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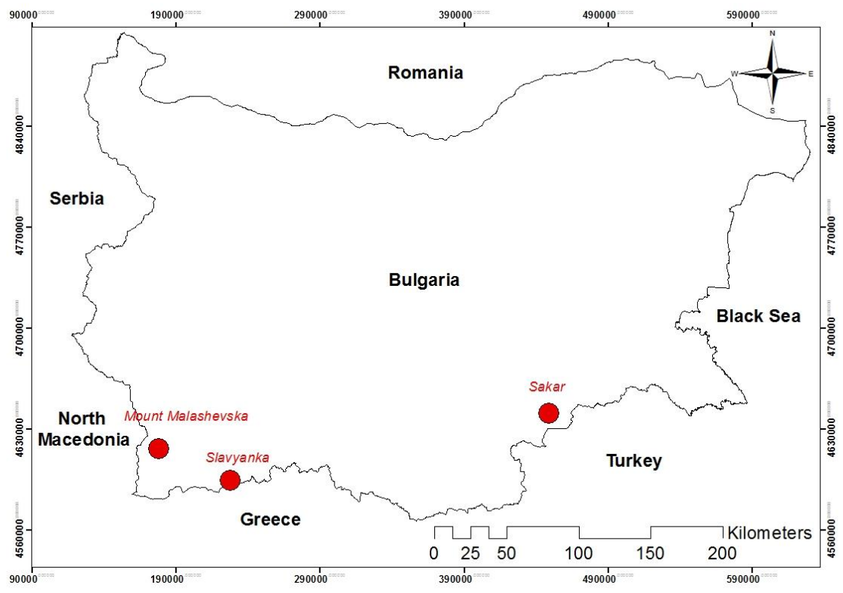
POST-FIRE RECOVERY DYNAMICS IN FOREST ECOSYSTEMS: A MULTISPECTRAL ANALYSIS OF RECOVERY TRAJECTTORIES

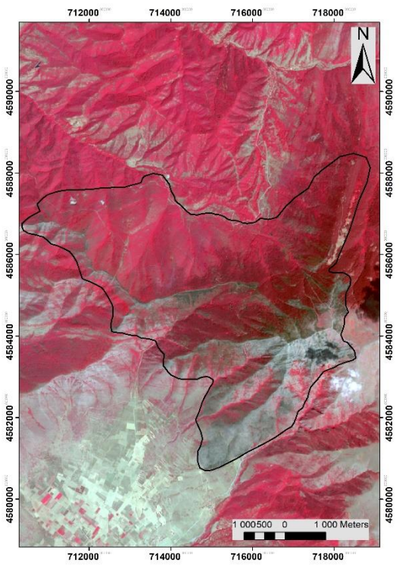
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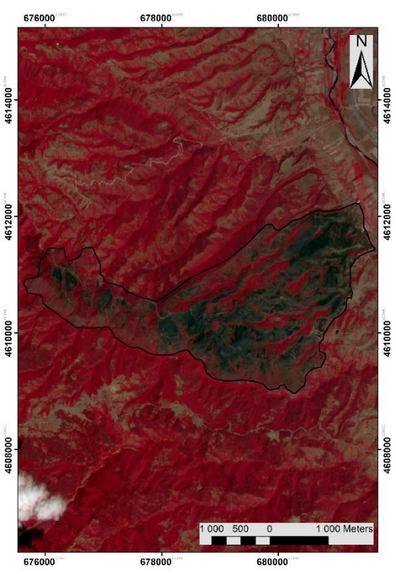
Abstract: *The Post-fire forest recovery is a complex and spatially heterogeneous process that may extend over several years and exhibit substantially different trajectories depending on fire severity, vegetation characteristics, and environmental conditions. This study investigates the temporal dynamics of post-fire vegetation recovery over a two-year period following three major wildfire events in Bulgaria, focusing on Slavyanka Mountain, Maleshevska Mountain, and Sakar Mountain. The analysis builds upon the previously developed and validated multispectral methodology based on the combined use of the Disturbance Index (DI) and Direction Angle (DA), implemented through the Post-Fire Recovery Module Output (PFRMO). Sentinel-2 multispectral imagery acquired during the 2024–2026 growing seasons was used to characterize post-fire ecosystem conditions and their temporal evolution. A Recovery Rate metric based on the temporal change in PFRMO between 2024 and 2026 is introduced to quantify the magnitude and direction of recovery. Based on the observed temporal response, affected forest areas are classified into four recovery categories: rapid, moderate, and slow recovery, and persistent disturbance. The results are expected to reveal substantial spatial differences in recovery rates among the three study areas and within individual burned landscapes, reflecting differences in initial disturbance intensity, vegetation composition, topography, and post-fire regeneration potential. The proposed approach provides a quantitative framework for distinguishing contrasting recovery trajectories and for identifying areas where ecosystem recovery remains limited two years after wildfire. The study demonstrates the potential of multispectral satellite time series and the PFRMO-based Recovery Rate for supporting consistent, spatially explicit assessment of post-fire ecosystem resilience and informing priorities for long-term forest monitoring and restoration.*

STUDY AREA

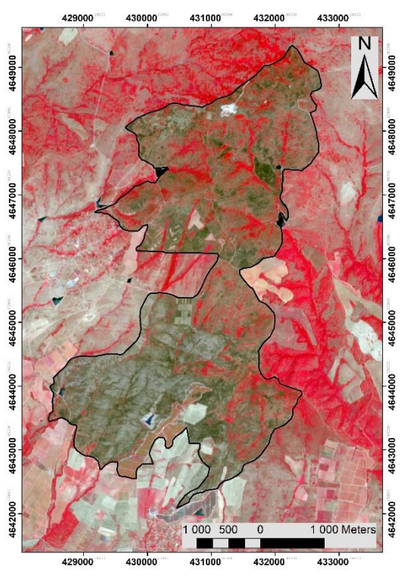




Slavyanka



Maleshevska



Sakar

Study area	Region	Fire Period	Burned area	Dominant vegetation	Topography
Slavyanka	SW Bulgaria, border with Greece	08/2024	2,000 ha	Mixed coniferous and broadleaf forests	Mountainous, steep slopes
Maleshevska	SW Bulgaria, Blagoevgrad Province	07/2024	3,000 ha	Drought-tolerant broadleaf species and shrublands	Hilly to pre-mountains
Sakar	SE Bulgaria Haskovo Province	07/2024	10,000 ha	Oak-dominated formations and shrublands	Low to mid-elevation mountainous

METHODOLOGY

- *Recovery Rate (RR) was introduced to quantify the temporal rate of post-fire recovery between 2024 and 2026*
- *Since higher PFRMO values indicate greater post-fire disturbance within the applied classification framework, the Recovery Rate was defined as the annual decrease in PFRMO*

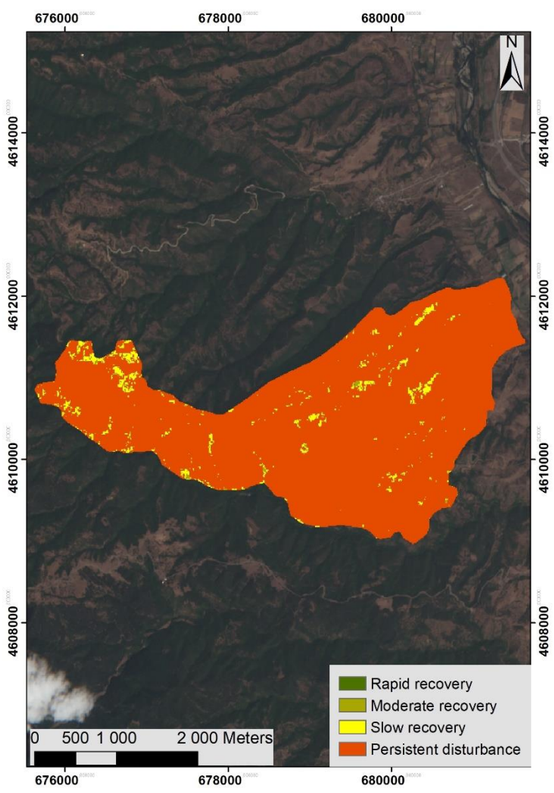
$$RR = \frac{PFRMO\ 2024\ - PFRMO\ 2026}{2}$$

- *Positive RR values therefore indicate a reduction in disturbance and consequently a recovery trajectory, whereas values equal to or below zero indicate persistent disturbance or deterioration*

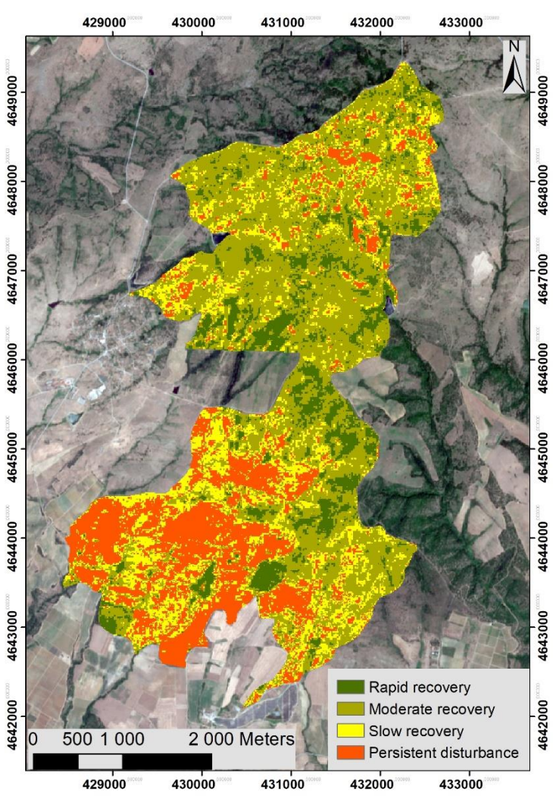
RESULTS



Spatial distribution of post-fire recovery classes on Slavyanka Mountain (2024–2026), classified as rapid, moderate, and slow recovery, and persistent disturbance based on Recovery Rate



Recovery Rate-based classification of post-fire vegetation recovery across Slavyanka Mountain (2024–2026), highlighting spatial patterns of rapid, moderate, and slow recovery, alongside persistent disturbance.



Recovery Rate-based mapping of post-fire vegetation dynamics in the Sakar Mountain study area (2024–2026), highlighting spatial contrasts among rapid, moderate, and slow recovery zones and areas of persistent disturbance