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Fires Beyond Fire-Prone Ecosystems: The Erosion of Beech Forest

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Received: 16 July 2026 | **Revised:** 16 July 2026 | **Accepted:** 30 July 2026

Fire regimes are changing, in part because of changes in land-use and management, but also due to climate change which is modifying vegetation flammability (Abatzoglou et al. 2025; Turco et al. 2026). For instance, in southern Europe, fires are historically common at low altitudes (mediterranean climate) but not at higher altitudes under mesic temperate environments (e.g., broad-leaved temperate forests). However, global warming is changing the altitudinal range where large fires occur (Alizadeh et al. 2021), generating climate-induced fire regime shifts. Here we report a recent example of such a shift and its biological consequences.

Beech (*Fagus sylvatica*) forests are not flammable. They occur in relatively cold, moist environments and, as shade-tolerant, winter-deciduous trees, their dense summer canopy suppresses understory vegetation and fires, often acting as flammability barriers. Small winter or spring fires, mainly of anthropogenic origin, may occur when trees are leafless (Conedera et al. 2010; Maringer et al. 2016; Moris et al. 2023).

In summer 2025, an exceptional 15-day heatwave generated a record-breaking number of large fires in Spain and Portugal (Sánchez-Hernández et al. 2025). They burned fire-adapted shrublands but also reached altitudes where summer fires are historically rare (Beltrán-Marcos et al. 2026), including *Fagus sylvatica* forests. For instance, the Barniedo fire (León, Spain; 19,100 ha; altitude range: 1120–2315 m [mean = 1612, SD = 202]) was ignited by lightning (14 Aug 2025) during the heatwave. The area was a mosaic of (i) shrublands dominated by woody legumes (mainly *Cytisus scoparius* and *Genista florida* ssp. *polygaliphylla*) and *Erica australis*; (ii) oak forests (mainly *Quercus petrea*); and (iii) beech forests (714 ha monospecific plus 430 ha mixed oak-beech). Shrublands and oak forests burned at high intensity (crown fires), and many species resprouted from the base (e.g., the oaks) or germinated profusely (e.g., legumes) after fire. In contrast, due to their low flammability, beech forests burned as low-intensity understory (litter) fire, without fire reaching the crowns. In fact, fire spread with high intensity across shrubland patches, but upon entering a beech patch, it decreased to low intensity and propagated through the litter; intensity rose again when the fire reached the next shrubland patch.

Remotely sensed fire severity (Figure 1a) indicates that approximately one-third of the beech forest was either unaffected (the flammability barrier was effective) or burned by a very low-intensity understory fire (99% of trees surviving). Another third burned in an understory fire that killed most trees (a low-intensity, high-severity fire). The remaining third comprised a mix of dead and surviving trees that did not fully recover their crowns (moderate severity).

Field sampling of severely affected beech patches revealed size-related mortality, though some large trees also died (Figure 1b). On average, 74% of trees with DBH > 10 cm died (100% for DBH < 10 cm), while the remaining 26% resprouted epicormically, albeit slowly (crown recovery < 15%; June 2026). The ultimate fate of these resprouting trees remains uncertain, as some post-fire delayed mortality is expected (Maringer et al. 2016; Moris et al. 2023). Basal resprouting of beech was observed only in a few juvenile trees outside the sampled plots, consistent with previous observations (Moris et al. 2023).

Beech seedlings were scarce and patchy (six plots with 0, one with 4, and one with > 300 seedlings per 300 m^2 plot). In contrast, woody legume seedlings were about two orders of magnitude more abundant (mean 9 m^{-2}). These species store seeds

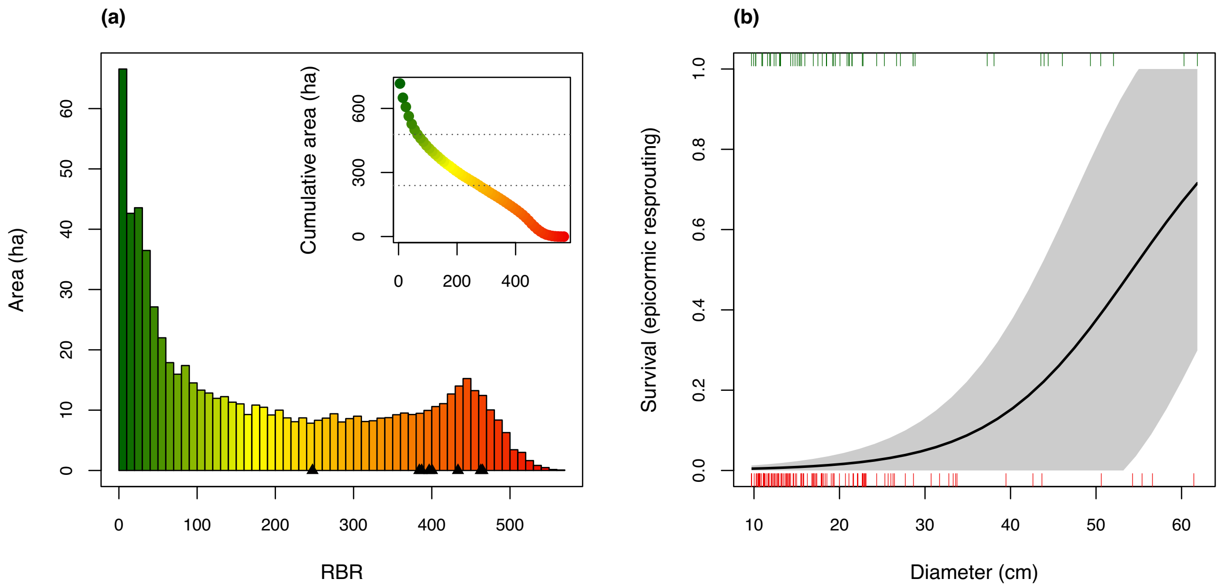

FIGURE 1 | Effect of the 2025 Barniedo fire (Picos de Europa, León, Spain) on the beech forest (*Fagus sylvatica*). (a) Area (in ha) of pure beech forest affected by fire in relation to the remotely sensed fire severity (*x*-axis; RBR: Relativized Burn Ratio). Black triangles on the *x*-axis indicate the RBR values of the 8 field plots sampled. Inset: The same data in cumulative area; horizontal lines are the 1/3 and 2/3 of the total beech forest within the fire (714 ha). RBR was estimated for 24 June 2026 using Sentinel-2A MSI Level-2A (surface reflectance) imagery as detailed in Beltrán-Marcos et al. (2026); the beech forest was delimited with the 4th Spanish National Forest Inventory and field observations. (b) Relation between the tree diameter and the probability of surviving in the 8 plots sampled (with relatively high severity; Figure 1a); the black line is a significant GLMM fit ($p < 0.0001$) considering plot as random factor (gray area is the 95% confidence interval). Trees with diameter < 10 cm (not included) were all dead. All surviving trees resprouted from epicormic buds, but crown recovery remained low (< 15%).

in the soil and have fire-released seed dormancy (Pausas and Lamont 2022). Given current climatic trends and observed seedling densities, beech is unlikely to colonize open spaces from unburned forests. A type-conversion to shrublands is very likely, implying a shift from non-flammable forest to flammable shrubland. To what extent this could generate a feedback that, in the long term, may erode most of the beech forest in the region remains to be studied.

Previous abrupt fire regime shifts in southern Europe have been driven primarily by landuse changes (Pausas and Fernández-Muñoz 2012). However, as warming intensifies, the relative role of climate in explaining fire regime changes is increasing. Overall, the Barniedo fire reduced more than one third of the beech forest, likely triggering a transition to more flammable shrublands and potentially generating a self-reinforcing feedback. Another third of the beech forest will be drastically reduced, and a proportion of the mixed *Fagus*–*Quercus* forest (433 ha) will lose its *Fagus* component. This reduction of beech is a consequence of the upslope advance of fire; similar advances are likely to occur latitudinally (northwards). This serves as a warning call for the renowned European beech forests and other temperate ecosystems.

Future vegetation projections typically emphasize climate-driven processes (e.g., niche shifts, physiological limits, climatic migrations) while often overlooking fire regime changes (e.g., Geßler et al. 2007; Cesaretti et al. 2026). Here we provide evidence that fire regime shifts may outweigh direct climatic effects. Nevertheless, climate change, in addition to enhancing fire activity, is likely to limit postfire regeneration and colonization of beech, thereby amplifying the impact of fire.

Global warming weakens the flammability barrier and enables fire to spread beyond fire-prone ecosystems, affecting fire-sensitive species. In the Anthropocene, terms like "non-flammable" and "pyrophobic" are becoming increasingly irrelevant.

Author Contributions

Juli G. Pausas: conceptualization, methodology, data curation, investigation, validation, formal analysis, visualization, writing – original draft, funding acquisition. **David Beltrán-Marcos:** investigation, data curation, writing – review and editing. **Luz Valbuena:** writing – review and editing, investigation, data curation.

Disclosure

AI statement: No text or figures were generated by AI tools; these tools were used only for minor English correction.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

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