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Classifying and comparing spatial models of fire dynamics

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Wildland fire is a significant disturbance in many ecosystems worldwide [1] and the interaction of fire with climate and vegetation over long time spans has major effects on vegetation dynamics, ecosystem carbon budgets, and patterns of biodiversity. Landscape-Fire-Succession Models (LFSMs) that simulate the linked processes of fire and vegetation development in a spatial domain are one of the few tools that can be used to explore the interaction of fire, weather and vegetation over century-long time scales [2]. There is a diverse set of approaches to predicting fire regimes and vegetation dynamics over long time scales, due in large part to the variety of landscapes, fuels and climatic patterns that foster frequent forest fires, and variation in modeller's approaches to representing them.

Over recent years, an international group of scientists working under the auspices of Global Change and Terrestrial Ecosystems (GCTE) and funded by the US National Centre for Ecological Analysis and Synthesis classified an extensive set of spatial models of fire and vegetation dynamics and compared the behaviour of a subset of the models to determine the relative sensitivity of simulated area burned to variation in terrain, fuel pattern, climate and weather. A set of recommendations for the incorporation of fire dynamics into global dynamic vegetation models was also developed.

Keane et al. [3] identified and classified 44 published spatial models of fire and vegetation dynamics. The models were evaluated according to four components (succession, fire ignition, fire spread, and fire effects) by the three evaluation gradients (stochasticity, complexity, and mechanism) using a scale from 0 to 10 (zero meant that it was not modelled or applicable and 10 represented the highest level of stochasticity, mechanism, or complexity). Rankings were assigned by model developers and Keane et al.'s [3] own review of publications of the models.

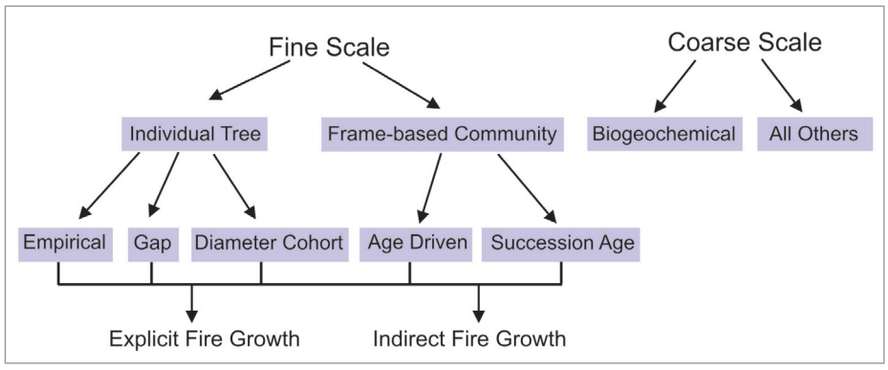

Figure 1. Final set of categories for landscape fire succession models classified using the degree of stochasticity, complexity, and mechanism in the design of the model components of succession, fire ignition, fire spread and fire effects.

A general classification of spatial fire models was developed by combining results from a principal components analysis and a TWINSPAN (Two-way Indicator Species Analysis) clustering analyses of the evaluation element data. Given the high variance in evaluation elements across models, explanatory categories such as approach, strategy, scale and other descriptive elements were assigned to models. The frequency of keywords for each category across all LFSMs was then analysed to qualitatively identify similar characteristics and natural clusters.

The classification (Fig. 1) had 12 hierarchically nested classes that are distinguished by their scale of application (coarse vs fine), representation of vegetation (individual plant cohorts vs framed-based community), simulation of succession (empirical, gap diameter, age, or successional pathway) and the explicit or implicit simulation of fire spread. A full description of the classification results are presented in Keane et al. [3].

Direct comparison among models can be difficult [4]. Cary et al. [5] developed an approach to compare the sensitivity of modelled area burned to a range of factors in a standardised design across a subset of the spatial models of fire dynamics (EMBYR, FIRESCAPE, LAMOS(DS), LANDSUM and SEM-LAND). Ideally, the comparison would have selected models from all categories of the classification, however, model selection was also constrained by the availability of modellers with sufficient resources to implement the design. The five models represented a spectrum of complexity in model formulation and represented three out of the twelve classification categories presented by Keane et al. [3].

SOURCE OF MODEL VARIATION	EMBYR	FIRESCAPE	LAMOS	LANDSUM	SEM-LAND
Terrain		●			
Fuel	●				
Terrain x Fuel					
Climate		●	●	●	●
Terrain x Climate					
Fuel x Climate					
Terrain x Fuel x Climate					
Weather	●	●		●	●
Terrain x Weather		●			
Fuel x Weather	●				
Terrain x Fuel x Weather					
Climate x Weather	●			●	●
Terrain x Climate x Weather		●			
Fuel x Climate x Weather					
Terrain x Fuel x Climate x Weather					

Table 1. Important sources of variation (●) in area burned in five spatial models of fire and vegetation dynamics. Variation in terrain (Terrain), fuel pattern (Fuel), climate (Climate) and weather (Weather) factors, and their interactions, was considered important if they explained more than 0.05 and 0.025 of total variation within a model respectively.

Variation in terrain was introduced by varying the minimum and maximum elevation of the simulation landscape so that flat, undulating, and mountainous landscapes had relief of 0, 1250 and 2500 m respectively. Fuel pattern was varied to represent finely clumped (25 ha patches) and coarsely clumped (625 ha patches) patterns of varying fuel age. Weather and climate can be different at fine temporal scales and were treated as orthogonal. Variation in weather was introduced by selecting ten representative years of daily weather records for the landscape where the model has undergone most rigorous validation. Three types of climate were included in the design, including observed, warmer/wetter (+3.6°C, +20% precipitation), and warmer/drier (+3.6°C, -20% precipitation) climate. In this experiment, simulations were limited to one year and vegetation dynamics were not invoked.

Modelled area burned was most sensitive to climate and variation in weather, with four models sensitive to each of these factors and three models sensitive to their interaction (Table 1), giving similar results to the findings of Bessie and Johnson [6]. Models generally exhibited a trend of increasing area burned from observed, through warmer and wetter, to warmer and drier climates. Area burned was sensitive to fuel pattern for EMBYR and terrain for FIRESCAPE which was the only model that incorporated the effect of elevation on site weather by invoking lapse rates in temperature, humidity and precipitation.

These findings have particular significance for the inclusion of fire in Dynamic Global Vegetation Models (DGVMs). The lack of sensitivity of area burned to fine scale fuel pattern indicates that coarse scale DGVMs may not need to incorporate pattern of vegetation within simulation cells, although this depends on the importance of vegetation succession on area burned which was not tested in this experiment. Also, the general finding of the importance of inter-annual variability in weather (compared with climate) has important implications for the inclusion of fire into DGVMs, because an increase in the year-to-year variation in weather may translate into large effects on area burned as long-term changes in mean temperature and precipitation brought about by climate change. On the other hand, landscape scale pattern in terrain was demonstrated to be important by the one landscape-fire-succession model that incorporates the effect of terrain on weather.

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