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## Integrating green and grey measures for rockfall protection: technical and economic aspects

Stefano Bruzzese<sup>1</sup>, Simone Blanc<sup>1</sup>, Filippo Brun<sup>1</sup>, **Battista Taboni**<sup>2</sup>, Gessica Umili<sup>2</sup>, and Anna Maria Ferrero<sup>2</sup>

<sup>1</sup>Department of Agriculture, Forest and Food Sciences, University of Turin, Turin, Italy ([stefano.bruzzese@unito.it](mailto:stefano.bruzzese@unito.it))

<sup>2</sup>Department of Earth Sciences, University of Turin, Turin, Italy

Forests can effectively mitigate rockfall risk in mountainous contexts, acting as “nature-based solutions” (NBS). However, the use of artificial structures, for example, rockfall barriers, is usually necessary and complementary to ensure continuous and effective protection of specific elements at risk. In this work, we evaluate the forest protection service and the complementary effectiveness between NBS and rockfall barriers. The case study analysed, known as Alpe di Bazena, is located in the Italian Alps (municipality of Breno); it is a coniferous forest of about 8 hectares that, together with existing flexible barriers, protect from recurrent rockfall phenomena the underlying provincial road SP 345. At present, the forest partly fulfils its protective role, having been damaged by storm Vaia in 2018. Results from recent studies focused on the identification of rockfall source areas and block volume distribution were used for characterizing rockfall phenomena. For the economic evaluation of the forest protection service, the ASFORESEE model was used and a scenario analysis was carried out with four different levels of protection desired by stakeholders: 25, 50, 75 and 100%. The results show the effectiveness of the forest protection for all scenarios, with an estimated annual unit value of approximately 7,000 € ha<sup>-1</sup> y<sup>-1</sup> for both the first three scenarios, where the role played by the forest is sufficient, and in the last scenario, where an undersized rockfall barrier is required to complement the forest's action. This study proves quantitatively that the integration of green and grey measures could represent an optimization strategy in terms of costs and environmental benefits when dealing with rockfall phenomena.