

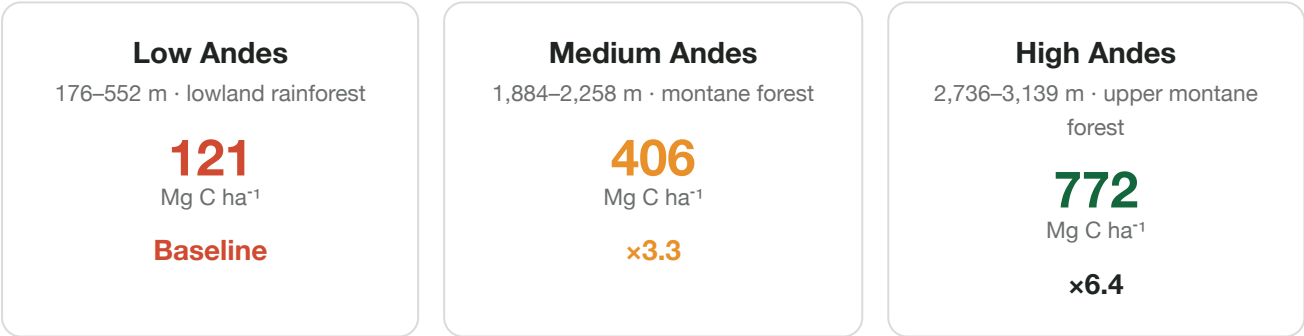
High-Andean forests store six times more soil carbon — a durable pool invisible to carbon markets

Across the Colombian Andes, soil carbon stocks rise six-fold from lowland to high-elevation forests, and a fire-derived (pyrogenic) fraction nine times the Amazon-wide average makes this pool exceptionally persistent — even where land has been cleared and farmed. Yet no carbon-credit standard currently rewards its protection.

Author and contact: Prof. Ted Feldpausch, University of Exeter, with Dr. Carmen R. Montes-Pulido (UNAD, Colombia). Brief based on Montes-Pulido et al. (2025), Global Change Biology 31: e70135. · Colombian Andes, 176–3,139 m · 36 plots in five nature reserves · Soil depth 0–100 cm.

Key terms. **Soil organic carbon (SOC)** — carbon held in soil from decomposed plants; one megagram per hectare (Mg C ha^{-1}) is one tonne per hectare. **Pyrogenic carbon (PyC)** — charcoal-like carbon formed when vegetation burns incompletely; it resists decomposition for centuries to millennia, making it a natural marker of *permanence*. **Verra / VCS** — the world's most widely used voluntary carbon-credit programme; soil carbon is an optional pool that most forest projects leave out.

AT A GLANCE · THE ELEVATION GRADIENT: SOIL CARBON CLIMBS WITH ALTITUDE (0–100 CM)



Mean soil organic carbon stocks to 1 m depth. One hectare of high-Andean forest soil holds more carbon than six hectares of lowland forest soil.

01 · THE ELEVATION GRADIENT

The higher the forest, the more carbon is at stake per hectare

Key findings

- High-Andes soils store **772 Mg C ha^{-1}** to 1 m depth — **6× more** than the Low Andes — and their pyrogenic carbon stock is **10× higher**.
- In montane forests the soil, not the trees, holds most carbon: one hectare stores about **2,830 tonnes of CO_2** — roughly **1,000 return flights between Bogotá and London** — and about five times the aboveground carbon of an average intact Amazonian forest ($\sim 150 \text{ Mg C ha}^{-1}$).

Pyrogenic carbon endures land-use change — the fraction that anchors permanence

Key findings

- Andean soils hold on average **34 Mg C ha⁻¹ of pyrogenic carbon** — about **9× the Amazon-wide average** — reaching 83 Mg C ha⁻¹ in the High Andes.
- PyC is **~8% of total soil carbon** (vs 2%–5% in lowland tropical soils), and its share **rises with depth** (3% near the surface to 13% at 30–50 cm), where it is best protected from loss.
- The PyC share of soil carbon was **statistically unchanged across the full disturbance gradient** ($p = 0.77$) — from old-growth forest to actively farmed land. This carbon, laid down by historical fires, survives the disturbances that deplete the rest of the soil pool: the durability that permanence claims require.

FOUR LAND-USE INTENSITIES SAMPLED — PYROGENIC CARBON SHARE STATISTICALLY UNCHANGED ACROSS ALL OF THEM

Old-growth, selectively logged Low disturbance	Farmed until 10–15 yr ago Medium disturbance	Cleared 16–20 yr ago High disturbance	Active agro-silvopasture Very high disturbance
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The pyrogenic fraction of soil carbon did not differ significantly across the four disturbance classes (Kruskal–Wallis $\chi^2 = 1.12$, $p = 0.77$): soil PyC reflects historical fire regimes rather than recent land use, providing a durable, creditable core within the soil carbon pool. Companion research in lowland Amazonia shows that total soil carbon, unlike PyC, is depleted by conversion to agriculture (Naval et al. 2025, Catena 254: 108924).

03 · FROM MEASUREMENT TO MAPS

Baselines can be predicted from measurable local drivers

Clay content and annual precipitation — combined with pH, calcium, and satellite greenness (NDVI) — explained **56% of the variability** in pyrogenic carbon across the region. One field campaign plus free satellite data can therefore deliver credible, locally calibrated soil-carbon baselines at project scale. Global gridded soil products miss this fine-scale variation; local calibration corrects them in the conservative direction carbon standards require.

The policy gap. Under Verra’s VCS and similar programmes, soil carbon is an optional pool that projects routinely exclude. In Andean conservation and restoration projects — where aboveground biomass is modest and most carbon sits belowground — this omission leaves the majority of the climate benefit unmeasured, unpriced, and unprotected.

CALL TO ACTION · FOR POLICYMAKERS, CARBON STANDARD BODIES, AND PROJECT DEVELOPERS

Bring Andean soil carbon into conservation finance

Recognising some of the Neotropics' largest and most persistent soil carbon stocks in carbon methodologies would redirect finance to the ecosystems where each protected hectare locks away the most carbon.

01

Include locally calibrated soil carbon baselines (to 1 m depth, not just 0–30 cm) in Andean conservation and restoration projects — the deepest carbon is the largest and most persistent share.

02

Recognise the pyrogenic fraction as evidence of permanence in soil carbon crediting: measure carbon fractions, not just bulk totals.

03

Prioritise high-elevation Andean forests in conservation finance and land-use planning — the region's largest soil stocks, under pressure from burning, grazing, and agricultural expansion.

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Brief based on research from Montes-Pulido, C.R., Bird, M.I., da Silva Carvalho, L.C., Serrano, J., Quesada, C.A. & Feldpausch, T.R. (2025). Climatic and edaphic drivers of soil organic carbon and pyrogenic carbon stocks across elevation and disturbance gradients in Colombian Andean forests. *Global Change Biology* 31: e70135. doi:10.1111/gcb.70135

Everyday-terms conversion uses carbon $\times 44/12$ to obtain CO₂, and ~2.8 t CO₂ per economy passenger for a return Bogotá–London flight. Amazonian aboveground carbon comparator (~150 Mg C ha⁻¹) derived from basin-wide old-growth biomass of 200–350 Mg dry weight ha⁻¹ (Malhi et al. 2006, *Global Change Biology* 12: 1107–1138).

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