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A REVIEW OF FIRE EFFECTS ON VEGETATION AND SOIL IN THE MEDITERRANEAN BASIN

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The topic of wildfire is a major research focus in the Mediterranean area. It was twenty years ago when was held a seminar titled «El papel del fuego en los ecosistemas mediterráneos» by Manuel costa in the «Universidad Internacional Menéndez Pelayo» de Valencia with the attendance of prestigious scientists. Now wildfire and its management remain a major socio-economic issue and fire research keeps on progressing and clarifying important questions. The aim of this review is to summarise the key outputs from research carried out over the last 20 years on the effects of wildfire in the ecosystem of the Mediterranean basin with a particular focus on fire effects on vegetation, soil and hydrological processes.

Fire has played a significant role in Earth processes for over 400 millions of years. Its occurrence influenced the composition of gases in the atmosphere, climate, weathering rates, erosion and deposition processes and acted as an ecological agent in ecosystem evolution. The composition and distribution of ecosystems are not only shaped by the climate but also by fire recurrence. In ecological terms, fire acts as a huge herbivore consuming biomass and affecting the world's biome distribution.

The Mediterranean environment is one of world's key fire prone ecosystems. Its climate is characterised by hot, dry summers, providing ideal fuel conditions for combustion. Lightning and volcanic eruptions were the most common ignition sources before the humans existed, and fire was perhaps less frequent, but the areas affected larger due to a more homogeneous landscape distribution. Human activity has modified the natural fire recurrence by using it as a tool for clearing the forest for habitation, agri- and silviculture and hunting. The Neolithic agricultural revolution may have initiated the biggest change when fire was used to clear forests for agriculture and pastures. Such controlled use of fire has been in use in some form almost until the 1960's in the Mediterranean basin. The rural population was dispersed, managing a mosaic-like landscape composed of crops, forest and pastures with low risk of extensive uncontrolled fire. Today's Mediterranean landscape is the result of millennia of intensive human use and management.

A major change in landscape management was initiated in the 1960's. Industrialization promoted people to move from rural settings into industrial centres producing a relatively sudden abandonment of farms. The abandonment of land, coupled with the establishment of mainly coniferous tree plantations, has led to increased fuel buildup, allowing larger, more severe and sometimes catastrophic wildfires to occur. At the same time urban areas have expanded into forest and shrubland, providing more ignition sources and exposing more people to the risk. The result was an increase in the number of fires despite an improved firefighting infrastructure. This has been a key factor in fire being viewed as negative agent, although (lower-severity) fire has long been an integral part of the ecosystem, promoting herbaceous vegetation and ecosystem diversity, and contributing to a faster return of nutrients to the soil.

At the regional scale, fire effects are heterogeneous and depend on a wide range of factors: climate, fuel available and type, intensity, duration, size of the burned area, time since the last fire, soil type, moisture content, slope and aspect. In this way, each ecosystem would be adapted to, and result from, a certain natural fire regime. However, even for the same regime, the severity and consequences of individual fire can be different. For the post-fire regeneration process, the initial effects of fire on the vegetation and soil are essential factors.

Most of Mediterranean vegetation has techniques to survive or even thrive after the fire. The apparent barrenness of the landscape after fire is often brief. There are two main mechanisms conditioning the regeneration pattern after the fire: a) the capacity to resprout (resprouter species) and b) the stimulation of the recruitment by fire (seeder or recruiter species).

Resprouting is the most rapid mechanism, allowing to always maintain some part of the plant alive (often belowground) and to recover quickly from fire. There are many examples in Mediterranean basin as *Quercus coccifera* or *Quercus suber*. The recovery of non-resprouting species is slower and depends more on the fire recurrence interval, the plant maturity to produce seeds and the seed resistance to the fire. Some species require a fire-related stimulus for seeds to germinate and others hold the seeds in the canopy until fire occurs (as *Pinus halepensis*).

After fire, a progressive reappearance of the initial species occurs. There often a greater diversity and number of species within 1-5 years after fire, compared to 20 or 30 years later. Through these adaptations, the Mediterranean ecosystem has become highly resilient to the natural fire regime that has existed in the past. The recent changes in fire regime, however, can have important impacts on the sustainability of many of the ecosystems components.

Soil is one of the fundamental components of the ecosystem. Its optimum functioning and post-fire recovery depends on the typically less obvious processes occurring below the litter layer. Fire affects the soil directly because of the direct heat input and indirectly due to the removal of vegetation and litter cover and the addition of ash.

For example, an increase of soil pH and electrical conductivity is commonly observed as a consequence of the input of cations contained in the ash. This increase of nutrients is important for the nourishment of the new vegetation. However, depending on the weather conditions following the fire, these nutrients can be lost by wind, enhanced runoff or leaching. Changes in the soil organic matter and carbon stores are complex. Usually at

low fire intensity, the soil carbon content can be increased, but reduced at high intensities. Organic matter quality can also be affected, for instance becoming more resistant to microbial degradation. Soil aggregate stability, porosity, water holding capacity and water repellency determine the infiltration, erodibility and soil aeration after the fire can be altered and are of particular importance while the vegetation cover and the litter layer are still absent. Aggregate stability can be reduced or enhanced after fire, depending for example, on the temperatures reached in the soil. Usually, if the organic matter content is reduced, this also applies to aggregate stability, porosity and water holding capacity. Water repellency can be increased in by soil heating, but is commonly destroyed above 270–300ºC. However, other factors such as combustion conditions, soil texture, pH, clay content or vegetation type also determine its presence and severity.

Changes sin soil hydrology are produced by the physical soil modifications outlined above, the reduction of the vegetation and litter cover, and a possible soil sealing by ash. Immediately after the fire, when the ash typically covers the landscape, overland flow and soil erosion rates are often low. Once the ash cover is removed by wind or water erosion, or becomes crusted, they increase until the re-growth of vegetation covers the ground again. The post-fire erosion rates in the Mediterranean are highly variable, but typically less than 1 Mg ha^{-1} $year^{1}$, and hence thought to be largely in the range of longer-term sustainability. Only for extreme rainfall events are runoff and erosion rates excessive. The reduction of the erosion rates to initial (pre-fire) levels varies typically from 2 to 8 years depending on the fire characteristics, weather patterns, fire effects on the soil properties, time since previous fires and the rate of vegetation recovery.

This brief review of 20 years of research confirms that Mediterranean environments are fire prone, but also adapted to a past fire regime. This fact is often not considered in their management. Up to now, its management consisted mostly of the attempt to exclude fire and of establishing extensive pine plantations in depopulated areas. These factors have contributed to a fire regime with larger and more intense fires, with more serious environmental and socio-economic consequences. Therefore a landscape management involving selective manual clearing and/or prescribed fires, as used for millennia in the Mediterranean, would be desirable. In that context it should also be recognised that fire effects are heterogeneous and the areas affected should not necessarily be treated in the same way.

As a conclusion, the Mediterranean ecosystem is adapted to a fire and the management during millennia of human occupation. However, the fire regime has recently changed with the new social trends and fire suppression approaches. The challenge nowadays is to integrate the scientific knowledge about the role of fire in the Mediterranean ecosystem, allowing optimum management of fire, and making it compatible with our social demands, hazard reduction needs and ecosystem sustainability.