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Burning intensity and low light availability reduce resprouting ability and vigor of *Buxus sempervirens* L. after clearing

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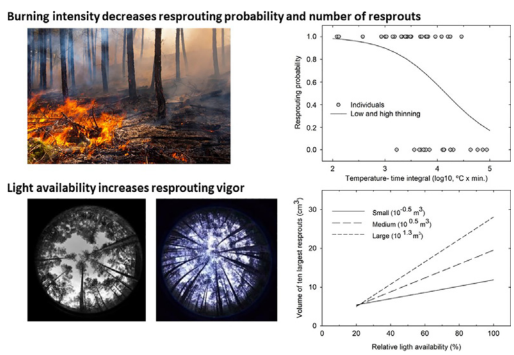
HIGHLIGHTS

- Burning after clearing reduces the resprouting ability of *Buxus sempervirens*.
- Resprouting probability and resprout number decrease as fire intensity increases.
- Resprout volume and light availability at an individual level are positively related.
- No tradeoffs between resprout growth and the number of resprouts were detected.

GRAPHICAL ABSTRACT



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ABSTRACT

Thinning and prescribed burning are two common operations for reducing fuel accumulation and decreasing the intensity and severity of wildfires. However, the resprouting response of understory species may reduce the effectiveness of fuel load treatments and thus negatively affect the cost-benefit ratio of these treatments. This study focuses on *Buxus sempervirens*, a slow-growing, multi-stemmed tree species, frequently dominant in the understory of temperate European forests, which resprouts strongly after clearing or burning. The aim was to assess how light availability and burning influence resprouting ability (resprouting or not) and vigor (i.e. the growth of resprouts) after clearing *B. sempervirens* in thinned stands without slash removal (unburned) or with burning of slash residues (burned), two years after the treatments. All individuals studied resprouted shortly after clearing in unburned stands, whereas almost ca. 40% never resprouted in the burned stands. Fire intensity, measured at the base of 49 individuals, contributed to explaining the likelihood of mortality. The number of resprouts was directly influenced by the pre-treatment size of individuals, but this relationship was lower in burned stands. Fire intensity, recorded in 29 resprouted individuals, also influenced the number of resprouts. Post-treatment light availability, in addition to pre-treatment size, contributed to explaining the volume of the ten largest resprouts and the length of the largest resprout. No tradeoffs between the resprout number and the volume of the ten largest resprouts or the maximum resprout length were found. Our study suggests that burning after clearing reduces the resprouting ability of *B. sempervirens*. Moreover, avoiding affecting the canopy cover reduces its resprouting vigor and, consequently, increases the effectiveness of understory fuel load treatments.

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1. Introduction

Although the behavior of a wildfire is mainly governed by topography and meteorological conditions, reducing fuel accumulation is a common practice for decreasing the intensity and severity of disturbances (Agee and Skinner, 2005; Fulé et al., 2012). Overstory thinning, by reducing canopy bulk density, decreases the potential of crown fire propagation (Agee and Skinner, 2005; Alvarez et al., 2013; Palmero-Iniesta et al., 2017). However, light reaching the understory favors the proliferation of herbs and woody plants, increasing the understory fuel load. Low thinning, in contrast, removes small trees and shrubs from below the upper canopy layers, thus reducing fuel ladder profiles (i.e. fuel that allows fire to move vertically from the surface to the crown) with only a small increase in understory light availability. If slash is left in the woods, although the fire hazard is reduced through decomposition (Palmero-Iniesta et al., 2017), the forest still has a high risk of understory fire (Alvarez et al., 2013; Brown et al., 2004). Therefore, low thinning and understory clearing are often combined with prescribed burning to reduce slash accumulations and thus the wildfire hazard (Piqué and Domènech, 2017). However, resprouting after a perturbation is widespread in different ecosystems, including the Mediterranean, temperate, boreal and tropical forests (Bond and Midgley, 2001). Understory can, therefore, re-grow quickly after clearing or burning, clearly reducing the benefit-cost ratio of treatments.

The present study focuses on the resprouting ability and vigor of *Buxus sempervirens* L. (box-tree). This species is a slow growing evergreen multi-stemmed tree, often dominant in both thickets and undergrowth of dense temperate forests of western and southern Europe. It is widely distributed throughout southern and western Europe, northern Africa and western Asia (Decocq et al., 2004). As observed by firefighters (Asier Larañaga com. pers. 2013), the plant structure of this species traps and holds the needles of sub-Mediterranean overstory pines when they fall at the beginning of summer. This increases the dry standing fuel content and dramatically affects the behavior of wildfires. *Buxus sempervirens* is a toxic unpalatable species, and its dense canopy impedes the growth of herbaceous cover and livestock grazing (Rousset and Lepart, 2003; Taüll et al., 2016). For these reasons, the understory dominated by this species is usually managed by mechanical clearing or prescribed burning. Understanding the response of *B. sempervirens* to different management types and understory environmental characteristics can assist managers in the decision-making process for achieving specific management objectives.

The ability for woody plants to resprout after the destruction of all of their aboveground biomass is determined by the existence of protected meristems, in particular the bud-forming tissues at the stem base, root crown or belowground plant organs (Clarke et al., 2013). Once these meristems begin to develop, resprouting vigor (i.e. the growth rate of resprouting shoots) depends on the allocation of belowground stored reserves and the capacity to acquire new resources (e.g. Kobe, 1997; Cruz et al., 2003a; Vesk and Westoby, 2004). The pre-treatment size, which is allometrically related to the bud bank and belowground stored resources (Canadell and López Soria, 1998; Lloret and López Soria, 1993), determines the resprouting ability and initial vigor of woody plants after the removal of aboveground biomass (e.g. Kauffman and Martin, 1990; Lloret and López Soria, 1993). After initial resprouting depletes the stored resources, resprout growth must depend more heavily on photosynthesis (Bowen and Pate, 1993; Shultz et al., 2009). It has been suggested that the lack of a clear relationship between the height of new resprouts and the pre-fire size of understory plants may be explained by differences in light availability between individuals of different species (Quevedo et al., 2007). Thus, light availability seems to be a stronger driver of the height growth of resprouts, at least in fertile forest (Knox and Clarke, 2011). The dominance of *B. sempervirens* in a wide variety of contrasting environments can be explained by the high morphological and physiological plasticity of this species, which allows it to live in environments with a wide spectrum of light availability (Hormaetxe et al., 2007; Letts et al., 2012). Hence, due to this plasticity, light availability may not be the main driver of the height growth of *B. sempervirens* resprouts.

In a framework of adaptive forest management strategies for reducing wildfire hazard (Life + DEMORGEST), the aim of this study was to assess how burning intensity and availability of light determine resprouting ability and vigor of cleared *B. sempervirens* in thinned stands without slash removal (unburned) or with slash residues burned (burned), two years after the treatments. This species resprouts vigorously after the destruction of the aboveground part. We hypothesized that: (i) The ability to resprout and the number of resprouts per individual would be lower in burned stands than in unburned ones, due to the bud damage caused by the heat generated during burning. However, (ii) if a tradeoff for the use of stored resources between the number of resprouts and the growth of resprouts exists, there would be a higher volume of dominant resprouts and maximum length in the burned stands (due to the lower number of resprouts as hypothesized). And finally, (iii) due to the plasticity of *B. sempervirens* to different light availability conditions (Hormaetxe et al., 2007; Letts et al., 2012), the height growth of *B. sempervirens* resprouts would not be higher in forest areas with higher light availability after treatments.

2. Material and methods

2.1. Study sites and experimental design

The study was performed in two localities, Llobera and Madrona, in the foothills of the Pyrenees, in the NE Iberian Peninsula (Table 1). Soils had developed from calcareous colluvium in Llobera and from conglomerates in Madrona. In both localities soils were basic (pH = 8.0–8.2), fine textured and 0.5–1 m deep. Soils were classified as Lithic (depth < 0.5 m) or Typic Xerorthent (Soil Survey Staff, 2014). The climate is sub-Mediterranean with milder summers and colder winters than the typical Mediterranean climate. In both localities, the mean annual temperature is 11–13 °C and mean annual precipitation is 600–650 mm (according to the georeferenced model of Ninyerola et al., 2000). The forest canopy is dominated by *Pinus nigra* ssp. *salzmannii* (Dunal) Franco, although some deciduous species are also present (i.e. *Quercus pubescens* Willd., *Acer monspessulanum* L., *Sorbus aria* (L.) Crantz). Pine density (DBH > 7.5 cm) ranged from about 1000 to 2000 trees ha^{-1} and the basal area, from 30 to 45 $m^2\ ha^{-1}$ (Table 1). The mean cover of understory, estimated by 12 belt transects (10 × 0.5 m), varied from 52 to 82% and the mean height, from 1.0 to 2.0 m. As a result, the woody understory volume ranged from 0.78 to 1.68 $m^3\ m^{-2}$ (Table 1). *Buxus sempervirens* was almost dominant in the understory (94–99% of the belt transect understory cover).

In each locality, we studied resprouting ability and vigor of *B. sempervirens* two years after treatments in a split plot design, with burned and unburned treatments nested into two stands with different thinning levels. This resulted in four experimental units per locality (ca. 1 ha per experimental unit, Table 1; Fig. A.1; Table A.1). Thinning and burning treatments are described below. We studied 28 individuals per experimental unit (224 individuals in total). The effect of burning temperature on resprouting ability and vigor was analyzed in a subset of 49 individuals. The fire temperature was recorded at the base of these individual plants during burnings (29 individuals in Llobera and 20 in Madrona).

2.2. Thinning and burning characteristics

Thinning treatments consisted in low thinning, aimed at reducing the fuel ladder without substantially affecting the tree density and canopy cover, and high thinning, aimed at achieving ~40–50% canopy openness by cutting down selected trees. High thinning reduced the basal area from 30 to 45 $m^2\ ha^{-1}$ to 20–30 $m^2\ ha^{-1}$ and canopy openness increased from 23 to 39% to 36–50% one year after treatment (Table 1). No