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Projected changes in biomass carbon under future climate scenarios in semi-arid southeastern Australia

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Abstract: Forests play a pivotal role in the global carbon cycle, storing the majority of their carbon in woody biomass where it can remain sequestered for decades to centuries. By effectively removing carbon from the atmosphere over long timescales, forests provide a critical natural climate solution, mitigating greenhouse gas emissions and supporting climate stability.

In Australia, the Avoided Deforestation Project—initiated in 2014 under the Australian Carbon Credit Unit (ACCU) Scheme (https://www.dcceew.gov.au/climate-change/emissions-reduction/accu-scheme)—represents a key carbon offset initiative designed to preserve native forests and promote sustainable land management. While such projects are central to meeting national emissions reduction commitments, the long-term carbon sequestration potential of forests protected under avoided deforestation remains unclear. Future trajectories are highly contingent on interactions between atmospheric CO_2 concentrations, projected warming, altered rainfall regimes, and ecosystem disturbance processes.

In this study, we assessed the aboveground biomass carbon dynamics and net primary production (NPP) of semi-arid forests in southeastern Australia, where avoided deforestation projects are concentrated. For the first time, the LPJ-GUESS dynamic global vegetation model was calibrated and validated against forest inventory data in eastern Australia, achieving strong performance in biomass carbon predictions ($R^2 = 0.70$, nRMSE = 16.8%) and successfully capturing interannual NPP variability driven by rainfall anomalies.

Future projections, based on 27 Global Climate Models and two Shared Socioeconomic Pathways (SSP245 and SSP585), revealed biomass carbon increases of 6–10% and 8–20% under the two SSPs, respectively. Corresponding NPP changes ranged from 4–11% under SSP245 to 16–38% under SSP585. Sensitivity analysis excluding CO_2 fertilization showed marked declines in both biomass carbon and NPP, underscoring the dominant role of rising atmospheric CO_2 in driving future productivity gains. Notably, while NPP responses were largely attributable to CO_2 enrichment, biomass carbon outcomes exhibited greater uncertainty across climate scenarios, reflecting complex interactions among climate variability, mortality processes, and turnover dynamics.

These findings provide evidence that avoided deforestation projects will likely deliver enhanced carbon benefits under future elevated CO_2, but the reliability of enhanced biomass is contingent on not only climatic uncertainties but also ecological constraints. Importantly, our simulations did not incorporate phosphorus limitations or fire disturbances—two critical processes that may substantially reduce the realized CO_2 fertilization effect in nutrient-poor and disturbance-prone Australian ecosystems.

Overall, this work highlights the promise of avoided deforestation as a long-term mitigation strategy. It calls for further integration of nutrient cycling, fire regimes, and disturbance dynamics into dynamic vegetation models, as well as continued field-based monitoring, to better constrain projections and strengthen the credibility of forest carbon offsets in national and global climate policy frameworks.

Keywords: *Aboveground biomass, climate change, LPJ-GUESS, CO_2*

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