Mapping Woody Cover Dynamics in Silvopastoral Systems using Landsat Time Series

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Abstract

Tropical dry forests and savannas are ecologically valuable yet highly threatened ecosystems, increasingly affected by agricultural expansion. In South America's Gran Chaco, silvopastoral systems, in which trees are retained within pasture lands, are promoted as a sustainable landuse strategy that supports livestock production while preserving ecosystem services. Yet, their structure, extent, and long-term dynamics remain poorly understood, in part because conventional categorical monitoring detects abrupt clearing but misses gradual within-pasture decline. To capture these gradual changes, this study reconstructs annual fractional woody cover dynamics from 1985 to 2024 using Landsat time series. Dry-season spectral-temporal metrics were computed for each year, smoothed with the LandTrendr algorithm and used to train a Random Forest regression model on synthetically mixed endmember spectra. Predictions were validated against an independent point dataset from very high-resolution imagery ($R^2 = 0.643$, RMSE = 23.96%). Woody cover was analysed across pasture areas and within expert-identified silvopastoral polygons, and post-clearing trajectories were reconstructed within these polygons. In addition, post-clearing woody cover was compared between yellow and green zones of Argentina’s National Forest Law using a difference-indifferences event study with entropy balancing. Within pastures, woody cover was widespread but mostly sparse (median 21%) and estimates of silvopastoral extent were highly sensitive to the threshold applied. Within confirmed silvopastoral systems, woody cover declined by approximately one percentage point per year after clearing, consistently across two independent datasets and most Argentine provinces (all $p < 0.001$). Yellow zones retained slightly more woody cover than less restricted green zones, but this advantage narrowed over the post-clearing decade. These continuous declines reveal hidden deforestation processes invisible to categorical monitoring, raising questions about the long-term sustainability of silvopastoral systems.

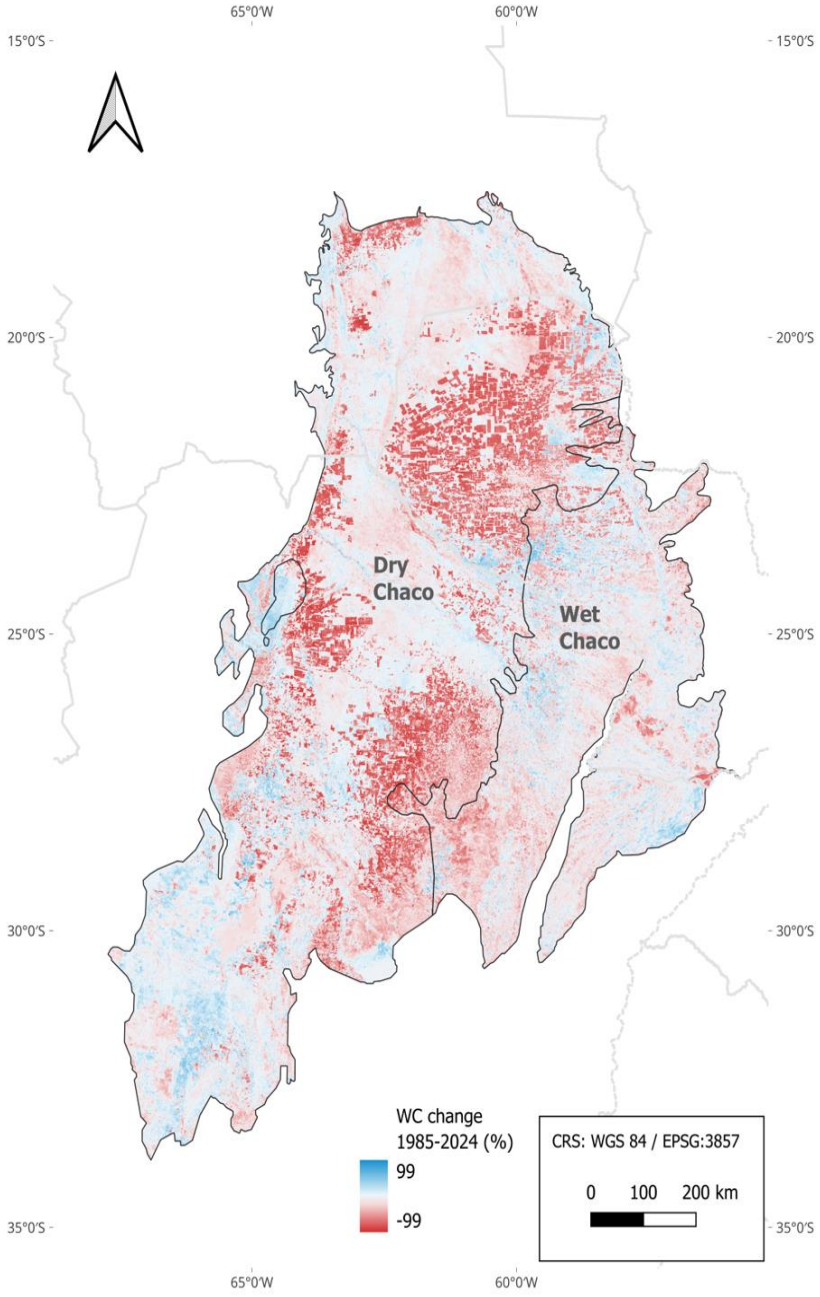


Figure 1 Change in fractional woody cover across the Gran Chaco between 1985 and 2024*. Values represent the difference in predicted woody cover (percentage points) between the two years with blue indicating woody cover gain and red indicating woody cover loss.*

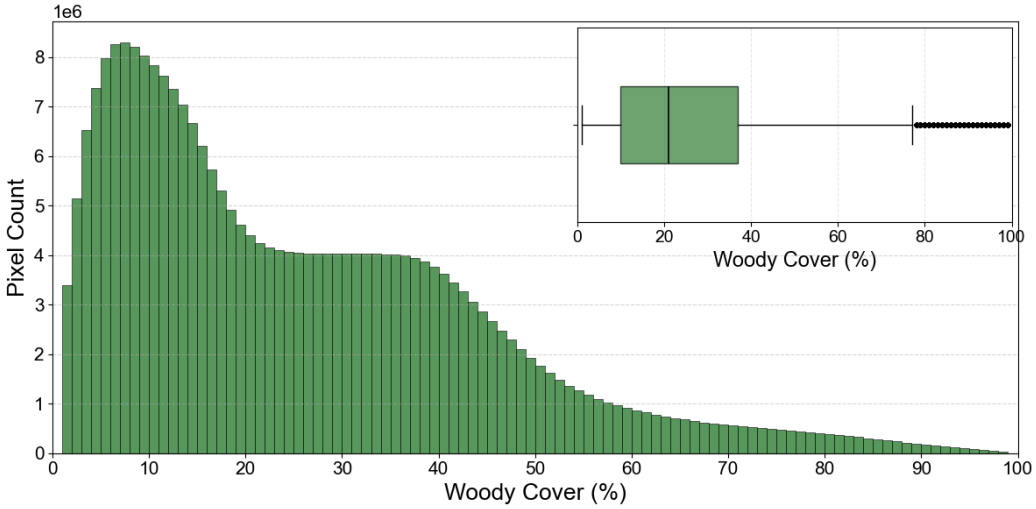


Figure 2 Pixel-level woody cover distribution within pasture areas (2024). *The histogram shows the proportion of pasture pixels within each 1% woody cover class from 0% to 100%. The inset boxplot summarises the same pixel values, showing the median, interquartile range (IQR), whiskers, and outliers.*

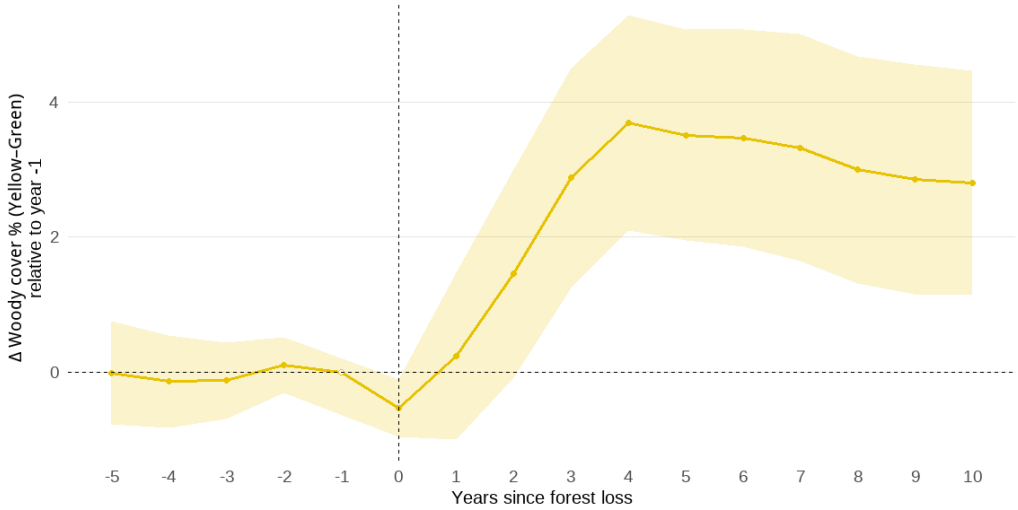


Figure 3 Event study estimates of the difference in fractional woody cover between yellow and green zone pixels in the Argentine Chaco. *Each point represents the estimated yellow–green woody cover difference (in %) for a given year, with year −1 (one year before forest loss) as the reference baseline. Shaded ribbons indicate 95% confidence intervals. The dashed vertical line marks the year of forest loss.*