# An Integrated Socio-Ecological Simulation Model of Succession-Disturbance Dynamics in a Mediterranean Landscape

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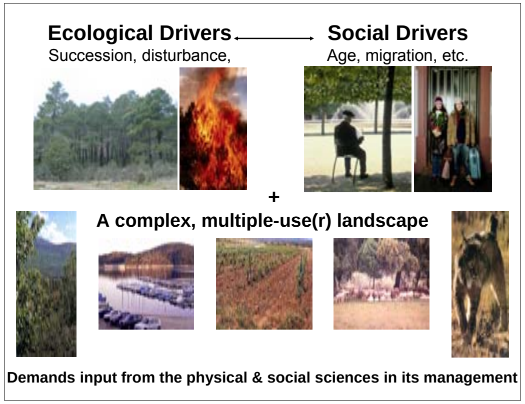
## Introduction & Study Area

Socio-economic and political trends have led to changes in the ecological structure and dynamics of many landscapes throughout the Mediterranean Basin. Special Protection Area number 56 (SPA 56) 'Encinares del río Alberche y Cofio', is 830 km$^2$ in area, lying 30 km west of Madrid, central Spain. The area is experiencing Land Use/Cover Change (LUCC) driven by both ecological and socio-economic drivers (Figure 1).



**Ecological Drivers** ⟷ **Social Drivers**

Succession, disturbance,

Age, migration, etc.

\+

**A complex, multiple-use(r) landscape**

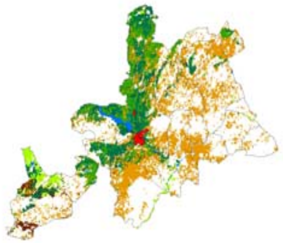
**Demands input from the physical & social sciences in its management**

**Figure 1.** Drivers of landscape change in the study area

Recent increases in forest and shrub land-cover have occurred commensurate with decreases in agricultural land uses, resulting in increased vegetation biomass and spatial homogenisation at the landscape scale. Such changes are likely to increase wildfire risk. However, the importance of feedbacks between landscape pattern and process inherent in the occurrence of wildfires, means that the implications of this recent LUCC for the wildfire regime in the future remain unclear. We have developed an integrated socio-ecological simulation of LUCC-wildfire interaction to examine potential implications of these changes. Model structure is presented on the right, initial results from the model are presented below. For more details, and to experiment with the agent-based model component, visit http://landscapemodelling.net.

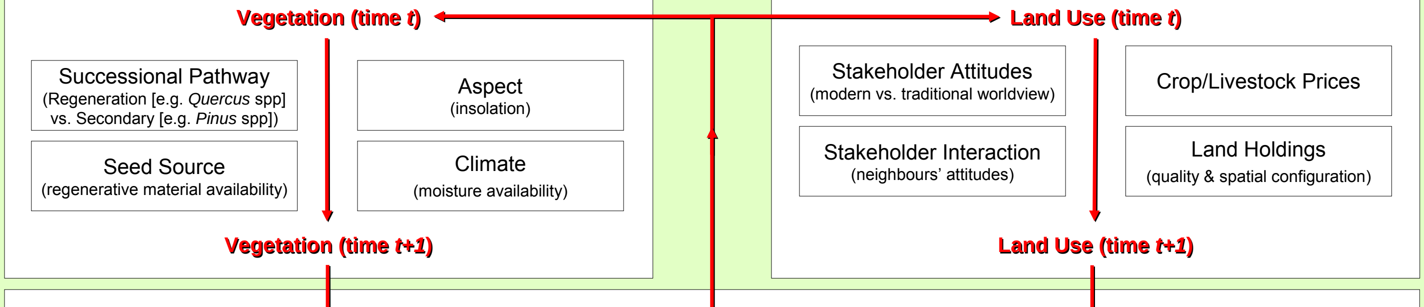
## Ecological Change

This **cellular automata** model module represents vegetation cover change due to processes of succession and species competition (life-history traits). Direction & time to change from one cover to another are dependent upon the four primary factors shown below.



## Land Use Change

This **agent-based** model module represents land use change by considering individual stakeholder (mainly farmers') decision-making. Farmers are not modelled as perfectly economically rational actors; other social influences (e.g. attitudes toward traditional farming practices) are also considered, as shown below.



**Vegetation (time *t*)**

Successional Pathway
(Regeneration [e.g. *Quercus* spp] vs. Secondary [e.g. *Pinus* spp])

Aspect
(insolation)

Seed Source
(regenerative material availability)

Climate
(moisture availability)

**Vegetation (time *t+1*)**

**Land Use (time *t*)**

Stakeholder Attitudes
(modern vs. traditional worldview)

Crop/Livestock Prices

Stakeholder Interaction
(neighbours' attitudes)

Land Holdings
(quality & spatial configuration)

**Land Use (time *t+1*)**

**Ignition Location** may be

a) Spatially random across the landscape

b) Spatially determined across the landscape by:

- human presence (distance to settlement/road/trail)
- vegetation type (flammability risk)
- solar insolation (vegetation moisture state)

## Wildfire Simulation

**(time *t+1*)**

This **cellular automata** model module represents the wildfire regime by simulating individual wildfire ignitions & spread spatially explicitly. LUCC influences wildfire (fuel availability) which in turn influences ecological change & land use decision-making.

**Wildfire Spread** is simulated using a cellular automata approach. Spread is constrained by:

- slope (quicker/more likely uphill)
- vegetation type (flammability risk)
- fire breaks (management, watercourses, roads)
- fire fighting (maximum fire size restriction)

## Results

One of the novel features of this simulation model is the spatially and temporally-explicit representation of wildfire ignition from both 'natural' (i.e., lightning) and human sources. Fires may also be ignited at spatially random locations. Explicitly representing multiple ignition sources allows us to analyse the wildfire regimes of fires ignited by these different sources. We find that mean largest fire areas are smaller for lightning fires than for human fires, with correspondingly less total burned area, for model replicates of the same temporal length.

To investigate the potential causes of the difference in mean largest fire and mean burned area between causes, we examine the relative frequencies of ignition and the relative proportions of burned area in each land-cover. For ignition frequency for each land-cover *y* we calculate the ratios $R_i$ and $R_b$:

$$R_i = \frac{prop_{iy}}{prop_y} \qquad R_b = \frac{prop_{by}}{prop_y}$$

where $prop_{iy}$ is the proportion of total wildfire ignitions in land-cover *y*, $prop_{by}$ is the proportion of total burned area burned by land-cover *y*, and $prop_y$ is the mean annual proportion of total area occupied by land-cover *y*. $R_x \approx 1.0$ indicates unbiased ignition or burning. $R_x > 1.0$ indicates a bias toward ignition or burning of a specific land-cover type.

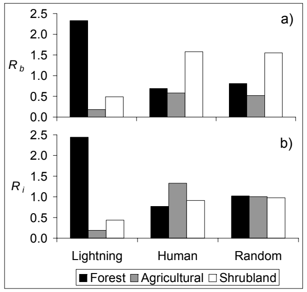


**Figure 2.** a) $R_b$ and b) $R_i$ for lightning, human-caused and randomly located fires.

Results for $R_i$ indicate a bias in lightning fires to ignite in Forest land covers, while human-caused fires are biased toward ignition in Agricultural land covers, and randomly located fires are unbiased (Figure 2a). $R_b$ values indicate a bias in lightning fires burning of Forest land-cover types, and that human-caused and randomly-located fires burning Shrubland (Figure 2b).

Lightning fires are more likely to ignite in lower flammability Forest covers because of their predominance at higher elevations where these land-covers are dominant. Fire ignition in locations near areas of high human activity (e.g. near roads and trails) results in human-caused fires preferentially burning highly flammable Shrubland. This pattern is a due to agricultural abandonment and repeated localised burning in these areas of high human ignition risk. Despite the bias of human-caused fires toward ignition in Agricultural land covers, the highly flammable (and abundant) nature of adjacent Shrubland results in larger fires. This high flammability also leads fires ignited at random locations to burn Shrubland preferentially.

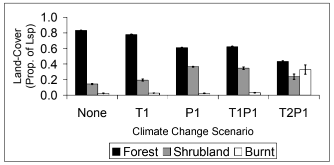


**Figure 3.** Landscape land-cover proportions after 100 model years for climate change scenarios

**Table 1.** Scenarios used to examine the influence potential climate change reflect latest estimates by IPCC.

| Scenario | Annual Temperature Change (°C/yr) | Annual Precipitation Change (mm) |
|---|---|---|
| *None* | 0.000 | 0.0 |
| *T1* | 0.018 | 0.0 |
| *P* | 0.000 | -1.3 |
| *T1P* | 0.018 | -1.3 |
| *T2P* | 0.040 | -1.3 |

The influence of climate on wildfire ignition *frequency* is explicitly represented in the model and the influence of climate on wildfire *spread* is implicitly represented via soil moisture (which is a control on vegetation dynamics). Mean largest fire and mean total burned areas increase in hotter and drier climates, with greatest areas at the upper extreme of current estimates of climate change (Figure 3, scenarios specified in Table 1).

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