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Short note

Modelling the response of eucalypts to fire, Brindabella Ranges, ACT

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Abstract A new algorithm for the responses of *Eucalyptus* species to fire was developed to be used in BRIND, an existing forest gap simulation model. After a fire, trees may be: (i) killed outright; (ii) have their above-ground parts killed but resprout from basal lignotubers; or (iii) continue to grow from undamaged and epicormic above-ground buds. Data collected after a fire in the Gudgenby region, Brindabella Ranges, southern Australian Capital Territory, indicate that tree size and vigour can be used to predict the response of individual trees. There was not enough information about fire intensity to estimate its effect on the response of trees. The new algorithm was tested using data from a 1982 fire in Bushrangers Creek, Brindabella Ranges. The predicted probabilities of stem death were similar to the field data.

Key words: *Eucalyptus*, fire response, modelling, mortality, resprouting.

INTRODUCTION

Recurrent fire is a common feature of eucalypt forests and many species have characteristics indicative of adaptation to a particular regime of fire intensity and frequency (Gill 1975; Noble & Slatyer 1981). Trees of some eucalypt species are sensitive to fire and are killed by full canopy scorch (e.g. *Eucalyptus regnans*; Ashton 1976, 1981; Attiwill 1994). However most eucalypt species survive complete canopy scorch and show recovery immediately afterwards (e.g. *Eucalyptus dives*; Gill 1978). The principal mechanism of recovery in fire-resistant eucalypt species is sprouting from lignotuberous and epicormic buds (Gill 1981a,b).

BRIND is a forest gap model of high-altitude eucalypt forests (Shugart & Noble 1981) adapted from the FORET model of North American hardwood forests (Shugart & West 1977). Forest gap models simulate the year-by-year establishment, growth and mortality of individual trees on a small forest plot (Botkin *et al.* 1972; Shugart 1984). When a fire occurs in BRIND, the response of each tree is calculated according to its species and amount of canopy scorch. Trees of fire-resistant species are unlikely to be killed by a fire but suffer increased mortality in following years. A deficiency of BRIND is that sprouting is simulated with the replacement of most dead trees by vigorous sprouts, which is not necessarily a 'real' response to fire.

This paper describes the construction of a new fire-response algorithm for fire-resistant eucalypts that can be used in forest gap models. It is designed to mimic better the sprouting behaviour of fire-resistant eucalypt species than that in BRIND and thus make better predictions of habitat quality. The new algorithm was constructed by modelling field data collected after a 1983 fire in a eucalypt forest, and then testing it with data from a 1982 fire in a different area.

Examination of the overall response of trees to several different fires suggested an algorithm of fire response with three stages: (i) trees may be killed outright by the fire; (ii) surviving trees may have their above-ground tissue killed but resprout from a basal lignotuber; and (iii) trees with surviving stems may resprout from these stems but show reduced size. In a gap model the first two stages can be implemented by calculating probabilities of tree death and stem death, respectively, and the third by calculating the extent to which tree size is reduced by the fire.

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METHODS

In January and February 1983 a fire burnt approximately 36 000 ha of forest in the Gudgenby region of the southern Australian Capital Territory. Most of the trees were fully scorched by the fire and some experienced 'fire-storm' conditions in which all vegetative material less than ~5 cm in diameter was consumed. In May–July 1983 10 sites were selected at Gudgenby to sample a range of fire intensities, judged visually from the extent of leaf scorch. At each site, a sample plot 20 m wide and 50–75 m long was marked out. Diameter at breast height (DBH), height (pre-fire height) and an estimate of leaf scorch height were recorded for each tree judged to have been alive before the fire. Trees were marked with numbered tags. A total of 1111 trees were tagged, mostly of four species: *Eucalyptus dives* (336 trees), *Eucalyptus rubida* (227), *Eucalyptus viminalis* (107) and *Eucalyptus pauciflora* (397). Of the 1111 trees, 986 (89%) suffered full leaf scorch. In April–May 1985 the plots were revisited. At this time the status (dead or alive), extent of sprouting (lignotuberous *vs* epicormic) and the height to the tip of the tallest living shoot (recovery height) were recorded.

Considerable variation in height within most DBH classes was apparent for trees at Gudgenby. This variation may be an indication of tree vigour, so a 'vigour index' was constructed as the ratio of a tree's height to the apparent maximum height for a tree of its DBH in that species. Curves of expected maximum height (H_e) were calculated from DBH (D) for the four major species at Gudgenby using the exponential equation:

$$H_e = H_{max} - e^{b-cD} \quad (1)$$

where b is the intercept of the height axis for zero DBH at 137 cm (the height at which DBH is modelled in gap models), c determines the initial slope of the line and H_{max} is the maximum height for the species. This equation was used because it is asymptotic to H_{max}. Values of H_{max} used in equation 1 were 25 m for *E. dives* and *E. pauciflora* and 30 m for *E. rubida* and *E. viminalis*, according to Boland *et al.* (1984) and our observations in the study area. A value for c in equation 1 of 0.1 was found to give a suitable envelope for each of the species at Gudgenby (Fig. 1).

This index of vigour is simple, and fails to take into account many indicators of tree health, but it is suitable for use in a gap model like BRIND. Tree size in BRIND is described only by DBH and assumes a fixed relationship between DBH and height for each species (i.e. all trees in a species with the same DBH have the same height). The index of tree vigour proposed here can be incorporated into gap models as a variable in the DBH–height relationship.

Probability of mortality, probability of stem death and percentage recovery were modelled by fitting a generalized linear model (GLM) with binomial error distribution and logit link function (McCullagh & Nelder 1989) to DBH and vigour index. Differences between species were also tested.

We have no independent data with which to validate all of the fire-responses in the new algorithm, however data collected after a 1982 experimental fire in the catchment of Bushrangers Creek in the Brindabella Ranges (O'Loughlin *et al.* 1982) was used to validate the prediction of stem death for some species. These data include DBH and stem death of 2627 trees of *E. dives*, *E. pauciflora* and *E. dalrympleana* that survived the fire. There were too few trees of *E. dalrympleana* recorded at Gudgenby for a separate GLM for this species to be fitted (Table 1), hence GLM equations for *E. viminalis* and *E. rubida* were used to predict stem death of *E. dalrympleana*. These three species are taxonomically closely related (subgenus *Symphyomyrtus*) and morphologically similar (Boland *et al.* 1984). The percentage of trees with a predicted probability of stem death above 0.5 were compared with the observed proportion of stem death at Bushrangers Creek. Error of prediction was

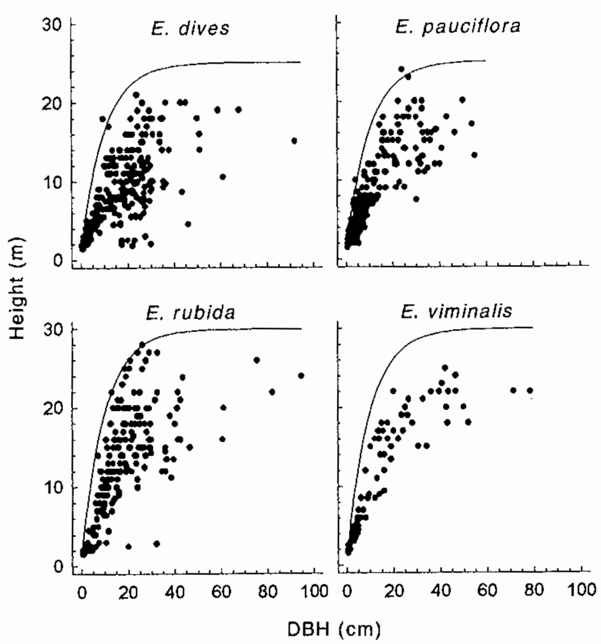

Fig. 1. Height *vs* DBH for the four major species recorded at Gudgenby. Lines are exponential curve envelopes.

Table 1. Summary of fire response of trees at Gudgenby, showing percentage mortality of all trees and percentage stem death of surviving trees

Species	Total no.	Mortality (%)	Stem death (%)
E. dalrympleana	33	3.0	46.9
E. dives	336	8.0	47.9
E. pauciflora	397	5.3	81.9
E. radiata	3	0.0	33.3
E. rubida	227	6.2	37.1
E. viminalis	107	12.1	55.3
Unknown	8	75.0	50.0
All species	1111	7.5	58.7

calculated as the number of 'wrong' predictions (probability >0.5 when the tree's stem survived, and probability ≤0.5 when it was killed) divided by the total number of trees.

RESULTS

Overall mortality of trees was approximately 7.5% due to fire (Table 1). Of the four common species, mortality was highest in *E. viminalis* and lowest in *E. pauciflora*. Analysis of deviance indicated that vigour index, DBH and an interaction term of the two were significant predictors of mortality. Only one species (*E. viminalis*) had a different rate of mortality (higher) than the others. This species had the fewest trees of the four major species so the GLM without the species term was chosen. The predicted probability of tree mortality against DBH and vigour index was highest in trees of medium to large size with low vigour (Fig. 2). Vigorous trees (all sizes) and small trees, even of low vigour, are all less likely to be killed by fire.

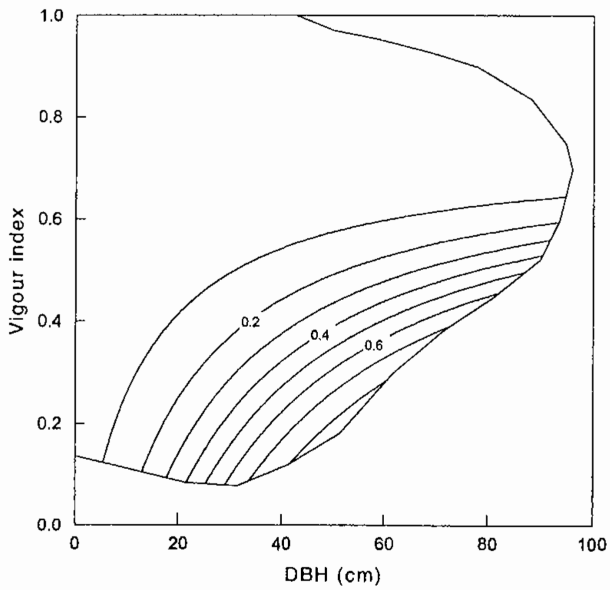

Fig. 2. Contour plot of predicted probability of mortality from vigour index and DBH (cm). Also shown is the approximate boundary of DBH and vigour values observed in the Gudgenby data.

Of the surviving trees, an average of 58.7% had their stems killed but resprouted from lignotuberous buds (Table 1). Stem death varied significantly between species: of the four major species it was highest in *E. pauciflora* and lowest in *E. rubida*. Separate GLM were fitted for

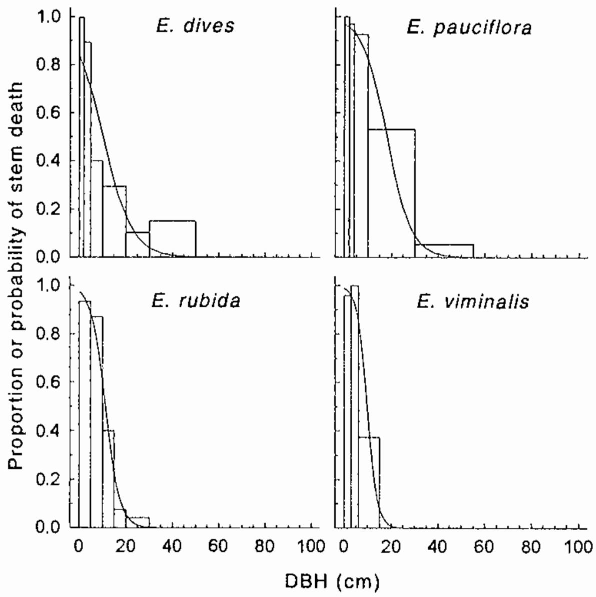

Fig. 3. Observed (histogram) and predicted (line) stem death in surviving trees of four species. Because of low numbers of large trees histograms have uneven diameter classes.

Table 2. Regression equations for prediction of probability of tree mortality, probability of stem death for each species and proportion height recovery after fire

Dependent variate (y)	Linear predictor (l)
Tree mortality	$-2.517-1.715V+0.1185D-0.1603VD$
Stem death	
E. dives	$1.641-0.1603D$
E. pauciflora	$3.455-0.1916D$
E. rubida	$3.645-0.3234D$
E. viminalis	$4.541-0.4653D$
Growth recovery	$0.513+0.0477D$

Independent variables are vigour index (V) and diameter at breast height (D). The relationship between the dependent variate y and the linear predictor l is $y = e^l/(1+e^l)$. All equations are significant at $P<0.05$.

Table 3. Comparison of stem death predicted by the model and observed in the Bushrangers Creek fire

Species	No. trees	Range of probabilities	Predicted stem death (%>0.5)	Observed stem death (%)	Prediction error (%)
E. dives	808	0.000–0.815	52.6	62.9	16.7
E. pauciflora	1451	0.000–0.963	93.3	89.5	6.5
E. dalrympleana (i)	368	0.000–0.983	34.5	36.0	6.0
E. dalrympleana (ii)	368	0.000–0.965	39.9	36.0	8.4

Predicted values for *E. dalrympleana* are calculated using the equation of *E. viminalis* (i) and *E. rubida* (ii).

each of the four species and DBH was the only significant term in all of them (Table 2; Fig. 3).

Height to the tips of the tallest living shoot on trees with surviving stems was used as an indicator of recovery after fire. Many trees were observed to have full crown recovery and be as tall as before the fire, or taller. With the exception of *E. viminalis* with 29%, 50–60% of all trees showed full canopy recovery. There was no significant difference between species in the fitted GLM, which predicts better recovery in larger trees (Table 2).

Predicted probabilities of stem death from the model based on the Gudgenby fire were similar to field results for all species at Bushrangers Creek, with the ranking of the species responses predicted correctly (Table 3). Of the two models for *E. dalrympleana*, the *E. viminalis* model (model (i) in Table 3) made better predictions compared to the field data, although both models had lower error of prediction than the models for the other two species.

DISCUSSION

Our results are generally in accord with the findings of others: larger trees cope with fire better than smaller ones. The exception is high mortality of large trees of low vigour. A possible explanation for this phenomenon is that these trees had been weakened by previous fires or by insects and were more likely to be killed by an intense fire. Old eucalypts can be hollowed out by fire scars and later killed when another fire burns up through the hollow centre like a chimney (Luke & McArthur 1978). This phenomenon was observed in the fire in the Bushrangers Creek where most of the large, hollow trees were killed by the intense fire. There was some evidence of species differences in mortality but because these were confined to uncommon species they were not significant. Differences in response between species were only found in the stem death stage of the model.

Fire intensity is known to be important in the response of trees to fire (e.g. Gill & Ashton 1968; Vines 1968) and a model of eucalypt fire response should include it if possible. There was not enough reliable information about fire intensity at Gudgenby for it to be included in our new algorithm because so many of the trees were completely scorched. As a result, the new algorithm may not be reliable for predicting response of trees to low-intensity fires. In general we expect less mortality, less stem death and greater growth recovery with lower fire intensity. However, the new fire-response model is an improvement on that in BRIND and will enable more realistic prediction by gap models of fire effects on communities of fire-resistant eucalypt species.

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