Ecological restoration after windstorm Vaia: soil processes and functional diversity of vascular plants

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The increasing frequency and intensity of extreme climatic events threaten forest ecosystems, generating substantial economic and environmental impacts. Windstorms can alter ecosystem structure and functioning, with long-lasting consequences for ecosystem services. In 2018, north-eastern Italy was hit by the extreme windstorm Vaia, which damaged approximately 45 kha of forested areas and caused the loss of more than 12 million m³ of timber. Forest stands characterized by simplified structures and monoculture management were particularly vulnerable, highlighting the key role of biodiversity and soil health in determining ecosystem resilience to disturbance. This study assessed the effectiveness of restoration actions at three forest sites on the Asiago Plateau (Marcesina, Mosciagh, and Zebio) following windstorm Vaia. An integrated approach was adopted to evaluate ecosystem responses to disturbance and restoration. Soil properties, vegetation composition, and functional attributes were investigated in undisturbed inner woodland stands and compared with windthrown areas subjected to contrasting restoration strategies, including spontaneous revegetation and active planting after salvage logging. Soil health was evaluated using indicators related to microbial activity and nutrient cycling, including enzyme activities associated with carbon, nitrogen, and phosphorus cycles, as well as enzyme stoichiometry. Plant diversity was assessed in terms of species composition, richness, and functional diversity. Enzyme stoichiometry did not reveal significant differences in carbon and nutrient availability among areas, suggesting a resilience of soil processes to disturbance and management. Areas undergoing spontaneous succession hosted more diverse and functionally heterogeneous plant communities. Functional diversity was consistently higher in actively reforested areas, whereas functional redundancy tended to increase in passively restored areas, apart from the Zebio site. Overall, these findings provide valuable insights to support adaptive forest management strategies and inform the selection of restoration approaches aimed at enhancing forest resilience and improving the capacity of forest ecosystems to cope with future extreme climatic events.