DeepTrees: Advancing Large-Scale Automated Tree Inventories with Deep Learning and Public Multispectral Imagery

Taimur Khan[1]

[1] Community Ecology, Helmholtz Centre for Environmental Research - UFZ, Theodor-Lieser-Straße 4, 06120 Halle (Saale), Germany – taimur.khan@ufz.de

Tree inventory mapping is a critical task for municipalities and environmental planners across Europe, supporting urban sustainability, biodiversity conservation, and adherence to EU environmental regulations such as the EU Biodiversity Strategy for 2030 and the Urban Greening Plans outlined in the European Green Deal. Traditionally, tree inventories have relied on manual field surveys, a process that is time-consuming, labor-intensive, and often costly. Moreover, these traditional methods are typically constrained in both spatial and temporal coverage. However, advancements in remote sensing technologies and deep learning now offer opportunities to leverage publicly available remote sensing imagery and artificial intelligence to automate and enhance tree inventory processes [1].

The DeepTrees project provides tools to train, fine-tune, and deploy deep learning models for tasks such as tree crown segmentation, tree trait detection, and tree species classification using publicly accessible imagery from Germany's Digital Orthoimages Program (DOP) at a resolution of 20 cm. These DOP images are standardized according to the "*Amtliches Topographisch-Kartographisches Informationssystem*" (AKTIS) guidelines, ensuring their reliability and consistency for long-term use [2]. Utilizing the DeepTrees python package, we successfully mapped 218,742,901 trees across Saxony (137,293,260 trees) and Saxony-Anhalt (81,449,641 trees), demonstrating the tool's scalability for applications in forest, urban, and rural environments (Figure 1). These datasets provide valuable insights for municipalities and agencies to manage street trees, monitor urban greenery, and assess forest health, enabling more informed decision-making and sustainable management practices.

The resulting tree crown datasets generated by DeepTrees are enriched with ecological metrics such as crown radius, crown projection area (CPA), chlorophyll indices, and hue-based health assessments (Figure 2). These metrics offer detailed information about individual trees. For instance, a tree's fitness is strongly influenced by the structure and size of its crown, which affects its access to resources, spatial utilization, growth dynamics, and reproductive potential [3 ,4].

Despite its advantages, the approach also presents challenges [5]. Validation of large-scale tree segmentation remains difficult due to the lack of comprehensive ground truth datasets at fine-grained, individual-tree levels. Additionally, the training datasets currently available are limited to trees observed during summer months and medium crown sizes, which restricts the model's representation of diverse tree conditions and reduces its applicability to broader scenarios.

The DeepTrees project comprises of three key components:

1. Python Package: Enables standardized tree inventorying through deep learning backbones, along with tree allometry and classification analysis.
2. PostGIS Database: A comprehensive dataset of trees in Saxony and Saxony-Anhalt, available for scientific applications.
3. Training Datasets: Supports further research and downstream learning tasks.

The DeepTrees project website is available at https://deeptrees.de. Participants of the sessions will gain insights into cutting-edge tree inventory methods using AI and remote sensing, enabling efficient urban and rural greenery management and compliance with EU environmental goals. They will also gain an overview over our open-source tools, datasets, and workflows for scalable tree mapping and analysis. We seek feedback on improving model generalization for diverse tree conditions and validation strategies for large-scale segmentation, as well as potential collaborations for expanding the dataset and enhancing tree monitoring with practitioners and researchers.

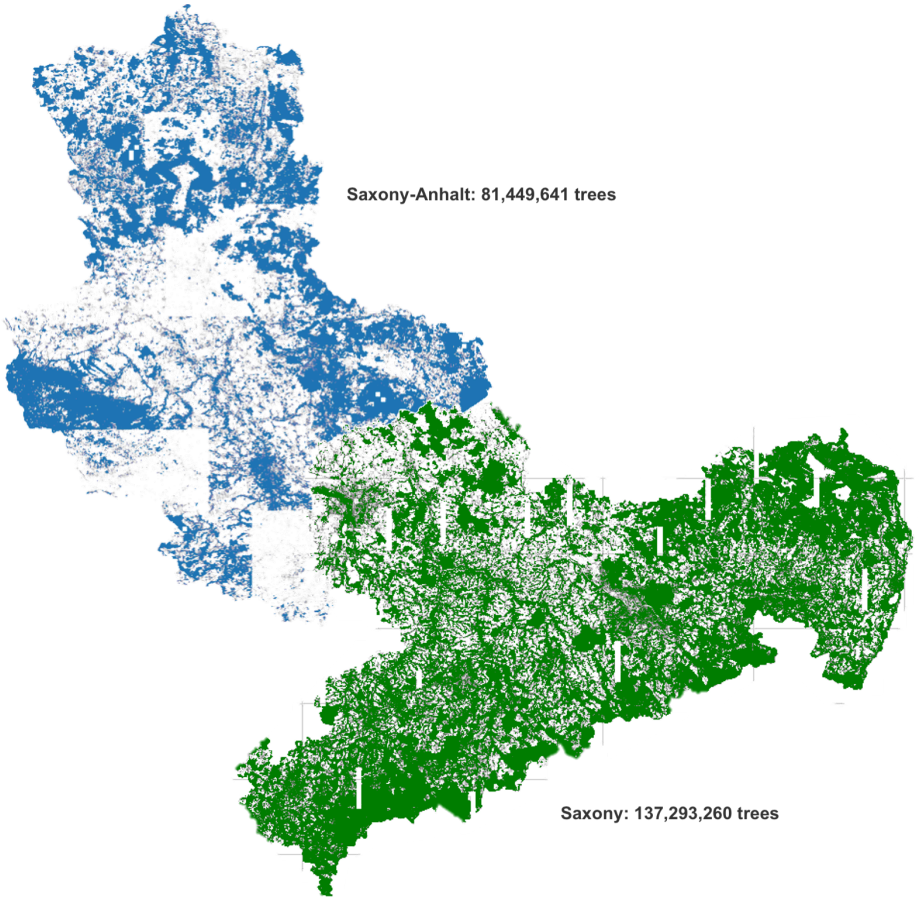

Figure 1 – Results of tree crown segmentations using DeepTrees python package and Digital Orthophotos at 20 cm resolution from the Federal States of Sachsen-Anhalt and Sachsen. In total, 218,742,901 trees were mapped, as shown in this image.

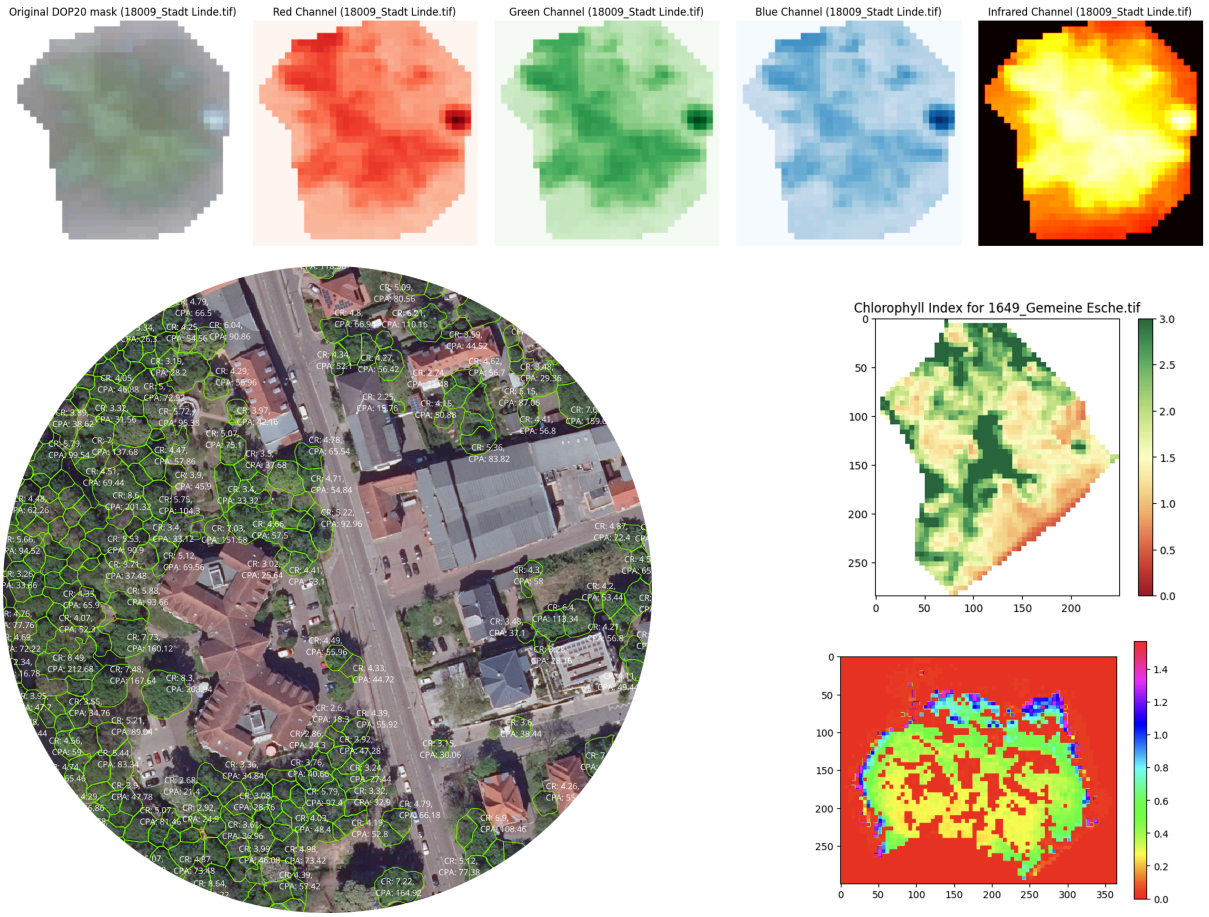

Figure 2 – To image is a single tree segmentation and all the bands visualised. On the bottom left are individual tree crowns with their corresponding crown projection area and crown spread calculations and on the bottom right are samples of derived chlorophyll green index and crown hue for single trees.

References

1. Zhao, H., Morgenroth, J., Pearse, G., & Schindler, J. (2023). A Systematic Review of Individual Tree Crown Detection and Delineation with Convolutional Neural Networks (CNN). Current Forestry Reports, 1-22.
2. Informationssystem, A. A. T. K. (2003). Arbeitsgemeinschaft der Vermessungsverwaltungen der Länder der Bundesrepublik Deutschland (AdV).
3. White, E. P., Ernest, S. M., Kerkhoff, A. J., & Enquist, B. J. (2007). Relationships between body size and abundance in ecology. Trends in ecology & evolution, 22(6), 323-330.
4. Knoke, T., Ammer, C., Stimm, B., & Mosandl, R. (2008). Admixing broadleaved to coniferous tree species: a review on yield, ecological stability and economics. European journal of forest research, 127, 89-101.
5. Weinstein, B. G., Marconi, S., Bohlman, S. A., Zare, A., & White, E. P. (2020). Cross-site learning in deep learning RGB tree crown detection. Ecological Informatics, 56, 101061.