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Mediterranean woody agroecosystems in a warming and drier climate: the importance of knowledge-based management☆

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ABSTRACT

The Mediterranean region is often described as a climate change hotspot. Not surprisingly, climate change impact on Medieterranean Agroecosystems sustainability, biodiversity, and productivity has been receiving a lot of interest from the research community. It is reported that the frequency, intensity and duration of droughts, as well as hotter droughts, are interfering with ecosystems' structure, composition, and functions. To minimize some of the risks of the ongoing climate change, and maintain the economic viability of the agroecosystems, management strategies and practices need to be changed/adapted at the local and regional levels. This is of fundamental importance for the design of future human societies and their relationships with other species.

The increased warming and precipitation decline in the Mediterranean region makes it a climate change hotspot (Cos et al., 2022). The foreseen temperature increase in this region (0.03°C rise per year if the current trend is maintained), surpasses the global average increase (0.02°C rise per year; IPCC 2019; UNEP 2020). Additionally, the water scarcity is expected to worsen as regional trends for increasing frequency and intensity of drought are also projected (UNEP, 2020). Over the last century, human-induced drivers of climate change, notably greenhouse gases, are considered to be much larger than natural ones (Allison, 2015). Greenhouse gases, that trap the sunś heat, provide the crucial link between temperature rise and human activities and many ecosystems are already being strongly affected by the quick shifts in environmental conditions. The expression "survival of the fit" does not always fully evidence the delicate web of biological interactions and the long-standing co-evolution processes. So, addressing ecosystem sustainability in a climate change context is of fundamental importance for the design of future human societies and their relationships with other species. As this special issue is focused on woody species' adaptations to multiple abiotic stressors, we would like to gather attention on plant-based agroecosystems in the Mediterranean region, whose productivity, biodiversity and sustainability are under threat due to the more frequent and intense extreme events, namely, heatwaves and droughts (e.g. Ermitão et al., 2021; Guion et al., 2021). In line with political-strategic foresight in the last decades, e.g., UN 2030 Agenda for Sustainable Development and its Sustainable Development Goals (SDGs, and the Mediterranean Strategy for Sustainable Development 2016-2025), climate change impact on Mediterranean woody agroecosystems is receiving a lot of interest from the scientific community. This is clearly illustrated by a bibliographic search at the Web of Science (WoS) database performed on 1st October 2021 (Fig. 1). Details on the bibliographic search are provided in the legend of Fig. 1. In brief, we made use of several search strings to retrieve records addressing Mediterranean woody plants and climate change in the WoS Core Collection.

While the total number of records in the database steadily increased over the last decades (2x, Fig. 1A), the records addressing Mediterranean woody plants and climate change increased 177x (Fig. 1B-1C). The

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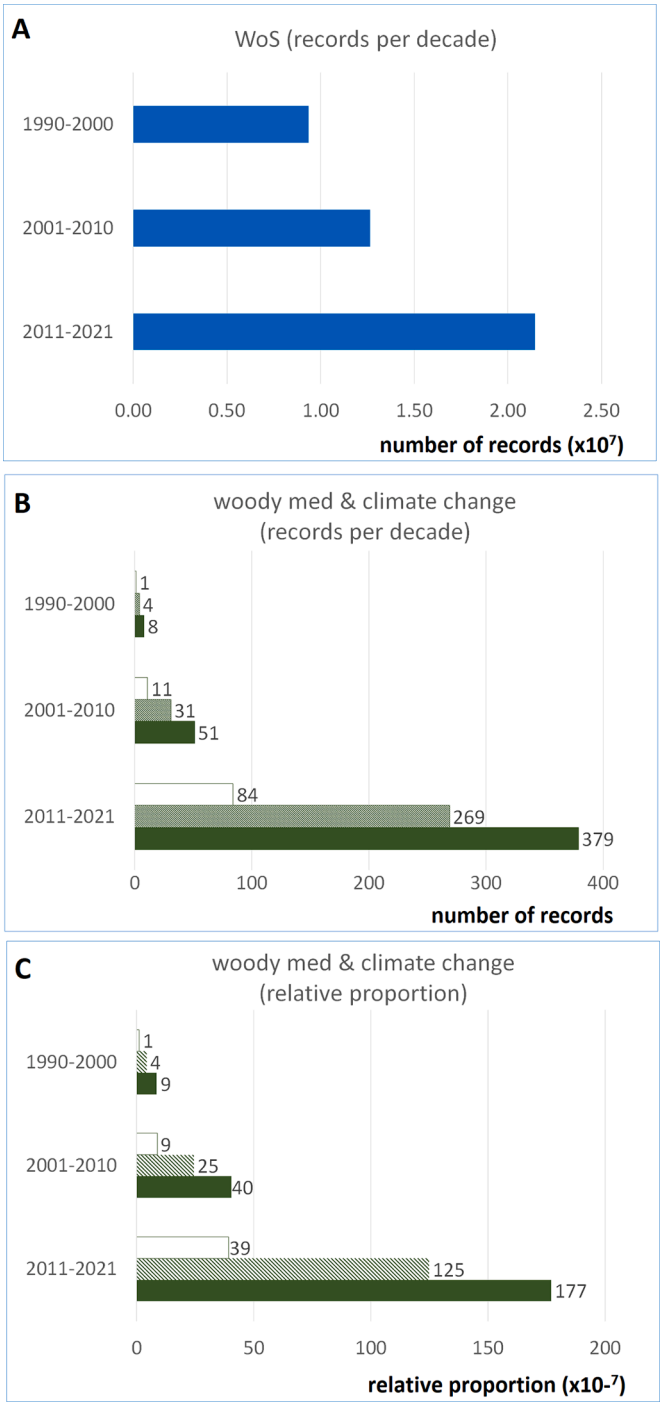

Fig. 1. Bibliographic records available at the Web of Science (WoS, www.webofscience.com, 1st October 2021) per decade from 1990 to 2021

A. Total number of records available in the WoS Core Collection (All databases, solid, dark bars).

B. Number of records at the WoS Core Collection (All databases) retrieved with distinct search strings. **Search string #1**: TOPIC: (Mediterran*) AND TOPIC: ((((woody) or (orchad*) or (forest)))) AND TOPIC: (climate change) AND TOPIC: (adapt*) (solid, dark bars); **Search string #2**: Search string #1 AND TOPIC: (((water stress) or (drought) or (heat) or (temperature))) (solid, light bars); **Search string #3**: Search string #1 AND TOPIC (fire) (empty bars)

C. Relative proportion of the publications retrieved with the search strings over the total number of publications in the WoS Core Collection (numbers in figure 1B over numbers in figure 1A)

number of records addressing "heat" and "drought" (search string #2) comprises circa 75% of the records in the last decade clearly demonstrating the relevance of the topic.

In the above mentioned survey several authors report that frequency, intensity and duration of droughts are affecting the survival and growth of woody plants, thus, interfering with ecosystems structure, composition, and functions (e.g. Bussotti et al., 2015; Prichard et al., 2017; Buras and Menzel, 2019; Roces-Díaz et al., 2021). The increase in temperature and drought also affect plant phenology, by inducing an earlier budburst and constraining the length of the growing season and, thus, negatively impacting plant growth. Hot droughts may also modify the distribution and/or impact of biotic factors (e.g. Sardans and Peñuelas, 2013; Carnicer et al., 2021). Pests and pathogens are changing their habitat ranges and becoming virulent in areas where they had not reached critical population densities earlier (e.g. Jandl et al. 2019).

The effects of climate change on Mediterranean ecosystems will depend on site-specific features and management practices. For instance, soil compaction through heavy machinery or livestock overload should be avoided to prevent reductions in soil water infiltration. Agronomic practices that promote soil biodiversity may also help to increase carbon sequestration, and to reduce and/or optimize the use of fertilizers. There is a consensus around the ecological benefits of maximizing the ecosystem stability by maintaining high genetic variability (e.g., increasing within, and between, species diversity) and securing productivity under changing environmental conditions.

To minimize some of the risks of the ongoing and predicted climate change, and maintain the economic viability of the agroecosystems, management strategies and practices need to be changed/adapted. In our view, knowledge and knowledge-based management are key partners in such adaptation (Fig. 2). Natural variability and local specificities add additional levels of uncertainty limit the effective implementation of adaptation measures and so each agroecosystem poses its own challenges. On this point, we would like to focus on climate change effects and management options, on two emblematic agroecosystems: olive groves, one of the oldest permanent crops of the Mediterranean, and montados/dehesas, savannah-like ecosystems shaping large areas in the southwestern Iberian Peninsula. Both systems play a key role in the areas they occupy, because of their spatial extension and their economic, social and environmental relevance.

1. Olive crop (*Olea europaea* L.)

Two main types of olive orchards are found in the Mediterranean area. In the traditional system, with a low density of plantation (up to 100 trees/ha), olives are usually grown under rainfed conditions and managed with few agrochemicals inputs and a low degree of mechanization. This growing system is typically associated with the presence of high biodiversity, thus providing several ecosystem services. On the hand, intensive (200–500 trees/ha) and super-intensive (up to 2500 trees/ha) olive groves are expanding in several countries, particularly in Spain, Italy and Portugal (Guerrero-Casado et al., 2021). Although more profitable than the traditional orchards, their management makes use of several agrochemicals, irrigation and mechanization (Guerrero-Casado et al., 2021), leading to agrobiodiversity reduction.

Productivity goals and associated management options will be further challenged due to the expected heat and water stress increase. The economic impact of climate warming across the Mediterranean basin olive orchard is not uniform. In some areas, productivity may increase while others are predicted to decrease in the future (Ponti et al., 2014). A major effect of warming will be alterations in flower and fruit settings (Morales et al., 2016; Gabaldon-Leal et al., 2017), which is also impacted by water availability (Arampatzis et al., 2018). In our view, the implementation of practices linking farming with local soil water availability will be crucial. This is a challenging task since these practices need to be adjusted to local conditions and to the socio-economic reality of farmers and orchard's growing systems (traditional vs

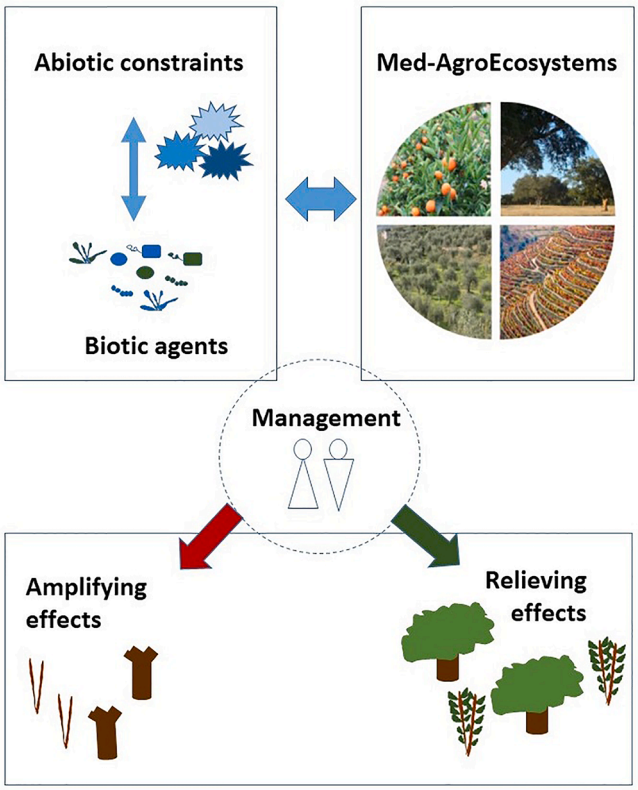

Fig. 2. Life under stress. Under Mediterranean field conditions plants are exposed to multiple abiotic and biotic factors. Interactions between plants, plant communities and their enemies, friends and foes can result in distinction outcomes. While hard to decipher, knowledge of such interactions is essential for local management options and political decisions. Producer associations and other relevant stakeholders are key to the transition to a climate resilient paradigm. Sustainable and biodiverse agro-forest ecosystems strongly contribute to its achievement. Vineyards, olive orchards, fruit trees and "montados/dehesas" are emblematic ecosystems of the Mediterranean basin region. This region represents a hot spot for climate change and for species' genetic diversity
Photographic credits: Olive grove, CCBY2.0 www.flickr.com/photos/65847118@N06/15112616707; montado, CCBYNC ND2.0 www.flickr.com/photos/agforward/13626444104; vineyard, CC0 https://pixabay.com/pt/photos/vinicola-douro-portugal-1357947; Orange tree, CC0 https://www.pxfuel.com/pt/free-photo-xgmzz

intensive or super intensive). Key action points includ: 1) crop water use efficiency optimisation using new irrigation techniques and advanced technologies (e.g. IoT, machine learning); 2) promotion of practices to conserve water in soil (e.g. conservation tillage systems like zero-tillage or minimum tillage, crop residue on the soil surface); 3) the use of functional plants-microorganisms symbiosis in order to increase plant tolerance to stresses. Appropriate economic incentives will be of utmost importance for the adoption of these strategies by the farmers. Additionally, it is necessary to develop new cultivars better adapted to water deficit conditions and high temperatures.

2. Montados and dehesas

These man-made agro-silvo-pastoral ecosystems, characterized by a two-layered structure with a sparse tree stratum mainly dominated by evergreen oaks - *Quercus suber* L. and *Quercus rotundifolia* Lam. - and an understory of shrubs and grasses, were designed to overcome food needs in a scarce resource environment. They have high potential economic and social value, sustain high biodiversity and provide multiple goods and ecosystem services. *Q. suber* is mainly exploited for cork production and *Q. rotundifolia* produces acorns to feed livestock. Both species must cope with the seasonal summer hot drought of the Mediterranean climate. They have developed structural and physiological traits to cope with drought, minimizing water losses through leaves and maximizing water uptake by deep rooting (Baldocchi and Xu, 2007). However, under low precipitation and high temperature, tree vitality may be reduced and tree death may occur. Pests and diseases may amplify, and be amplified, by drought-induced stress (Millar and Stephenson, 2015; Hartmann et al., 2018). Oak regeneration and establishment, tree growth, productivity and product quality may also be affected.

Ecosystem management should consider the ongoing environmental changes and the species evolutionary adaptation traits. Key action points are: 1) mapping of water availability across different areas, given the high spatial heterogeneity in montado/dehesa ecosystems; 2) adjusting tree density to the local water availability; 3) adopting practices that do not damage or destroy roots to prevent decoupling trees from their water and nutrient sources (David et al., 2013, 2016); 4) in severely dry years avoid *Q. suber* cork stripping as it poses additional stress (Costa e Silva, 2021); 5) improve oak resilience to drought through genetic breeding; 6) in some areas, control shrub encroachment in order to decrease competition for water and nutrients (Caldeira et al., 2015) and reduce the risk of fire.

3. Conclusion

Knowledge-based management is a cornerstone when addressing the upcoming climate challenges. The continuous monitoring of the agro-ecosystems with the local and regional resolution is needed to refine models, implement early warning systems and adjust management. This will enable a better understanding of tree/crop dynamics under diverse climate conditions and identify the most appropriate management practices to improve Mediterranean agroecosystems sustainability. Mapping water availability and its use is of utmost importance. The implementation of adaptive management concepts challenges the current practices and implies a redefinition of economic, social, and ecological goals.

Thus, scientific sound data as the pillar of knowledge-based management is no doubt our best approach as well as an active stakeholder engagement that will help to develop and establish more successful actions. However, as the recent pandemics reveal, the societal trust in science and how science works is challenged every day. Trust must be earned and while the public awareness of the risks of climate change is growing, the price of the change needs to be clear to all the stakeholders and perceived as fair and evenly distributed.

CRediT authorship contribution statement

Carla Pinheiro: Conceptualization, Writing – review & editing. **Teresa S. David:** Conceptualization, Writing – review & editing. **Paula Baptista:** Conceptualization, Writing – review & editing. **Leonor Guerra-Guimarães:** Conceptualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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