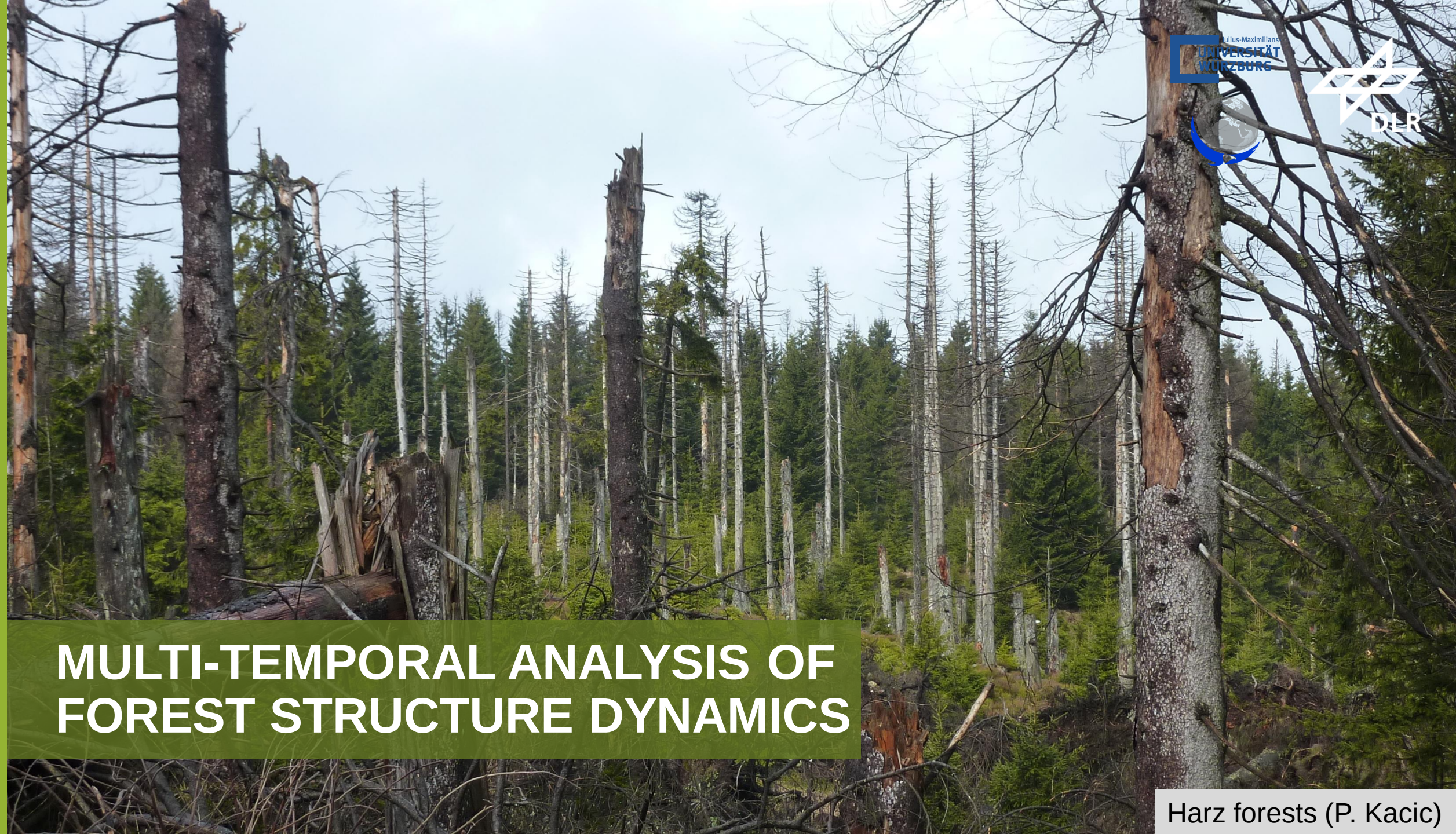
CHARACTERIZING RECENT FOREST STRUCTURE DYNAMICS IN GERMANY BASED ON GEDI, SENTINEL-1 AND SENTINEL-2

Patrick Kacic [1], Frank Thonfeld [2], Ursula Gessner [2], Claudia Kuenzer [1,2]

patrick.kacic@dlr.de

[1] Julius-Maximilians University Würzburg (JMU), Germany

[2] German Aerospace Center (DLR)



MULTI-TEMPORAL ANALYSIS OF FOREST STRUCTURE DYNAMICS

Harz forests (P. Kacic)

Forest Structure Characterization in Germany – Methodology

remote sensing

MDPI

Article

Forest Structure Characterization in Germany: Novel Products and Analysis Based on GEDI, Sentinel-1 and Sentinel-2 Data

Patrick Kacic [1,*], Frank Thonfeld [2], Ursula Gessner [2] and Claudia Kuenzer [1,2]

[1] Department of Remote Sensing, Institute of Geography and Geology, University of Würzburg, 97074 Würzburg, Germany
[2] German Remote Sensing Data Center (DFD), German Aerospace Center (DLR), 82234 Wessling, Germany
* Correspondence: patrick.kacic@dlr.de

Abstract: Monitoring forest conditions is an essential task in the context of global climate change to preserve biodiversity, protect carbon sinks and foster future forest resilience. Severe impacts of heatwaves and droughts triggering cascading effects such as insect infestation are challenging the semi-natural forests in Germany. As a consequence of repeated drought years since 2018, large-scale canopy cover loss has occurred calling for an improved disturbance monitoring and assessment of forest structure conditions. The present study demonstrates the potential of complementary remote sensing sensors to generate wall-to-wall products of forest structure for Germany. The combination of high spatial and temporal resolution imagery from Sentinel-1 (Synthetic Aperture Radar, SAR) and Sentinel-2 (multispectral) with novel samples on forest structure from the Global Ecosystem Dynamics Investigation (GEDI, LiDAR, Light detection and ranging) enables the analysis of forest structure dynamics. Modeling the three-dimensional structure of forests from GEDI samples in machine learning models reveals the recent changes in German forests due to disturbances (e.g., canopy cover degradation, salvage logging). This first consistent data set on forest structure for Germany from 2017 to 2022 provides information of forest canopy height, forest canopy cover and forest biomass and allows estimating recent forest conditions at 10 m spatial resolution. The wall-to-wall maps of the forest structure support a better understanding of post-disturbance forest structure and forest resilience.

Keywords: forest; forest structure Germany; canopy height; Global Ecosystem Dynamics Investigation; GEDI; Sentinel-1; Sentinel-2; random forest regression

Citation: Kacic, P.; Thonfeld, F.; Gessner, U.; Kuenzer, C. Forest Structure Characterization in Germany: Novel Products and Analysis Based on GEDI, Sentinel-1 and Sentinel-2 Data. *Remote Sens.*

Combination of **complementary sensors**:

GEDI ECOSYSTEM LIDAR sentinel-1 sentinel-2

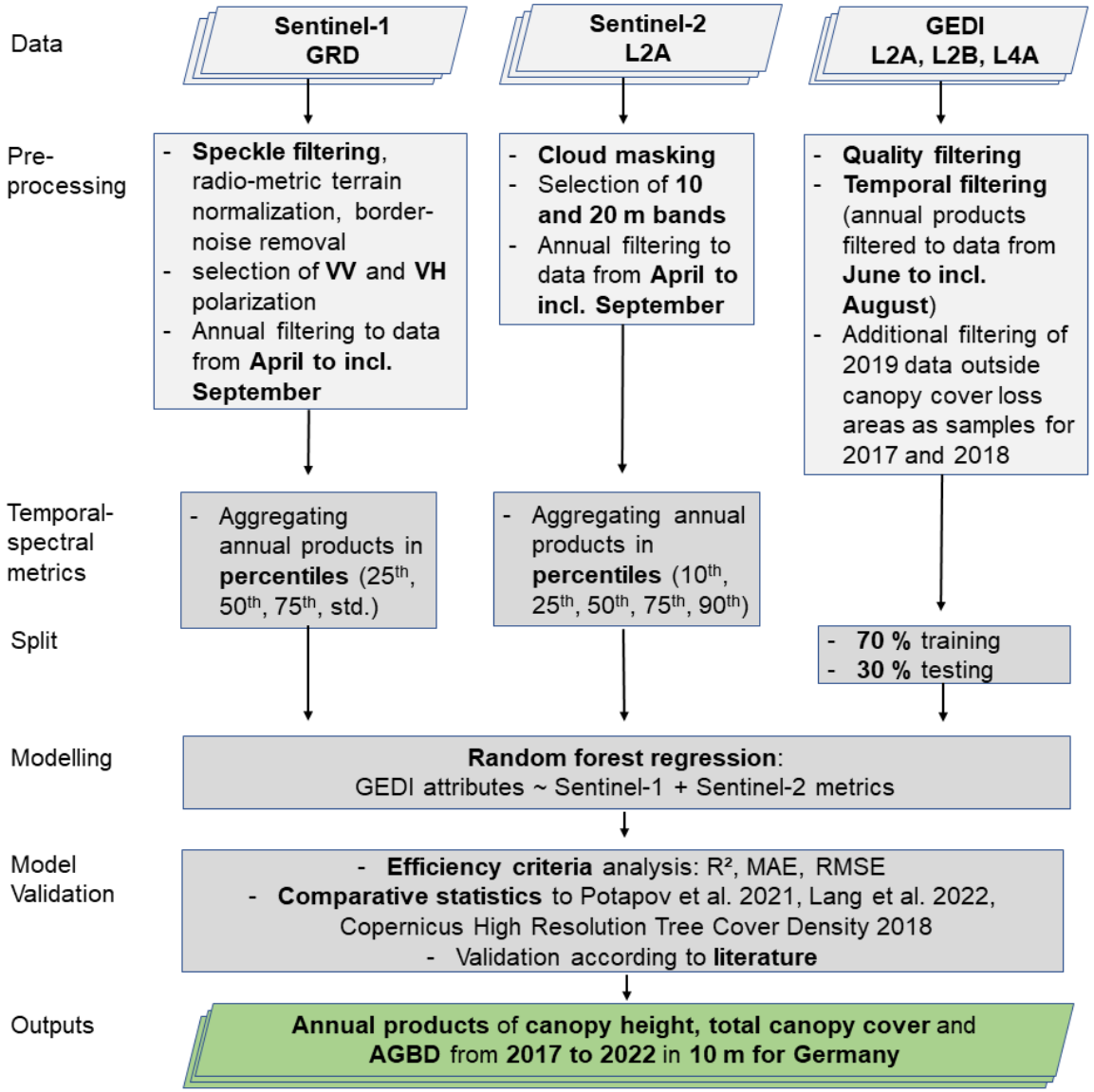
https://daac-news.ornl.gov/content/moving-version-2-gedi-data-products, https://www.esa.int/eologos/

Quantitative assessment of

- forest **canopy height,**
- forest **total canopy cover,**
- forest **above-ground biomass density (AGBD)**

from **2017 to 2022** in **10 m** spatial resolution

Forest Structure Characterization in Germany – Methodology



Combination of **complementary sensors**:

GEDI ECOSYSTEM LIDAR sentinel-1 sentinel-2

https://daac-news.ornl.gov/content/moving-version-2-gedi-data-products, https://www.esa.int/eologos/

Quantitative assessment of

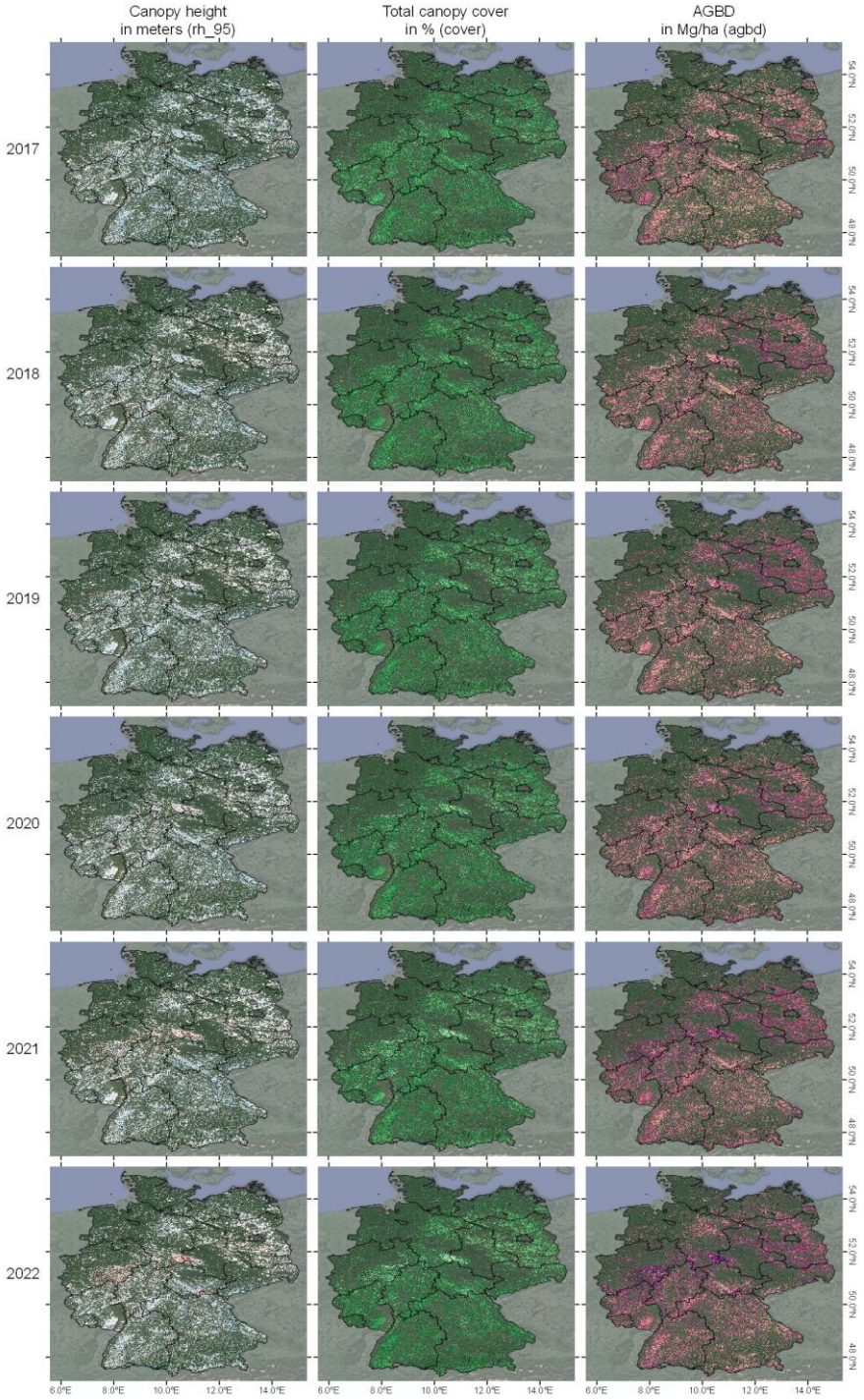
- forest **canopy height,**
- forest **total canopy cover,**
- forest **above-ground biomass density (AGBD)**

from **2017 to 2022** in **10 m** spatial resolution

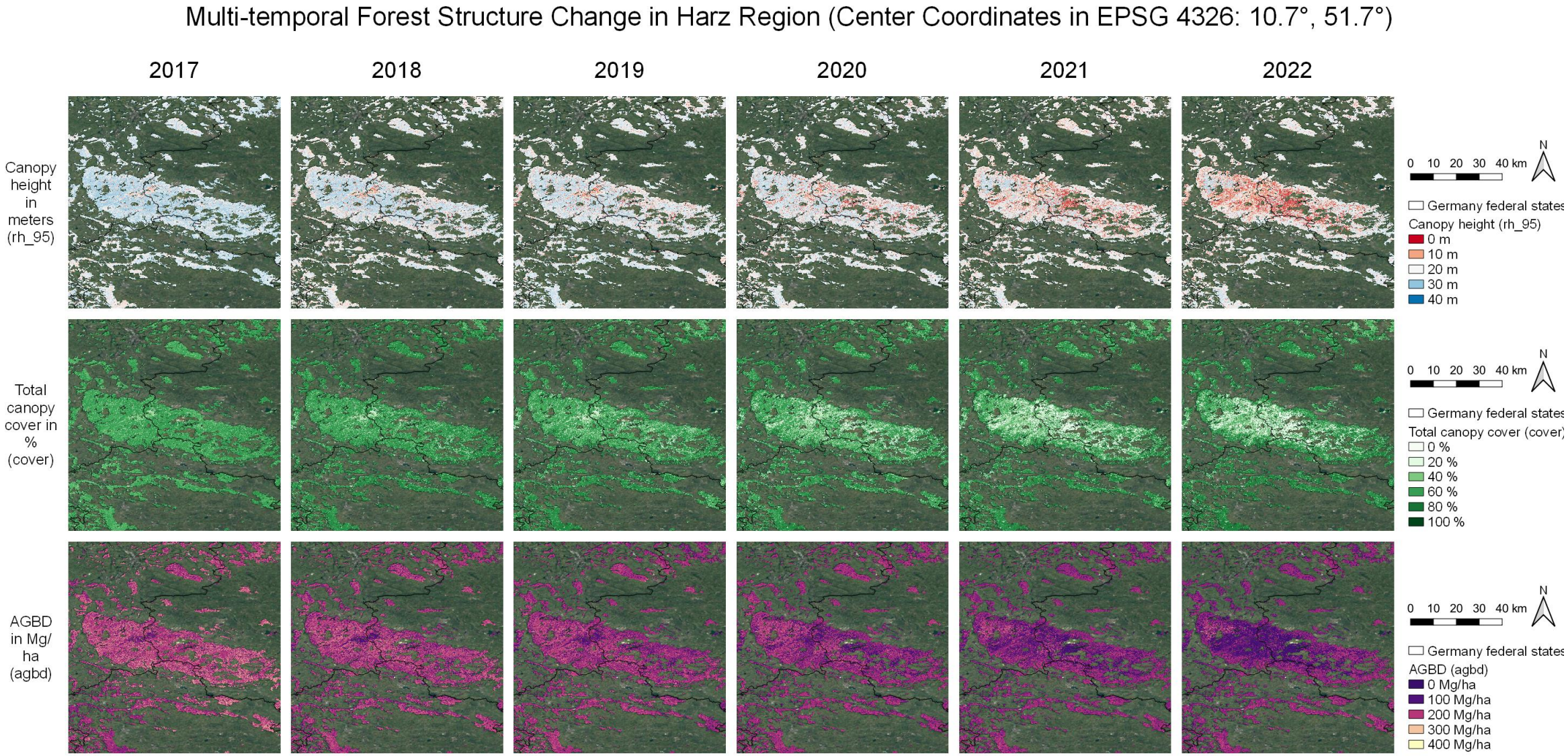
Forest Structure Characterization in Germany – Model Accuracy

Mean Statistics of all years:
R^2=coefficient of determination, MAE=Mean Absolute Error

Canopy height:	64.6 % (R^2)	4.4 m (MAE)
Total canopy cover:	67.0 % (R^2)	12.5 % (MAE)
AGBD:	58.8 % (R^2)	41.0 Mg/ha (MAE)



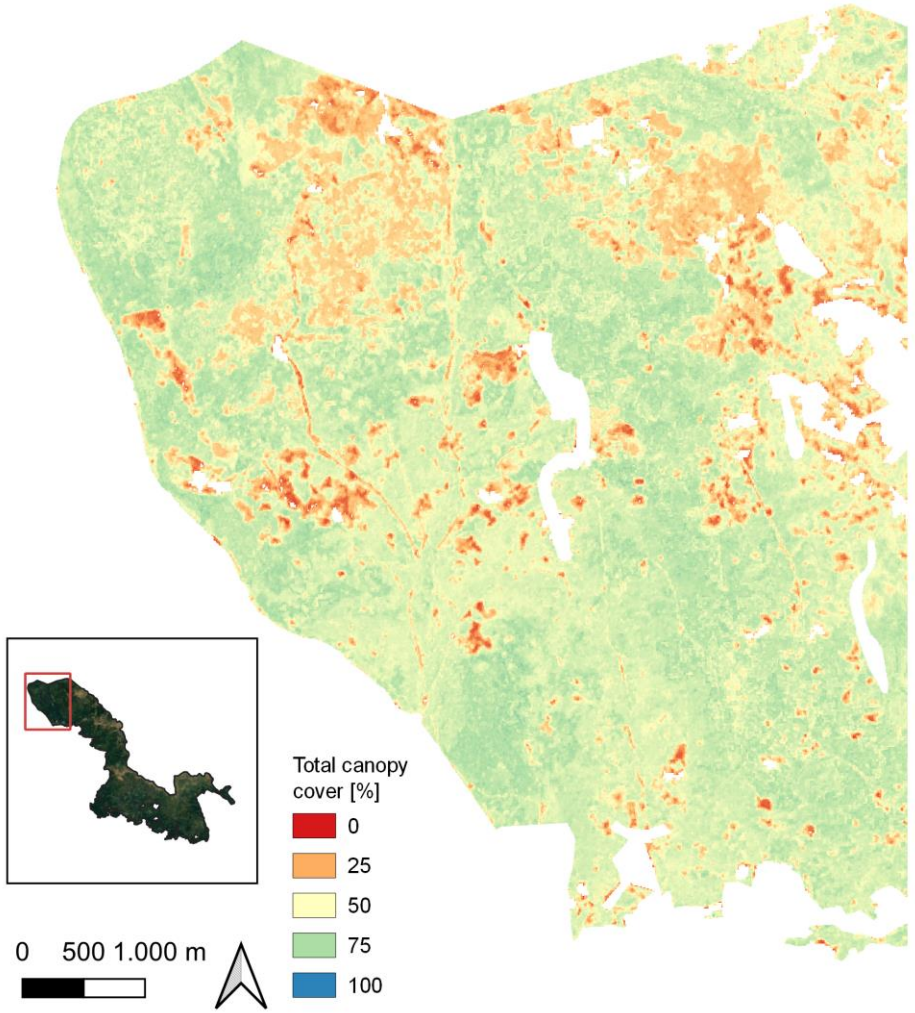
Forest Structure Characterization in Germany – Harz Forest Region



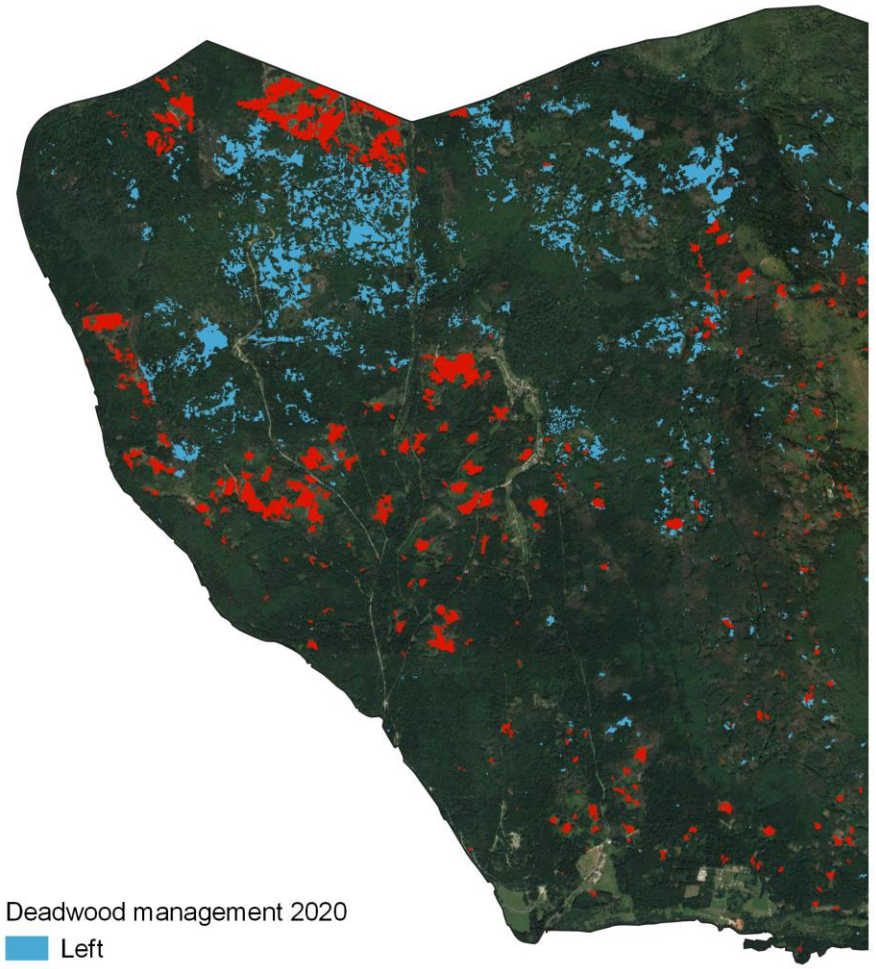
Forest Structure Characterization in the Bavarian Forest NP – Canopy Height

Forest Structure Characterization in the Bavarian Forest NP – Total Canopy Cover

Forest Total Canopy Cover 2020

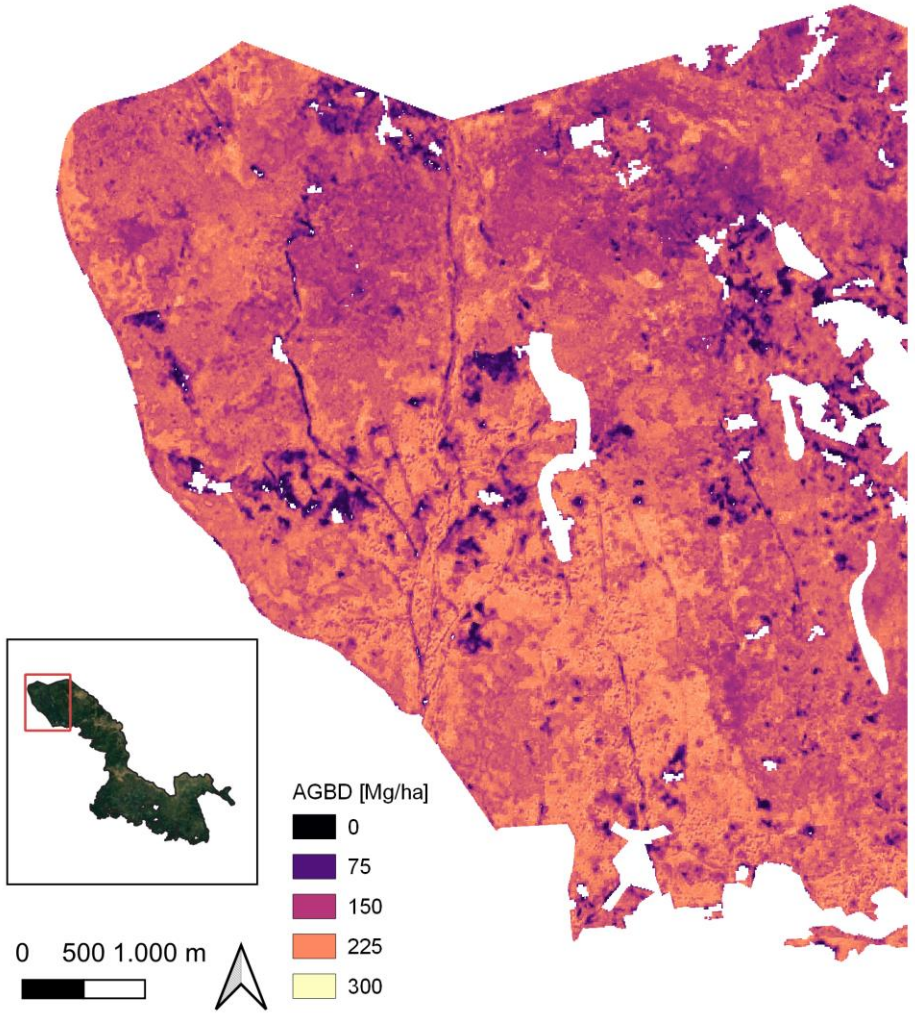


Deadwood Mapping (2020)

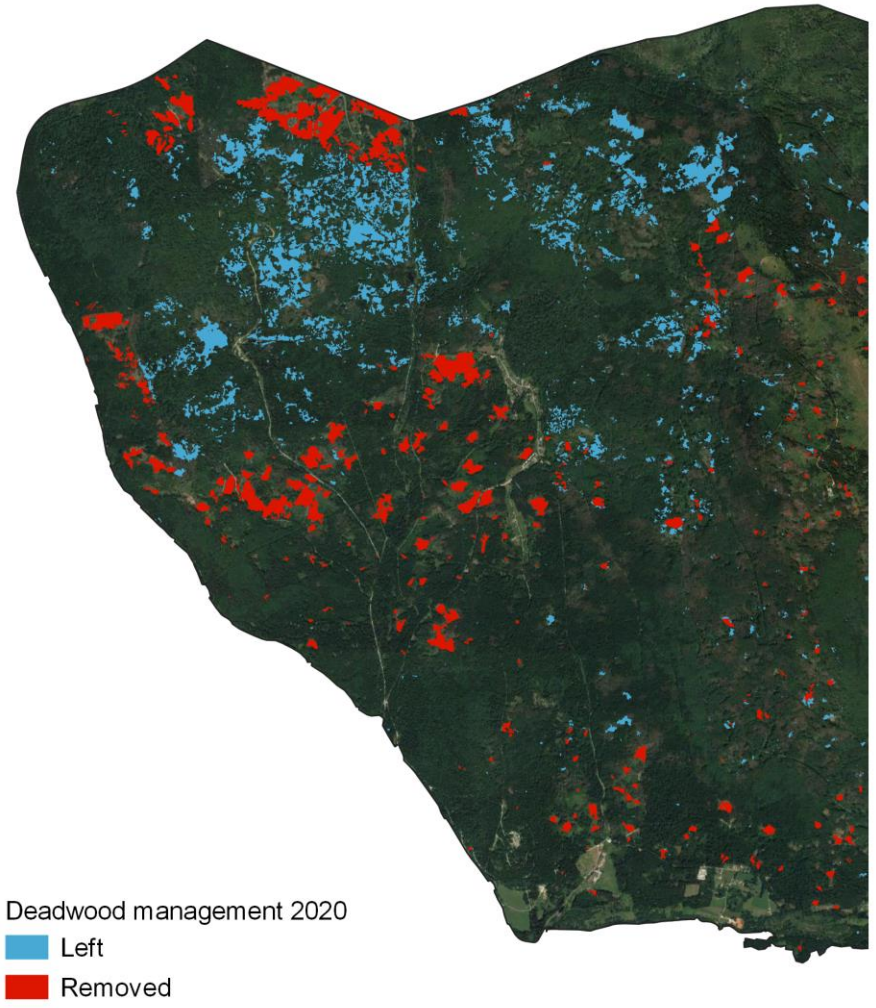


Forest Structure Characterization in the Bavarian Forest NP – Above-Ground Biomass Density (AGBD)

Forest AGBD 2020



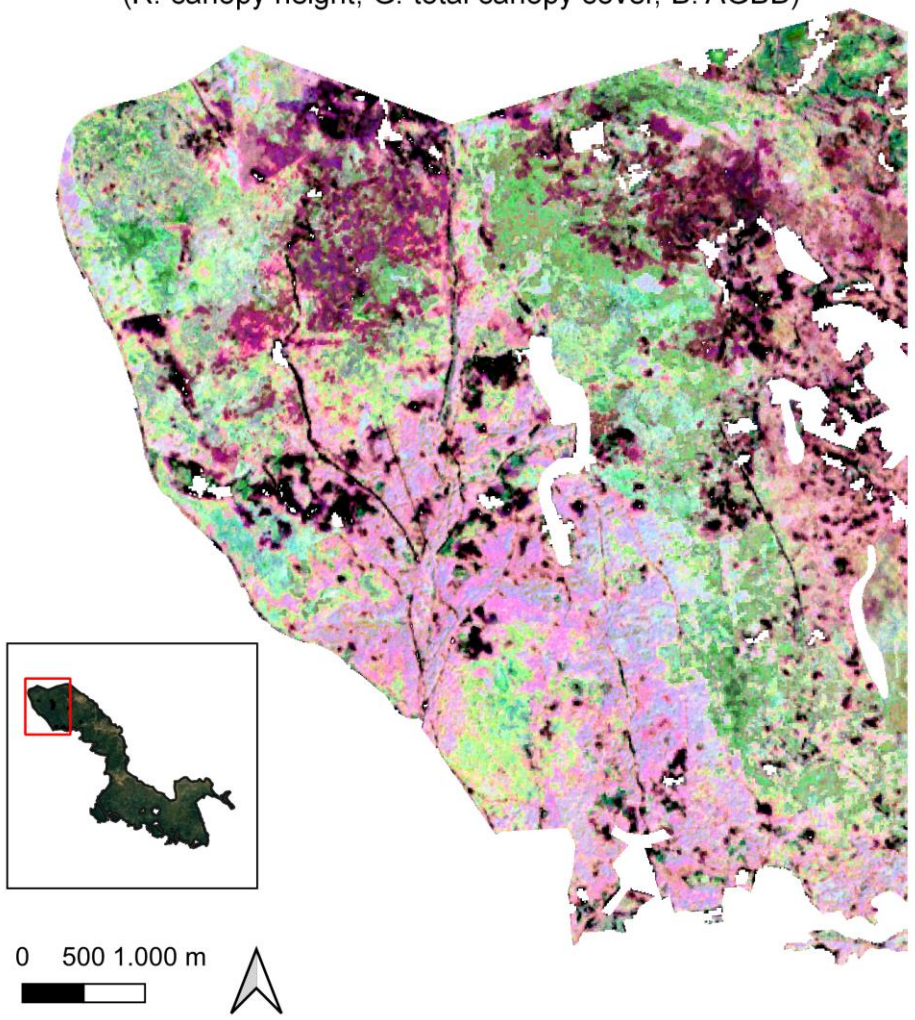
Deadwood Mapping (2020)



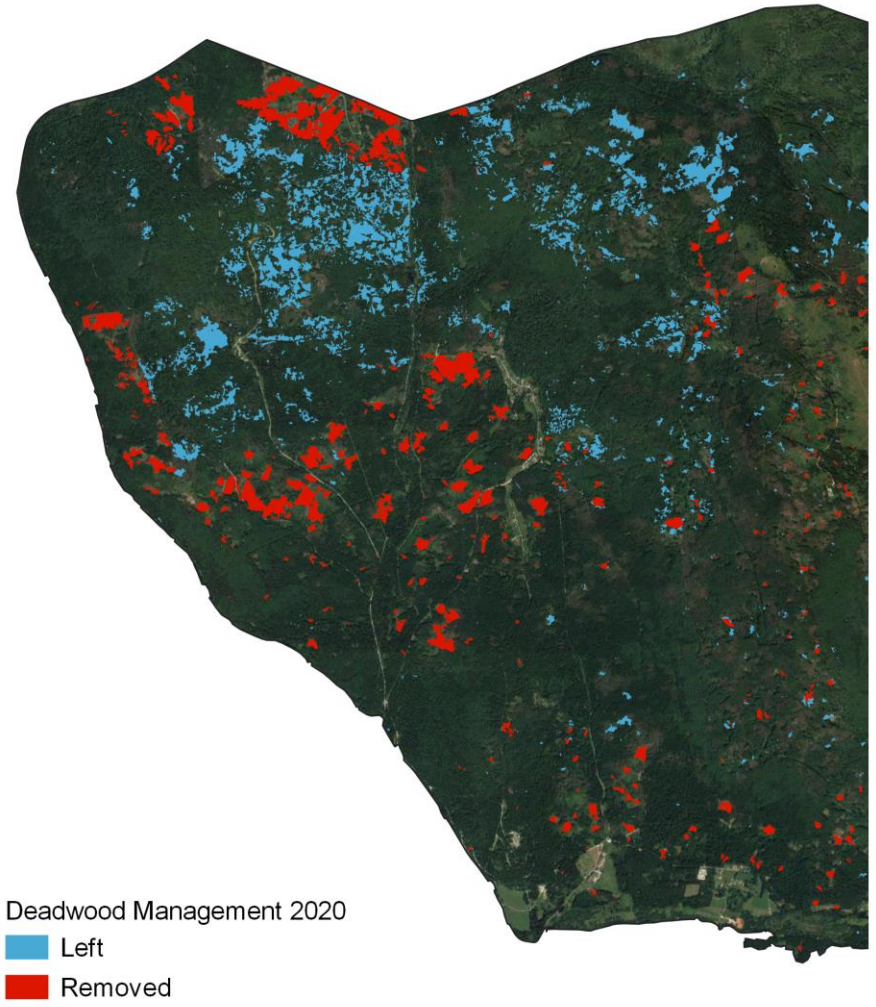
Forest Structure Characterization in the Bavarian Forest NP – Stacked Forest Structure

Forest Structure 2020

(R: canopy height, G: total canopy cover, B: AGBD)



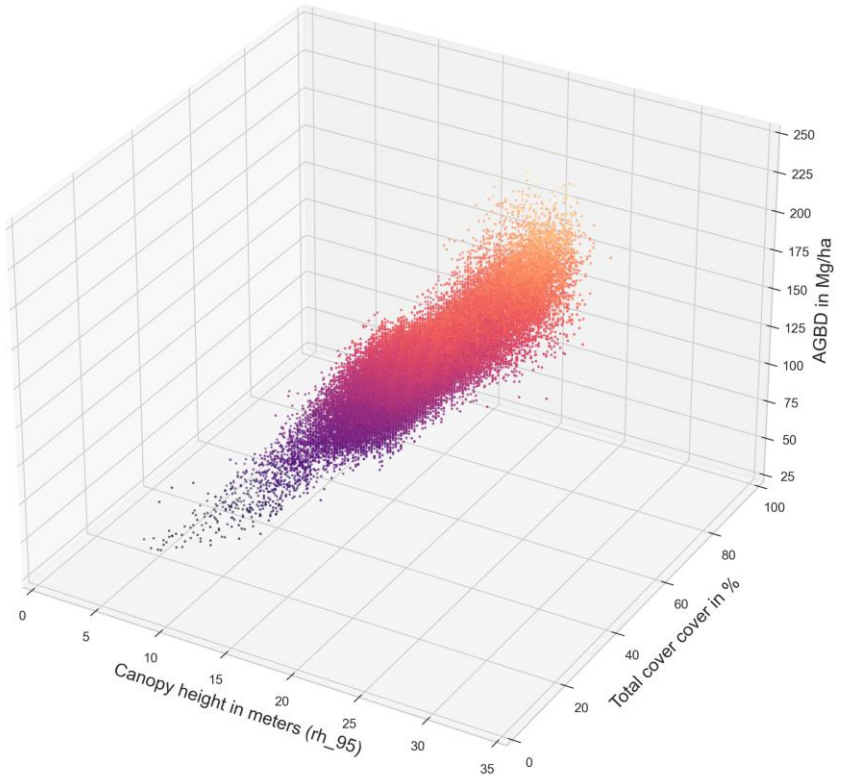
Deadwood Mapping (2020)



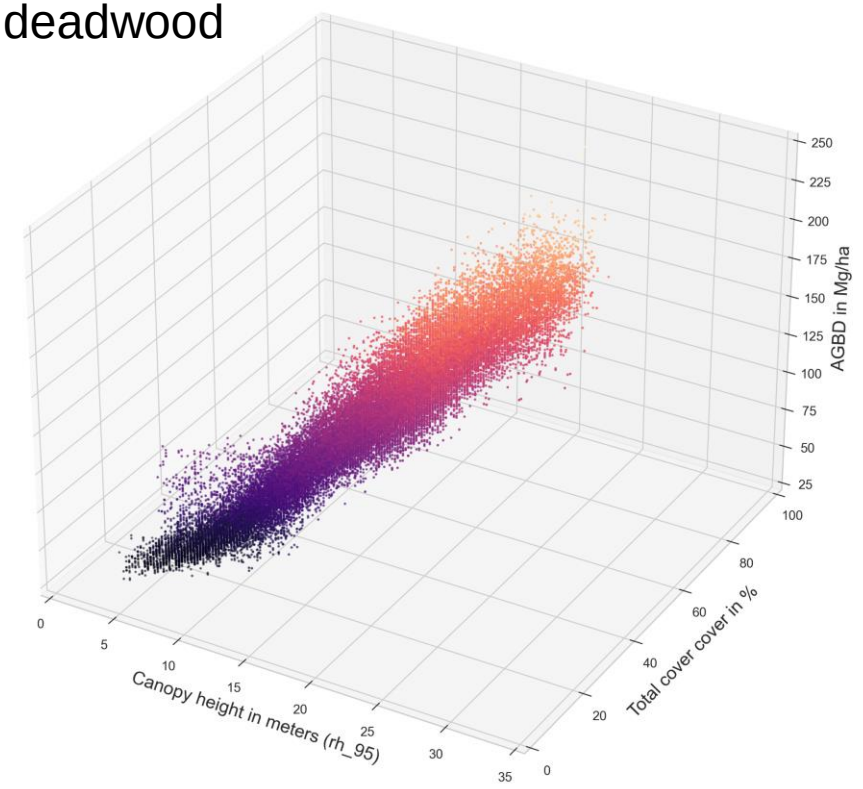
Forest Structure Characterization in the Bavarian Forest NP – Deadwood management 2020

Year of forest structure data: 2020
Year of Deadwood mapping: **2020**
→ Colorization according to AGBD axis

Left
deadwood



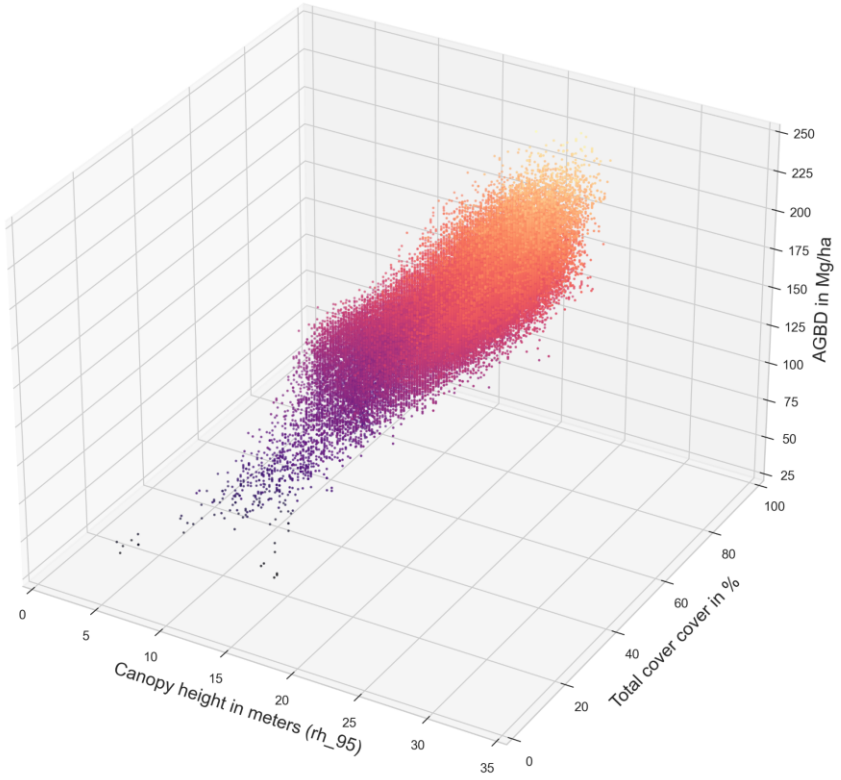
Removed
deadwood



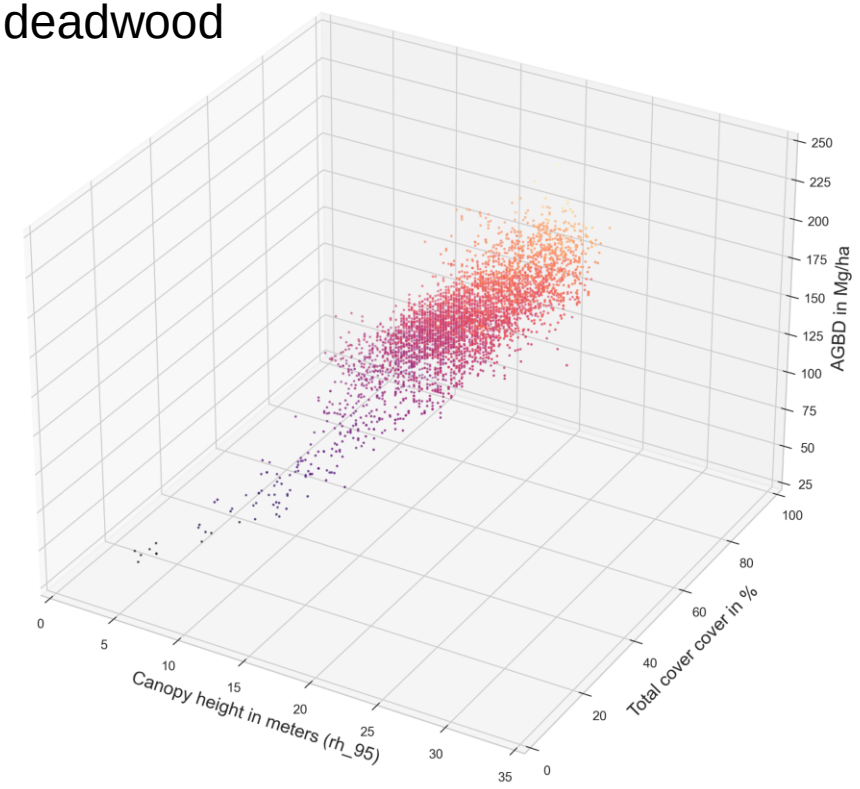
Forest Structure Characterization in the Bavarian Forest NP – Deadwood management 1998

Year of forest structure data: 2020
Year of Deadwood mapping : **1998**
→ Colorization according to AGBD axis

Left
deadwood



Removed
deadwood



SUMMARY & OUTLOOK

Harz forests (P. Kacic)

Summary and Outlook

- **Recent forest structure dynamics** can be accurately characterized by fusion products of GEDI, Sentinel-1 and Sentinel-2

→ **Declining forest structure** in the context of recent multiple **drought** years

- Different **post-disturbance structures** can be assessed

→ **Standing deadwood** as an important structure promoting biodiversity

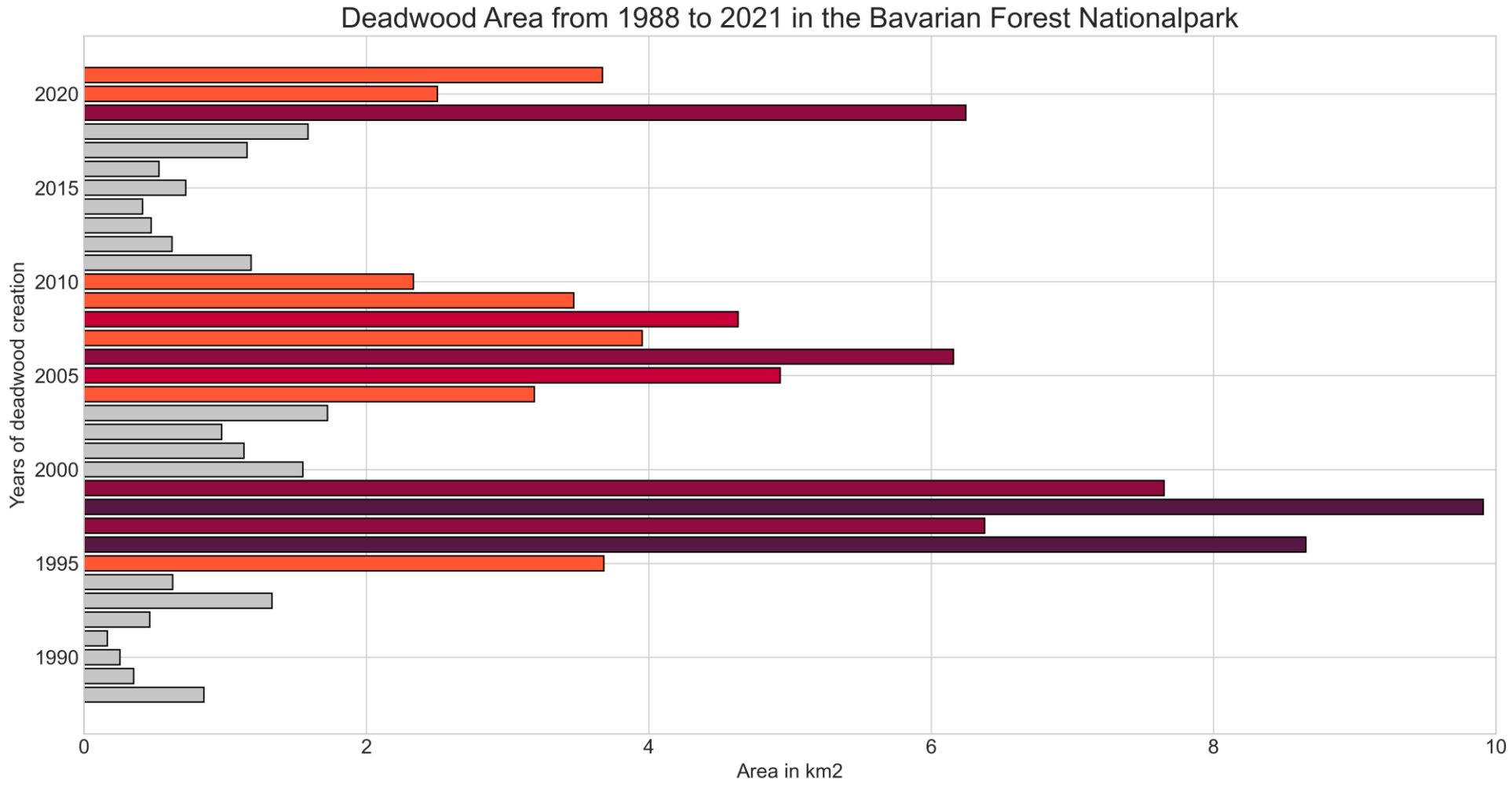
Next steps:

- **Validation** based on ALS data
- **Post-disturbance characterization** of different structures:
  - windthrow, fire, clear-cut, standing deadwood

APPENDIX

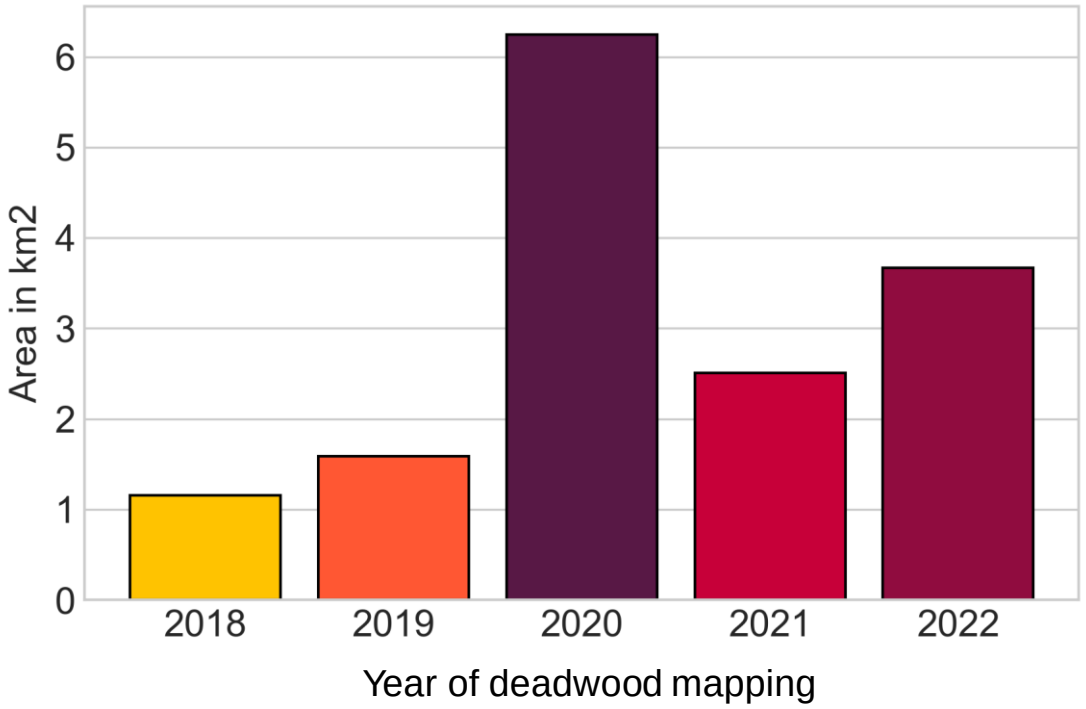
Harz forests (P. Kacic)

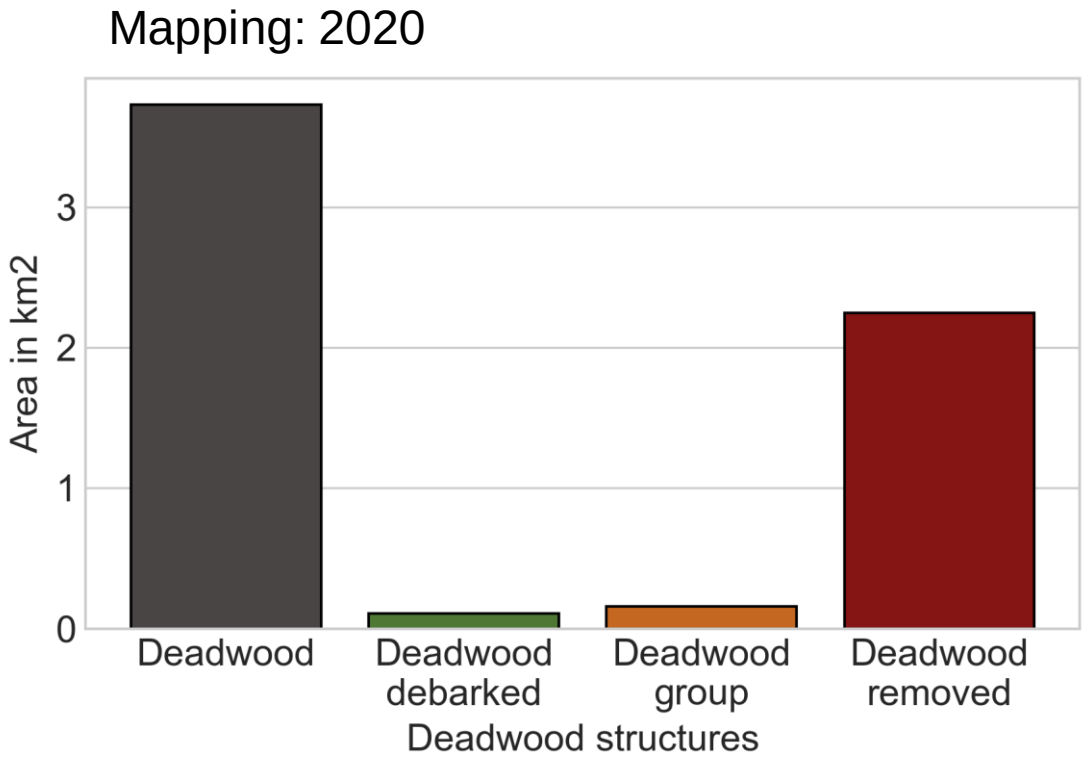
Deadwood History in the Bavarian Forest NP



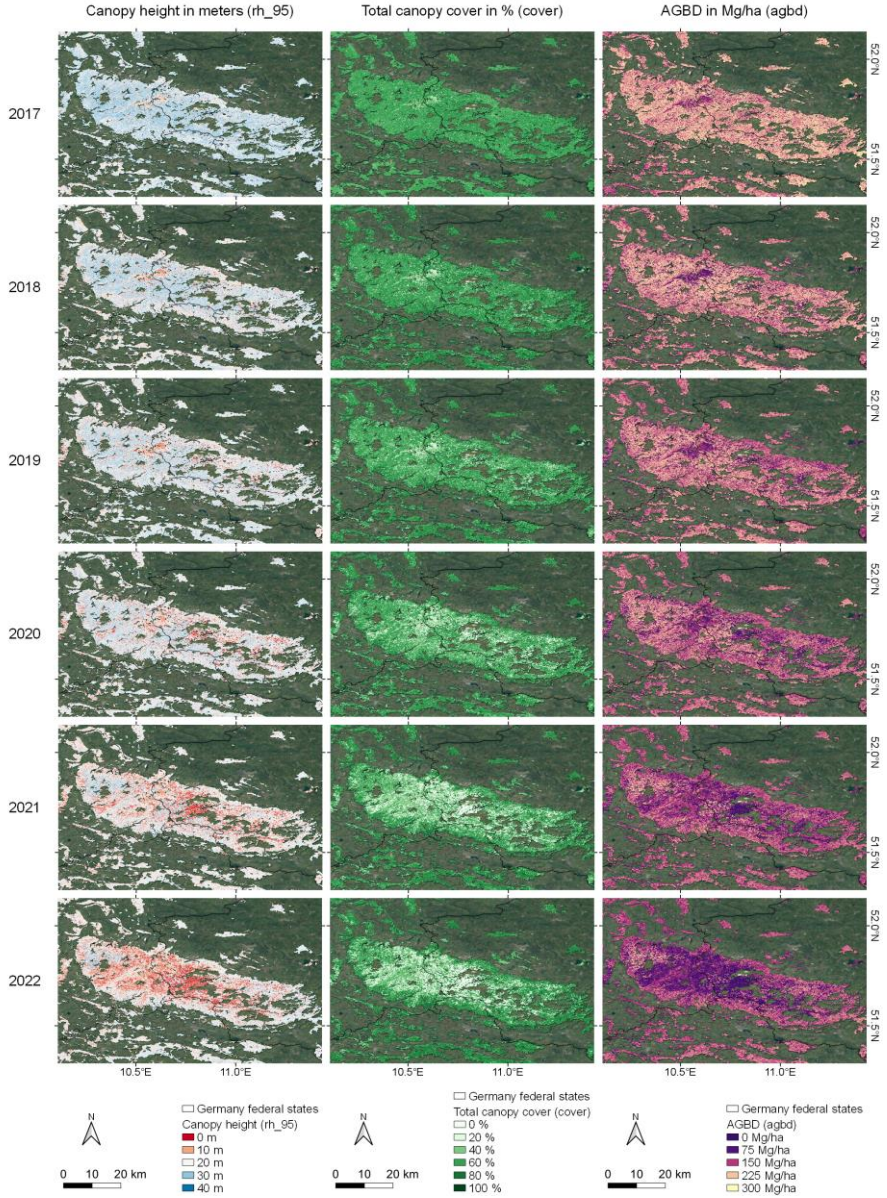
→ Colorization according to Area in km²

Recent Deadwood Occurrence



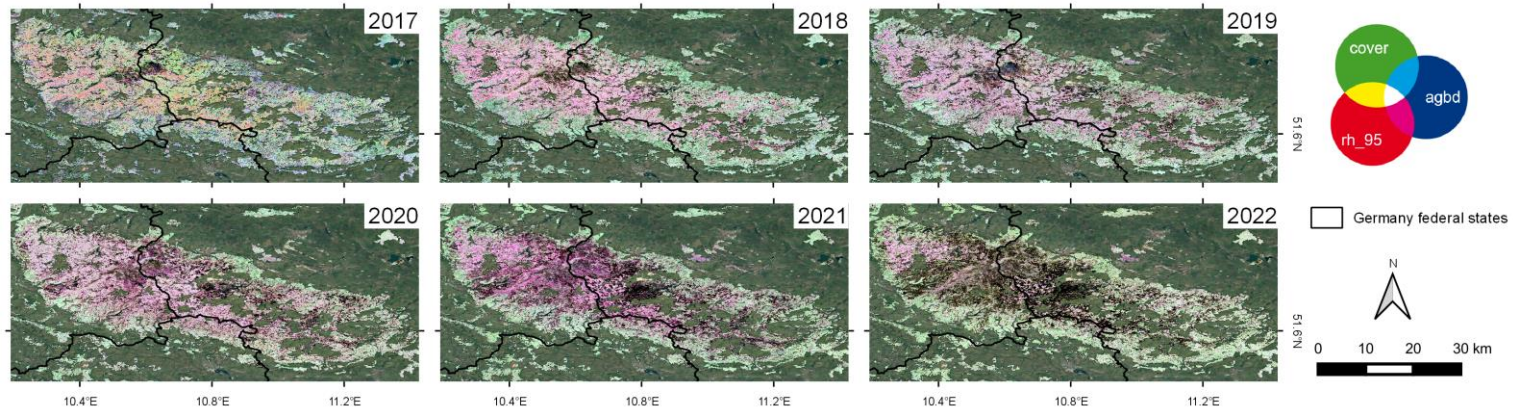


Forest Structure Characterization in Germany – Results Harz region

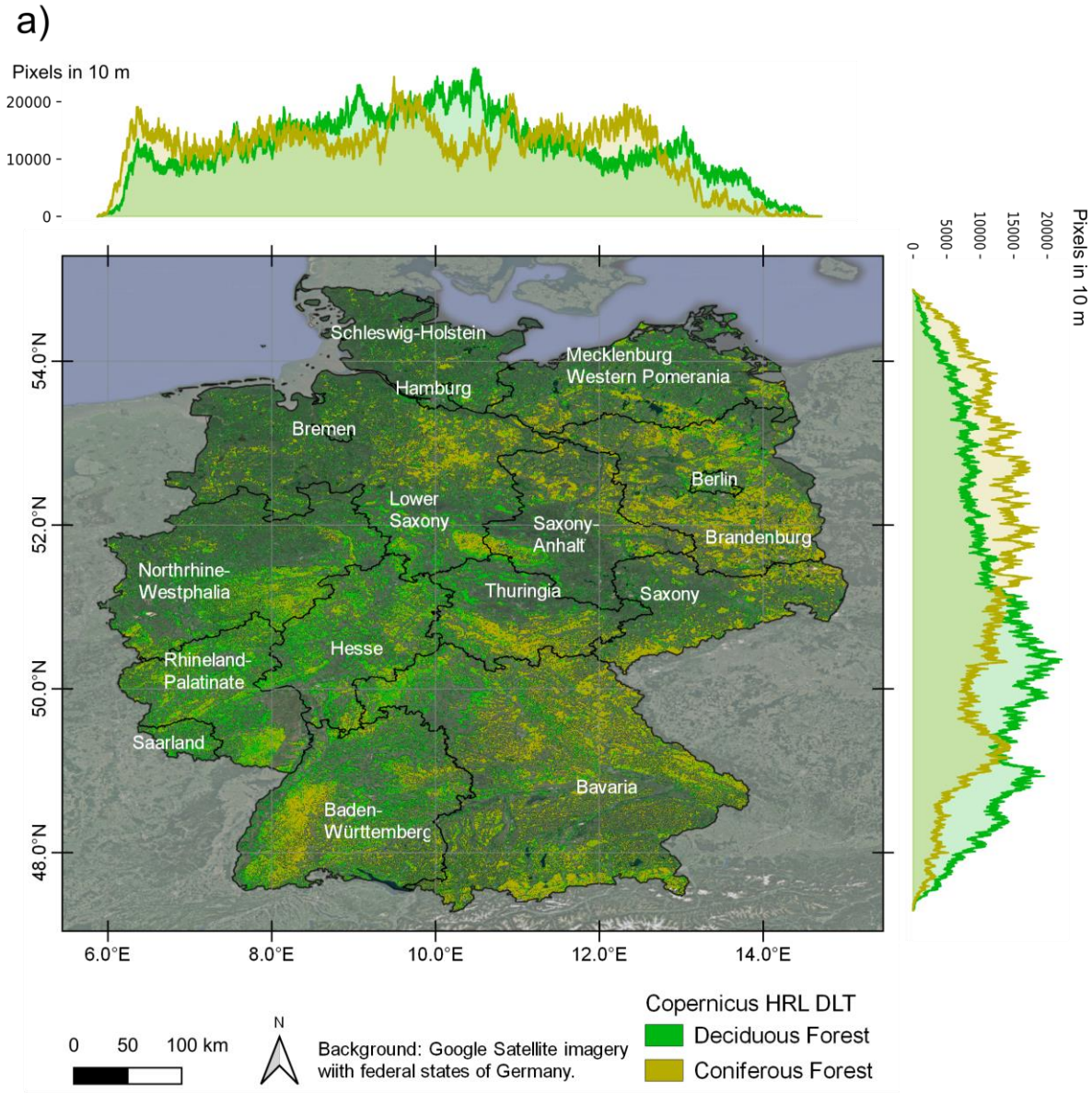


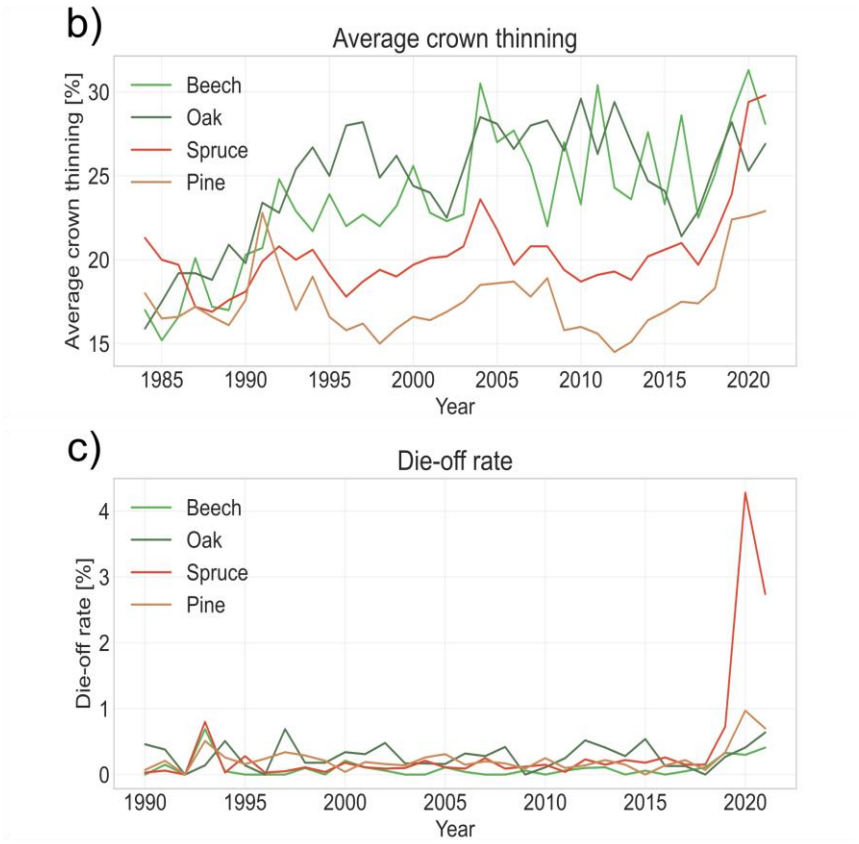
- **Major losses** in all attributes of forest structure since 2017
- Disturbance hotspots are **spruce mono-cultures**
- **Asynchronous temporal dynamics** in forest structure decline
  - **Canopy cover loss** followed by **reduction in canopy height**

  → **drought**-affected stands → **salvage-logging**

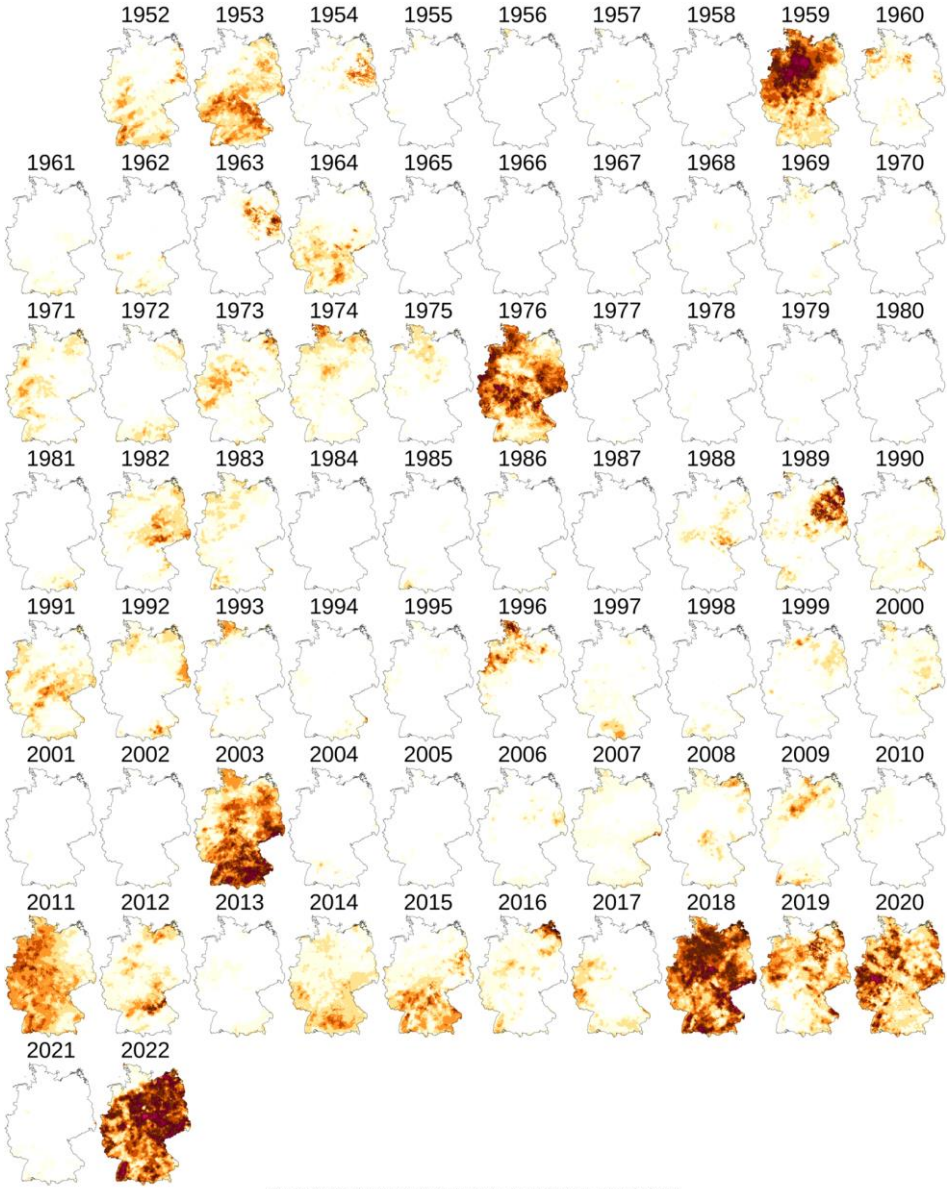


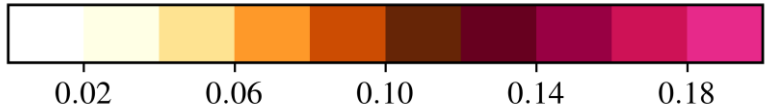
Forests in Germany





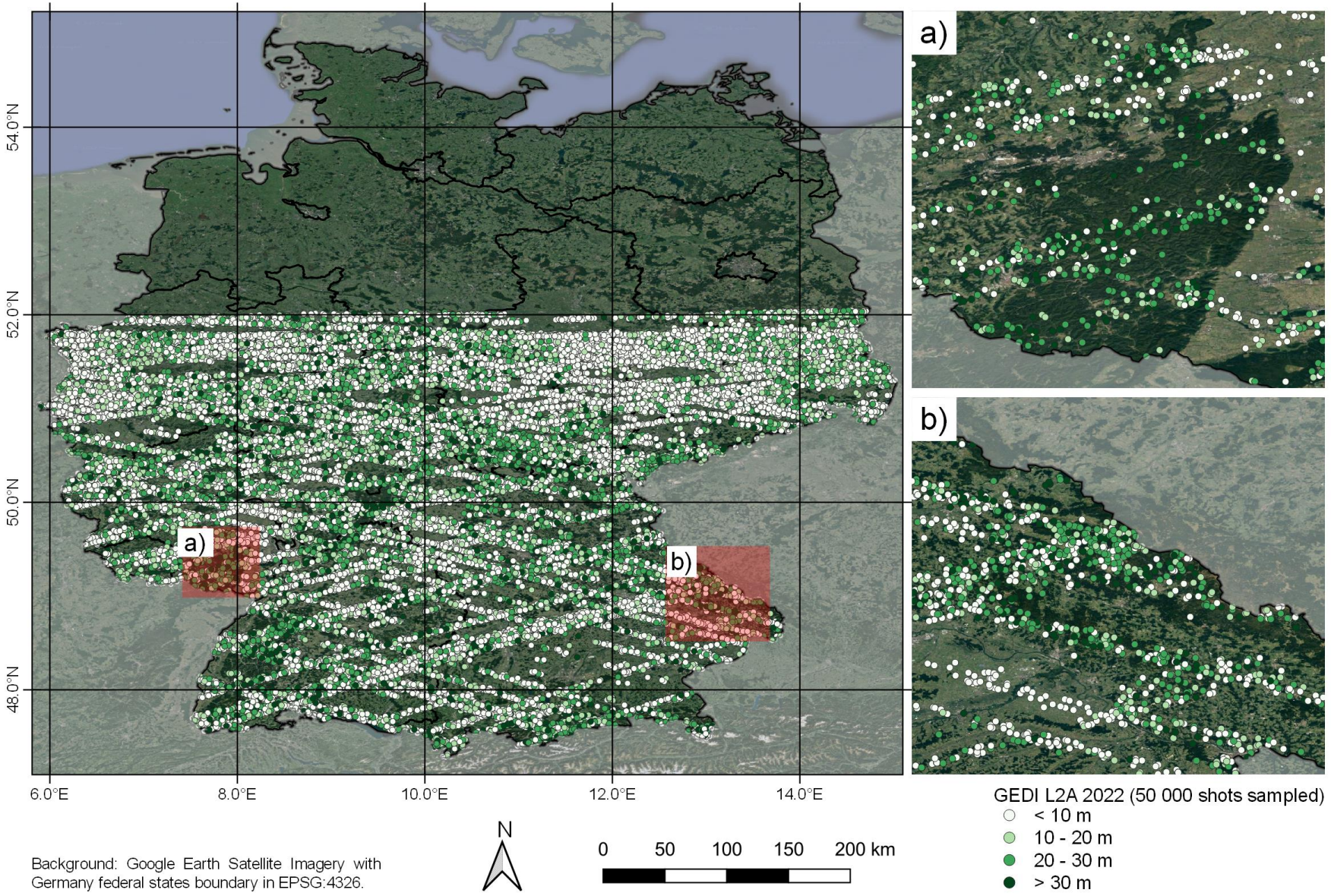
Drought-Intensity in Germany (UFZ Drought-Monitor)





Drought-Intensity

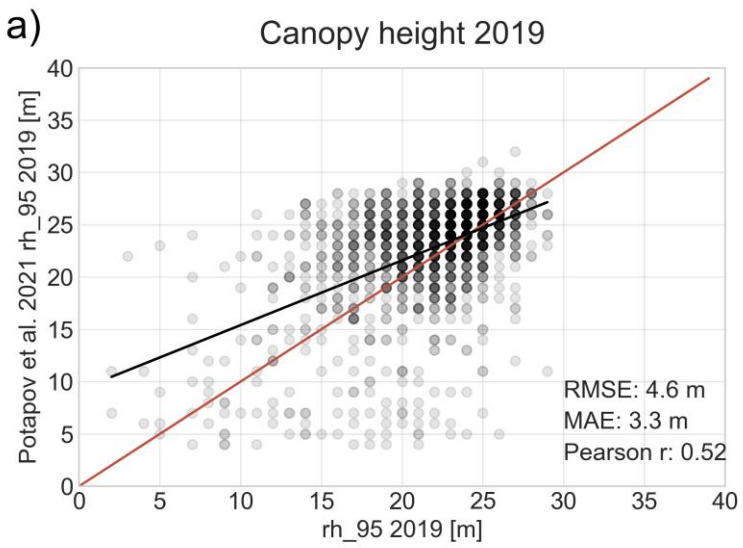
GEDI Data for Germany

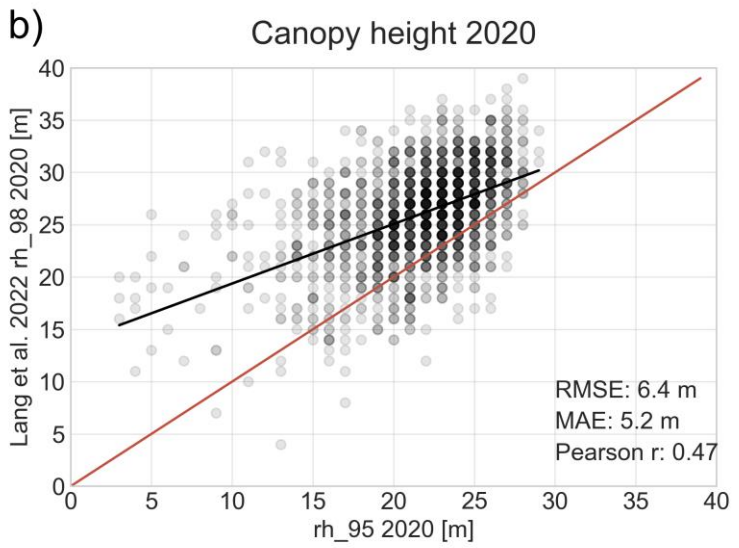


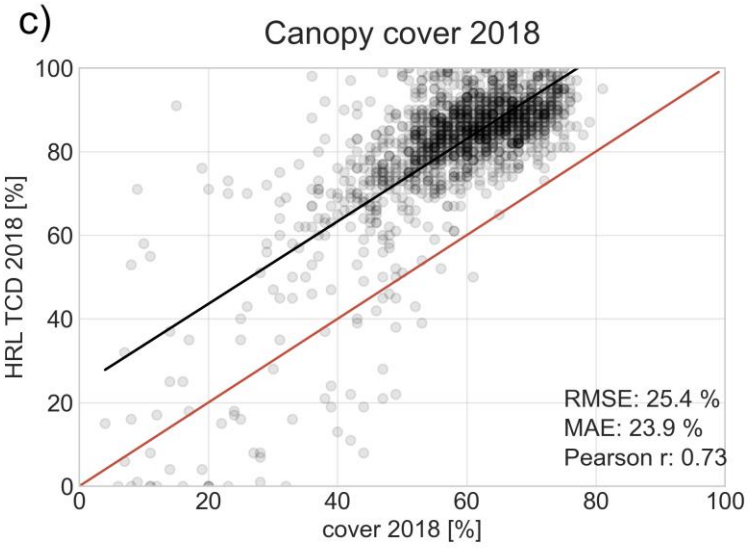
Background: Google Earth Satellite Imagery with Germany federal states boundary in EPSG:4326.

Comparison to other Products

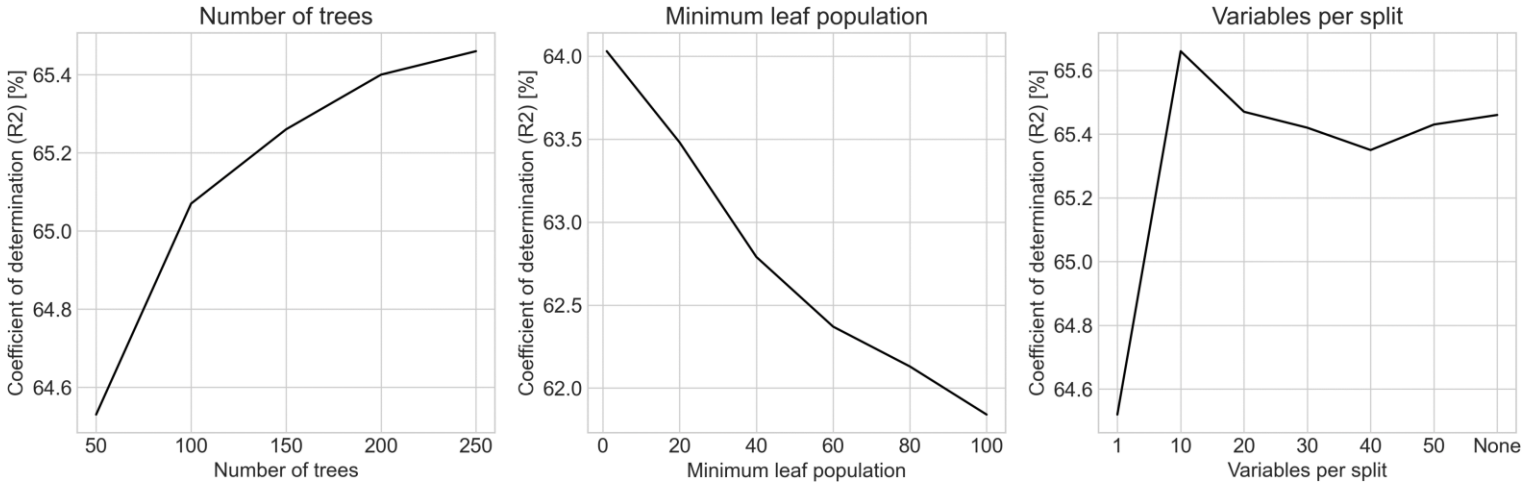
a) Potapov et al. 2021: Landsat + GEDI rh_95 globally (2019)
b) Lang et al. 2022: Sentinel-2 + GEDI rh_98 globally (2020)
c) Copernicus HRL Tree Cover Density (2018)

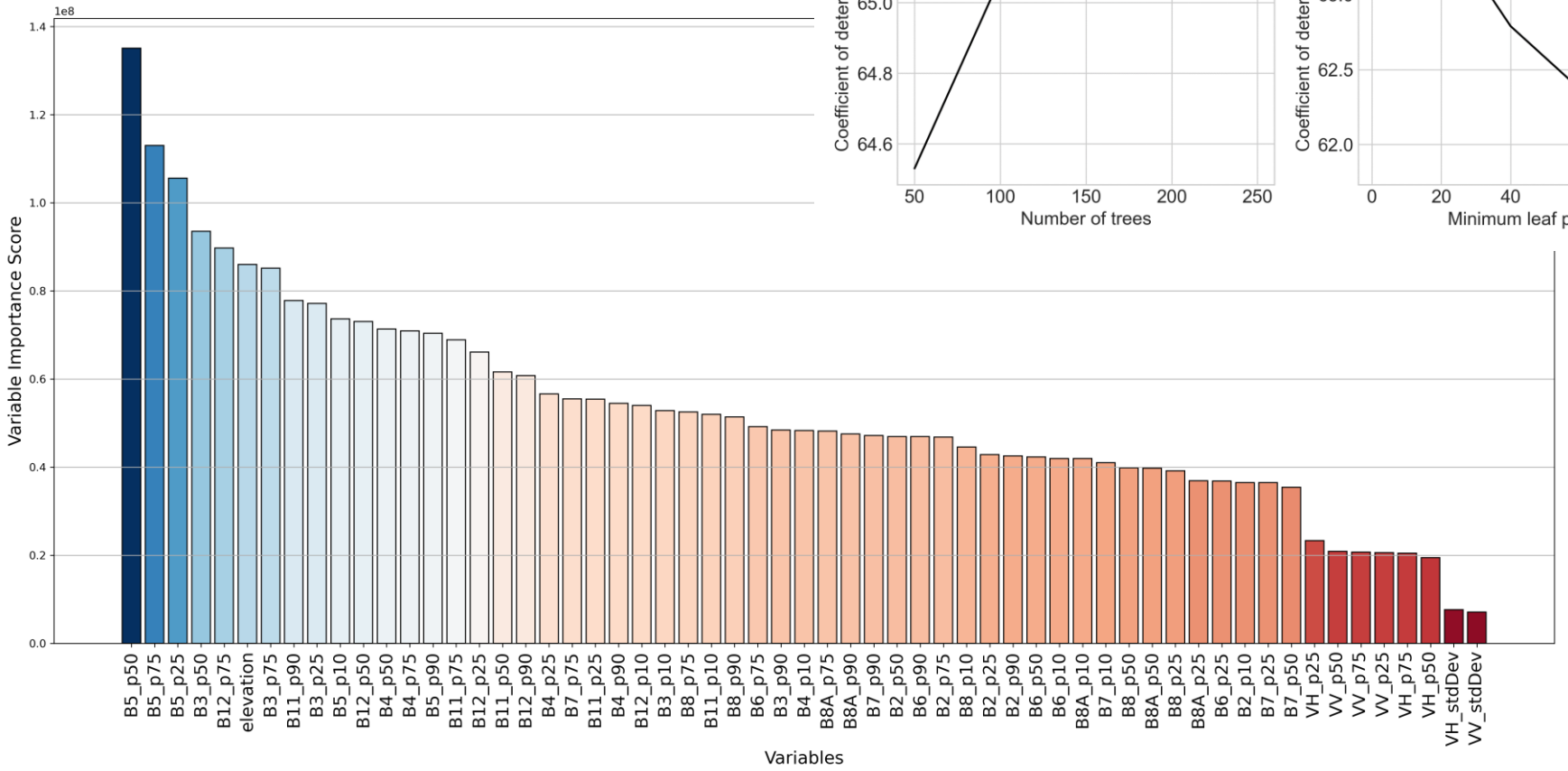






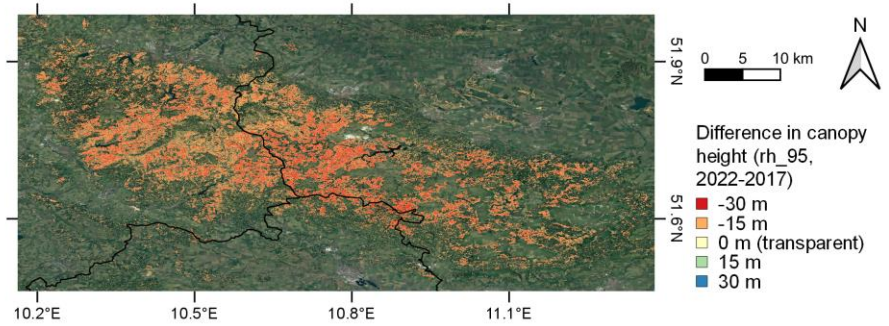
Model Sensitivity



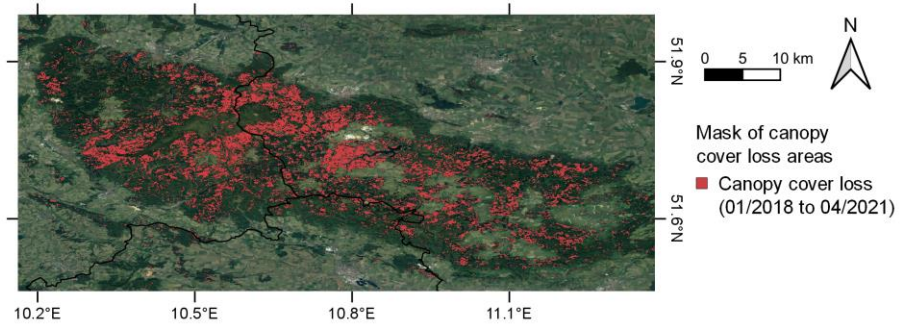


Forest Structure Dynamics in the Harz region

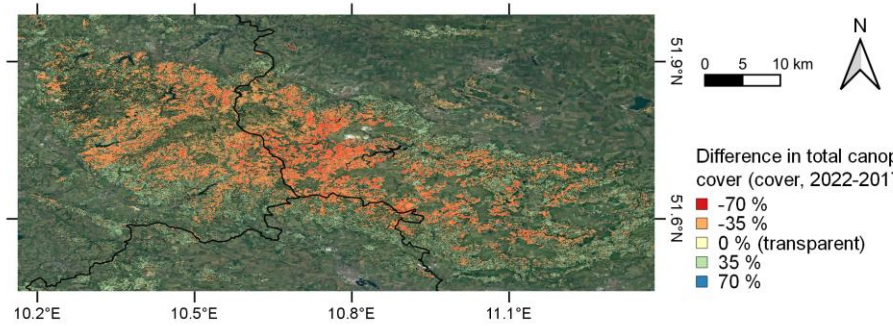
Difference in canopy height (rh_95, 2022-2017)



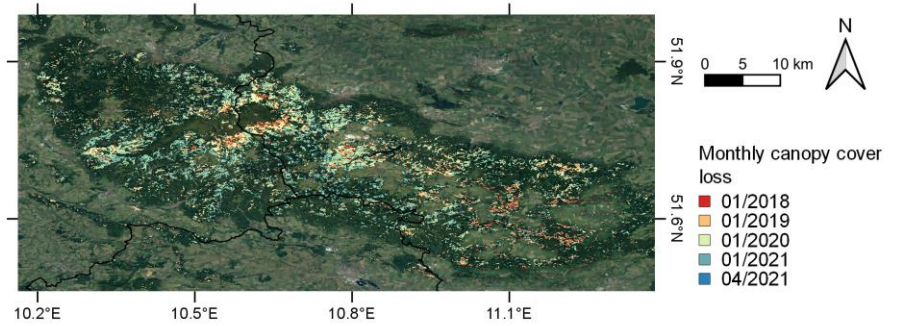
Canopy cover loss areas (Thonfeld et al. 2022)



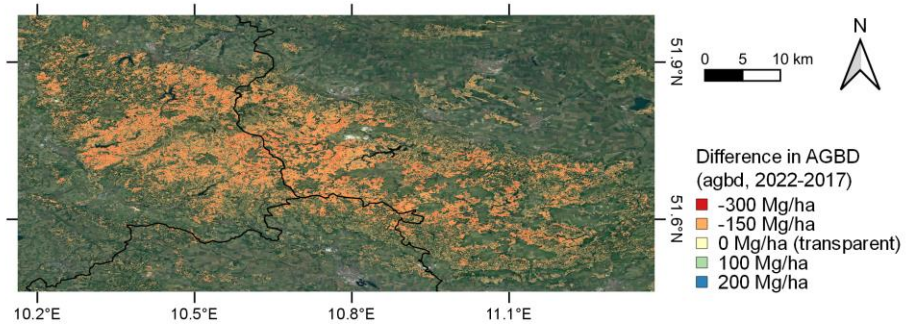
Difference in total canopy cover (cover, 2022-2017)



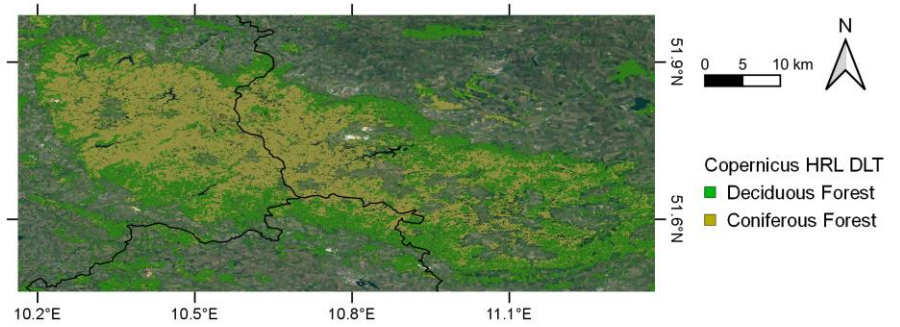
Monthly canopy cover loss areas (Thonfeld et al. 2022)



Difference in AGBD (agbd, 2022-2017)



Dominant Leaf Type (Copernicus HRL DLT)



National Statistics – canopy height

a) Annual statistics for Germany
b) Difference statistics per federal state between 2022 and 2017
c) Annual statistics per federal state