Plant Sociology 58(2) 2021, 41–48 | DOI 10.3897/pls2021582/04

PENSOFT

Società Italiana di Scienza della Vegetazione (SISV)

'Back to the Future'—Oak wood-pasture for wildfire prevention in the Mediterranean

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Subject editor: Daniele Viciani ♦ **Received** 26 November 2021 ♦ **Accepted** 18 December 2021 ♦ **Published** 31 December 2021

Abstract

In the summer of 2021, enormous wildfires in the Mediterranean eliminated huge areas of mainly coniferous forest, destroyed adjacent settlements and claimed the lives of many people. The fires indicate effects of climate change and expose consequences of rural demographic changes, deficits in regional and touristic development planning and shortcomings in forest policy. This forum article highlights the dimensions of the problem, calls for a paradigm shift and shows solutions. Land abandonment, woody plant encroachment and non-reflective afforestation are leading to increasing amounts of combustible biomass. To prevent disastrous fires in future, fundamental changes in tree species composition, forest structure and management are essential. Plantations of reseeding pines are to be substituted by spacious or periodically open woodlands of long-lived trees with resprouting capacity such as Mediterranean oaks. Biomass-reducing practices including wood-pasture have to be revived in rural and peri-urban areas. Exemplary fire-resistant multifunctional oak woodlands occur throughout the Mediterranean. Urgent and medium-term measures in the burnt areas include promoting natural ecosystem regeneration, developing regionalized seed banks and nurseries to support native genetic resources, fostering vegetation mosaics of groves and multiple-use open and coppice woodland maintained by traditional practices, and in general forest management aiming at fuel biomass reduction and a policy counteracting land abandonment.

Keywords

biomass reduction, fire prevention, forest fire, forest management, Mediterranean Basin, oak, pine forest, wood pasture

Forest fire risk and its causes

In recent years Mediterranean-type climate regions (Walter 1979; Schroeder 1998; Rivas-Martinez et al. 2011) have frequently and in ever greater degree been hit by disastrous wildfires (Le Houerou 1993; Pausas 2004; Syphard et al. 2009; Sarris et al. 2014). In this year's summer of 2021, many countries of the Mediterranean Basin were severely affected, especially southern and western Turkey, southern and central Greece, southern Italy, Algeria, Spain, and southern France (EFFIS 2021). The fires came with tremendous heat waves, they destroyed forests, fields, equipment, houses and settlements, and they took many human lives. In central Greece alone the burnt area comprised about 130,000 ha. In the Turkish region of Manavgat, a single fire, unprecedented in the history of

the country, devastated 60,000 ha. In Italy, this year more than 140,000 ha have been in flames, equalling the catastrophic record of 2017. In that year 2017, in June, a wildfire in pine forests in Central Portugal killed 66 people and burnt nearly 500 houses. People everywhere realized, many perhaps for the first time, that in Mediterranean forest landscapes, pre-shaped by land abandonment and land-use change, climate change constitutes a real and immediate threat, not merely a theoretical one.

Wildfires are often caused by arson, even more commonly are they initiated through carelessness. They happen mostly in the periods of drought, which are a characteristic of the Mediterranean summer. As a consequence of climate change and water overuse, the Mediterranean experiences increasing drought, springs dry up and seasonal streams carry less and less water and run dry earlier in the season (Körner et al. 2005). Climate change scenarios indicate rising temperatures and decreasing amounts of precipitation and as a result, longer summer aridity, soil water shortages and increasing fire risk (Mouillot et al. 2002; Moriondo et al. 2006; Lozano et al. 2017; IPCC 2021). Moreover, it has become apparent that through climate change fires shift towards higher altitudes, thereby increasing the hazard in forest ecosystems not well adapted to fires (Koutsias et al. 2012).

Land abandonment, a process that is taking place in much of the Mediterranean Basin chiefly after the mid-20th century, contributes to the increased fire hazard (Le Houerou 1993; Plieninger et al. 2016). As a result of decreasing populations inhabiting rural areas accompanied by a decrease of pasture and arable lands, land abandonment is often associated with an increase of forest and scrub cover and overall with an accumulation of biomass that fuels potential wildfires (Mantero et al. 2020). Formerly, farmland and open grazing land around the villages comprised a fire-resisting zone and prevented the flames from spreading to the houses. In mountainous regions the previously higher number of inhabitants in villages, the closer relationship of the rural population with nature (many of them were farmers and animal breeders) formed a body of volunteers capable of fighting a fire to protect their properties.

Fire adaptation and flammability of Mediterranean forests

In general, burns in forested and shrubby landscapes are not uncommon in regions of Mediterranean-type climate and there is a long history of evolutionary adaptation of plants and ecosystems to fire (Naveh 1975; Margaris 1981; Bond and van Wilgen 1996; Ne'eman et al. 2012; Rundel et al. 2018). Many plant species have adapted to more or less tolerate fires by morphological and life history traits (Ne'eman et al. 2012). Ecosystems as a whole are able to cope with recurrent fires by their successional dynamics, resilience and regeneration capacities (Trabaud 1994). Even though adaptations to fire are more common or diverse in some other regions of Mediterranean-type climate, such as Southwest Australia and South Africa (Bowen and Pate 1993; Pignatti et al. 2002; Brown et al. 2003), than in the Mediterranean Basin, there are numerous examples in the Mediterranean flora interpreted as adaptations generally to disturbances or more specifically to fire (Pignatti et al. 2002; Guarino et al. 2006). Well-known examples of such pyrophytes are the cork oak (*Quercus suber*) with its thick bark (Pausas 1997), the fire-induced dispersion of seeds from bursting pine cones (Thanos and Dousi 2000), some pyrophile *Cistaceae* with seeds germinating if triggered by the heat and smoke of fire (Thanos and Georghiou 1988; Aronne and Mazzoleni 1989), many woody plants resprouting from basal or below-ground buds (Mazzoleni 1994), and in a passive way the short life-cycle of many herbaceous plants. The high proportion of annual plants, alive only in late-winter and spring, in the native Mediterranean flora is as such instructive for the degree of adaptation of the vegetation to various kinds of disturbance including fire (Bergmeier 1998; Pignatti et al. 2002; Guarino 2006).

While pine forests in Mediterranean landscapes can cope with moderate fires or even benefit from them through the destruction of potentially competitive plants, they are severely hit by intense and frequently recurrent fires destroying not only the undergrowth but the pine stems and crowns altogether (Tapias et al. 2004). Mediterranean pines are fire-adapted reseeders which have evolved adaptations to fire in that the post-fire habitat is optimized for the germination of their seeds. Post-fire regeneration of natural stands of pine forests depends on various factors (Kavgacı et al. 2010). Site physiography and soil properties play an important role in regeneration success but stand age and the persistence of scattered unburned trees, or groups of trees, that can act as source of seeds are also relevant (Kavgacı et al. 2016). Pine stands of high naturalness tend to regenerate easily after wildfires and generally there is no need for external input for their restoration.

Wildfires become catastrophic if the forests adjoin to houses, villages and suburbs, the more so in areas of urban sprawl in what had formerly been rural landscapes. Many coniferous forests in such areas are plantations or established as secondary growth originating from plantations (Tapias et al. 2004; Maiullari et al. 2005). Fast-growing pines, cypresses and eucalypts predominate. They are particularly prone to fire if they form thick stands, generate dense undergrowth with high amounts of dead biomass and thick layers of litter. It was chiefly for silvicultural or ornamental reasons and to increase the proportion of forested area in otherwise non-forested lowland environments that led to many of the coniferous plantations in the Mediterranean Basin (including Tyrrhenian coastland *Pinus pinea* stands which, in spite of their partly anthropogenic status, are often considered to represent autochthonous 2270* habitats of the EU Habitats Directive 92/43/EU throughout.) A landscaping design commonly

used on slopes arranged the pine plants at a regular distance of 60-80 cm between each other on narrow steps of 2-5 m distance along the contour lines. On average, the initial tree density of these plantations was between 2,500 and 3,000 plants per hectare (Ciancio 2014), in Turkey 1600 seedlings at 3 x 2 m distance. After years of dead phytomass and litter accumulation they are particularly flammable and fires spread rapidly if the combustible pine bark, needles, twigs and cones cause crown fires when blown up and hurled away under the influence of strong wind and heat. A comparable case is that of the *Eucalyptus globulus* or *E. camaldulensis* plantations which cover immense areas especially in the western Iberian Peninsula as well as south and central Italy (Fernandes et al. 2019). As to their richness in flammable aromatic compounds, bark pieces flying off many metres when burned, and the accumulation of dry fine litter, we consider eucalypt plantations, in all, ecologically analogous in terms of fire to conifer stands. Around settlements, such forests are highly dangerous firetraps.

High stand densities, thick understory namely of ericoids, genistoids and cistuses, and litter accumulation are the result of management absence and policy failure. Formerly, especially in more humid areas of the western Mediterranean, heath and gorse in pine forests were regularly removed, for use as cattle bed and further incorporated in the soil as organic fertilizer. Socio-economic changes in rural territories and intensification of agriculture put an end to such traditional practices. Moreover, forms of prescribed fire existed, mostly promoted by shepherds to feed the animals with resprouting shoots. Rural exodus mainly in the 1960s to 80s facilitated land use change from agriculture and animal grazing to large stretches of monotonous forests. In recent years, land use changes were due to macroeconomic reasons, absent land ownership and misplaced state policies that lead to chronical absence of effective forest management (e.g., De Rossi 2018). Adding to the decline of traditional biomass-reducing practices, an insufficient wildfire prevention policy allowed the accumulation of forest biomass and litter on an unprecedented scale. Often, the absence of territorial policies promoting discontinuous and mosaic-diverse rural landscapes is making Mediterranean lowland forest areas prone to an accident waiting to happen.

How to avoid catastrophic fires

Land-use diversification, as general principle, is a key element to effectively avoid catastrophic fires and severe climate-related disturbances (Lloret et al. 2002). As the above statements on the current situation of the lowland Mediterranean forests suggest, policymakers and forestry have an obligation to society to encourage the maintenance or restoration of land-use mosaics and multiple-use forests—as opposed to extensive tree monocultures. As J.R. Goldammer, head of Global Fire Monitoring Center, put it, "to stop the increasing threat of wildfires [in southern Europe] we'll have to focus our efforts on stopping rural flight" and to make it a priority "to increase a woodland's resilience against drought, strong winds and heavy rainfall" (Deutsche Welle 2021). Economic incentives to assure rural livelihoods and to support local-scale production (including but not restricted to wood, field crops, meat, cheese, game and honey) are needed to counteract land abandonment and migration from the land.

To reduce the forest fire risk and to avoid fire events to become catastrophic, the questions arise what to do with the vast burnt areas and how to improve the fire safety of the highly flammable extant Mediterranean lowland forests. To answer the questions different aspects must be taken into account—tree species composition, forest structure and forest management.

Tree species composition

As part of the European Green Deal, the EU Biodiversity Strategy for 2030 commits to planting at least 3 billion additional trees in the EU by 2030 (https://www.eea.europa.eu/highlights/mapmytree-new-data-tool-to). The aims are to "increase the EU forest area and resilience, enhance biodiversity, and help with climate change mitigation and adaptation". To do this as promised "in full respect of ecological principles" requires more than just creating new plantations. We consider promoting the natural regeneration of the tree species that formed natural pre-fire stands of paramount importance. In cases where the forest regeneration requires external input and reforestation, then other tree species may be selected, provided that they are native to the territory and ecologically compatible to meet the specific site characteristics. That excludes non-native eucalypt plantations in sensitive areas. Although many of the lowland coniferous plantations and reforestations consist of tree species native to the Mediterranean such as *Pinus halepensis*, *P. brutia*, *P. pinaster*, *P. pinea* or the fastigiate form of *Cupressus sempervirens*, they are often extraneous to the region or habitat. Moreover, as a result of forest management the stands are often monotonous, even-aged and evenly spread, and do not represent natural stages of vegetation.

Much more suitable than the reseeding pines are native trees which have other fire adaptations than reseeders. In the lowlands of the Mediterranean Basin, these are in particular oak species (Bohn and Neuhäusl 2002; Merlo and Croitoru 2005). Oaks are less flammable, characteristic of climax vegetation, and their life strategy is that of a long-lived competitor with recalcitrant seeds. If they are nevertheless damaged by fire to such an extent that they lose most of their above-ground biomass, the Mediterranean oaks are able, albeit to various degree, to resprout from buds at the stem base. The most important oak species of the lower (thermo- and meso-) Mediterranean zones are the evergreen representatives of the subgenus *Cerris*, namely the kermes oak, *Quercus coccifera*, the holm and ballota oaks, *Q. ilex* and *Q. rotundifolia*, and the cork oak,

Q. suber, as well as the deciduous (or semi-evergreen) valonia oak, *Q. ithaburensis* subsp. *macrolepis*, and Aleppo oak, *Q. infectoria* s.l. Other species occurring in the lower Mediterranean zones include the downy oak complex, *Q. pubescens* s.l., the Turkey oak *Q. cerris* and the Hungarian oak *Q. frainetto*, which are submediterranean in general distribution. *Q. coccifera* s.l. and *Q. ilex* are widespread in the Mediterranean, while *Q. suber* and *Q. rotundifolia* occur in the western Mediterranean Basin. *Q. infectoria* s.l. and *Q. ithaburensis* subsp. *macrolepis* are East Mediterranean in distribution, the former between the East Aegean and Iran and the latter chiefly between Albania and South Turkey (with few isolated stations in SE-Italy). The Mediterranean oaks are characterized by more or less thick bark–most literally in the cork oak–and considerable capacity to regenerate from buds at the stem bases. As deep-rooted plants, they are well adapted to dry habitats, at least on soils that promote the regeneration of fine roots (de Sampaio e Paiva Camilo-Alves et al. 2013). Evergreen and deciduous oaks are main components of the Mediterranean forest landscape and the locals regard veteran trees often as symbols of the identity and recognizability of places (Antrop 2005). Since ancient times, oaks are highly esteemed among peoples in the Mediterranean as being useful in many ways (Grove and Rackham 2001), the foliage and acorns as fodder for animals and, as to *Q. rotundifolia* and *Q. ithaburensis* subsp. *macrolepis* acorns, also as human food, the wood for timber and charcoal, and the bark and cupules with their tannin components for traditional medicinal uses and for the tanning of leather. They are also host plants for truffles which live in ectomycorrhizal association with the trees' roots (EFIMED 2009; Pasta et al. 2016). And why not locally attempt reviving the ancient tradition of natural crimson dye production based on *Kermes vermilio*, a scale insect of Mediterranean kermes oak forests that feeds on the sap of the oaks.

Oaks are no universal remedy, though. Decline of cork oak trees has occurred in the Iberian Peninsula throughout the 20th century and of both cork and holm oak especially in the 1980s (Brasier et al. 1993). Vitality and tree resilience to drought and the invasive pathogenic fungus *Phytophthora cinnamomi* which also affects seedling establishment (Domínguez-Begines et al. 2020) was reduced especially on shallow soils and under conditions of soil compaction that limit root expansion and water retention (de Sampaio e Paiva Camilo-Alves et al. 2013).

Forest structure

To further reduce the fire risk, open agroforestry stands are advisable (Le Houerou 1993; Moreno et al. 2018; Damianidis et al. 2021). Suitable are woodlands with open tree canopy interspersed with denser groves and open land. Such stand structures, in Spain known as dehesa, have been used for mixed animal grazing and have a long tradition in Mediterranean cultural landscapes involving sylvopastoral (or agrosylvopastoral) systems (Caballero et al. 2009; Bergmeier et al. 2010; Hartel and Plieninger 2014; Guarino et al. 2020). In fact, to keep the woodlands open, systems of extensive grazing are essential to control the encroachment by shrubs and young trees (Rouet-Leduc et al. 2021). Most suitable for this purpose of cultural landscape management have been goats and, in grasslands with scattered trees and woodlands with grass- and herb-rich undergrowth, sheep. Cattle are suitable in more productive sites. Woodland management with goats, sheep, cattle or pigs, provided the grazing pressure is not too heavy, has a number of advantages–apart from keeping forests open for fire prevention:

- Forest inclusion in production processes increases acceptance by the local population.
- Dairy products and meat for local consumption and for products typical of the region increases the local economic basis.
- Farming involving extensive wood-pasture creates and maintains local jobs without being overly capital-intensive.
- Wood pasture maintains cultural landscapes of scenic value.
- Habitats created and maintained by wood pasture are biodiverse, rich in ecotones and substantially contribute to the local species richness.

As a current example in Portugal, a wealth of ecosystem services from cork-oak groves include 180,000 tons of cork per year (70% of world production), standing for 2% of national export, cattle grazing in understory swards, game, wildlife and nature conservation. Furthermore, recent studies on oak wood pastures show considerable ecological improvement namely in higher organic matter and carbon stock in the soil, less erosion and, most relevant, a much higher resilience to fire (EC–LIFE Public Database 2021).

Experiences in extant oak woodlands and nurseries have shown that the establishment success of young oak trees by germination from acorns is mostly superior to that by plantation of seedlings. This is explained by the lower costs and especially by the fact that juvenile oaks derived from in-site germination commonly have a root system which is better adapted to interact with the local microbiome (Maghnia et al. 2019).

In other multiple-use oak and mixed deciduous woodlands of the Mediterranean phytomass is periodically removed by coppicing. Such rotational cutting of tree stems at intervals of several years depending on the tree species and the use of the products has been an integral component of silvicultural management throughout the Mediterranean and beyond. Although a decline of tree health has been observed in Mediterranean beech copses (Cullotta et al. 2017), coppiced woods are beneficial in multiple ways (e.g., Bergmeier et al. 2010; Fartmann et al. 2013): (1) to produce small wood or, mostly historically, other products such as charcoal or oak bark; (2) to allow wood-pasture management after the shoots have grown out of reach of browsing animals; (3) to promote biodiversity by patterns of different-aged coppice woodlands; and

last but not least (4) to reduce fire hazards by regularly removing biomass fuel.

Forest management and policy

Promoting open (or periodically open) oak woodland and thus supporting wood pasture is tantamount to a paradigm shift in Mediterranean landscape management. Today, in much of the European Mediterranean, with the change in socio-economic conditions in rural areas, wood pasture has become a scarce practice: almost ceased in the lowlands and in decline in many mountainous areas. However, open multipurpose woodlands and wood pasture had a long tradition in the Mediterranean since ancient times and until well into the previous century, and regionally remained in practice to the present or were revived (Plieninger et al. 2015). They have been of high importance for the sustenance of the population which depended on subsistence economy. Things changed in the course of 20th century demographic processes involving urbanisation, domestic migration and emigration with economic changes including industrialization and agricultural intensification (Hartel and Plieninger 2014). With this, the traditional knowledge of the shepherds is being lost (Varela et al. 2018). In relation to these transformations former pasture lands were afforested with conifers, the practice of wood pasture declined and ceased, and dense forests developed and spread, especially so in the vicinity of towns and touristic agglomerations. The effects of Mediterranean wood pasture have been denounced as deforestation and overexploitation, while disregarding its contribution to the maintenance of a structurally diverse cultural landscape with all its ecosystem services including fire prevention.

While promoting oak wood pasture for fire prevention and landscape management is more topical than ever, especially in the more densely populated Mediterranean lowlands and submountainous areas, two major points should be stressed. First, in extant native forests areas of wood-pasture should be managed alongside natural non-grazed forest areas, for instance in exclosures, for the maintenance of grazing-sensitive plants and animals typical of the woodland ecosystems. Second, Mediterranean natural pine forests, not originating from plantations in sites unsuitable, are to be maintained targeting ecosystem conservation. In some areas such as the island of Euboea (Evia) and the Muğla province in Turkey, native pine forests form an important basis for the local bee-keepers and for resin tapping. In Turkey and the East Mediterranean lowland mature natural pine forests are often associated with oaks such as kermes and Aleppo oaks. To improve the adaptability of such pine forests to fire, it is appropriate to create a more open structure and to increase the proportion of oaks in the pine forests.

Natural pine forests can be subject of a management regime of iterate fire disturbance, where the fire frequency is compatible with the constitution of an adequate pine crown seed bank (Mazzoleni et al. 2001). The shrub layer under the pine canopy should be controlled by means of appropriate forms of disturbance such as grazing (with goats, sheep and cattle depending on habitat), but also by prescribed fires ignited in autumn-winter, when the air temperature is low and the humidity high enough to minimize the fire risk. Mosaics of different native forest patches including natural pine-dominated stands on ridges and steep slopes are in fact beneficial both to the local biodiversity and to reduce the fire speed rate and flame propagation (Leone et al. 2000).

In view of the disastrous forest wildfires in the Mediterranean in this and in previous years and bearing in mind the effects of global change with the disturbing prospect of more such catastrophes in the years ahead require nothing less than a paradigm shift and consequences in woodland management both in peri-urban and rural environments. Fortunately, in almost all Mediterranean countries there are extant open wooded landscapes shaped by oak trees that may serve as examples for the kinds of woodlands and management needed, such as the Iberian dehesas and montados and, in different environments and a smaller scale, wooded garrigues with *Quercus crenata* in western central Italy, the valonia oak woodlands of Xiromero in western Greece, in some Aegean islands and in the hinterland of the Mediterranean coast of Turkey. They are not only important oak genetic resources for the provision of seeds but also model areas for the transformation of the dense fire-prone coniferous plantations and for the management of the already devastated forest sites.

Urgent measures and guidelines

Such paradigmatic change involves moving 'back to the future' towards grazed wooded oak parklands and multiple-use mixed deciduous woodlands as relevant pieces of the novel Mediterranean landscape mosaic. The replacement of large stretches of dense forests of site-maladjusted conifers – or eucalypts – under intensive silviculture is mandatory to break the cycle of biomass accumulation – wildfire – biomass accumulation and so on. The preference of wooded structures, including both grazed or coppiced oak groves and well-integrated small oak mixed woodlands over monotonous pine and eucalypt plantations, would contribute greatly to ecological, social and ecological rural territory amelioration and to high resilience to wildfires (Varela et al. 2014, 2018). To summarize our appeal the following response and precautionary measures and aims are suggested:

- As a prerequisite of measures in response to the devastating fires an assessment and accurate delineation of the burnt areas and fire scars and the affected plant communities is essential to determine the rates of ecosystem recovery and regeneration success. Natural regeneration is to be promoted and when necessary, seeding or planting should be performed with material collected locally from indigenous populations.

- Woodlands of native tree species for multipurpose use as substitute for plantations with pines or exotic species. Various native oak species are exemplary trees in the Mediterranean lowlands. Species should be selected from the local species pool, considering also the vegetation history of the area which may involve species now absent. Special care requires the selection of genetic resources so as to form genetically diverse well-adapted tree populations of local origin.
- Promoting a vegetation mosaic of groves, structurally diverse cropland, coppice woods and half-open land developed and maintained as wood pasture. This can be achieved by means of silvicultural treatments taking account of the diversity of local ecological factors (i.e., soil, relief) and aiming to differentiated genetic, structural, compositional and functional diversity at the plant population, community and landscape level. Such vegetation mosaics prevent the spread of fires and at the same time enhance biodiversity.
- Development of regionalized seed banks and nurseries for the tree species of Mediterranean woodlands to conserve the species' genetic variability and to make them available for local-scale restoration purposes whenever needed.
- Elaboration of a woodland management plan that includes fire prevention (Varela et al. 2018). Forest management aiming at the reduction of fuel biomass and the promotion of traditional practices is to be encouraged. Motivations against land abandonment including a reasonable agriculture and agro-tourist policy as well as the enhancement of multiple local-scale forest use are of the utmost importance.

Author contributions

E.B. wrote the first paper draft and discussed the topic with all authors. All authors contributed to and commented on the final paper version.

Bibliography

Antrop M (2005) Why landscapes of the past are important for the future. Landscape and Urban Planning 70: 21–34. https://doi.org/10.1016/j.landurbplan.2003.10.002

Aronne G, Mazzoleni S (1989) The effects of heat exposures on seeds of *Cistus incanus* L. and *Cistus monspeliensis* L. Giornale Botanico Italiano 123: 283–289.

Bergmeier E (1998) Combined effects of fire and grazing on phrygana vegetation - a case study in SW Crete (Greece). Ecologia Mediterranea 23(3/4, "1997"): 1–10. https://doi.org/10.3406/ecmed.1997.1832

Bergmeier E, Petermann J, Schröder E (2010) Geobotanical survey of wood-pasture habitats in Europe: diversity, threats and conservation. Biodiversity and Conservation 19: 2995–3014. https://doi.org/10.1007/s10531-010-9872-3

Bohn U, Neuhäusl R (and contributors) (2002) Karte der natürlichen Vegetation Europas / Map of the natural vegetation of Europe. Maßstab / Scale 1 : 2 500 000. Part 1. Bundesamt für Naturschutz, Bonn-Bad Godesberg.

Bond WJ, van Wilgen BW (1996) Fire and plants. Chapman & Hall, London etc. https://doi.org/10.1007/978-94-009-1499-5

Bowen BJ, Pate JS (1993) The significance of root starch in post-fire shoot recovery of the resprouter *Stirlingia latifoli*a R.Br. (*Proteaceae*). Annals of Botany 72: 7–16. https://doi.org/10.1006/anbo.1993.1075

Brasier CM, Robredo F, Ferraz JFP (1993) Evidence for *Phytophthora cinnamomi* involvement in Iberian oak decline. Plant Pathology 42: 140–145. https://doi.org/10.1111/j.1365-3059.1993.tb01482.x

Brown NAC, van Staden J, Johnson TA, Daws MI (2003) A summary of patterns in the seed germination response to smoke in plants from the Cape Floral Region. In Smith RD, Dickie JB, Linington SL, Pritchard HW, Probert RJ (Eds) Seed conservation: Turning science into practice. Royal Botanic Gardens, Kew, UK, 563–574.

Caballero R, Fernández-González F, Pérez Badia R, Molle G, Roggero PP, Bagella S, D'Ottavio P, Papanastasis V, Fotiadis G, Sidiropoulou A, Ispikoudis I (2009) Grazing systems and biodiversity in Mediterranean areas: Spain, Italy and Greece. Pastos 39(1): 1–154.

Ciancio O (2014) Storia del pensiero forestale. Rubbettino, Soveria Mannelli.

Cullotta S, La Placa G, Maetzke F (2017) Effects of traditional coppice practices and microsite conditions on tree health in a European beech forest at its southernmost range. iForest-Biogeosciences and Forestry 9: 673–681. https://doi.org/10.3832/ifor1603-008

Damianidis C, Santiago-Freijanes JJ, den Herder M, Burgess P, Mosquera-Losada MR, Graves A, Papadopoulos A, Pisanelli A, Camilli F, Rois-Díaz M, Kay S, Palma JHN, Pantera A (2021) Agroforestry as a sustainable land use option to reduce wildfires risk in European Mediterranean areas. Agroforestry Systems 95: 919–929. https://doi.org/10.1007/s10457-020-00482-w

De Rossi A (Ed) (2018) Riabitare l'Italia-Le aree interne tra abbandoni e riconquiste. Donzelli, Roma.

De Sampaio e Paiva Camilo-Alves C, da Clara MIE, de Almeida Ribeiro NMC (2013) Decline of Mediterranean oak trees and its association with *Phytophthora cinnamomi*: a review. European Journal of Forest Research 132: 411–432. https://doi.org/10.1007/s10342-013-0688-z

Deutsche Welle (2021) Europe's wildfires also driven by rural flight. https://www.pressreader.com/germany/deutsche-welle-english-edition/20210820/282149294391615 [Accessed 15 December 2021]

Domínguez-Begines J, Ávila JM, García LV, Gómez-Aparici L (2020) Soil-borne pathogens as determinants of regeneration patterns at community level in Mediterranean forests. New Phytologist 227: 588–600. https://doi.org/10.1111/nph.16467

EC-LIFE Public database (2021) MARONESA - Market Awareness Raising for Opportunities in Needed Extensification and Soil-friendly Agriculture. Available at https://webgate.ec.europa.eu/life/publicWebsite/index.cfm?fuseaction=search.dspPage&n_proj_id=7555 [Accessed 15 September 2021]

EFFIS (2021) European Forest Fire Information System. Available at https://effis.jrc.ec.europa.eu/ [Accessed 25 November 2021]

EFIMED (2009) A Mediterranean Forest Research Agenda - MFRA 2010–2020. https://efi.int/sites/default/files/images/publications/Mediterranean%20Forest%20Research%20Agenda%202010-2020_.pdf [Accessed 25 November 2021]

Fartmann T, Müller C, Poniatowski D (2013) Effects of coppicing on butterfly communities of woodlands. Biological Conservation 159: 396–404. https://doi.org/10.1016/j.biocon.2012.11.024

Fernandes P, Guiomar N, Rossa CG (2019) Analysing eucalypt expansion in Portugal as a fire-regime modifier. Science of The Total Invironment 666: 79–88. https://doi.org/10.1016/j.scitotenv.2019.02.237

Grove AT, Rackham O (2001) The nature of Mediterranean Europe. Yale University Press, New Haven & London.

Guarino R (2006) On the origin and evolution of the Mediterranean dry grasslands. Berichte der Reinhold Tüxen Gesellschaft 18: 195–206.

Guarino R, Giusso Del Galdo G, Pignatti S (2006) The Mediterranean dwarf shrubs: origin and adaptive radiation. Annali di Botanica 5: 93–101.

Guarino R, Vrahnakis M, Rodriguez Rojo MP, Giuga L, Pasta S (2020) Grasslands and shrublands of the Mediterranean region. In: Della Sala DA, Goldstein MI (Eds) The Encyclopedia of the World's Biomes, 1st edition, vol. 3. Academic Press-Elsevier, Oxford, 638–655. https://doi.org/10.1016/B978-0-12-409548-9.12119-0

Hartel T, Plieninger T (Eds) (2014) European wood-pastures in transition. Routledge, Abingdon & New York. https://doi.org/10.4324/9780203797082

IPCC (2021) Sixth Assessment Report. AR6 Climate Change 2021: The physical science basis. https://www.ipcc.ch/report/ar6/wg1/#Regional [Accessed 25 November 2021]

Kavgacı A, Čarni A, Başaran S, Başaran MA, Košir P, Marinšek A, Šilc U (2010) Long-term post-fire succession of *Pinus brutia* forest in the east Mediterranean. International Journal of Wildland Fire 19: 599–605. https://doi.org/10.1071/WF08044

Kavgacı A, Örtel E, Torres I, Safford H (2016) Early postfire vegetation recovery of *Pinus brutia* forests: effects of fire severity, prefire stand age, and aspect. Turkish Journal of Agriculture and Forestry 40: 723–736. https://doi.org/10.3906/tar-1601-21

Körner C, Sarris D, Christodoulakis D (2005) Long-term increase in climatic dryness in the East-Mediterranean as evidenced for the island of Samos. Regional Environmental Change 5: 27–36. https://doi.org.10.1007/s10113-004-0091-x

Koutsias N, Arianoutsou M, Kallimanis AS, Mallinis G, Halley JM, Dimopoulos P (2012) Where did the fires burn in Peloponnisos, Greece, the summer of 2007? Evidence for a synergy of fuel and weather. Agricultural and Forest Meteorology 156: 41–53. https://doi.org/10.1016/j.agrformet.2011.12.006

Le Houérou HN (1993) Land degradation in Mediterranean Europe: can agroforestry be a part of the solution? A prospective review. Agroforestry Systems 21: 43–61. https://doi.org/10.1007/BF00704925

Leone V, Saracino A, Trabaud L, Vélez R (2000) Fire prevention and management policies in West Mediterranean pine forests. In: Ne'eman G, Trabaud L (Eds) Ecology, biogeography and management of *Pinus halepensis* and *P. brutia* forest ecosystems in the Mediterranean Basin: 335–353. Backhuys Publishers, Leiden.

Lloret F, Calvo E, Pons X, Díaz-Delgado R (2002) Wildfires and landscape patterns in the Eastern Iberian Peninsula. Landscape Ecology 17: 745–759. https://doi.org/10.1023/A:1022966930861

Lozano OM, Salis M, Ager AA, Arca B, Alcasena FJ, Monteiro AT, Finney MA, Del Guidice L, Scoccimarro E, Spano D (2017) Assessing climate change impacts on wild fire exposure in Mediterranean areas. Risk Analysis 37: 1898–1916. https://doi.org/10.1111/risa.12739

Maghnia FZ, Abbas Y, Mahé F, Prin Y, El Ghachtouli N, Duponnois R, Sanguin H (2019) The rhizosphere microbiome: A key component of sustainable cork oak forests in trouble. Forest Ecology and Management 434: 29–39. https://doi.org.10.1016/j.foreco.2018.12.002

Maiullari G, Leone V, Lovreglio R (2005) La rinnovazione post-incendio in rimboschimenti di Pinus halepensis Mill. Italia Forestale e Montana 6: 687–702.

Mantero G, Morresi D, Marzano R, Motta R, Mladenoff DJ, Garbarino M (2020) The influence of land abandonment on forest disturbance regimes: a global review. Landscape Ecology 35: 2723–2744. https://doi.org/10.1007/s10980-020-01147-w

Margaris NS (1981) Adaptive strategies in plants dominating Mediterranean type ecosystems. In: Di Castri F, Goodall DW, Specht RL (Eds) Mediterranean type shrublands. Ecosystems of the World 11: 309–315. Elsevier, Amsterdam.

Mazzoleni S (1994) Vegetation regrowth after fire and cutting of Mediterranean macchia species. In: Trabaud L, Prodon R (Eds) Fire in Mediterranean ecosystems, Edition 5.ECSC-EEC-EAEC, Brussels.

Mazzoleni S, Bellelli M, Esposito A, Ricotta C, Di Pasquale G, Blasi C (2001) Incendi e paesaggio vegetale: il caso del Cilento, Campania. Italia Forestale e Montana 6: 417–429.

Merlo M, Croitoru L (Eds) (2005) Valuing Mediterranean forests: Towards total economic value. CABI Publishing, Wallingford & Cambridge. https://doi.org/10.1079/9780851999975.0000

Moreno G, Aviron S, Berg S, Crous-Duran J, Franca A, García de Jalón S, Hartel T, Mirck J, Pantera A, Palma JHN, Paulo JA, Re GA, Sanna F, Thenail C, Varga A, Viaud V, Burgess PJ (2018) Agroforestry systems of high nature and cultural value in Europe: provision of commercial goods and other ecosystem services. Agroforestry Systems 92: 877–891. https://doi.org/10.1007/s10457-017-0126-1

Moriondo M, Good P, Durao R, Bindi M, Giannokopoulos C, Core-Real J (2006) Potential impact of climate change on fire risk in the Mediterranean area. Climate Research 31: 85–95. https://doi:10.3354/cr031085

Mouillot F, Rambal S, Joffre R (2002) Simulating climate change impacts on fire frequency and vegetation dynamics in a Mediterranean-type ecosystem. Global Change Biology 8: 423–437. https://doi.org/10.1046/j.1365-2486.2002.00494.x

Naveh Z (1975) The evolutionary significance of fire in the Mediterranean region. Vegetatio 29: 199–208. https://doi.org/10.1007/BF02390011

Ne'eman G, Lev-Yadun S, Arianoutsou M (2012) Fire-related traits in Mediterranean Basin plants. Israel Journal of Ecology and Evolution 58: 177–194.

Pasta S, de Rigo D, Caudullo G (2016) *Quercus pubescens* in Europe: distribution, habitat, usage and threats. In: San-Miguel-Ayanz J, de Rigo D, Caudullo G, Houston Durrant T, Mauri A (Eds) European Atlas of forest tree species: 156–157. Publ. Off. EU, Luxembourg.

Pausas JG (1997) Resprouting of *Quercus suber* in NE Spain after fire. Journal of Vegetation Science 8: 703–706. https://doi.org/10.2307/3237375

Pausas JG (2004) Changes in fire and climate in the Eastern Iberian Peninsula (Mediterranean Basin). Climate Change 63: 337–350. https://doi.org/10.1023/B:CLIM.0000018508.94901.9c

Pignatti E, Pignatti S, Ladd PG (2002) Comparison of ecosystems in the Mediterranean Basin and Western Australia. Plant Ecology 63: 177–186. https://doi.org/10.1023/A:1020968010349

Plieninger T, Hartel T, Martin-López B, Beaufoy G, Bergmeier E, Kirby K, Montero MJ, Moreno G, Oteros-Rozas E, Van Uytvanck J (2015) Wood-pastures of Europe: Geographic coverage, social-ecological values, conservation management, and policy implications.

Biological Conservation 190: 70–79. https://doi.org/10.1016/j.biocon.2015.05.014

PlieningerT, Draux H, Fagerholm N, Bieling C, Bürgi M, Kizos T, Kuemmerle T, Primdahl J, Verburg PH (2016) The driving forces of landscape change in Europe: A systematic review of the evidence. Land Use Policy 57: 204–214. https://doi.org/10.1016/j.landusepol.2016.04.040

Rivas-Martínez S, Rivas Sáenz S, Penas A (2011) World bioclimatic classification system. Global Geobotany 1: 1–634.

Rouet-LeducJ, Pe'er G, Moreira F, Bonn A, Helmer W, Shahsavan Zadeh SAA, Zizka A, van der Plas F (2021) Effects of large herbivores on fire regimes and wildfire mitigation. Journal of Applied Ecology 00: 1–13. https://doi.org/10.1111/1365-2664.13972

Rundel PW, Arroyo MTK, Cowling RM, Keeley JE, Lamont BB, Pausas JG, Vargas P (2018) Fire and plant diversification in Mediterranean-climate regions. Frontiers in Plant Science 9: 851. https://doi.org/10.3389/fpls.2018.00851

Sarris D, Christopoulou A, Angelonidi E, Koutsias N, Fulé PZ, Arianoutsou M (2014) Increasing extremes of heat and drought associated with recent severe wildfires in southern Greece. Regional Environmental Change 14: 1257–1268. https://doi.org/10.1007/s10113-013-0568-6

Schroeder F-G (1998) Lehrbuch der Pflanzengeographie. Quelle & Meyer, Wiesbaden.

Syphard AD, Radeloff VC, Hawbaker TJ, Stewart SI (2009) Conservation threats due to human-caused increases in fire frequency in Mediterranean-climate ecosystems. Conservation Biology 23: 758–769. https://doi.org/10.1111/j.1523-1739.2009.01223.x

Tapias R, Climent J, Pardos JA, Gil L (2004) Life histories of Mediterranean pines. Plant Ecology 171: 53–68. https://doi.org/10.1023/B:VEGE.0000029383.72609.f0

Thanos CA, Dousi MA (2000) Post-fire regeneration of *Pinus brutia* forests. In: Ne'eman G, Trabaud L (Eds) Ecology, biogeography and management of *Pinus halepensis* and *P. brutia* forest ecosystems in the Mediterranean Basin: 291–301. Backhuys Publishers, Leiden.

Thanos CA, Georghiou K (1988) Ecophysiology of fire-stimulated seed germination in *Cistus incanus* ssp. *creticus* (L.) Heywood and *C. salvifolius* L. Plant Cell Environment 11: 841–849. https://doi.org/10.1111/j.1365-3040.1988.tb01910.x

Trabaud L (1994) Postfire plant community dynamics in the Mediterranean Basin. In: Moreno JM, Oechel WC (Eds) The role of fire in Mediterranean-type ecosystems. Ecological Studies 107. Springer, New York, NY. https://doi.org/10.1007/978-1-4613-8395-6_1

Varela E, Jacobsen JB, Soliño M (2014) Understanding the heterogeneity of social preferences for fire prevention management. Ecological Economics 106: 91-104. https://doi.org/10.1016/j.ecolecon.2014.07.014

Varela E., Górriz-Mifsud E, Ruiz-Mirazo J, López-i-Gelats F (2018) Payment for targeted grazing: integrating local shepherds into wildfire prevention. Forests 9(8): 464. https://doi.org/10.3390/f9080464

Walter H (1979) Vegetation und Klimazonen. Ulmer, Stuttgart.