

Natural disturbances, from severe winds, through wildfires and droughts, to insect outbreaks, have shaped forest structure for centuries. Today, rising temperatures and prolonged drought periods are accelerating both their scale and pace. In Central-European forests the greatest losses are now caused by the European spruce bark beetle (*Ips typographus* L.), which exploits drought-weakened Norway spruces (*Picea abies* (L.) H. Karst). Since 2012 this insect has triggered an unprecedented wave of mortality in the Polish part of the Białowieża Forest: between 2015 and 2019 almost two million spruces died. The resulting canopy gaps have expanded deadwood resources and hastened a shift toward deciduous dominance. While opening a new chapter in ecosystem development, these changes also raise pressing questions about the future resilience and biodiversity of Białowieża Forest stands.

The complexity of these transformations exceeds the reach of conventional field measurements. Only wall-to-wall, time-series remote-sensing data can capture them comprehensively. Cutting-edge techniques, especially airborne laser scanning (ALS) and multispectral imagery, provide three-dimensional information on tree height, canopy closure and deadwood distribution, while simultaneously distinguishing species through their spectral and structural signatures. Four-date ALS (2015, 2019, 2022, 2026) span the entire disturbance–recovery trajectory, forming a globally unique dataset that tracks both the course of the outbreak and the subsequent regeneration of this unique forest.

The project aims to clarify the spatial and temporal processes of succession, structural reconstruction, and biodiversity changes in Białowieża Forest stands following large-scale disturbance. By integrating multi-temporal ALS, multispectral imagery and measurements from a network of monitoring plots, we will quantify the rate and direction of spruce replacement by deciduous species across habitat types and management zones; map the dynamics of structural metrics such as height, canopy density and gaps; and relate these patterns to selected biodiversity indicators. We will also evaluate how effectively multi-temporal remote sensing combined with machine-learning algorithms can depict these processes from individual trees to the landscape level.

The project will deliver time-series maps of species composition, vertical structure and biodiversity change. Spatial statistical models will identify factors that accelerate or inhibit post-disturbance succession. All outputs will be published through an interactive web-GIS platform, enabling foresters, scientists and conservation agencies to track regeneration, delineate passive-protection zones and forecast the risk of future outbreaks.

Backed by an interdisciplinary team that merges expertise in remote sensing, geoinformatics, statistics and forest ecology, the project will generate not only new scientific insights but also practical tools for sustainable forest management under mounting climatic pressure. The methods developed in Białowieża Forest will offer a reference framework for disturbance monitoring across Europe's forests and strengthen the implementation of EU biodiversity strategies and climate-reporting obligations.