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MODELLING FIRE-PRONE VEGETATION DYNAMICS

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Abstract.

Two modelling approaches applied to two fire-prone ecosystems are reviewed. The first approach is based on the descriptive (statistical) models of resprouting after a fire. The second is based on the long-term simulation models. The fire-prone areas studied were: NE Spain and SE Australia. The results of the statistical model on resprouting suggested a similar pattern of resprouting between *Quercus suber* (NE Spain) and some *Eucalyptus* species (SE Australia), i.e., stem death was inversely related, and recovery was positively related to tree size. Results using two dynamic simulation models (the EDEN model for SE Australia, and the BROLLA model for NE Spain) suggested clear changes in vegetation structure and composition when fire recurrence was increased.

Keywords: fire response, fire recurrence, gap model, resprouting, vegetation dynamics

Introduction

Long term consequences of disturbance on landscapes are difficult to predict, especially when interval-dependent (in contrast to event-driven) processes may be important. Recent human-induced changes (e.g., land use changes, climate change) in the Mediterranean region are modifying the fire regime. Models of vegetation dynamics may help to predict the consequences of this change on Mediterranean landscapes.

Modelling vegetation dynamics in fire-prone ecosystems requires two approaches (Table 1). One is based on field observations after wildfire or experimental fire, to produce descriptive (often statistical) models. These models are a simplified description of the response of vegetation to disturbance events (fires). The second approach is to include ecological knowledge of how plants function and descriptive models from field observations in a mechanistic simulation model. The latter approach allows us to simulate the long-term vegetation dynamics, and to test alternative scenarios or management options. Both approaches, as used here, assume that the best way of understanding the dynamics of plant communities is to work from a knowledge of how individual plants function.

Table 1. Characteristics of the two modelling approaches.

Approach	Process	Based on	Time scale	Tools
Descriptive models	event-dependent	field or experimental observations	short-term	Statistics
Simulation models	interval-dependent	ecological knowledge and descriptive models	long-term	Programming

In the present work, we exemplify these two approaches in two different fire-prone ecosystems: SE Australia and NE Spain. The descriptive models are those of the resprouting after a wildfire. The simulation models are used to create a gradient of increasing fire recurrence to study the long-term changes of vegetation. The most standard simulation technique currently used to predict vegetation dynamics is the gap model approach (individual-based gap dynamic modelling approach, Botkin et al. 1972, Shugart 1984, Urban & Shugart 1992, Shugart & Smith 1996) which simulates stand development by modelling mechanistically the establishment, growth, and death of individual plants. In the present study, two gap simulation models are assayed: the EDEN model for SE Australian forests and the BROLLA model for NE Spain communities.

Methods

Descriptive Models

Two descriptive models based on field data in two fire-prone areas are presented (Table 2): Eucalypt forests in SE Australia, and, cork oak (*Quercus suber* L) forests in NE Spain. Both data sets were collected after a summer wildfire, and the objective was to study the resprouting process of the tree species. Measured variables were: diameter at breast height (DBH), tree height (pre-fire height), bark thickness and the height to the tip of the tallest living shoot (recovery height). For eucalypt trees, a vigour index was computed as a ratio of the tree height to the apparent maximum height for a tree of its DBH in that species. Sampling details are given in Strasser et al. (1996) and Pausas (1997). Statistical models for both data sets were fitted to compute: probability of tree mortality, probability of stem mortality (resprouting from basal buds), and amount of recovery (recovery height *vs*. pre-fire height).

Table 2. Characteristics of the two data sets used for the descriptive models of resprouting after wildfire.

Fire Date	Location	Species	# trees
August 1994	Montseny, Catalonia, Spain	*Quercus suber*	115
Jan./Feb. 1983	Gudgenby, ACT, Australia	*Eucalyptus* sp. pl.	1111

Table 3. Fire scenarios for the two simulation models (EDEN and BROLLA). For BROLLA scenarios, mnemonic names are in brackets.

EDEN scenarios		**BROLLA scenarios**		
No fire	-	No fire	-	(NF)
Annual probability	0.012	Fire every	100 yr	(F100)
"	0.025	"	40 yr	(F40)
"	0.050	"	20 yr	(F20)
"	0.100	"	10 yr	(F10)
		"	5 yr	(F5)

Simulation Models

Two models are assayed: EDEN and BROLLA. Both are non-spatially explicit gap simulation models. EDEN is a gap model of vegetation dynamics for the SE Australian forests (Pausas et al. 1997). It is an improved model from the original BRIND model (Shugart & Noble 1981). EDEN predicts the vegetation dynamics and the habitat quality of arboreal mammals under different scenarios of fire and/or harvesting and in different landscape positions. Because it includes different landscape positions, EDEN initially includes 43 species. Full description of the model may be found in Pausas et al. (1997). The model was set to simulate the forest communities of SE Australia on ridges at 600 m. a.s.l.

BROLLA is a simplified gap model for Eastern Spain that aims to capture the main features for modelling the dynamics of Mediterranean vegetation. BROLLA is based on other gap models (Botkin et al. 1972, Shugart 1984, Coffin & Lauenroth 1990, Pausas et al. 1997) and includes 4 main plant functional types: *Quercus* (broadleaved evergreen resprouter), *Pinus* (needle-leaved non-resprouter with serotinous cones), *Erica* (heath, ericoid-leaved resprouter), and *Cistus* (broadleaved non-resprouter with germination stimulated by fire). The precise species (rather than functional types) would depend on some environmental parameters such as climate and soil type, which are not currently included in the model.

The two simulation models were set to simulate the dynamics of a forest without fire, and then a set of simulations were carried out with increasing fire recurrence to create a fire recurrence gradient. Due to constraints in the software of each simulation model, the fire recurrence gradient was created in a different way for each model. That is, for BROLLA a constant fire interval was used, while for EDEN, we used a random fire with constant hazard (Table 3). BROLLA scenarios were run for 500 yr and replicated 10 times, EDEN scenarios were run for 1000 years and replicated 20 times. The results presented are average values. For both models it is assumed that the patch modelled is surrounded by vegetation, and the arrival of seeds is not a limiting factor.

Results

Descriptive Models

Probability of mortality of eucalypt trees (Fig. 1) was highest in trees of medium to large size with low vigour. Vigorous trees (all sizes) and small trees (even with low vigour) were less likely to be killed by fire. Of the surviving trees, 59% had their stems killed but resprouted from lignotuberous buds. Stem death was negatively related to tree size (i.e., DBH) and bark thickness; and the recovery (in height) was positively related to tree size.

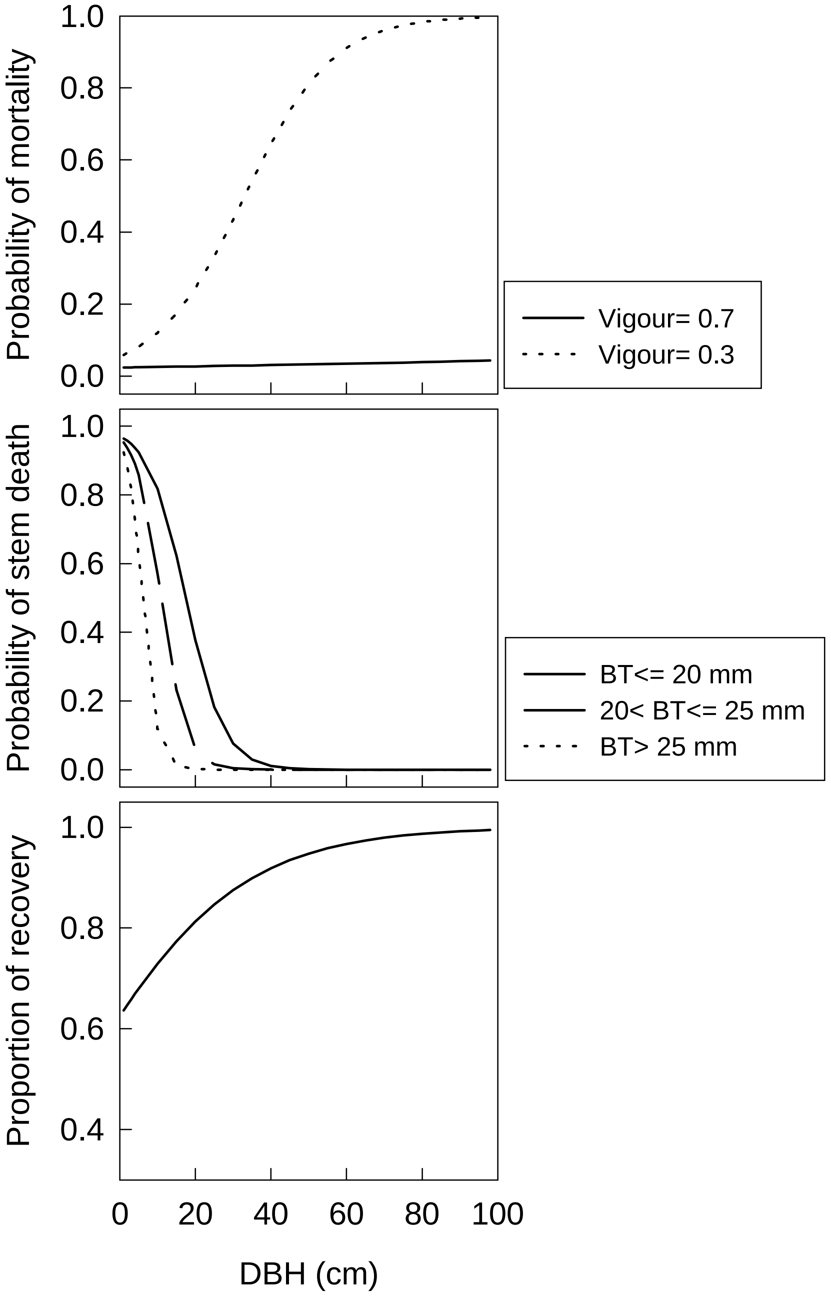

Figure 1. Response of *Eucalyptus* trees to fire. Probability of tree mortality at two Vigour Index values (top); probability of stem death at different bark thickness (BT); and, percent recovery (bottom). All regression models are significant at $P<0.05$. Elaborated from data in Strasser, Pausas & Noble (1997).

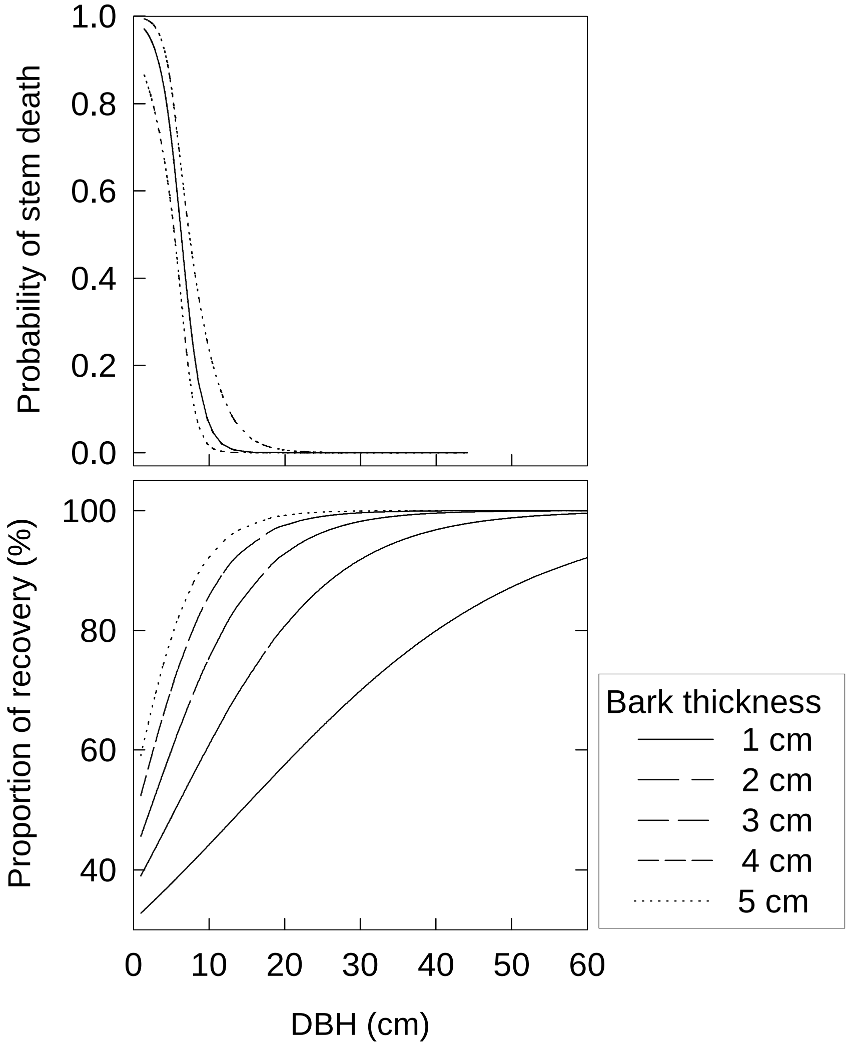

Figure 2. Response of *Quercus suber* trees to fire in relation to tree diameter. Probability of stem death (top; dotted lines are 95% confidence interval); and, percent recovery at different bark thickness (bottom). Regression models are significant at $P<0.0001$. From Pausas (1997) with permission from the International Association for Vegetation Science.

Cork oak showed very low tree mortality (only one of the 115 trees sampled) and the probability of mortality could not be statistically studied. Stem death was negatively related to tree size and recovery was positively related to tree diameter and bark thickness (Fig. 2).

Simulation Models

The EDEN model predicted clear changes in forest composition with changes in fire recurrence in SE Autralian forests (Fig. 3; Austin et al. 1997). The model without fire produced a community dominated by *Eucalyptus cypellocarpa*. *E. sieberi* was the second species in abundance, followed by *E. fraxinoides* and *E. muelleriana*. Increasing the fire recurrence increased the abundance of *E. sieberi* and *E. muelleriana*, and reduced the abundance of *E. cypellocarpa* and *E. fraxinoides*. The observed relative abundance of eucalypt species (Austin 1978, Fanning & Mills 1989) corresponds with the predicted composition at high fire recurrence values, with the exception of *E. goboidea* which was observed in the field but not predicted by the model (Fig. 3).

The BROLLA model also predicted changes in the relative abundance of the different species with changes in the fire recurrence in NE Spain (Fig. 4). *Quercus* showed a progressive decrease in relative abundance, from ca. 80% (NF) to 5% (F5) of the total basal area. *Pinus* had its maximum relative abundance at intermediate fire recurrences, but it occured at all fire regimes. *Erica* and *Cistus* increased up to ca. 30% of the total basal area with increased fire recurrence (F5).

Discussion

The trees studied, eucalypts and the cork oak, are genetically and chorologically very distinct, but they share some ecological characteristics (adaptative convergence). After fire, both were able to resprout from stem buds or from lignotuber (basal) buds, and both resprout in a similar way. Tree mortality was low, probability of stem death was negatively related to tree size, and recovery was positively related to tree size in both trees. The results are generally in accord with the findings of others: large trees cope with fire better than smaller ones. Bark thickness also played an important role in the recovery of the tree (Gill & Ashton 1968, Vines 1968, Hare 1965, Uhl & Kauffman 1990). The response of these species suggests a three-stage model of resprouting (Fig. 1, 2): the first stage predicts whether or not a tree dies as a direct result of being burnt; for the surviving trees, the second stage predicts whether or not their above-ground parts survive the fire; and the third stage determines the amount of recovery by trees whose stems have survived the fire. Cork oak is the only European species that resprout from stem buds and produces a quick regeneration of the canopy after fire. This feature together with its economic importance (e.g., cork for wine bottles, among other things) make this species a good candidate for reforestation programs in fire-prone areas.

Simulation results suggested a clear change in the relative species composition with the increased fire recurrence in both ecosystems studied. However, while in SE Australia, at high fire recurrence, the predicted vegetation was a forest, in NE Spain the predicted vegetation structure changed to a shrub community (*Erica* and *Cistus*) with some pines.

These types of models provide us some insights into the fate of vegetation with changes in fire recurrence, and can be used to test alternative management scenarios. However, further work is needed before we can obtain reliable models for global change predictions. The main research needed includes, the extension to spatially explicit gap models (including realistic dispersion processes); realistic environmental (especially temperature) response of the species; knowledge of key species

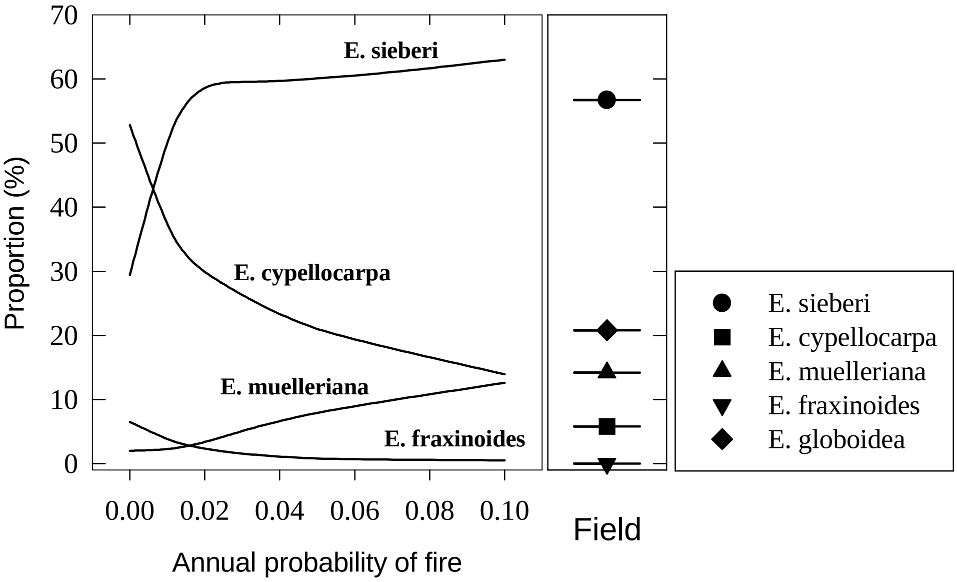

Figure 3. Summary of the EDEN simulations on ridges at 600 m a.s.l. in SE Australia. Y-axis is the mean proportion of biomass of 20 replicated simulations of 1000 years. Field data are the average importance values of 6 plots from Fanning & Mills (1989).

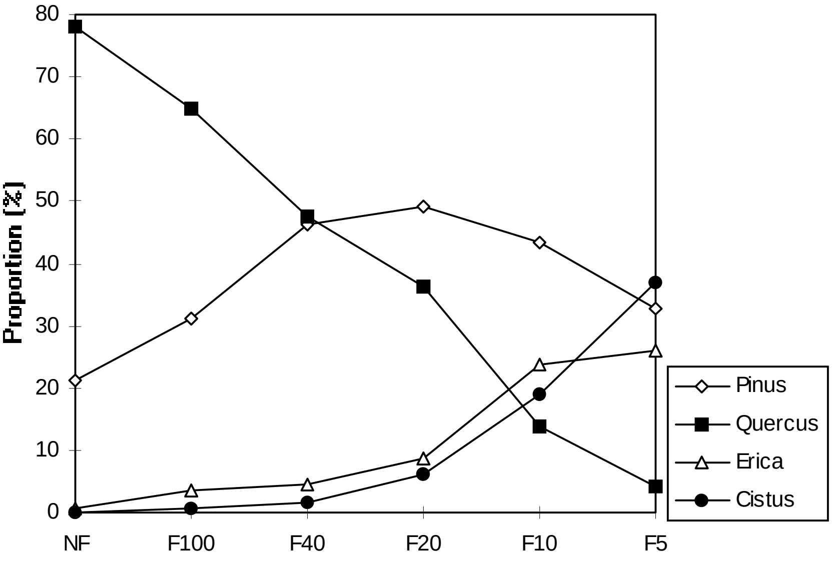

Figure 4. Summary of the BROLLA simulations. Y-axis is the mean percent basal area of 10 replicated simulations of 500 years. Scenarios as in Table 3.

attributes; and, the inclusion of below-ground competition. Descriptive models on these topics would improve our ability to produce more accurate simulation models. I believe this Conference is contributing to some of these descriptive models which may soon be incorporated into simulation models.

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