

Ecosystem disturbances in Central European spruce forests: a multi-proxy integration of dendroecology and sedimentary records

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Disturbance dynamics in forest ecosystems shows signs of perturbation in the light of changing climate regimes with the frequency and intensity of events (e.g. pathogens in North America and Central Europe) amplified, becoming more frequent and severe. The montane Norway spruce (*Picea abies*) dominated forests of Central Europe are a niche habitat and environment; situated outside their natural boreal distribution (e.g. Fenno-Scandinavia). These communities are at or near their ecological limits and are vulnerable to both short term disturbances (e.g. fire, windstorm and pathogens) and longer-term environmental change (e.g. climate induced stress and changing disturbance patterns).

Researches have linked negative impacts on spruce forest with both wind disturbance (wind-throw) and outbreaks of spruce bark beetle (*Ips typographus*), and there is growing evidence for co-association with wind damage enhancing pathogenic outbreaks. Examples include: in the Bohemian Forest (Czech Republic) the mid-1990s spruce bark beetle outbreak and the 2007 windstorm and subsequent bark beetle outbreak. In the High Tatra Mountains (Slovakia) there is a further co-association of forest disturbance with windstorms (2004 and 2014) and an ongoing bark beetle outbreak. The scale and severity of these recent outbreaks of spruce bark beetle are unprecedented in the historical forest records.

Here, findings from ongoing research developing and integrating data from dendroecological, sedimentary palaeoecological and geochemical time series to develop a longer-term perspective on forest dynamics in these regions. Tree-ring series from plots or forest stands (>500) are used alongside lake (5) and forest hollow (3) sediments from the Czech and Slovak Republics to explore the local, regional and biogeographical scale of forest disturbances. Dendroecological data showing tree-ring gap recruitment and post-suppression growth release highlight frequent disturbance events focused on tree or forest stand spatial scales, but are patchy in terms of reoccurrence. However they highlight levels of disturbance in the late 19th Century. Sediment records from lakes and forest hollows record variable pollen influx (beetle host / non-host ratios) and a stratigraphy that includes mineral in-wash events. μ XRF scanning of lakes in the region with varying catchments and catchment-to-lake area ratios show spikes in K, Zr, Ti concentrations reflecting frequent erosive episodes throughout the Holocene.

Linking across the temporal scales inherent in dendroecological (0 to 250 years) and sedimentary (0 to 11,500 years) is enhancing our understanding of disturbance dynamics. The identified recent and ongoing forest disturbances coupled with well-evidenced events in the 19th century highlight the need for the longer sedimentary perspective to assess whether contemporary climate warming has and continues to stretch the resilience of these fragile ecosystems. Our data are informative to the ongoing land-management conflict between active forest management (harvesting valuable timber and salvage logging) and forest conservation agenda encouraging forest dynamics and disturbance recovery.