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Forest management for adaptation to climate change in the Mediterranean basin: A synthesis of evidence

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ABSTRACT

As global climate becomes warmer, the maintenance of the structure and function of Mediterranean forests constitutes a key challenge to forest managers. Despite the need for forest adaptation, an overall evaluation of the efficacy of current management strategies is lacking. Here we describe a theoretical framework for classifying management strategies, explicitly recognizing trade-offs with other, untargeted ecosystem components. We then use this framework to provide a quantitative synthesis of the efficacy of management strategies in the Mediterranean basin. Our review shows that research has focused on strategies aimed at decreasing risk and promoting resistance in the short-term, rather than enhancing long-term resilience. In addition, management strategies aiming at short-term benefits frequently have unintended consequences on other adaptation objectives and untargeted ecosystem components. Novel empirical studies and experiments focusing both on adaptation objectives and multiple responses and processes at the ecosystem level are needed. Such progress is essential to improve the scientific basis of forest management strategies and support forest adaptation in the Mediterranean basin.

1. Introduction

In an era of global environmental change the maintenance of ecosystem functions and the provision of ecosystem services are being compromised (Millennium Ecosystem Assessment, 2005). This is especially true for forest ecosystems in the Mediterranean basin, which have sustained human populations for millennia (Blondel and Aronson, 1999). In particular, increased aridity with climate change and widespread forest expansion due to socioeconomic changes during the last century have resulted in more recurrent and severe wildfires (Pausas and Fernández-Muñoz, 2012) and drought-induced forest decline episodes (Carnicer et al., 2011). At the same time, the vulnerability of forests to biotic attacks is amplified (Sangüesa-Barreda et al., 2015) and the impacts of windstorm events have increased during the last decades (Gardiner et al., 2013). As a consequence, forests of the Mediterranean basin are undergoing changes at accelerated rates, which could have cascading effects for biodiversity and ecosystem functions (Falcucci et al., 2007; Sheffer, 2012; Valladares et al., 2014).

Forests in the Mediterranean basin have a set of particular features. The geographic location and the heterogeneous topography of this territory determine an exceptional variety of forest ecosystems, including elements of Atlantic, sub-Atlantic, and sub-Mediterranean deciduous forests; montane, subalpine, and Mediterranean coniferous forests; and sclerophyllous and evergreen shrublands and forests (Blanco et al., 1997). These forests contain an impressive plant and animal diversity, with high tree species richness relative to forests in Northern latitudes (Scarascia-Mugnozza et al., 2000), and high genetic diversity as the region played as glacial refugia for many taxa (Hampe and Petit, 2005). Consequently, anticipating global change impacts constitutes a key challenge for forest managers, regarding the maintenance of ecosystem service and programs to ensure the preservation of the functional and structural characteristics of Mediterranean forests (MFRA, 2009).

Management strategies for forest adaptation to climate change needs to consider the different temporal scales over which ecological mechanisms and rapid environmental changes act. Therefore, the use of such strategies should not be only addressed towards attaining short-term objectives such as decreasing the immediate risk of a particular disturbance, but also towards the promotion of resilience as a key objective for long-term adaptation. Resilience is quantified using a broad range of metrics, which makes comparisons across systems difficult and precludes applicability in forest management. Acknowledging the

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ongoing debate around resilience, here we consider 'resistance' and 'recovery' as complementary and measurable components that together represent resilience (Hodgson et al., 2015; Millar et al., 2007).

At the same time, forest managers must recognize the existence of trade-offs among ecosystem responses when planning and implementing any management action. There is increasing evidence that the implementation of a given management practice may be beneficial for reaching a specific objective but, at the same time, it can impair the consecution of other objectives or induce negative impacts on untargeted ecosystem components (Bradford and D'Amato, 2012). In a Mediterranean context, for instance, managers may seek forest resistance to droughts by releasing competition after thinning (Calev et al., 2016), but such treatments can reduce the benefits for carbon storage (Ameztegui et al., 2017; Ruiz-Peinado et al., 2013) or modify the habitat conditions needed for some forest-dwelling species (De La Montaña et al., 2006).

The use of appropriate management strategies to enhance the adaptive capacity of Mediterranean forests to climate change has been increasingly argued by scientists (Bravo-Oviedo et al., 2014; Doblas-Miranda et al., 2015; Fernandes et al., 2013; Keenan, 2015; Kolström et al., 2011; Resco de Dios et al., 2007; Scarascia-Mugnozza et al., 2000). The efficiency of some of these strategies have been empirically assessed in individual case studies, such as forest thinning to increase resistance to drought stress (Cotillas et al., 2009) or to promote forest recovery after a wildfire (de las Heras et al., 2013). Yet a general evaluation of the efficacy of management strategies and the associated trade-offs is lacking. Here, our goals are to (1) present a theoretical framework for classifying and assessing management strategies for forest adaptation, explicitly recognizing the need to account for trade-offs; (2) provide a quantitative synthesis on the evidence of the efficacy of management strategies achieving adaptation objectives; and (3) assess evidence of potential trade-offs of management strategies with other, untargeted ecosystem components.

2. Material and methods

2.1. Theoretical framework

Our framework for the implementation of forest management strategies for adaptation in the Mediterranean basin includes four components: disturbances, management strategies, objectives for adaptation, and indirect effects on other ecosystem components (including trade-offs) (Fig. 1). The framework aims at synthetizing the potential effects of a management action in a given forest system. As a generic example, we can imagine that the initial state of a given forest has been altered or it is expected to change due to a disturbance. Managers seek to accommodate the altered (or potentially altered) forest ecosystem to the new or expected environmental conditions, so they define a given management strategy to attain specific adaptation objectives. However,

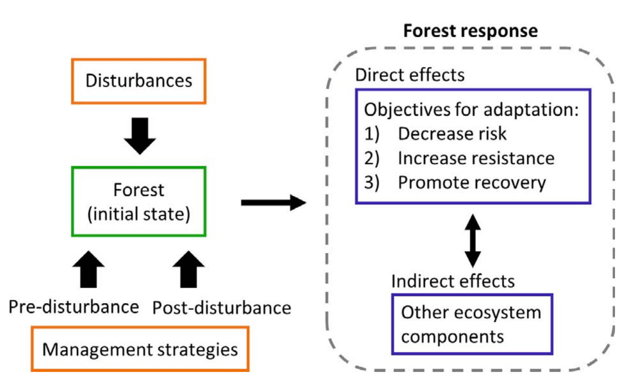

Fig. 1. Theoretical framework for assessing forest management for adaptation in the Mediterranean basin. For the description of each component and the interpretation of the framework see the main text.

the implementation of a management practice could cause unexpected forest responses through indirect effects on other ecosystem components. Trade-offs may arise between the targeted objective for adaptation and other ecosystem aspects, including untargeted adaptation objectives and ecosystem responses affecting forest functions or biodiversity.

The different components of the framework (disturbances, management strategies, objectives for adaptation, and indirect effects–trade-offs) are described below:

(i) Disturbances

We consider the four most threatening forest disturbances in the Mediterranean basin: fires, droughts, pests, and windstorms. These disturbances are becoming more frequent and severe (see *Introduction*) and are already causing important structural and compositional changes in Mediterranean forest ecosystems (Carnicer et al., 2013; Vayreda et al., 2016, 2012).

(ii) Management strategies

We consider five different management strategies - four at the stand level and one at the landscape level. Each management strategy is expected to induce short/mid-term effects (see below strategies a, b and e) or long-term effects (see below strategies c, d and e), and it can be implemented before disturbance (e.g. to improve resistance to drought) or after disturbance (e.g. to improve forest recovery after fire). We define these management strategies according to forest management manuals (Alonso et al., 2013), as well as expert knowledge (see examples below).

a. *Reduction of stand density*. Thinning treatments aimed at removing some trees to increase the growth, health and value of the remaining ones. This management strategy has a strong scientific and technical basis. Thinning typically reduces fire risk and the associated carbon losses (Hurteau et al., 2008), and stimulates resistance to drought (D'Amato et al., 2013) and pests (Waring and O'Hara, 2005).
b. *Management of the understory*. Treatments aimed at reducing the understory cover towards breaking vertical and horizontal fuel continuity. These actions can include both mechanical treatments and prescribed burning and are considered efficient tools to reduce fire risk (Adams, 2013).
c. *Promoting mixed forests*. Strategies aimed at promoting mixed forests at the species or genotype levels, or actions focused towards the promotion of forest structural diversity (i.e. uneven-aged forests). There is growing interest towards managing for forest diversification given that mixed forests may exhibit greater resistance and recovery capacity as a consequence of niche partitioning and differential response to stressors (de-Dios-García et al., 2015; del Río et al., 2017; Sánchez-Pinillos et al., 2016). Uneven-aged forests are also expected to show higher stability to disturbances (Martín-Alcón et al., 2010).
d. *Changing species or genetic composition*. Strategies aimed at promoting changes in forest composition towards species or genotypes better adapted to the conditions forecasted under future climates. These strategies can include actions in-situ by using extant species or ex-situ by using assisted-migration (Martín-Alcón et al., 2016; Mason and Connolly, 2014).
e. *Promoting spatial heterogeneity at the landscape-scale*. Strategies at the landscape scale aimed at promoting spatial heterogeneity for disturbance prevention and control, as well as enhancing connectivity in order to assist gene flow and species migration. For example, fuel treatment patches have been suggested as effective measures to control fire behaviour (Regos et al., 2016), while the conservation of key areas within landscapes might increase not only the spatial heterogeneity but also the potential for adaptation through the