Projecting the Impacts of Forest Management Under Climate Change Across Germany

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Climate change poses significant challenges to forest ecosystems, impacting carbon storage, timber production, and biodiversity. Forest management is crucial for mitigating these effects, with various adaptation strategies proposed, including climate-smart forestry, tree species diversification, and rotation length adjustments. While process-based models can simulate forest trajectories under climate change, forest owners and practitioners require information tailored to their specific conditions. This study presents a novel approach for generating high-resolution forest projections across Germany, incorporating various climate change adaptation strategies.

A comprehensive literature review of forest management adaptation recommendations across German federal states informed the development of diverse management scenarios. The iLand model, a process-based, high-resolution, individual-based forest simulator, was used to generate detailed forest trajectories and management impacts under climate change. iLand simulates forest dynamics at the individual tree level, considering physiological processes, competition, and disturbances. Simulations were conducted in representative generic landscapes, roughly corresponding to growth regions, to produce a set of forest indicators. Additionally, iLand simulations determined potential natural vegetation to identify target species adapted to future conditions. Model performance was evaluated against BWI (National Forest Inventory) data across Germany. Remote sensing and BWI data provided large-scale datasets for forest vegetation, climate, and site conditions. AI-based scaling (SVD) was employed to scale simulations to 100m resolution for all forested areas in Germany for climate and management scenarios assessed with iLand. SVD utilizes a deep neural network trained on iLand simulations to efficiently project forest dynamics across large spatial scales.

The integrated modeling framework is operational and capable of generating high-resolution forest projections across Germany. The evaluation of iLand revealed an overall satisfactory performance, with $r^2 = 0.45$ and root mean squared error of 4.5m in predicting dominant height at age 100. Example results for individual stands and management scenarios demonstrate the model's ability to simulate detailed forest dynamics under climate change. The framework's outputs serve as the data basis for a multi-criteria-decision analysis tool which targets the evaluation of forest management alternatives under climate change for a broad set of indicators. Large-scale results for Germany include projections of species proportions, timber volume, and harvests under various climate and management scenarios.

This study provides a powerful tool for assessing the impacts of forest management under climate change across Germany. The high-resolution projections can inform forest owners and practitioners in developing adaptation strategies tailored to their specific conditions. The framework's ability to simulate various management scenarios and evaluate their impacts on key forest indicators supports informed decision-making for sustainable forest management under climate change.