Modeling post-fire regeneration patterns under different restoration scenarios to improve forest recovery in degraded ecosystems

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Applied nucleation (AN) is a nature-based solution alternative to traditional regular plantations. It is a cost-effective technique that integrates artificial seedlings and natural regeneration dynamics to enhance forest recovery, mimicking successional processes. Given the current shift of disturbance regimes caused by global change, this technique will likely be a valuable active restoration approach for many forest ecosystems affected by extreme disturbance events. Indeed, AN is suitable for ecological restoration after stand-replacing events, improving seed availability and microsite conditions supporting natural regeneration. AN has been mostly applied in tropical forests, but its use in Mediterranean forests should be increasingly considered since a higher occurrence of large and severe fires has been observed over the last decades and further increases are expected in the future. These changes are raising concerns about regeneration recruitment, particularly for obligate seeders in mountain ecosystems. In these ecosystems, it is crucial to reconsider current post-fire policies to identify strategies that promote and maintain the ecosystem services of degraded forests, particularly when natural regeneration is ineffective. The main aim of this study was to define the best methodology for implementing AN in a mountain area affected by a large stand-replacing fire that occurred in 2005 in the Aosta Valley Region (North-Western Italy). After the fire salvage logging was performed, increasing ecosystem degradation, and, 16 years later, natural regeneration is still scarce and struggling to settle.

Hotspots for AN were identified based on post-fire natural regeneration response to a series of site characteristics, such as topography, fire severity, and distance from seed trees. We assessed the drivers of post-fire regeneration through a machine learning correlative model (Bayesian Regression Tree, BART). The probability of regeneration presence across the landscape was then predicted under the current situation and a set of AN scenarios. Starting from the current scenario, we reclassified the prediction raster into three levels, according to the probability of presence and uncertainty. Polygons with low uncertainty and probability (< 0.3) were included in level one and considered hotspots for AN. From these predictions, it was possible to assess the most efficient active management scenario to speed up the regeneration process. Our results showed that AN could be a promising post-fire management technique for promoting natural regeneration while limiting anthropic interventions and their related economic and ecological...
costs.