^*		Confidence interval		Prediction interval ($k = 5$)	
		Density (stems ha^{-1})	Basal area (m^2 ha^{-1})	Density (stems ha^{-1})	Basal area (m^2 ha^{-1})	Density (stems ha^{-1})	Basal area (m^2 ha^{-1})
1 to 15	Re	± 4.84	± 3.43	–7.82, 3.63	–4.62, 5.23	–9.68, 5.64	–6.32, 6.93
	De	± 3.41	± 5.23	–2.44, 4.31	–1.69, 5.64	–3.68, 5.73	–2.38, 5.54
15 to 50	Re	± 1.58	± 1.04	–0.48, 0.34	–0.49, 0.14	–1.13, 0.89	–0.83, 0.29
	De	± 2.07	± 1.44	–1.47, 0.43	–0.84, 0.62	–1.73, 1.34	–1.34, 1.24
15 to > 50	Re	± 2.08	± 1.34	–1.44, 0.13	–0.74, 0.04	–2.13, 0.79	–1.13, 0.48
	De	± 1.43	± 0.64	–1.43, 0.42	–0.38, 0.53	–1.79, 0.84	–0.64, 0.69

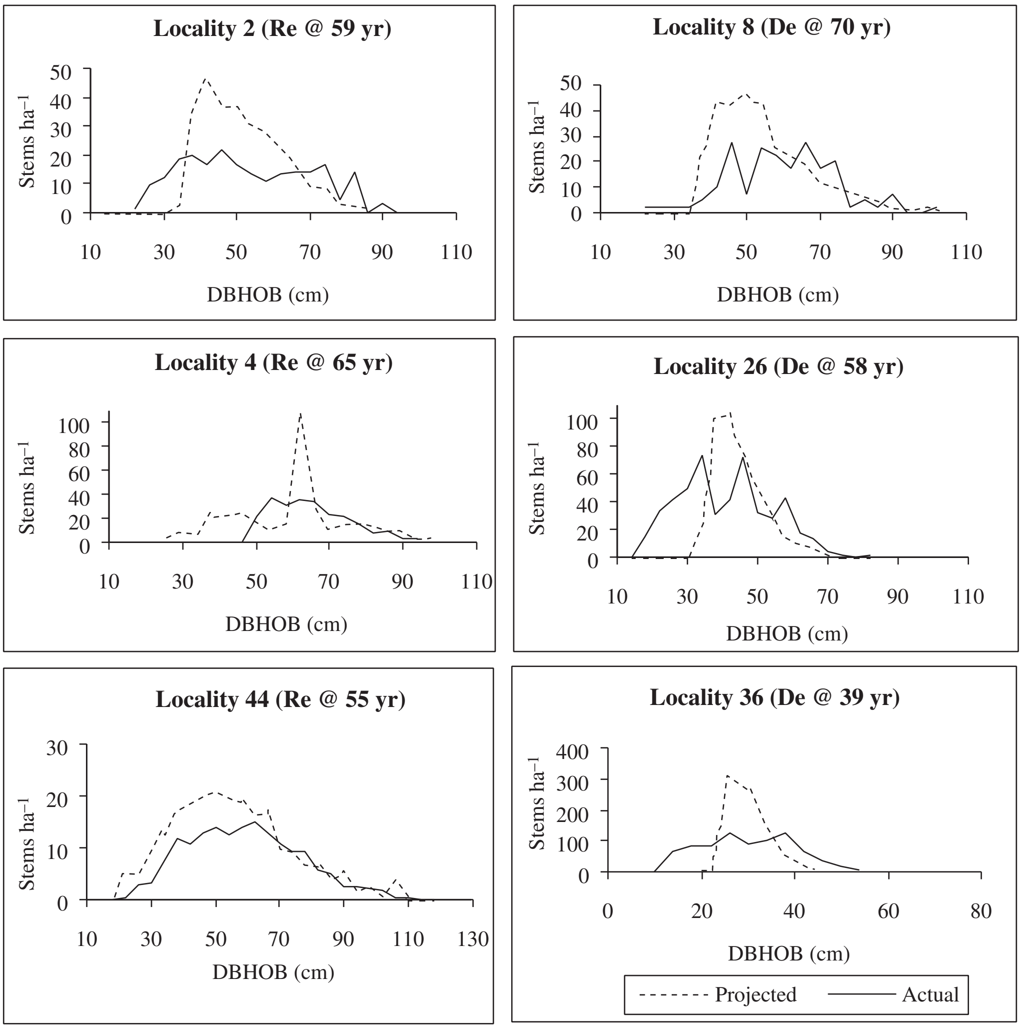

Figure 3. Plotting the average projected (dashed lines) versus observed (solid lines) diameter distributions for three selected localities of *E. regnans* (Re) and *E. delegatensis* (De)

the proportion of both small- and large-diameter trees, but overestimate the proportion of mid-diameter trees.

Projected product volumes

For both *E. regnans* and *E. delegatensis*, the mean annual per cent errors were generally less than ±1% of the observed values for projected sawlog, pulpwood or total product volumes per hectare (Table 6). This result showed that the errors of a one-year projection period were generally small for projected total product volumes per hectare. No obvious biases were found in the plots of projected against estimated product volumes of individual validation plots (Figs 1 and 2).

To test the null hypothesis that the differences between the projected and estimated product volumes per hectare are different from zero, the paired t-test procedure was applied, and none of these mean differences was found to be significantly different from zero at 5% probability level. Based on this result, the mortality mechanism of the STANDSIM model does not appear necessarily to lead to bias in projected product volumes.

Table 6. Mean annual per cent errors of projected product volumes based on the estimated product volumes using simulations

Species	Number of plots	Average projection period (yr)	Sawlog volume (%)	Pulpwood volume (%)	Total merchantable volume (%)
E. regnans	10	18.4	0.94 (2.54)	–0.02 (9.62)	0.11 (0.76)
E. delegatensis	10	15.3	0.79 (6.26)	–0.91 (16.13)	–0.26 (0.81)

The numbers in the brackets are the standard deviations of mean annual per cent errors

Discussion

In this study, the accuracy of projected yields from the growth model, STANDSIM, was evaluated using long-term measurements of permanent plots in naturally regenerated, even-aged ash-type eucalypt stands in Victoria. In general, if the yield projections were initiated at a stand age of 15 yr or more, mean annual per cent errors were within ±1.0% of the observed values for projected stand densities per hectare, ±0.5% of the observed values for projected basal areas per hectare, and within ±1.0% of the observed values for projected total product volumes per hectare. This means that for a projection period of 20 yr, the cumulative errors of STANDSIM's projections can be expected to be less than ±20% of the observed values for projected stand densities per hectare and total product volumes per hectare, and less than ±10% of the observed values for projected stand basal areas per hectare. However, if the yield projections were initiated at a stand age of less than 15 yr, the mean annual per cent errors can be as large as ±3.6% of the observed values for projected stand densities or basal areas per hectare.

The resultant error estimates obtained in this study are similar to those reported by other researchers. Opie (1972) found that for unthinned ash eucalypt forests, STANDSIM underestimated the number of live stems by 30% and basal area by 15% for a projection period of 19 yr. For three plantation plots of *E. regnans* used by West (1991), and for a projection period of 28 yr, the per cent errors of predicted stocking were calculated as 34.0%, 22.4% and 27.0% of the actual plot stocking.

Statistical procedures were used to draw conclusions on the projection accuracy of STANDSIM. The per cent biases found in projected stand densities and basal areas per hectare were generally small for short-term yield projections (i.e. less than 20 to 30), if the projections were initiated at a stand age of 15 yr or older. As indicated by the resulting maximum anticipated errors, the projected stand densities and basal areas per hectare of the STANDSIM model could be as precise as about ±5.2% of the observed values for a one-year projection interval and up to 15 yr of stand age, but about ±2.0% of the observed values for a one-year projection interval for stand ages from 15 to over 50 yr.

This study also confirms the observation by West (1991) that the STANDSIM model under-represents the proportion of small-diameter trees in the projected diameter distributions. This problem may indicate that the STANDSIM model overestimates the competition-induced mortality of natural ash-type eucalypt forests. However, our results did not indicate that this problem would directly result in bias of the projected product volumes. Because STANDSIM underestimates the proportion of both small- and large-diameter trees, but overestimates the proportion of mid-diameter trees in natural ash-type eucalypt forests, these errors may compensate for each other.

Based on the estimated product volumes of the validation plots, the mean annual per cent errors of the projected product volumes were generally less than 1% of the estimated product volumes, and no consistent projection bias was identified for the projected product volumes.

It can be concluded from this study that the future yield estimates derived from the STANDSIM model are generally accurate for a projection period of less than 30 yr if the projection is initiated at a stand age of 15 yr or more. This conclusion is consistent with that of Incoll (1983). However, the actual age of stands to which the model is applied can be up to 120 yr, while the age of the validation plots in this study is less than 80 yr. More data are required to determine the accuracy of STANDSIM for the entire range of stand ages to which the model may be applied.

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