Differentiating standing deadwood and clear-cuts in recent Bavarian spruce forest disturbances

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Recent years have seen a continuing increase in tree mortality in European forests[1,2], with multiple biotic and abiotic drivers exerting pressure on the ecosystem. The response to these forest disturbance dynamics by forest managers has significant consequences on the local forest structure, biodiversity and regrowth. Especially the decision on how deadwood is treated after a disturbance is crucial, due to the value of remaining deadwood concerning local biodiversity and habitats, as well as its role in nutrient cycles and water regulation. In terms of carbon sequestration, detection and removal of deadwood with follow-up treatment of cleared areas is common practice. In order to assess forest dynamics beyond binary classifications of disturbed and intact forest and to gain insights into deadwood treatment, a differentiation of standing deadwood and clear-cut areas is required.

While several Germany-wide products on forest disturbances, condition, or vitality are available at varying temporal and spatial resolution, a distinction between standing deadwood and clear-cut areas following a disturbance is usually not made. An exception are the annual maps of fractional standing deadwood since 2018 by Schiefer et al. 2023[3]. Although valuable in many contexts, it is unable to provide information for discrete forest disturbance events that occur within a year.

Our work aims at filling this gap by providing a distinction between standing deadwood and clear-cut for disturbances in Bavarian spruce forests between late 2017 and 2025. For the disturbance dataset, we relied on a biweekly map for Bavaria at 10 m resolution that follows the canopy cover loss detection method by Thonfeld et al. 2022[1]. From this dataset we extracted only the disturbances that occurred in spruce forests using

[1] Thonfeld, F., Gessner, U., Holzwarth, S., Kriese, J., da Ponte, E., Huth, J., & Kuenzer, C. (2022). A First Assessment of Canopy Cover Loss in Germany's Forests after the 2018–2020 Drought Years. *Remote Sensing*, 14(3), 562, https://doi.org/10.3390/rs14030562

[2] Schiefer, F., Schmidtlein, S., Hartmann, H., Schnabel, F., & Kattenborn, T. (2025). Large-scale remote sensing reveals that tree mortality in Germany appears to be greater than previously expected. *Forestry: An International Journal of Forest Research*. Volume 98. Issue 4. Pages 535–549. https://doi.org/10.1093/forestry/cpae062

[3] Schiefer, F., Schmidtlein, S., Frick, A., Frey, J., Klinke, R., Zielewska-Büttner, K., Junttila, S., Uhl, A. & Kattenborn, T. (2023). UAV-based reference data for the prediction of fractional cover of standing deadwood from Sentinel time series. *ISPRS Open Journal of Photogrammetry and Remote Sensing*, 8, 100034.

a tree type map for the year 2017. We applied a temporal convolutional neural network (TempCNN)[4] on satellite image time series to perform the classification for each disturbance pixel. This model works by convoluting along the time dimension and consequently learns temporal features. We relied on time series of the disturbance index (DI) derived from all Sentinel-2 and Landsat observations in the analyzed time frame. For each disturbance event, we extracted the index values for 6 months pre- and post-disturbance to retrieve representative signals for the classes standing deadwood, clear-cut and intact forest. The training data was labelled with the use of the Bavarian digital orthophotos. We therefore only selected disturbances for which we could retrieve orthophotos that were acquired close to the detection date.

First results in a local test region in northern Bavaria indicate good results for the classes *clear-cut* and *intact forest*, with an F1 score of 0.97 and 0.98, respectively. The class *standing deadwood* achieved a F1 score of 0.79. This is most likely due to this class being the most ambiguous in terms of raw signal as well as signal stability over time. We plan to expand this analysis and a thorough validation to all spruce forests in Bavaria in order to provide differentiations for all disturbances between 2017 and 2025.

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[4] Pelletier, C., Webb, G. I., & Petitjean, F. (2019). Temporal Convolutional Neural Network for the Classification of Satellite Image Time Series. *Remote Sensing*, 11(5), 523. https://doi.org/10.3390/rs11050523