Are changes in fire regime threatening cork oak-shrubland mosaics?

T. Curt, J. Pausas

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Thomas Curt [1], Juli Pausas [2]

[1] Cemagref, UR EMAX Ecosystèmes méditerranéens et Risques,
3275 route Cézanne - CS 40061 - 13182 Aix-en-Provence cedex 5, France
E-mail address: thomas.curt@cemagref.fr (T. Curt)
Phone: +33 4 42 66 99 24; fax +33 4 42 66 99 23
[2] CIDE, CSIC Apartado Oficial
Camí de la Marjal s/n 46470 Albal, Valencia, Spain
E-mail: juli.g.pausas@uv.es
Tel: +34 96 122 0540; fax: +34 96 127 0967

Abstract

We simulated the changes of vegetation abundance and richness among mosaics of cork oak woodlands and shrublands using the LASS model (Pausas and Ramos, 2004). During simulations, similar mosaics have been submitted to different fire regimes including fire recurrence, fire size, and fire severity. The results showed that cork oak populations are stable under such fire regimes, suggesting that the shift from cork oak to pure shrublands are likely to be due to a combination of disturbances by fires and by droughts.

Keywords: Shrubland, cork oak (Quercus suber L.), fire regime, LASS Fateland, Mediterranean landscape

1. Introduction

Mosaics of shrublands and trees are a common feature in the Mediterranean fire-prone ecosystems such as in cork oak woodlands associated with so-called maquis (Aronson et al., 2009). In these ecosystems, trees interact strongly with shrubs in the context of disturbance by recurrent wildfires. Actually, shrubby understory is a key factor determining the interval between successive fires and the intensity of fires as shrubs are flammable fuels that can rebuild rapidly after disturbance (Baeza et al., 2006). The composition, cover and flammability of shrubby fuels may lead to a high mortality of mature woody seeders (Moreira et al., 2007), but also limit drastically the resprouting of surviving stems (Pausas, 1997) and the establishment of young individuals from seeds (Curt et al., 2009).

Cork oak (*Quercus suber*) is renowned as especially fire-resistant and fire-resilient (Pausas, 1997). However, the legally-protected cork oak ecosystems experience increasing tree mortality and regeneration failure in the Maures massif (southern France), likely due to recurrent wildfires and severe summer droughts. This is hypothesized to cause major population impacts in a context of climate change, as fire recurrence and fire severity should increase. Land and forest managers need the help of simulation tools to predict landscape-scale impact of different fire regimes, and to set up and to test reliable scenarios in order to limit the impact of fires and drought, and for helping cork oak conservation. To test the impact of the size of the patches of cork oak woodlands and of different fire regimes on the stability of the oak-shrubland mosaic we used a simulation approach using data from the field and literature to implement and to calibrate the model.

2. Methodology

2.1 Study area and species

The study area is the Maures massif located in the southeastern part of France (43°3 N, 6.3°E), which is the largest French area for cork oak (*Quercus suber* L.). This massif is composed of a granitic and metamorphic basement covered with acidic Cambisols. The climate is typically Mediterranean and subhumid xerothermic. The massif is a hotspot for fires, including zones with up to five recurrent fires since 1959 (Curt et al., 2009). The Maures massif has features common to many Mediterranean countries that explain the recurrence of wildfires: the predominance of human-induced fires owing to population and urban growth (Curt and Delcros, 2010), the development of large and intense summer wildfires during dries and windy spells (Pausas, 2004), enhanced by the abundance of flammable vegetation types (Mouillot et al., 2003). The cork oak (*Quercus suber*) populations are protected by the European Union (Habitat directive 92/43/EEC) due to their high conservation value. They are intermingled with shrublands dominated by the resprouter *Erica arborea* and various seeders (*Cistus* spp.).

2.1 Model and simulation plan

In order to simulate the fate of cork oak population, the vegetation dynamics and the spread of fire we used the LASS model (Pausas and Ramos, 2006. LASS has been used to model the dynamics of Mediterranean vegetation submitted to different scenarios of disturbance by fires in Spanish ecosystems (Pausas and Lloret, 2007). For all simulations we selected four main species that correspond to the most representative and dominant plant types in the study area, and to various plant functional types: a resprouter tree (cork oak, *Quercus suber* L.), a resprouter shrub (heath tree, *Erica arborea* L.), seeder shrubs (rockroses, *Cistus* spp.) and a perennial grass (*Brachypodium retusum* (Pers.) P.Beauv.) that resprouts after fire (Caturla et al., 2000).

We built an artificial landscape of 200 x 200 square cells, each one equivalent to 10 x 10 meters. The total area is thus 400 ha, i.e. an area sufficient to take into account the spatial interactions between species, and coherent with the maximal distance of seed dispersal. On the basis of our field survey of vegetation and fuels (Curt et al., 2009), we simulated two mosaics of cork oak woodlands, shrublands dominated by *Erica arborea* and *Cistus* species, and patches of *Brachypodium* grass. The first one corresponded to small patches of cork oak within the shrubland matrix while the second one corresponded to large patches of cork oak within the shrubland matrix. Both mosaics had a similar total area for cork oak and shrublands, but they had different spatial patterning of vegetation.

All simulations had 110 years duration, the last fire being at year 100 to allow vegetation to recover. In all simulations, the disturbance started at year 10. At the beginning of each simulation, the initial conditions of vegetation were set equal for each mosaic. During simulations, each mosaic was submitted to variable fire regimes including different fire recurrences, fire sizes and fire severities:

- the fire recurrence was simulated by setting different fire intervals, i.e. 10, 20, 30, 40 and 50 years
- the maximum fire size was set to three levels: small fires (25% of the landscape), medium fires (50%) and large fires (75%)
- the fire severity for cork oak was modeled by two levels of fire response: low (i.e. low mortality and high resprouting rate for cork oak) *versus* high (high mortality and low resprouting rate for cork oak)

The persistence of all plants was assessed at the end of the simulations using the total abundance of all cohorts, and the abundance of four cohorts representing the life stages (i.e. seeds, immature individuals, mature trees, and mature high trees). In order to analyze the spatial changes of the mosaics we also compared the spatial patterning of cork oak and of the whole mosaic before and after the simulations. For this purpose we assessed the 'total edge length' (McGarigal et al., 2002), this statistics being expected to be a good indicator of species' spatial interactions (Pausas, 2006). We also tested the spatial autocorrelation for species richness at the end of simulations by computing the Moran's *I* index (Cliff and Ord 1981). The comparison of the effect of different fires regimes on the mosaics was done using multiple analyses of variance (MANOVA) with the variables describing species abundance, richness and patterning as dependent variables and the variables of fire regime as independent variables.

3. Result

The multiple analyses of variance (Table 1) indicated that the overall abundance of cork (i.e. the number of cells in which cork oak was present whatever the cohort) was quite stable among all the simulations runs. It varied from 46.5 to 62% of the landscape (mean value 50.7% with a coefficient of variation of 6.6%) while the area at the beginning of all simulations was 50% of the landscape. The total abundance of cork oak after simulation did not relate to the type of mosaic: large and small patches of cork oak woodlands resulted in similar cork oak abundance under a similar fire regime. Likewise, the different cohorts of cork oak (i.e. from seeds to mature high trees) were not significantly affected by the size of the woodland patches at the beginning of simulation. Conversely, all the variables of the fire regime clearly impacted the abundance of cork oak in the landscape (Table 1): its overall abundance decreased with low fire recurrence and small fires. While the presence of cork oak in the landscape was quite stable among simulations, the different cohorts behaved differently. Seeds were more abundant with a mean fire interval of 30 to 40 years. Immature individuals were more abundant at a 20-years fire interval and with large fires. Mature cork oak trees tended to increase with longer fire intervals but not statistically significantly. High mature trees that form the overstory increased at low fire recurrence, and with low severity and small fires. In all the simulations, lower disturbance by fire (i.e. long fire-free intervals, small fires and low-severity fires) favored the development of mature cork oak woodlands dominated by mature trees, with fewer immature individuals.

Table 1. Multiple analysis of variance of cork oak abundance and landscape metrics as a function of the size of the patches of cork oak woodlands and the fire regime. The total abundance of cork oak and the abundance of the different cohorts were computed as the mean value at the end of the simulations (years 100 to 110). ^{NS}= non statistically significant (Tukey's HSD test 95%)

	Size of the woodland patches	Fire Recurrence	Fire Size	Fire Severity
Cork oak				
Total abundance	NS	6.59 P<0.0002	13.97 P<0.0001	NS
Seeds	NS	2.82 P<0.0345	3.88 P=0.0270	6.88 P=0.0115

Immature	NS	5.82 P<0.0006	18.20 P<0.0001	NS
Mature	NS	NS	NS	NS
Mature high	NS	3.15 P<0.0217	3.66 P=0.0327	5.60 P=0.0218
Landscape Heterogeneity				
Total Edge	NS	41.39 P<0.0001	56.86 P<0.0001	NS
Moran's I	NS	10.37 P<0.0001	204.57 P<0.0001	9.55 P<0.0032

4. Discussion

Our simulations indicate a clear ability of cork oak populations to persist in two contrasted mosaics with shrublands, even for populations present only in small woodland patches. This is coherent with the high fire resistance and resilience of this species that resprouts efficiently and can survive even after intense wildfires (Pausas, 1997, 2006). Resprouting species such as cork oak are generally less sensitive to fire regime than seeder species (Delitti et al., 2004). However, the fire regime impacts differently the cohorts of cork oak. Seeds and seedlings (i.e. immature individuals) are favored by medium fire recurrence and large fires, presumably because such fires open large and clear areas in shrublands allowing cork oak seedlings to establish or to persist. Conversely, long fire-free periods and small or low-severity fires allow mature high trees to grow and to persist. This would favor the establishment of high cork oak woodlands and progressively eliminate the shrubby understory made of *Erica* and *Cistus*. In such mosaics, disturbances by fires have two contrasted effects on cork oak populations: one the one hand they limit cork oak populations by killing some individuals and on the other hand they favor it by opening gaps in the shrub cover that offer windows of opportunity in space and time for its regeneration (Pons & Pausas 2006). In total, cork oak populations appear stable under such fire regime and in such shrubland communities. Recently, some authors observed shifts in cork oak (Acácio et al. 2009) due to the combination of disturbances by fires and by droughts.

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