Methodology

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### Study Area and Data Collection

This study was conducted in the Leipzig Floodplain Forest, specifically in the southern section of the NSG - Elser Plaßer Auwald, a protected floodplain forest in central Germany. Two plots, P81 and P82, were selected for this study due to their exposure to regular flooding. Primary data collection for these plots occurred during the 2024 census and included measurements of tree diameter at breast height (DBH), tree height, and tree status (alive, dead, or newly recruited). Historical data from the 2020 census for the same plots were used to establish baseline growth and demographic patterns. Canopy layer data for P81 and P82 were obtained from the dataset Suedaue\_P1\_P86\_with\_crown\_layers\_MS\_20241202.csv.

In addition to the primary data, demographic rates and initial forest states for three groundwater conditions—dry, intermediate, and moist—were sourced from the GitHub repository associated with Elles et al. (2024). This repository contained data collected during the 2013 census for similar plots in the southern section of the Leipzig Floodplain Forest. By combining primary data for the flooded plots with reference data for other groundwater conditions, the study aimed to comprehensively evaluate the effects of flooding on forest dynamics, species composition, and carbon stocks.

### Data Preprocessing and Demographic Rate Calculations

The 2020 and 2024 datasets for P81 and P82 were merged to create a unified dataset. Tree species names were standardized, and trees were grouped into DBH classes for analysis. Canopy layer classifications were integrated into the dataset, and tree density per hectare was calculated for each species and DBH class. From this dataset, demographic rates were calculated separately for each canopy layer.

Growth rates ( for canopy layer 1 and for canopy layer 2) were determined by calculating the mean annual increase in DBH between 2020 and 2024 for each species. The equation used for growth rate calculation was:

where and represent the DBH in 2024 and 2020, respectively, and Δ*t* is the four-year interval between the two censuses. Mortality rates ( for canopy layer 1 and for canopy layer 2) were calculated based on the proportion of trees that transitioned from alive to dead during the census interval. The annual mortality rate was derived using the formula:

where is the fraction of trees that died during the census period. Recruitment rates () were calculated as the number of newly recruited trees per hectare per year using the equation:

where is the number of new recruits, *A* is the area of the plot in hectares, and Δ*t* is the census interval. To address missing parameters such as the inflection point, steepness, and logistic growth coefficients, values were imputed from the demographic rates of the moist dataset. This imputation was based on the assumption that moist soil conditions were the closest approximation to flooded conditions.

### Comparative Analysis of Demographic Rates

To address Research Question 1 (RQ1), whether regular flooding impacts tree growth, mortality, and recruitment, the demographic rates calculated for flooded plots were compared to those for dry, moist, and intermediate groundwater conditions. Growth rates (), mortality rates (), and recruitment rates () were plotted and statistically analyzed across the four groundwater conditions. These comparisons helped identify significant deviations in demographic processes caused by regular flooding. Visualization scripts were employed to generate graphical representations of these trends.

### Simulation of Long-Term Forest Dynamics

The Perfect Plasticity Approximation (PPA) model was used to simulate forest dynamics under flooded, dry, moist, and intermediate conditions to explore the long-term effects of flooding on species composition (Research Question 2). Initial forest states for each condition were combined with their respective demographic rates to model forest growth over a 100-year period using 5-year time steps. The simulation incorporated growth, mortality, recruitment, and canopy layer assignment processes.

During each time step, tree density (*n*) was updated based on species-specific mortality rates (μ):

DBH was updated for each cohort using growth rates (*G*):

Recruitment was simulated by adding new cohorts to the forest based on recruitment rates ():

Canopy layers were re-assigned based on cumulative crown area. The basal area (*BA*) was calculated at each time step as a measure of forest growth:

Simulation outputs, including basal area and DBH distributions, were recorded for each time step.

### Validation of Simulation Results

Model validation was performed to ensure the reliability of simulated results. The initial states for P81 and P82 were used to simulate forest dynamics under flooded conditions. These outputs were compared with the simulation results for the entire forest under flooded conditions. Validation metrics included Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and percentage error between observed and simulated basal areas.

### Carbon Stock Calculations and Simulations

To address Research Question 3, carbon stocks were calculated for the flooded plots and simulated for the next 100 years. Aboveground biomass (*AGB*) was estimated using species-specific allometric equations:

*AGB*=*Volume*⋅*WoodDensity*

Total carbon stock was calculated as:

Species-specific wood density values were sourced from the Global Wood Density Database. Height was estimated using the Chave et al. (2005) model:

where *k* and *p* were estimated for each species using nonlinear regression. Simulations of carbon stocks were conducted over 100 years using periodic updates of DBH based on growth rates ().