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Mismatch between the optimal ages for ecosystem productivity and net CO2 sequestration in Norway spruce forests

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Forests have climate change mitigation potential since they sequester carbon. However, their carbon sink strength might depend on management. As a result of the balance between CO_2 uptake and emission, forest net ecosystem exchange (NEE) reaches optimal values (maximum sink strength) at young stand ages, followed by a gradual NEE decline over many years. Traditionally, this peak of NEE is believed to be concurrent with the peak of primary production (e.g., gross primary production, GPP); however, in theory, this concurrence may potentially vary depending on tree species, site conditions and the patterns of ecosystem respiration (R_{eco}). In this study, we used eddy-covariance (EC)-based CO_2 flux measurements from 8 forest sites that are dominated by Norway spruce (Picea abies L.) and built machine learning models to find the optimal age of ecosystem productivity and that of CO_2 sequestration. We found that the net CO_2 uptake of Norway spruce forests peaked at ages of 30-40 yrs. Surprisingly, this NEE peak did not overlap with the peak of GPP, which appeared later at ages of 60-90 yrs. The mismatch between NEE and GPP was a result of the R_{eco} increase that lagged behind the GPP increase associated with the tree growth at early age. Moreover, we also found that newly planted Norway spruce stands had a high probability (up to 90%) of being a C source in the first year, while, at an age as young as 5 yrs, they were likely to be a sink already. Further, using common climate change scenarios, our model results suggest that net CO_2 uptake of Norway spruce forests will increase under the future climate with young stands in the high latitude areas being more beneficial. Overall, the results suggest that forest management practices should consider NEE and forest productivity separately and harvests should be performed only after the optimal ages of both the CO_2 sequestration and productivity to gain full ecological and economic benefits.