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The Role of Soil in Forest Drought Response: Remote Sensing-Based Monitoring of Disturbance Hotspots in Central Europe

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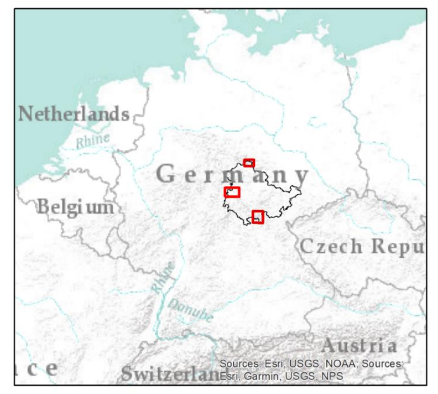

Crown defoliation of European beech (left) and standing deadwood of Norway spruce (right).

Introduction

Prolonged drought and increased susceptibility to biotic stressors have led to a far-reaching calamity in forests dominated by Norway spruce (*Picea abies*) across Central Europe. European beech (*Fagus sylvatica*) has suffered from crown defoliation and increased mortality. The drastic consequences for forestry and ecosystems urge for comprehensive insights to guide future forest management. The recent drought represents an experimental **setting for applying remote sensing-based anomaly detection to understand the role of site conditions for drought response**. As quantitative information on soils is scarce and usually available at coarse spatial resolution, knowledge on the role of soil properties is limited. To close this gap, **our study pioneers a fine-scale assessment on the role of soil properties based on satellite remote sensing-derived forest disturbance**.

Methods

We applied an existing **forest disturbance modeling framework, based on Sentinel-2 time series data** on 340 km² in Central Germany (Fig. 1) [1], representing regions with hotspots of forest disturbance.

Forest disturbance information was intersected with fine-scale soil information (1:10,000) based on roughly 2,870 soil profiles in three study areas.

We then on how percentages of disturbed area varied among sites with different **soil type, texture, stoniness, effective rooting depth and available water capacity (AWC)** in forest stands of Norway spruce or European beech.

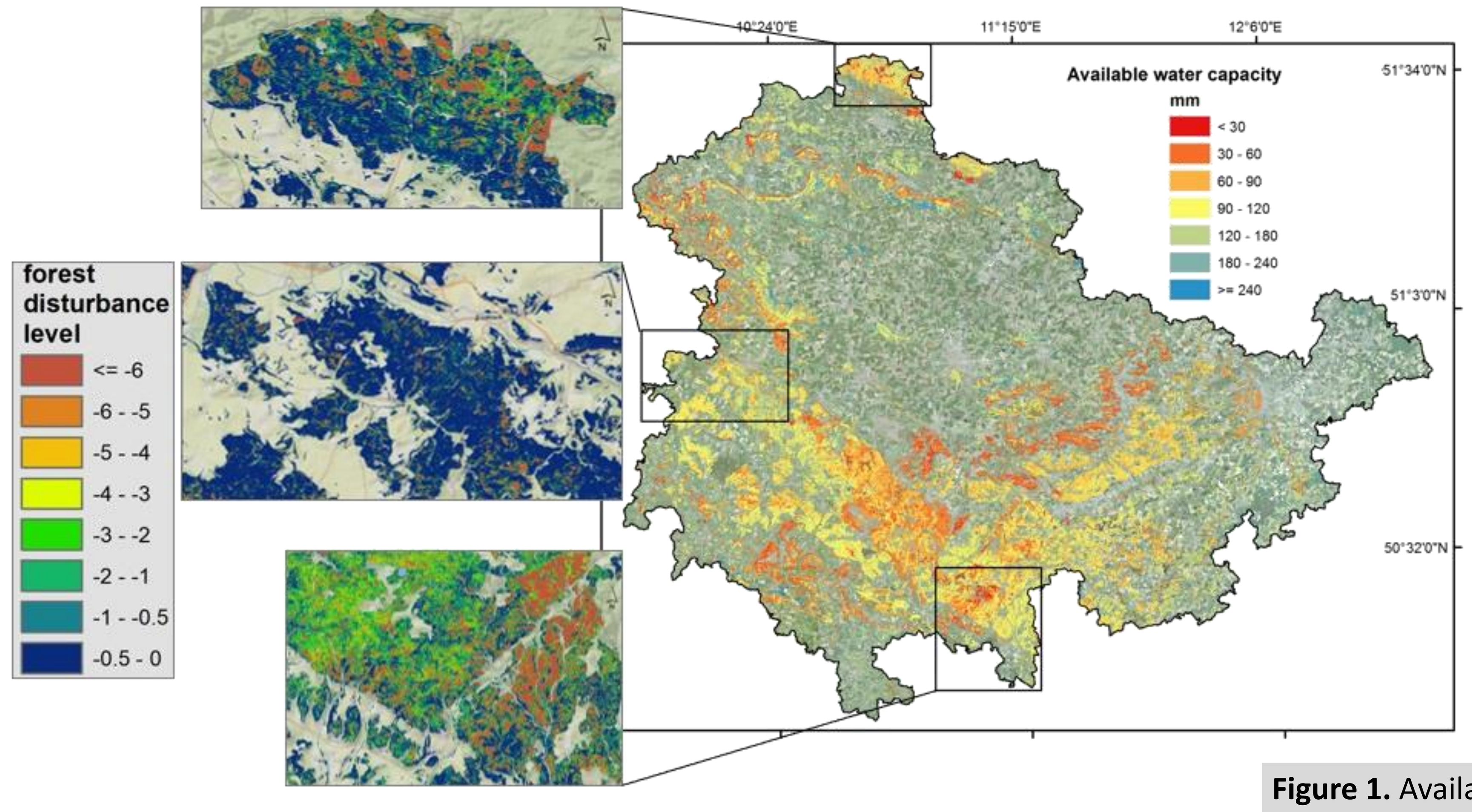

Figure 1. Available water capacity in mm across forest areas in Thuringia, Germany and forest disturbance levels by the end of 2021 in the study regions.

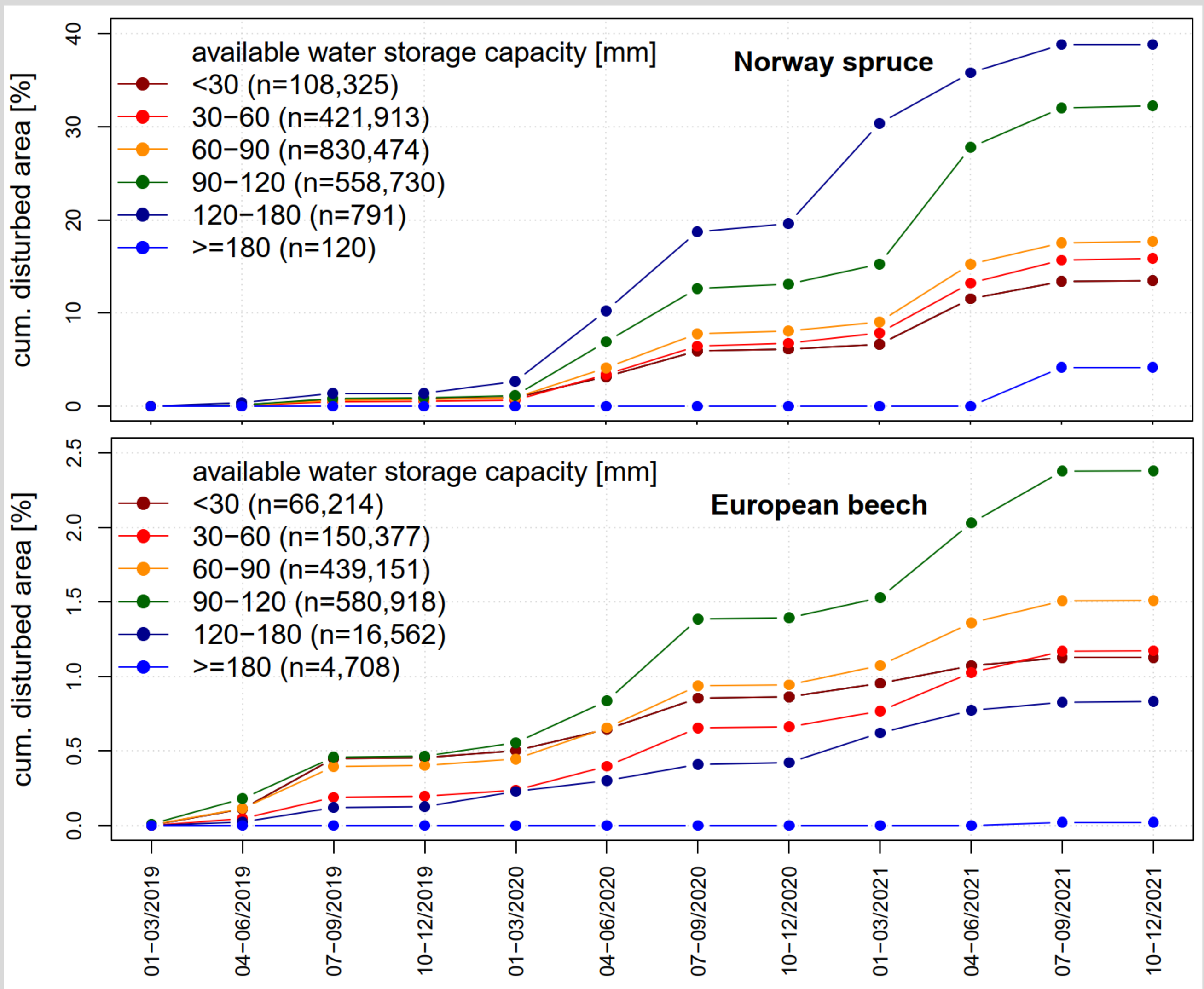

Figure 2. Evolution of cumulative severely disturbed area calculated in 3-month intervals in (a) spruce and (b) beech stands across different levels of AWC. Number of observations n (i.e., referring to extracted values at pixel centers) are given.

Results & Discussion

Our approach allowed for a reconstruction of spatio-temporal-dynamics of forest disturbance at 10 m spatial resolution over the initial period (2019 to 2021) of the recent drought (Fig 1, 2). Stands of **Norway spruce were most affected on deep Cambisols with medium to high AWC (90 to 160 mm) and rather low stone content** (Fig. 3, 4). Overall, we could not find evidence for pronounced disturbance on shallow soils or soils with high stone content. This finding coincides with field studies, associating lower risk of spruce bark beetle attacks with stands on chronically dry soils [2]. The drought response of beech seemed less clearly directed to soil properties, but based on our results, we support the general concern on drought vulnerability of this species [3]. Although long-term post-drought effects are unknown, **stands initially affected did not necessarily develop the highest proportions of disturbed area** (Fig. 2), thereby indicating recovery or adaptive mechanisms.

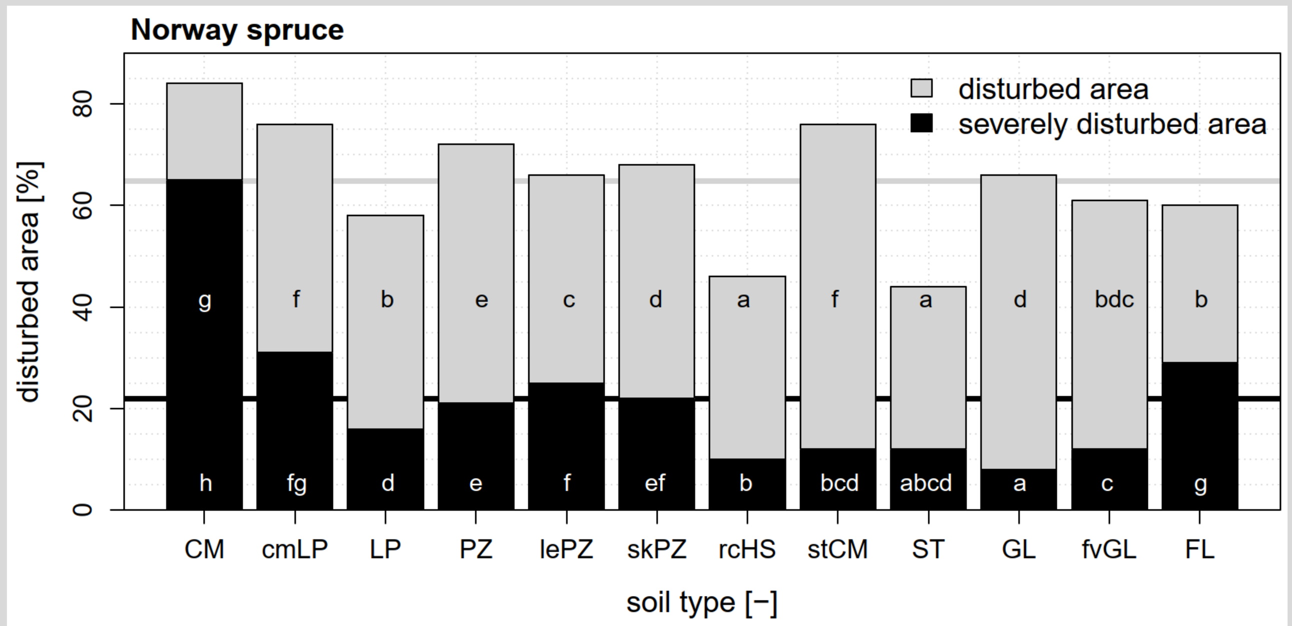

Figure 3. Disturbed area across different soil types. Disturbed area (FDL ≤ -1) shown in light gray and severely disturbed area in black (FDL ≤ -7); The horizontal lines correspond to the mean disturbed area; Different lowercase letters indicate significant ($p < 0.05$) differences with soil properties for forest disturbance. Abbreviations of soil types: ablV = Albic Luvisol, CM = Cambic Leptosol, cmLP = Cambic Leptosol, LP = Leptosol, PZ = Podzol, lePZ = Leptic Podzol, skPZ = Skeletic Podzol, rcHS = Rockic Histosol, stCM = Stagnic Cambisol, ST= Stagnosol, GL= Gleysol, fvGL = Fluvic Gleysol, FL = Fluvisol.

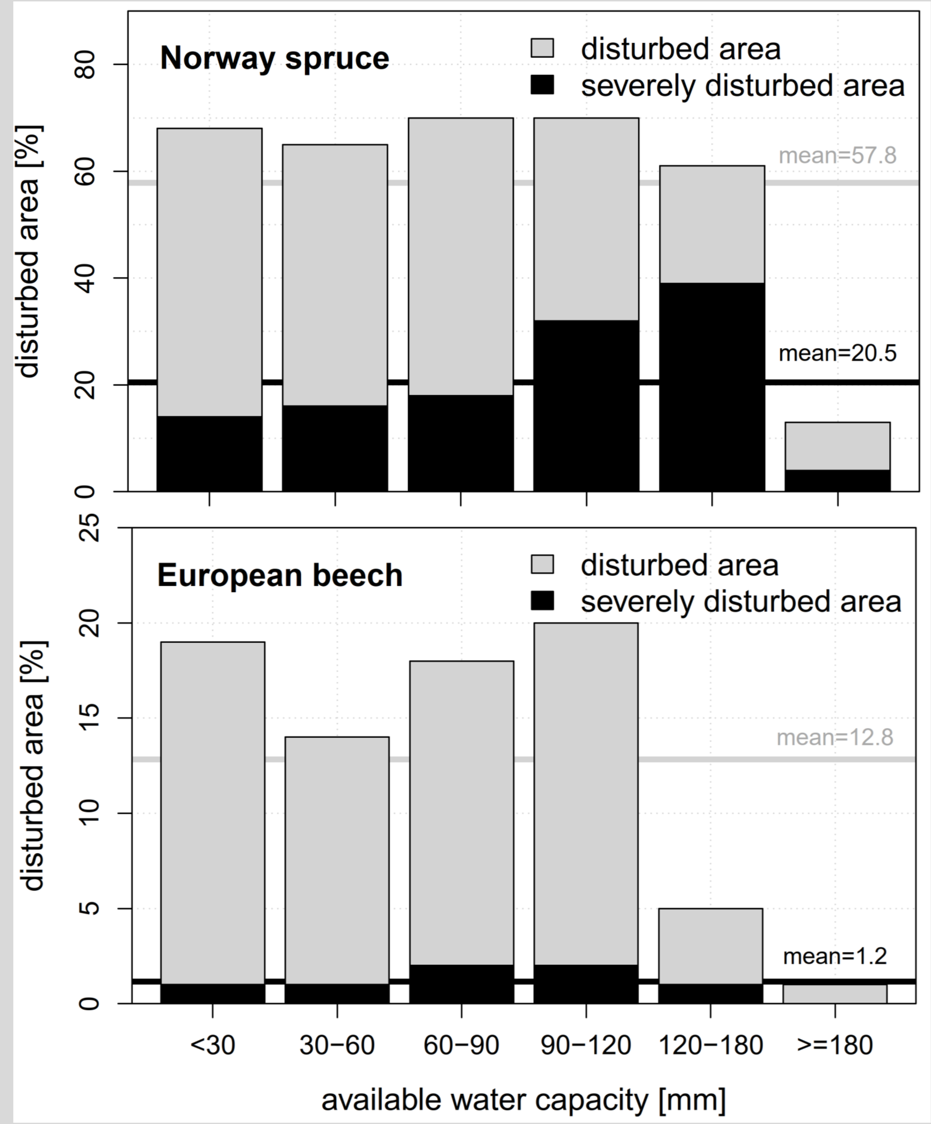

Figure 4. Disturbed area across different classes of available water capacity. Disturbed area (FDL ≤ -1) shown in light gray and severely disturbed area in black (FDL ≤ -7); The horizontal lines correspond to the mean disturbed area.

Conclusion

We conclude that the integration of remote sensing-based forest disturbance monitoring with fine-scale soil information allows insights into soil-related drought risks. In view of the currently still high level of spruce die-back due to bark beetle infestation, disturbance in the hotspot regions we investigated will hardly to be stopped. Nevertheless, other, more Northern areas with a high proportion of spruce could benefit from our findings, by identifying vulnerable stands and target in situ monitoring at an early stage of drought.

References

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Sharing is encouraged

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