Modelling interactions between vegetation, wildfire, soil and human land use in Mediterranean landscapes

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1. Overview

Socio-economic and political trends have led to changes in the ecological structure and dynamics of many landscapes throughout the Mediterranean Basin recently. For example, in many areas agricultural land abandonment has been ongoing with commensurate shifts in land cover to shrub and forest land (e.g. Millington et al. 2007). To examine relationships between changing human land use and the frequency and location of wildfires in a landscape typical of the Mediterranean Basin, we have developed an integrated socio-ecological landscape simulation model.

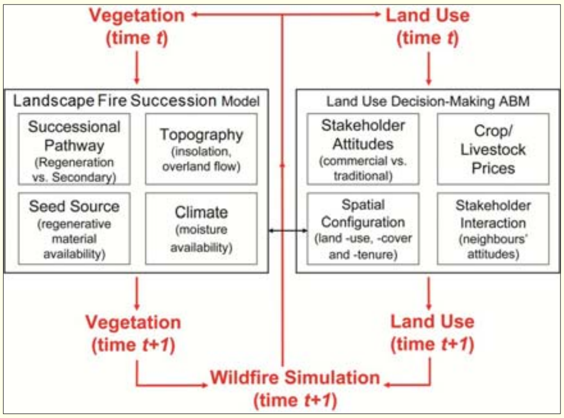

Fig 1. Flowchart showing basic model structure and interactions of components

The model is composed of a Landscape Fire Succession Model (LFSM, Millington et al. 2009) and an Agent-Based Land Use Model (ABLUM, Millington et al. 2008). The LFSM takes a state-and-transition approach to represent dynamics of several broad land-cover classes on a grid (of 30 m square pixels). The ABLUM represents agricultural land-use decision-making of individual small-scale farmers, with agents selecting one of three possible land uses: crops (vineyards, orchards), pasture (goats and sheep) or non-agricultural land based on economic and cultural rules.

More detail of model structure is presented on the right, with example results. This model also has the potential to examine the consequences of changes in human activity on linked ecological, hydrological and geomorphological systems at the landscape scale, discussed at bottom (and see Wainwright and Millington 2010).

For more details, and to experiment with the agent-based model component, visit http://www.landscapemodelling.net.

References

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2. Model structure and output

Landscape Fire Succession Model

•Uses vegetation classes based on **plant-functional types** which accounts for the importance of key **environmental resource constraints** (water and light availability) and disturbance (fire and agriculture).

•**Soil moisture and surface runoff** are calculated using the Soil Conservation Service curve number method. Surface runoff is routed **spatially** through the landscape as a function of topography.

•Represents the impacts of varying intensities and frequencies of **disturbance** by representing two **succession** pathways ('secondary' or 'regeneration') between vegetation classes (Figure 2).

• Locations of seed sources are tracked to represent spatially variable **seed availability and dispersal**.

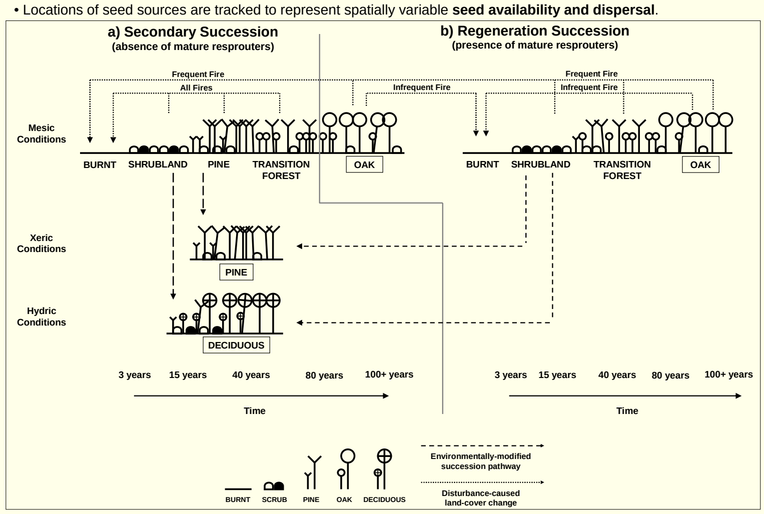

Fig 2. Directions and rates of transition in the LFSM differ for a) Secondary and b) Regeneration succession pathways. These may be modified from the default pathway (at top) by changes in environmental conditions (dashed arrows).

Agent-Based Land Use Model

Monitors status of each agent (age, wealth, perspective, pixels owned).

Commercial agents
Base land-use decisions on factors related to profitability: markets, land tenure fragmentation, transport costs and land productivity.

Estimate profit in the next time step and may change land uses to improve profit (includes abandoning land).

May buy and convert neighbouring abandoned pixels if it is likely to increase profit.

Traditional agents follow similar rules to commercial agents but

Do not consider any profit-making activities,

Do not seek to buy land from neighbours.

At each time step
Once land use has been established all non-agricultural pixels are subject to change via the state-and-transition component of the LFSM.

All pixels in the landscape may be subject to burning, represented by cellular automata in the LFSM.

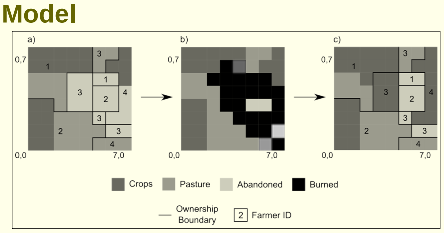

Fig 3. Example illustrating the importance of individual farmer context for agricultural land-use decision-making.

(a) An example landscape extract of 8 × 8 pixels contains land holdings of four farmers with heterogeneous land ownership and socio-economic circumstances.

(b) A fire preferentially burns more densely vegetated pixels (e.g. abandoned land).

(c) Following a fire event, subsequent use of burned pixels for crops varies between farmers dependent on their individual circumstances and the location of burned pixels as well as their assumptions, such as that burning acts to improve potential crop yields.

For example, to increase income whilst minimizing costs of farm fragmentation, Farmer 3 converts six conterminous burned pixels (at coordinates 3,3 to 4,5) to crops, but not individual pixels (5,2 and 7,1). Other farmers make similar, but varied, decisions.

3. Application to ecogeomorphic systems

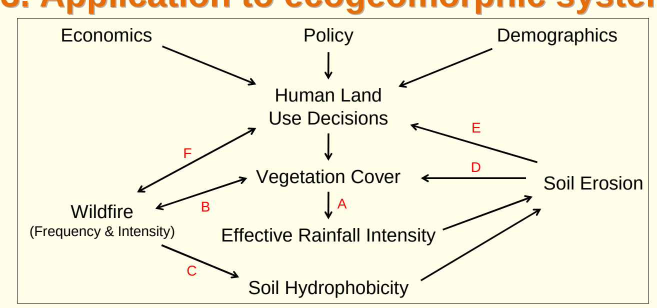

Fig 4. Multiple interactions between humans, wildfire, vegetation and soil

The implications of economics, policy and demographics for land-cover change, vegetation and soil conditions are unclear due to multiple interactions (Figure 4).

Although increasing vegetation cover in Mediterranean landscapes might reduce soil erosion by reducing effective rainfall intensity at the ground surface (A), it also brings the potential for changes in the frequency and magnitude of wildfire events (B). In semi-arid environments, thresholds of fire temperature and soil moisture are believed to shift soil hydrophobicity between water repellent and non-repellent states (C). Soil conditions will influence vegetation dynamics (D) and may contribute to human land use decisions (E). Wildfire will also likely have consequences for future human land-use decision-making (F and Figure 3).

The cumulative effects of multiple, spatially distributed, decisions are difficult to estimate analytically, but may be investigated via agent-based simulation (e.g. Figure 3). Future versions of our model will incorporate explicit representation of the feedbacks from changing soil and wildfire conditions on individual agricultural actors.